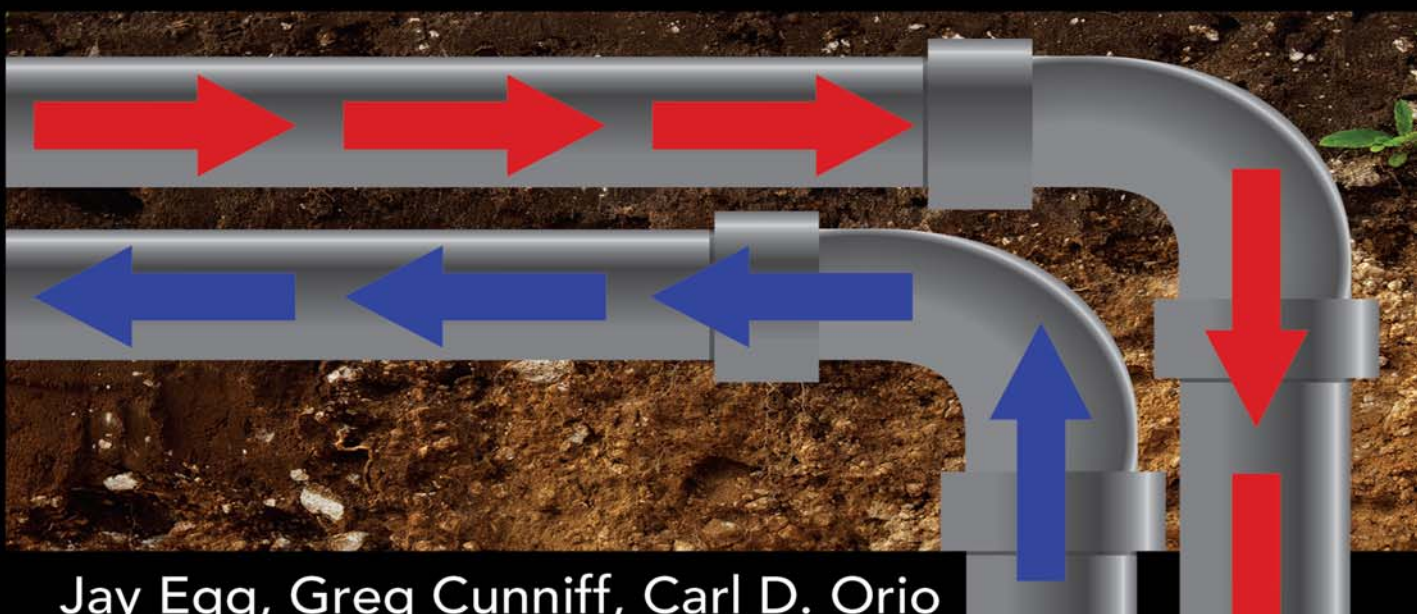
MODERN GEOTHERMAL HVAC

ENGINEERING AND CONTROL APPLICATIONS



Jay Egg, Greg Cunniff, Carl D. Orio

McGraw Hill Education

Modern Geothermal HVAC

About the Authors

Jay Egg started Egg Geothermal in 1990 to provide energy-efficient geothermal HVAC systems to the Florida market. Since then, the company has successfully installed thousands of such systems for residential and commercial customers in the Tampa, Orlando, and Atlanta regions—and beyond.

Mr. Egg served in the U.S. Navy as a nuclear field electrician, and subsequently trained with Dr. James Bose of Oklahoma State University, who many consider the father of the modern geothermal HVAC movement in the United States.

Mr. Egg is a Certified GeoExchange Designer/Installer through the International Ground Source Heat Pump Association (IGSHPA). He appears frequently on television and in print, and speaks regularly in front of industry groups. He is the coauthor of *Geothermal HVAC: Green Heating and Cooling,* also published by McGraw-Hill.

Greg Cunniff is manager of applications engineering for Taco, Inc. He received bachelor's and master's degrees in aerospace and mechanical engineering from Montana State University, and is a licensed Professional Engineer in California, Florida, and Montana. He is a member of ASHRAE and ASME.

Mr. Cuniff has worked as a consulting engineer designing mechanical, electrical, and plumbing systems for Drapes Engineering; as a manufacturer's representative for Vemco; and as a design-build contractor for GPD. He has also owned temperature control and building automation system (Electro Controls) and design-build contracting (Summit Group) businesses.

Mr. Cuniff has 40 years of experience designing, installing, and developing HVAC systems for a wide variety of buildings, including hospitals, schools, offices, military facilities, and industrial plants. Some of his more interesting projects include manufacturing facilities for the International Space Station, the historic renovation and infrastructure upgrade of the 100-year-old Montana State Capitol, and installing a renewable energy active solar collector system on his home in the 1970s. He is currently involved in developing energy-efficient technology for radiant cooling, chilled beams, geothermal, and building automation systems.

Carl D. Orio is chairman of Water Energy Distributors, Inc., one of the largest ground source heat pump distributors in the Northeast. He founded the company in 1974. He has been involved in over 14,000 heat pump installations, both commercial and residential.

Mr. Orio earned a B.S. in physical chemistry and physics at the College of the Holy Cross and an M.S. in systems engineering at the University of Texas. He is a Certified GeoExchange Designer and a Certified Geothermal Instructor (IGSHPA).

Mr. Orio is a member of ASHRAE and has contributed to ASHRAE transactions and handbooks. He was a member of IGSHPA's advisory board and served as chairman of several subcommittees. On multiple occasions he has spoken in front of industry groups.

Mr. Orio has been a geothermal consultant for over 70 power utilities and the U.S. Park Service, as well as numerous engineering firms in the northeastern United States and Canada. His consulting activities have included designs for closed-loop, standing-column well, and open earth-coupling applications.

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Jay Egg

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Preface

I have been involved in the geothermal HVAC industry for more than 23 years. My love of geothermal HVAC has grown remarkably over this time, but most especially during the last 3 years. C. S. Lewis in *The Screwtape Letters* spoke of an architect who could admire a structure and take delight in it—take "pride" in the structure's beautiful architecture, regardless of who designed it or built it—in other words, the pride was in the quality, excellence, and beauty of the results.

I stand on the shoulders of many who have gone before and many more who are currently working in the industry and wish to say, "Thank you for all the hard work that you've done to make this work possible."

In 2009, the U.S. federal stimulus package provided unprecedented incentives for the installation of geothermal HVAC systems. Geothermal HVAC equipment had evolved in much the same way air-source equipment had evolved. The challenges associated with integrating earth coupling with modern equipment have been persistent.

This book is not meant to replace the long-time geothermal entities and tradesman classes that provide the hands-on and technical training needed in the field. Organizations such as IGSHPA and GeoExchange will continue to serve a vital role in rolling this technology out into the mainstream of the world. This book is designed to educate our engineering minds about the potential of geothermal HVAC when properly integrated with hydronic systems and with controls that are designed to operate at a standard equal to or better than that for which the equipment was designed.

Good contractors will have no problem putting together a remarkable geothermal HVAC system if they have a well-designed set of documents from which to work. Students will quickly see that the evolution of state-of-the-art geothermal and hydronic design, combined with controls integration designed precisely for the project, will result in the longest-lasting and most efficient, space-saving, and aesthetically pleasing HVAC systems on the planet—period.

My coauthors and I have developed a curriculum that will provide every conceivable opportunity for thermal advantage, thermal load shed, thermal load share, use and reuse of Btu's again and again, all the while reducing pumping and fan power to the lowest consumption attainable.

This curriculum is a work in progress. Properly used, the student and the geothermal HVAC industry will flourish and be propelled into a new age of acceptance heretofore unknown. Jobs and prosperity and abundance for all will result. Enjoy, learn, and share it with the world.

Jay Egg

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Acknowledgments

Jay Egg

Thank you to our amazing team: Greg Cunniff, Carl Orio, Bob Mayoh, Dan Sheppard, Jay Holtzman, Jerry Baker, Ric Murray, Tony Campo, and David Hoffman. When we started this textbook project, it was only Greg Cunniff and me. We soon saw the opportunity to pull in decades' more experience from engineering, art, and technical professionals of remarkable caliber.

I would like to thank Judy Bass, Bridget Thoreson, and Amy Stonebraker from McGraw-Hill for the great trust placed in our efforts to bring the geothermal HVAC industry into the college curriculum mainstream.

Brian Clark Howard at *National Geographic* and Seth Leitman, the "Green Living Guy," will always receive my profound gratitude for the trust they placed in me and in this work early on.

Chris Integlia and Tommy Lawrence saw the vision and stuck with it. And to John Hazen White, Jr., thank you.

My entire family and, most importantly, my sweetheart and eternal wife, Kristy, have once again patiently and abundantly blessed my life through the last year and a half of writing and the major transitions as my business has evolved from contracting to writing, consulting, and speaking engagements. My children, Kevin, Katie, Jordan, Taylor, Hannah, and Theron III, have been patient as my travels have been far and wide. I love you all more than words can say.

Greg Cunniff

Thank you to Jay Egg for a telephone call asking if I would like to coauthor a textbook on geothermal HVAC systems with him. Jay explained that he had written a previous book on geothermal systems and was writing another, this time with more technical content on the hydronic industry as it related to geothermal systems. I had published technical articles on various subjects for the hydronic industry, and he thought a textbook was a logical extension of these efforts. Writing a textbook, however, requires a whole different level of commitment. This was an opportunity to share over 40 years of experiences in the HVAC industry. Jay has been more than encouraging through the whole process.

I would also like to thank our publisher, McGraw-Hill, and Judy Bass for having the vision to see us through the process. Interestingly, during the writing of this book, the geothermal industry has introduced new high-efficiency variable-speed equipment. With Judy's patience and encouragement, we were able to include this new information, a very important development in geothermal systems, in the book. Also during this time, additional empirical information became available on the efficiency of geothermal systems, especially in comparison with other HVAC systems. This information is also included in this book.

Thank you to Taco, Inc., and staff for giving me the time and resources to write the book. Taco is a leader in the hydronic industry. John White, Jr., owner and president, has shown an exceptional commitment to his employees and the industry. The company has just built a new Innovation and Development Center at headquarters in Cranston, RI, to highlight the latest in hydronic technology, including a geothermal heat-pump system, from a number of manufacturing partners. Special thanks to Tom Lawrence, Taco senior vice president for commercial sales and marketing. Tom has been especially understanding of the effort it takes to write a book and keep up with regular commitments. Thanks to my compatriot, Brett Zerba, who picked up the slack when needed.

Thanks to Jerry Baker, Jay Holtzman, and Jeff Pitcairn. Jerry, a college classmate, industry associate, and long-time friend, shared with me his 40+ years in the HVAC industry for the book. Jay was able to take industry technical concepts and vernacular and express and organize them in plain English, a rare talent. Jeff lent his experience and expertise in preparing basic research and materials.

I would like to sincerely thank my lovely wife and lifelong companion, Candy. She encouraged and motivated me despite the evenings and weekends spent working on the book instead of spending them with her. She continues to inspire me with her caring and loving attitude.

Carl D. Orio

A multitude of thanks to Jay Egg for immersing me in the art of publication. Jay has dragged me from 35 years of writing about geothermal heat pumps for the use and benefit of installers and engineers to the exponentially expanding world of geothermal interests. Realizing the difference between technical writing and interesting writing was a giant step upward. Jay introduced me to a series of impressive and competent writing partners, Greg Cunniff and his able staff at Taco, Inc.

I want to thank the technical teams with which I have worked over 35 years in the geothermal camp. One of the early-on experts was Dr. Jim Bose, OSU, who bought a geothermal heat pump in 1974, one of the first of over 2200 heat pumps we manufactured over the next seven years. Jim ably taught us and many others about closed-loop earth coupling. Dr. Harry Braud (deceased), LSU, validated the mathematics we used to better understand standing-column-well conductive and advective heat transfer. Bob Duggan, Jim Viera, and Jack Porter, early leaders in the well-drilling community, had the idea of the Porter shroud used in the geothermal well. Dr. Jeff Spitler, OSU, led me through many of the *ASHRAE Transactions*, seminars, and other documentation relating to the standing-column well. In particular, ASHRAE Technical Committee 6.8, Geothermal Research, and the ASHRAE Research Fund supported the standing-column research work. J. B. Singh introduced me to the wonders of urban geothermal with over 40 standing-column-well installations in New York City.

At Water Energy Distributors, Inc., the technical team headed by Dr. Carl N. Johnson (retired) from 1998 to 2008 provided understanding and validation to many of the subjective methods we developed in the late 1970s and early 1980s. Without CJ's heat-transfer insights and mathematics, the standing-column well would still be in the SWAG world. Dr. Johnson provided the foundation for a complete understanding of combined conductive and advective heat-transfer methods. He was followed by Tim Roos (now president of WellSpring Geothermal Engineering). Tim has my gratitude for his furthering and refinement of standing-column-well mathematics and its rational integration into commercial documentation and technical and construction management. Both Carl and Tim participated as instructors in our three-day standing-column-well engineering workshop. Thanks to Phil Rawlings for coining the term "standing-column well."

I am grateful to my family for tolerating the time I used for geothermal energies. Those energies transferred to five of the "gang of six." In the early 1980s, they became owners of and daily participants in the geothermal business. Since 2000, the driving force has been my daughter, Christina Orio, who has the support of brothers Martin, Matthew, and Nicholas and sister Diona.

The foremost thanks for her love, wit, and intelligence go to my wife, Claudette, the greatest partner on the planet, for allowing me to absorb and communicate 39 years of geothermal knowledge.

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CHAPTER 1

Low-Temperature Geothermal or Earth Coupling

This chapter will outline the basic concept of geothermal-assisted heating and cooling. Using clear and basic pictures and principles, the student will learn how it is that all of the heating or cooling needed for an application can come from the renewable and sustainable temperature of the earth beneath the home or building.

Geothermal heating, ventilation, and air-conditioning (HVAC) incorporates all the concepts and principals of HVAC. This chapter will touch on many of the fundamental principles of HVAC engineering. It will delve deeply into hydronic applications. Because ground-sourced heating and cooling systems primarily use an earth fluid loop of some sort, hydronic-based heating and cooling becomes the fundamental core of geothermal HVAC technologies.

There are several fundamental variations in geothermal heat-pump (GHP) systems (Fig. 1-1):

1. Water to water
2. Water to air
3. Water to water and air

Water-to-water GHPs are used frequently in heating applications worldwide. The heating elements are often placed in the floors and walls of the structure/environment to be heated (and/or cooled) by geothermal pumps. Pool GHPs are niche applications that have proven to save a tremendous amount of energy (Figs. 1-2 and 1-3).

Typically, heating is the mode in which GHPs have the highest efficiency. This can be attributed to many factors. In a cooling situation, the average high temperature for a hot region may be 100°F or more. The temperature to which one cools normally is about 72°F. This is a difference of 28°F. In a heating-dominant climate, the temperature may be 0°F much of the time. With an indoor comfort range of 68 to 72°F, this is a difference of 72°F or more.

To summarize why heating typically is the mode in which GHPs show the best energy savings: The heating application generally has a greater difference in temperature (ΔT). With a greater ΔT, heat-transfer efficiency goes up, operating time goes up,

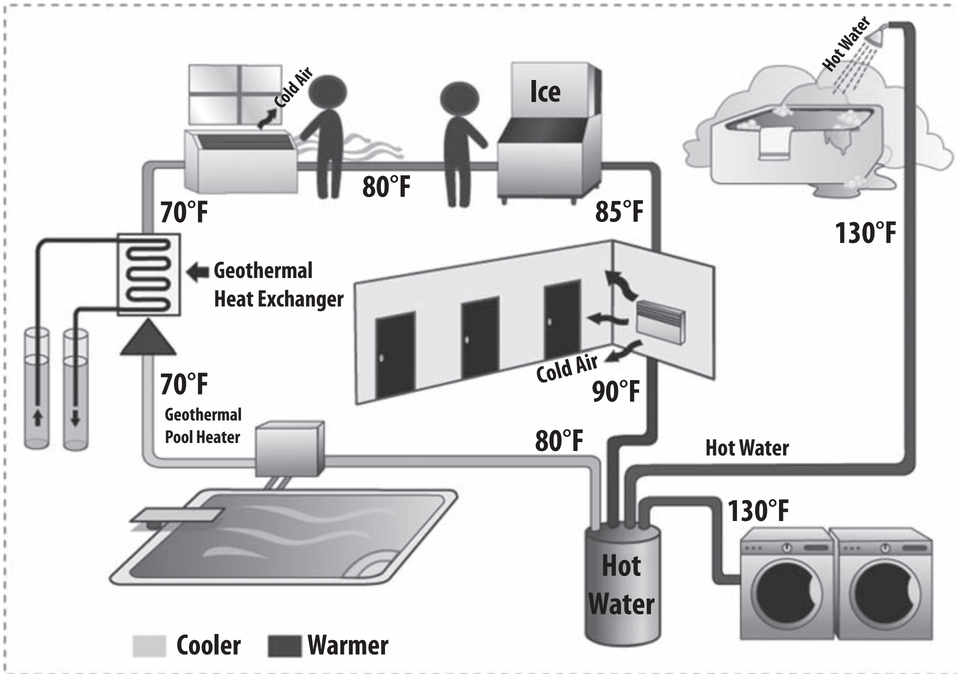


FIGURE 1-1 Geothermal heat-pump applications can be applied for the purposes of space conditioning (water to air), pool heating and domestic hot-water generation (water to water), and multiple other variations and combinations. (*Sarah Cheney*.)

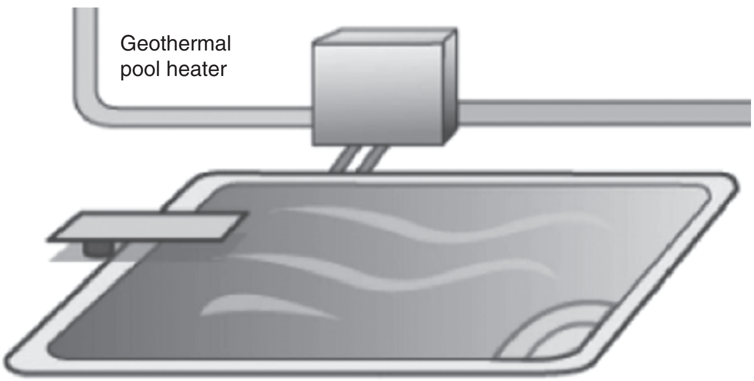


FIGURE 1-2 Geothermal heat pumps for pool applications are among those with the highest payback or return on investment (ROI). Pool GHPs are also used to heat or chill pool water. (*Sarah Cheney*.)

A

B

Figure 1-3 Geothermal heat pumps provide a fundamentally limitless source of heat for the purpose of pool heating at efficiencies that are not attainable by any other regularly used technology. (*a*) A geothermal heated pool. (*b*) The pool heat pump. (*EggGeothermal*.)

and any fuel savings are increased by a factor of the additional run time for the equipment. But there is more to this equation.

Let's look at cooling in a hot and humid climate. In Florida, Texas, and South America, for example, the ground temperature may be between 70 and 80°F. With a 10°F approach, this will produce a condenser water temperature for the heat pump of 80 to 90°F. In heating in a cold climate, the ground temperature may be between 40 and 50°F. This will produce a ground temperature of between 30 and 40°F. The important factor to note here is the ground temperature ΔT from the outdoor extreme temperatures. The hot climates are almost right on the mark, whereas the cold climates are about 40 to 50°F different, which provides a greater opportunity for energy savings.

Once you get your head wrapped around this concept (the relatively constant temperature of the earth as opposed to seasonal temperature extremes in the air), you will be armed with the knowledge to speak intelligently to those arguments that come up once in a while stating that GHPs are more efficient in the heating mode and cold climates than in climates that require cooling.

Let's not let this argument get to the point where GHPs are not considered in cooling climates because the energy savings are not equivalent in dollars and simple payback to their heating counterparts. In Appendix A you will see a reference to a Department of Energy (DOE) study in which the lead author was involved for about two years during 2009–2011. The study is appropriately titled, "Analysis of Energy, Environmental, and Life-Cycle Cost-Reduction Potential of Ground Source Heat Pumps (GSHPs) in Hot and Humid Climates."

Longevity versus Energy Savings

Geothermal heat pumps are an ideal upgrade for any application that is using cooling and heating. Energy savings when correlated with a payback analysis can be remarkably quick, sometimes under 5 years. When correlated with tax credits and rebates, the payback may be even better, making the choice to go geothermal the most cost-effective regardless of cost. However, there are many factors beyond simple payback that should be considered in this analysis.

The average residential or light commercial air-source heat pump (3–25 tons) is usually a split system or a package unit (see GHP types below). In either case, a portion of the system must by its very nature be placed in the outdoor environment. Because of its nature, the heat pump has to exchange temperature with a source to do the job of heat exchange for cooling or heating. In the case of an *air-source* heat pump, the air in question is the outdoor air.

The outdoor environment can be harsh in most places that need regular heating and cooling. In hot and humid climates, the compressors, fans, refrigerant coils, and other electronic components are housed in enclosures necessarily placed in the rain and sun and even the salt spray of the coastal ocean winds. The best components fail in less than a decade, even in as few as 3 or 4 years. Expansion and contraction of the refrigerant coils causes capillary separation of the fins from the tubing, which begins to reduce the heat-transfer efficiency the first year of operation (Figs. 1-4 and 1-5).

In cold climates, the treatment of the outdoor equipment is much the same, with an added difficulty: Many cold climates have remarkably hot summers. Greg Cunniff, a coauthor of this book, lives in Montana. The coldest temperature he recalls, in the 30 years that he has lived there, is –54°F. He also describes the largest temperature change he's ever experienced in one day. Before telling you the temperature change, which,

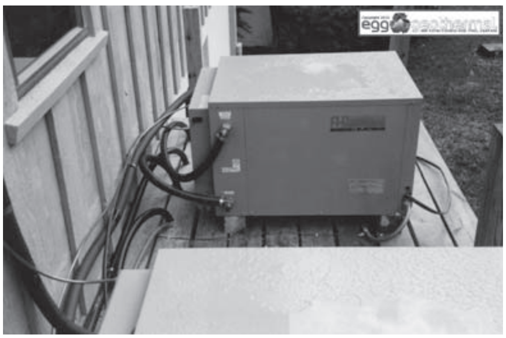
Figure 1-4 These air-cooled condensers are significantly weathered after only 4 years of exposure to the elements. This type of weathering is all but eliminated when the equipment is brought indoors, as in geothermal applications. (*EggGeothermal*.)

Figure 1-5 The aluminum fins that were formerly attached to this condenser's copper piping have separated and fallen to the ground. Long before condenser fins actually fall off the refrigerant piping, the capillary bond between the aluminum and the copper oxidizes and creates a type of insulation, significantly reducing efficiency. (*EggGeothermal*.)

by the way, the lead author finds difficult to comprehend, it is interesting to know that the phenomenon is referred to by the Montana locals as a *chinook*, which this author understands is the Native American word for "snow-eater." Greg told the lead author that the temperature swung from an icy few degrees below zero to nearly 100°F, a temperature change of 100°F in 1 hour!

Geothermal heat pumps typically are designed to be housed indoors. Preferably, they should be installed in the conditioned environment in an equipment room or an air-handler closet. Basement, attic, and above-ceiling applications are well suited for GHPs (Fig. 1-6).

When an appliance or a piece of equipment is placed in a controlled environment, it will last much longer. The lead author's experience has shown that the equipment lasts about three times longer. His father used to lecture him about the need to put equipment and tools such as wheelbarrows, lawnmowers, shovels, and rakes, as well as bicycles, in the garage or the shed. The lead author didn't think much of this practice until one year as spring came into full bloom and the family was doing the first yard maintenance of the year, he found a long-lost pair of shears. His father had purchased some pruning shears the spring before, three pairs as the lead author recalls, and somehow one of them



Split Direct Expansion (FHP-Bosch)

Water to Water (Spectrum Equip)

Vertical Water to Air (Spectrum Equip)

Horizontal Water to Air (ClimateMaster)

Figure 1-6 Geothermal heat pumps can be installed in any space and in any position imaginable. Here you can see horizontal, vertical garage, vertical closet, and split with the condenser either outside or in an equipment closet. The variations are as limitless as our needs. (*EggGeothermal*.)

had gotten lost. That spring day the lead author was very pleased—he thought he had found a World War II relic. He never would have believed that the "relic" was only a year old. After convincing him and his brothers of the authenticity of the pruning shears, the lead author's father lectured the boys once again on the need to keep things out of the weather.

So it stands to reason that among the most important benefits of GHPs is the longevity factor that results from placement of the equipment indoors and out of the weather and temperature extremes.

The lead author would be remiss if he didn't address one other issue that is along these same lines. The stable temperatures of the earth source used by the GHPs provide an easier load for the compressors to bear. Compare this, if you will, with the engine of a gasoline-powered car. If the driver is inclined to stomp on the throttle, squeal the tires, and push the engine harder than another driver with the same engine, the first engine will suffer some degree of premature wear and related reductions in efficiency. The point is clear that the properly engineered GHP will have an easier life as a result of stable ground temperatures.

Engineered Failure

Have you ever heard someone say, "They don't make them like they used to?" Have you ever wondered if that is really the case? And who are "they" anyway? If you Google "engineered failure" or something similar, you will find some interesting articles on the subject. To some people, the idea sounds a bit conspiratorial, and others just can't conceive of anything so malicious as a company that would spend time and money to make sure that a product breaks down according to a certain time interval. Yet it is so. You will find among the many articles and definitions that "engineered failure is made necessary by the lack of willingness of the public to pay for quality/longevity." The manufacturers make up for the lost income by making various items that last only so long. A good example is the plastic totes in which we like to store seasonal items. Many of these products contain plastic that is engineered to crack and fail. High-density polyethylene, which is the base for most durable plastics, is inexpensive and, if it is used in its pure high-grade form to create the totes, would last between 50 and 300 years. The lead author would go so far as to argue that it costs more in some cases to design products that fail in a few years. Has the point been made?

The lead author has no real knowledge of the degree to which engineered failure is affecting the products that we use, but as of this writing, his experience with the top manufacturers of GHPs has been good (Fig. 1-7). He has found them to be products of good quality and longevity. It is incumbent on all good engineers to endeavor to provide a good product to the clients for whom they are engineering building HVAC systems.

As with many products, industry professionals need to be vigilant in watching for trends in failure to protect consumers. If a product costs far less than the normal market price, you may have a reason to be careful in selecting it.

Another type of engineered obsolescence involves producing products with proprietary control systems, i.e., equipment that will only work with the company's own product line. The lead author has been seeing more and more of these products in which the control systems are shelved after only a few years and unavailable for upgrade. This results in the need to replace the entire system after a minor failure, even though the equipment is generally functional.

The lead author once purchased an all-terrain vehicle (ATV) that cost less than half the price of a comparable name-brand product. It ran for less than a month of normal

Figure 1-7 High-quality products such as this Geofinity GHP are available with options such as on-demand domestic hot-water generation and are highly desired by customers. As with any industry, engineered failure may begin to creep in, and designers must be vigilant to keep the best interests of their customers at heart. Be careful in your equipment selection and choice. (*Geofinity*.)

use before critical parts started failing. If that alone was not bad enough, the replacement parts were not to be obtained. It was a frustrating experience, and the lead author had no one to blame but himself for being so shortsighted.

Comfort Level

The lead author knows a number of people who claim that GHPs produce the most comfortable living environment they've ever experienced. This is a bold statement and one that is arguably subjective. So many factors go into producing a comfortable indoor environment that it's difficult to measure which are the result of a specific HVAC system. Some of the items that affect comfort level besides the HVAC system are lighting, noise, and smell.

The reasons that a properly engineered geothermal HVAC system will be more comfortable in the cooling mode come primarily from the stable geothermal source that allows a lower evaporator (cold-coil) temperature, providing somewhat better humidity removal. Most people are more comfortable in an environment that is dryer and a couple of degrees warmer rather than cooler and damper. In hot and humid climates, we see this time and time again.

In the heating mode, the comfort level of a GHP is superior to an air source because it can put out a warmer air stream owing to the warmer source. The outside air typically will be much colder than the geothermal or ground source, which provides for a greater final delivery temperature at the supply register.

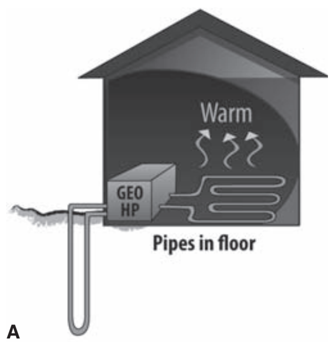
When a GHP is compared with a gas furnace, the GHP often comes out to be the favorite once again. This time it's because the air is not so hot and dry. The GHP does not "fry" and dry out the air. The air delivery tends to be more along the lines of warm with less of a drying effect owing to a reduction in intensity or concentration of heat. In the case of radiant heating or water-to-water geothermal applications, the GHP produces consistent, even radiant heat to the floors and floorboards of the structure to be heated.

Water to Water

There are a few different general applications for water-to-water heat GHPs.

Hydronic Heating and Cooling

Hydronic heating and cooling can be achieved through radiant or forced-air fan coils (Fig. 1-8*a*). Taco is a pioneer in the field of radiant cooling, often called *chilled-beam cooling*. This chapter will touch a little bit on chilled-beam systems, but the subject will be handled in depth later in Chaps. 10 and 11.



A

B

Figure 1-8 (*a*) Water-to-water heat pumps are used in geothermal applications with radiant heating and cooling loads. (*Sarah Cheney*.) (*b*) Commercial pool heat-pump applications are wide and varied. Many of these applications are indoors, whereas others are outside in the coolest of climates. The designer must remain vigilant in determining all the forces that act on a pool to create the need for heating and dehumidification and size the system properly. (*EggGeothermal*.)

C

FIGURE 1-9 A commercial heated pool.

Pool Heating

Geothermal pool heaters are remarkably effective and have the best return on investment or payback in the geothermal industry normally (Fig. 1-9). Pool heating is a necessary and costly practice. Typically, municipalities, hotels and motels, exercise clubs, and anybody who desires to swim throughout the year finds it necessary to heat a pool (Fig. 1-9).

There are several ways that pool heating may be accomplished. The most common method is a gas furnace, followed by electric resistance and then an air-source heat pump. An incredible number of solar-thermal pool-heating systems have been installed. Solar pool heating is very effective and has by far the fastest payback and lowest cost to operate. The only problem with solar-thermal heaters is that they are only as dependable as the amount of solar radiation available to work with. This means that pools that are not in a position to have any down time must have a backup. And in the winter, there can be weeks or even months in which the solar heating system cannot provide sufficient heat for demand, causing high electrical and fuel charges. It is not uncommon to see gas charges for a 50,000-gallon hotel pool approach $15,000 or more per month in the colder seasons of the year.

Geothermal pool heating is capable of eliminating or reducing the related gas or electrical charges and heating just as effectively for about 25 to 50 percent of the energy cost. In the following chapters you will learn about the coefficient of performance on pool heat pumps and be able to accurately calculate the cost difference and payback period or return on investment (ROI).

Understanding the Geothermal Heat-Pump Concept

In order to appreciate the geothermal or earth-coupled concept as related to heat pumps, it is necessary to have a fundamental knowledge of the *heat-pump cycle*. In 2009, the lead author read an article in *The Washington Post* about a writer who had a geothermal heat pump installed in his home. In the article, Christopher Gearon talked about the contractor and equipment-selection process. He indicated that in the first winter he saved about 40 percent on energy cost and that the equipment ran well. He went on to illustrate the process of the heat pump's operation and then explained a couple of terms used in energy, primarily the *coefficient of performance* (COP). He explained that the heat pump was rated by the Air Conditioning, Heating and Refrigeration Institute (AHRI) at a 4.2 COP, which means that for each unit of energy put into the heating process, the GHP puts out 4.2 units of heat. In other words, 1 kW of power puts out 4.2 kW of heat. He went on to better explain how the GHP uses the existing heat retained in the earth to produce this remarkable performance.

Like most articles published on the Internet, this one article had garnered quite a few comments. A few of these comments were negative. One in particular said, "Everybody knows you can't get energy out of thin air. . . nothing can be even 100 percent efficient, much less 420 percent!"

What you the student will learn, if you have not already, is that this is the essence of renewable energy. Renewable-energy products such as hydro, solar, wind, and geothermal products use energy that is abundantly available and renewable. A *renewable-energy source* might be defined as a source that is constantly in the process of being recharged by nature.

A very simple example of what a heat pump does can be given in an analogy. If a bicycle rider is peddling to a goal of 20 mi/h on a flat road, he will consume maybe 1000 calories per hour. This would be, for our purposes, a COP of 1; 20 mi/h for 1 hour equals 1,000 calories. Now suppose that the rider has a tailwind of 10 mi/h. For simplicity, the energy consumption is reduced. He is able to go 30 miles on 1000 calories. This would be a COP of 1.5. For one more step, suppose that the tailwind increases to 40 mi/h. For the same exertion, the rider with a 40 mi/h tailwind plus a speed of 20 mi/h pedaling would go 60 miles in 1 hour. This is a COP of 3.0 (Fig. 1-10).

Figure 1-10 As with the coefficient of performance (COP) for a heat pump, the bicyclist is not creating the speed by himself but getting help from a wind block. In the case of a heat pump, the help comes from stored heat. (*Wikipedia*.)

Now to apply this to heating, we start with an electrical resistance heater. When electricity is applied to an electrical resistance heater, the device will produce 1 kW of heat for 1 kW of energy. This process is literally converting electrical potential into heat energy. Taking this a step further, a heat pump moves heat from one location to another. If the temperature inside a house is 60°F and the temperature outside is 80°F, it would be simple to see how the heat can be moved from outside to warm the inside. Normally, though, heat is needed in a home when the temperature outside is colder than inside. So let's say that the temperature is 60°F inside and 50°F outside. It would appear that the outside temperature does not have the capacity to do anything but cool the space. But there is heat available there in the 50°F outside air. This is where the refrigeration circuit comes into the picture (Fig. 1-11).

A refrigeration circuit typically has four components, as indicated in the figure. The compressor has the capability of compressing the refrigerant to a higher temperature and pressure. This effectively takes the heat absorbed from the outside air at 50°F in this case and compresses it to a temperature of 100°F as an example. Now that the refrigerant in the circuit tubing is relatively warmer than the 60°F home, heat can be given off as air or water is passed over the 100°F circuit. A good example of this in a home appliance is a refrigerator. While cooling the food inside to 40°F, the heat is moved outside the refrigerator at a much warmer temperature of 100°F. The refrigeration circuit will be explained in greater detail in Chaps. 8 and 9.

Now that you have a basic concept of a heat pump moving heat energy from one place to another, it's clear that heat is not being created—it is being moved. The only energy consumed is used in manipulating the intensity of the heat and moving it from one place to another. The efficiency of doing this is the COP. Typically, a heat pump rated by the AHRI is rated under conditions that would be considered normal for the application. So the rating for a heat pump would include the given temperatures shown in Fig. 1-12.

The temperatures for rating heat pumps in the heating mode, as indicated in Fig. 1-12, are 50 and 32°F. The related COPs are 5.1 and 4.6, respectively.

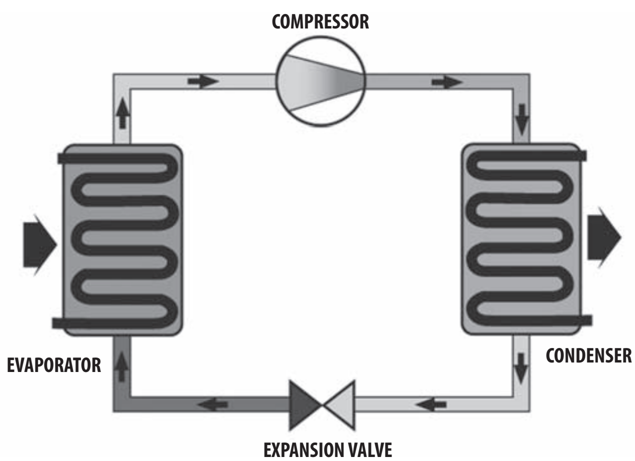


Figure 1-11 The beauty and wonder of the heat-pump refrigeration circuit is that it concentrates and moves heat energy from one place to another. No fuel is burned to create heat; it is concentrated and moved once again from one source to another. (*Sarah Cheney*.)

Ground Water Heat Pump				Ground Loop Heat Pump			
Cooling 59°F [15°C]		Heating 50°F [10°C]		Cooling 77°F [25°C]		Heating 32°F [0°C]	
Capacity	EER	Capacity	COP	Capacity	EER	Capacity	COP
Btuh [kW]	Btuh/W [W/W]	Btuh [kW]		Btuh [kW]	Btuh/W [W/W]	Btuh [kW]	
22,200 [6.51]	30.8 [9.0]	18,600 [5.45]	5.1	21,300 [6.24]	26.0 [7.6]	16,500 [4.83]	4.6
30,200 [8.85]	31.5 [9.2]	24,800 [7.27]	5.1	28,900 [8.47]	27.0 [7.9]	22,100 [6.48]	4.5
40,700 [11.93]	28.7 [8.4]	35,400 [10.38]	5.1	39,600 [11.61]	24.9 [7.3]	31,200 [9.14]	4.6
51,900 [15.21]	29.7 [8.7]	49,800 [12.25]	4.7	49,800 [14.60]	25.3 [7.4]	37,500 [10.99]	4.3
59,800 [17.53]	24.5 [7.2]	51,700 [15.15]	4.3	57,700 [16.91]	21.4 [6.3]	45,400 [13.31]	3.9

Figure 1-12 As you can see here, the energy efficiency rating (EER) depends on the geothermal source. Although groundwater heat-pump applications provide the best energy efficiency, closed-loop systems may be the better option in certain geologic and economic situations. The designer must thoroughly investigate each project site to determine the best earth coupling method for the geothermal source ISO-13256 Standard Rating Chart. (*ClimateMaster*.)

A geothermal heat pump uses the temperature of the shallow earth to assist in heating and cooling a home. The temperature of the earth is fairly constant and usually a good annual average figure. Even in the coldest of climates, you'll find the earth temperature to be near 50°F or so. This is a remarkable advantage when trying to heat or cool a building. This is where the tailwind analogy of the bicyclist makes sense. The warmer earth correlates with the stronger tailwind when the system is in the heating mode. The temperature outside may be 20°F, but with an earth temperature of 50°F, there is effectively a "temperature tailwind" of 30°F.

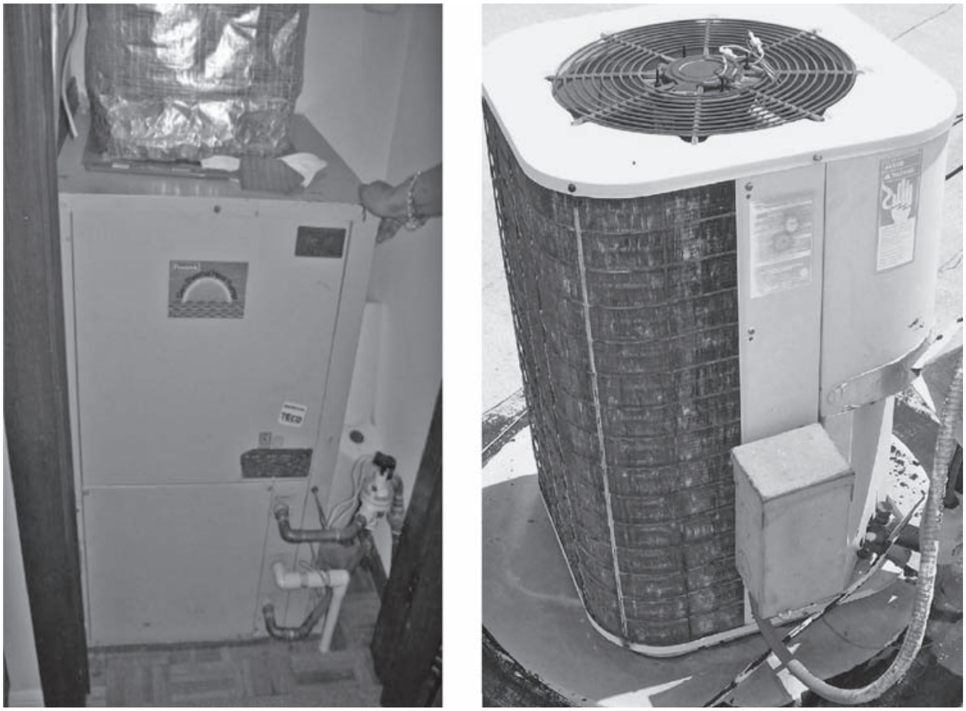
Typically, the engineering that goes into an air-source heat pump is no less impressive than the engineering that goes into a geothermal heat pump, speaking specifically of the heat-pump equipment. The main difference is that the GHP is set up to be enabled to take advantage of the "tailwind factor"—the constant temperature of the earth.

The lead author often can be heard making statements such as, "Here sits your geothermal heat pump, fat and happy, never being pushed too hard because the exchange medium is always relatively neutral 40 to 70°F. When compared with their air-source relatives that must endure the extreme temperature fluctuations of 0 to 100°F, it's easy to see why GHPs last much longer, not to mention the weatherizing aspect of having to stay outside all the time" (Fig. 1-13).

General Methods of Earth Coupling

There are as many ways to design an earth-coupled heat exchanger as there are ways to install a plumbing system. Generally, though, there are only three different kinds of earth-coupling methods that are considered acceptable (Fig. 1-14):

1. Closed-loop earth coupling
2. Open-loop earth coupling
3. Standing-column earth coupling



30-year-old GHP 14-year-old AHP

Figure 1-13 The 30-year-old GHP on the left looks as good as the day it was installed as opposed to the 14-year-old air-conditioning heat pump (AHP) on the right. This is a result of keeping the equipment inside the conditioned space and out of the brutal elements. (*EggGeothermal*.)

Within the scope of each of these methods are several variations that are covered in depth in Chap. 3. Basically, the closed-loop variations include vertical bore, horizontal loop, and lake/pond/surface-water loop.

Applications of the Various Types of Earth Coupling

Each of the applications for earth coupling just mentioned will operate under the proper conditions. There are conditions in which certain earth-coupling methods will work indefinitely and conditions under which certain earth-coupling methods will not work for an extended length of time. This may be a bit confusing, and the best way to clear this up will be by starting with a residential closed-loop application.

In the book *Geothermal HVAC: Green Heating and Cooling*, the lead author wrote a section entitled, "Geothermal as a Thermal Savings Bank." In this section he explained that the closed ground-loop heat exchanger operates in conjunction with the heat pump to move heat from the ground into the home all winter long. By the end of the winter, the ground temperature surrounding the loop is lower by some margin. For example, if the ground temperature started at 55°F, it might be 35°F by the end of the winter. As the summer heat begins to come into play, there is a clear advantage in the cooling mode; because the ground is cooler, the efficiency of the heat pump in moving the heat from

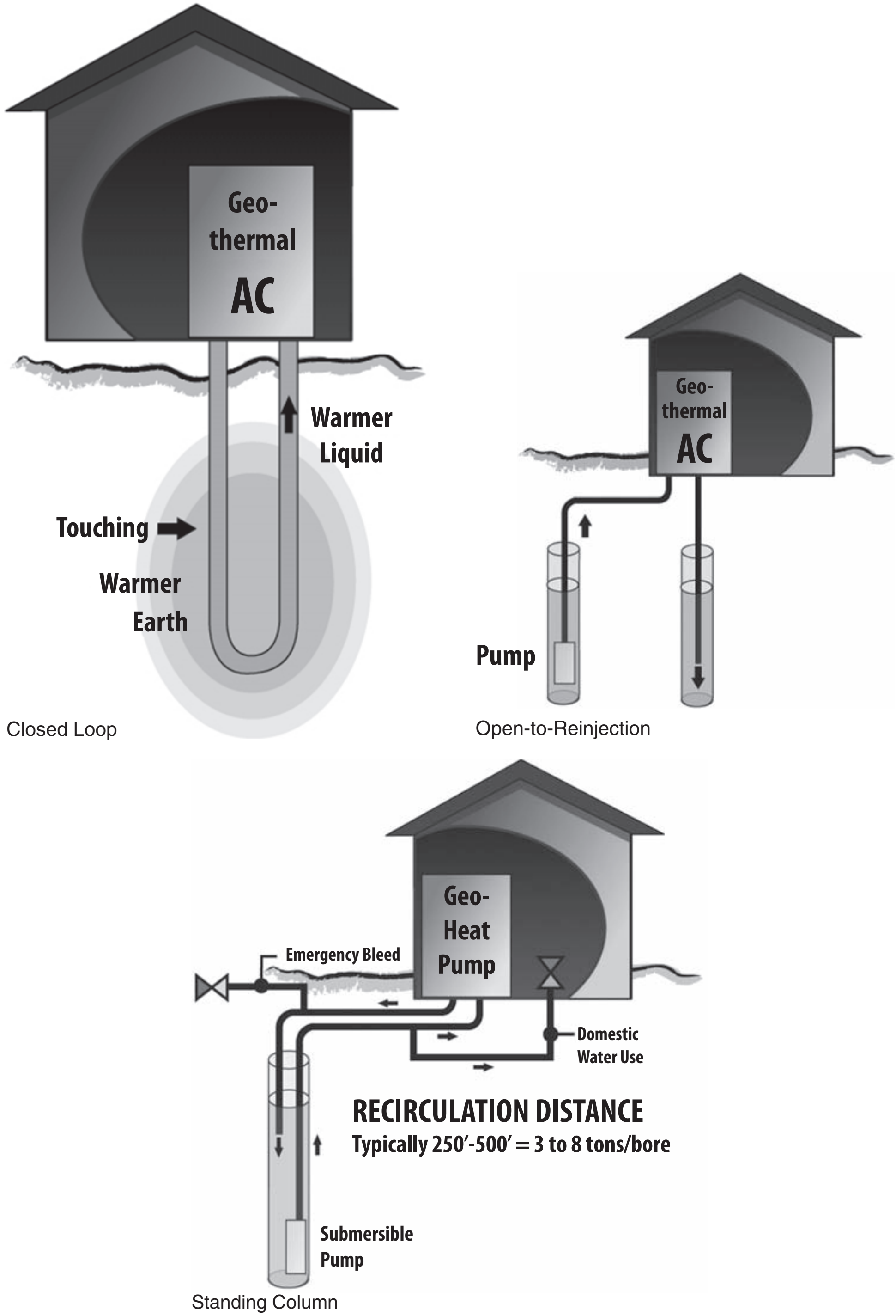


Figure 1-14 The three illustrations depicted here are just the beginning of the infinite variations for GHP application. (*Sarah Cheney*.)

the home to the earth is effectively increased. In a climate with balanced winter and summer conditions, the end of summer will bring a roughly equal heating effect to the earth. This, in turn, will be an advantage as the winter months come back into play and the need for heating the home returns. In this way, it's easy to visualize how the heat of the summer months can be saved and used in the winter, like a bank deposit can be withdrawn at a later date.

With this idea in mind, you might ask what happens if the summer and winter conditions are not balanced? To some degree, the relatively large mass of the earth can act as a heat source or sink infinitely. However, the unbalanced heating and cooling loads can be hard to overcome, especially in situations that are cooling-dominant. Cooling-dominant conditions exist in many commercial buildings, even in the coldest of climates. This is due to the high internal heat gains of commercial buildings—especially buildings that have an abundance of computers, servers, and related office equipment. In this situation, the temperature might be 10°F outside, and the need remains to remove heat from the building because of these heat sources. In such situations, the earth-coupled loop is nearly always in the process of using the earth as a heat sink, or the GHP is rejecting heat to the earth. With no reverse cycle time, the earth can suffer from a high degree of thermal retention (Fig. 1-15). Once the earth loop is unable to return water temperatures below about 105 to 110°F, the system will begin to suffer shutdowns related to high incoming water temperatures, meaning that the systems will fault on high head pressure. When this happens, the loop temperature must be returned to a lower temperature using an intermediate fluid cooler or by leaching the loop (covered in standing columns in Chap. 7).

Thermal retention is a real issue with closed-loop technology in cooling-dominant situations. The best method to avoid thermal retention is a well-engineered open-loop geothermal exchanger. This will be discussed in detail Chap. 3.

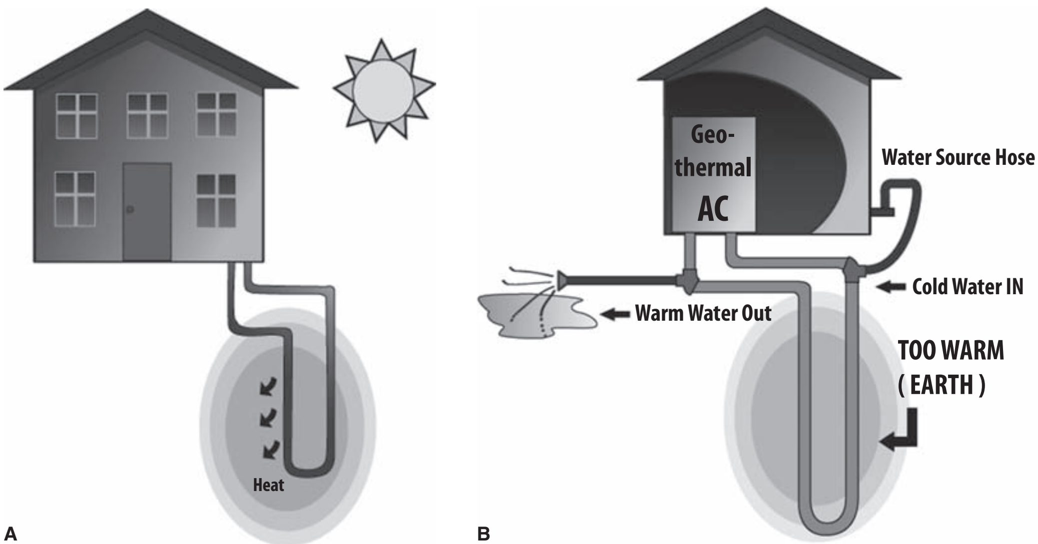


FIGURE 1-15 Thermal creep or thermal retention of the ground loop can cause failure of the geothermal system because of high (or low) incoming water temperatures that are outside the normal capacity of the heat pump. (*Sarah Cheney*.)

After many years dealing with this technology and many interviews with knowledgeable geothermal professionals and facilities managers, the lead author has noticed that thermal retention in closed-loop systems is far more widespread than anyone is aware of (or admits). Most of the time when a building begins to suffer the symptoms of retention, the building engineers come to the conclusion that either the system was designed wrong or the loop is just "worn out." Quietly, the loop is replaced with either a cooling tower or a different equipment altogether.

The tragedy here is that the engineers involved in these problematic jobs choose to avoid geothermal systems altogether after such experiences, and as a result, GHPs are sometimes considered a rogue technology. Open-to-reinjection and standing-column well-type systems have a far greater advantage because the entire aquifer to which they are connected is part of a much larger heat sink. As for anyone who would query the possibility of overheating the aquifer to which you are pumping, you may as well wonder if an air-sourced system would overheat the atmosphere of an entire city or region via the use of a cooling tower. It is as insignificant as a drop of water in the ocean.

Direct-expansion (DX) systems involve running refrigerant piping in much the same way that closed-loop piping is run. The primary differences are the type of tubing used for geothermal DX and the length of the tubing. Direct-expansion systems, by definition, are those where the refrigerant is run directly through the piping that is placed in the ground. The pressures and temperatures associated are extreme by comparison: 0 to 140°F and up to 550 lb/in^2. As such, the tubing must be copper or the equivalent. This is an expensive alternative when compared with the cost of plastic piping (Fig. 1-16), with maximum operations pressures of 160/PSI.

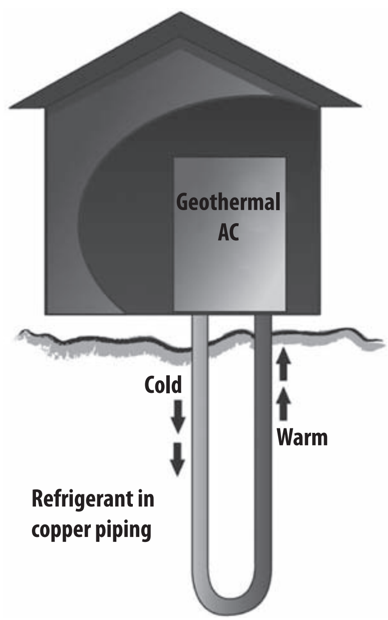


FIGURE 1-16 A direct-expansion (DX) geothermal heat pump involves placing the copper piping directly into the soil and running refrigerant through the copper for the purpose of heat exchange with the earth. (*Sarah Cheney*.)

Summary from David Hoffman, PE

[This chapter will conclude with a summary from a geothermal HVAC industry engineer, David Hoffman, PE. This will give you some things to consider as you go through the remainder of the geothermal and hydronic chapters in this book.]

In my opinion, geothermal heating and cooling are very simple, elegant, and cost-effective applications of the basic laws of thermodynamics and heat transfer. However, the lack of understanding of fundamental principles results in poorly designed and/or constructed systems that may not perform optimally and in many cases may not perform at all. Time after time, one sees these errors and/or miscalculations when conducting peer reviews or troubleshooting a geothermal system. The following is a summary of some of these concerns and remedies, much of which endorses information already included in this book.

Pump Sizing

Pumps are often far too large on installed systems. On inspection of Dr. Steve Kavanaugh's of Alabama State University rating system, one will find that to achieve a grade of "A", the system pump cannot be larger than 5 hp per hundred tons. This requires proper selection of not only the piping but also the flow valves, hose kits, solenoid valves, header piping, and of course, vertical U tubes when using the same.

As an example, in my own home when the driller met with me to discuss the vertical U-tube installation, he indicated that he would be using ¾-in vertical U tubes. I explained that the use of ¾-in U tubes as opposed to 1-in U tubes would increase the pump size from a 214-W pump to a 710-W pump. The additional cost is minimal for 1-in high-density polyethylene (HDPE) piping, yet resulting energy costs would be over 300 percent higher with the smaller pipe. The well driller agreed and installed 1-in HDPE piping, and I installed a 214-W pump. My system has operated for years without any issues and very minimal energy consumption (Fig. 1-17).

Figure 1-17 David Hoffman installed a geothermal HVAC system in his home. Using sensible practices, he has achieved superior energy efficiency with basic geothermal HVAC components. (*David Hoffman*.)

Pump Operation

With the recent improvements in the EER of geothermal equipment, energy use of fluid pumps has become increasingly important. When measuring overall system efficiency, not only the consumption of the actual geothermal heat pump but also the power of the fluid pump must be considered. Earlier designs used constantly operating variable-speed geothermal pumps. Yes, we were saving energy by using the variable-speed drives in conjunction with two-way operating solenoid valves at each heat pump, but the number of operating hours that are considered unoccupied (i.e., holidays, weekends, summers, etc.) are very large in many buildings and especially public schools (Fig. 1-18). Other strategies must be implemented to reduce the total energy use on the fluid pumps.

On recent projects, I implemented a variable-reset "night setback" strategy that allows the heat pump to set back temperatures that are based on the outside air temperature. When the outside temperature is either warm enough or cool enough to aid in heating and/or cooling, one may choose to cycle the system into a standby mode. This results in less heat-pump energy use during unoccupied periods, also reducing the hours of operation of the equipment and extending its life.

Hydronic Specialties

I'm not sure why, but the geothermal residential market has attempted to reduce first cost by implementing geothermal closed-loop designs without basic hydronic specialties. *Hydronic specialties* can be defined as components such as coalescing air separators for air and dirt removal, expansion tanks to absorb thermal expansion of the geothermal fluid, a relief valve to prevent excessive pipe pressure, and other items (Fig. 1-19).

Figure 1-18 Public schools regularly use geothermal heating and cooling equipment. Through proper control of this equipment and associated pumps, greater savings can be attained than currently seen. (*WaterFurnace*.)

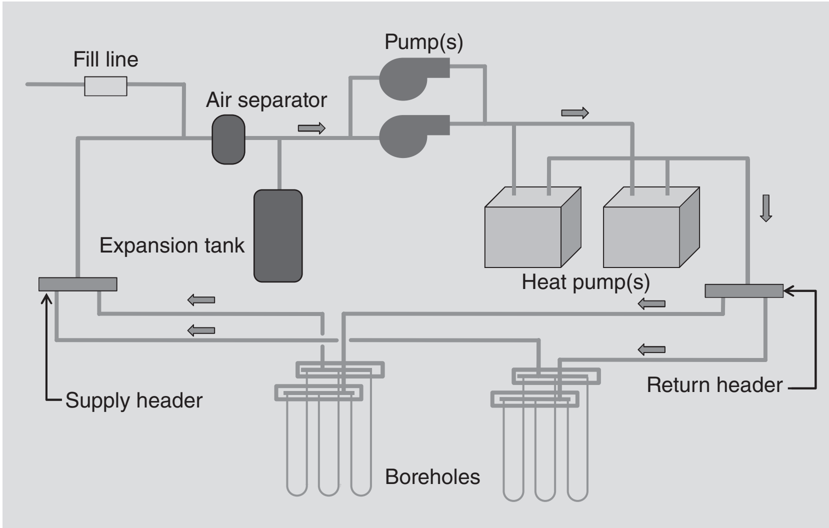


Figure 1-19 Flow diagram of David Hoffman's house. Geothermal and hydronic specialties used with commercial systems also should be applied to residential systems, says Dave Hoffman. This is a hydronic flow diagram of the system installed in his own home. Please note this system was designed specifically for this home, and may not be at fault for other situations. (*David Hoffman*.)

I believe that the size of the closed-loop system has nothing to do with the need to install proper hydronic components. The laws of physics do not change for size and economics. Regardless of whether the system is a 5-ton system or a 100-ton campus, both should be designed with

- A coalescing air separator
- An expansion tank
- A relief valve
- Makeup water with a backflow preventer
- Gauges for easy readout

Water-to-Water Heat Pumps

Water-to-water heat pumps are a great choice for applications that require

- Thermal storage
- Radiant heating
- Snow melt
- Pool heating
- Outside air conditioning
- Similar hydronic loads
- Low space temperature installation, e.g., warehouse

It's important that solid engineering design be implemented in these systems because they may require

- Buffer tanks
- Control valves
- Controllers
- Temperature sensors
- Specialty pumps

All these items add cost and complexity. I have been involved in many projects that involve a correction of improperly applied components in water-to-water systems.

Desuperheaters

Commonly referred to as *hot-water generators*, these devices are a great way to provide domestic hot water or other hot-water needs while at the same time improving the efficiency of the GHP to which they are connected. Desuperheaters are very simple, but if misapplied, they can be the ruin of what would otherwise be a great geothermal system.

Make sure that the desuperheater has another preheat tank large enough to allow the volume of water to absorb the heat that the hot-water generator or desuperheater is providing (Fig. 1-20). Standard residential water heaters are inexpensive, well built, and make great buffer tanks/preheat tanks. When in doubt, use a larger tank, and your client will appreciate the additional energy harvesting because of your generosity.

Commissioning

In addition to testing and balancing, I highly recommend that systems are commissioned. *Commissioning* is the process of "kicking the tires" on a system to verify that everything is operating properly as a system. A 90 percent efficient ECM pump does not save energy if the pump is operating for long hours when the control system should have deenergized it.

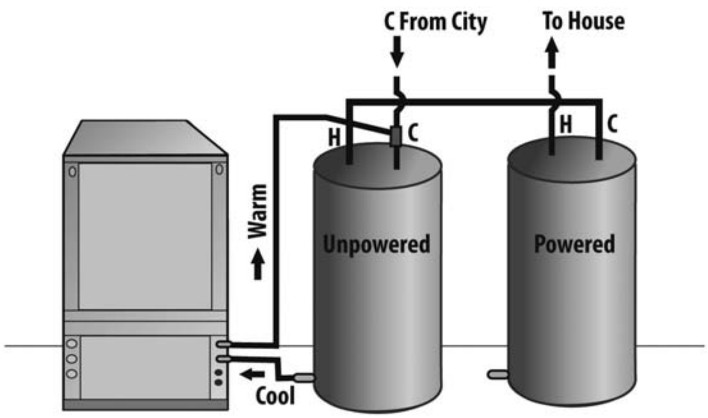


FIGURE 1-20 This is an example of a desuperheater or domestic hot-water generator involves installation of a buffer tank to bridge the gap during the times when the geothermal heat pump is not in operation. (*Sarah Cheney*.)

Dr. Steve Kavanaugh relates much the same results after inspecting dozens of commercial systems with variable-frequency drives. The systems were apparently not commissioned, and the pumps and motors are running inappropriately, too long, and at too high a frequency/speed.

Miscellaneous Efficiency Items

Do not think that a 30-rated EER geothermal system can overcome the problems of poor duct design. Contractors, engineers, consultants and the like *must* think of geothermal HVAC as a "system", not a series of individually efficient components. The recent popularity of ductless technology is partially a result of poor duct design and installation, especially related to leakage. When a geothermal customer is spending about $9000 or more per ton on their system, they will be disappointed to see these unnecessary shortcuts.

Finally, do not overlook the value of using hot gas or other recycling options for applications that require active dehumidification. I've seen many projects such as libraries, auditoriums, and theaters that require active dehumidification, and the designer did not consider "free" hot gas or condenser water reheat and instead used expensive and code-violating electric resistance or hot-water reheat coils. Many manufacturers of geothermal equipment provide systems that can be purchased with factory-installed reheat coils that use compressor waste heat to provide "free" reheat for dehumidification in lieu of "new" energy from a fossil fuel.

Review Questions

1. What percentage of the energy needed to heat or cool a space can be obtained from the earth by using geothermal heating, ventilation, and air-conditioning technologies?
   a. 60%
   b. 90%
   c. 20%
   d. 100%
2. Geothermal HVAC's primary advantages in the delivery of cooling and heating energy are
   a. that it is a primarily air-side technology.
   b. that it delivers more humid air.
   c. that it can be used in baseboard heating.
   d. that it is fundamentally hydronic in nature.
3. The application of geothermal HVAC technologies is more readily accepted in
   a. Asia.
   b. fluid cooling.
   c. heating-dominant climates.
   d. humidity removal.
4. The application of geothermal HVAC products in the cooling mode
   a. is not recommended.
   b. works far better than heating.
   c. has been proven to waste energy.
   d. has the same fundamental efficiency in the heating mode.

5. Geothermal HVAC equipment is ideal for replacing old air-side equipment under what conditions?
   a. When the existing equipment has low efficiency rating.
   b. At the time that replacement of equipment becomes necessary owing to attrition or failure.
   c. When the equipment is hydronic-based.
   d. All of the above.
6. Geothermal equipment can be expected to last longer than standard equipment for which of the following reasons?
   a. It can be housed inside the structure.
   b. It is not subject to temperature extremes.
   c. It is constructed better, to higher standards.
   d. Both a and b are true.
7. Geothermal equipment is not subject to extreme temperature differences because
   a. the temperature of water varies greatly.
   b. it is used in extremely cold climates such as Alaska.
   c. it is coupled with Earth temperature equipment.
   d. both a and b are true.
8. Geothermal HVAC equipment produces a more comfortable environment because
   a. it produces substantial, even abundant heat.
   b. it removes humidity more effectively in cooling mode.
   c. it removes less humidity in heating mode (than gas heat).
   d. all the above are true.
9. Geothermal as it applies to HVAC is more correctly referred to as
   a. geothermal heat pumps.
   b. geothermal heating and cooling.
   c. geoexchange.
   d. low-temperature geothermal.
10. Geothermal swimming-pool heat pumps can save the most energy in
   a. the cooling mode.
   b. the heating mode.
   c. the northeastern United States.
   d. Australia.
11. A geothermal pool heat pump saves more energy than
   a. solar thermal heating.
   b. photovoltaic.
   c. air-source heat pumps.
   d. wind power.
12. A geothermal pool heat pump is often considered favorable to solar heating because
   a. it saves more energy.
   b. it produces more heat.
   c. it heats 24 hours a day seven days a week.
   d. there are no solar collectors.

13. A gas heating appliance cannot possibly be more than 100 percent efficient. A heat-pump appliance can be more than 100 percent efficient because
    a. it is built better than gas heating equipment.
    b. the compressors have a higher efficiency rating.
    c. it does not create heat; it moves and concentrates heat.
    d. it does not have a fan.
14. The average temperature of the earth at a depth of 27 feet in the United States is between
    a. 0 and 100°F.
    b. 62 and 70°F.
    c. 40 and 66°F.
    d. 37 and 76°F.
15. A typical geothermal heat pump can handle source (ground) temperatures between
    a. 30 and 90°F.
    b. 0 and 90°F.
    c. 40 and 100°F.
    d. 25 and 110°F.
16. In a closed-loop application, the ground surrounding a closed-loop heat exchanger system may experience
    a. thermal retention.
    b. thermal extraction.
    c. seasonal temperature exchange.
    d. all the above.

CHAPTER 2

Geothermal Heat-Pump Equipment

This chapter will explore the different types of geothermal heat-pump (GHP) equipment and discuss their strong and not so strong points. Many different brands of geothermal equipment are available to end users. There is good reason to evaluate the different brands of equipment carefully and check the reviews from magazines and testing agencies such as the Air Conditioning, Heating and Refrigeration Institute (AHRI). The AHRI rates the efficiency of the geothermal equipment under Standards 325 and 330. It is a good idea to start with these ratings, but it would not be wise to stop there. That would be like judging a book by its cover (Fig. 2-1).

Some of the other items that need to be considered include the following.

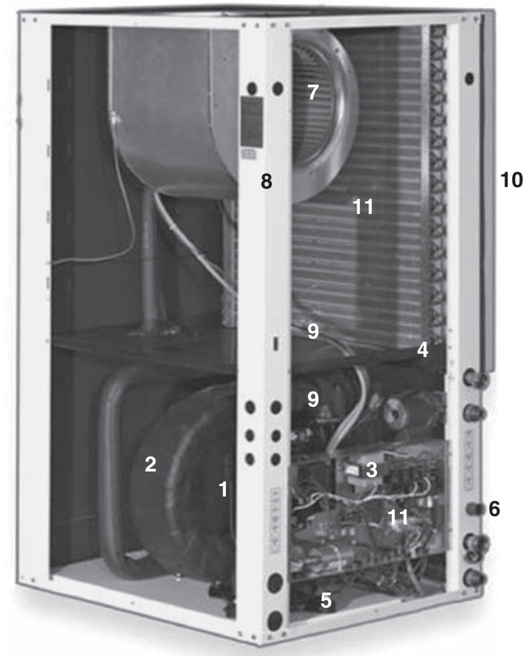
Cabinet Construction

The materials out of which the cabinets are made on a piece of equipment make a difference in the longevity of that piece of equipment. Residential and commercial heating, ventilation, and air-conditioning (HVAC) equipment can rust through in just a few years, especially in coastal applications. Some manufacturers make their cabinets out of G90 galvanized steel; others even make their cabinets out of varying grades of stainless steel or aluminum, as does such as Spectrum Manufacturing.

Sound Levels

The noise level of a GHP is of utmost importance. Remember that a GHP normally has the compressor inside the cabinet. In many other systems, such as split air-conditioning and heating systems, the compressor is outdoors, so it typically doesn't matter as much how loud the compressor is. When upgrading to a GHP system, if the new heat-pump compressor is louder than the old air handler, you will likely hear complaints from the client. Using a quality piece of GHP equipment will alleviate any potential problems associated with equipment selection. A good piece of equipment typically will produce noise levels approaching 50 dB, which is about the sound level of a library.

At one particular residence the lead author personally tested, the sound level with the equipment door open was found to be 49 dB. That piece of equipment was ordered with an ultraquiet package, so always be attentive to the sound requirements of the installation on which you are specifying equipment.



1. Two-stage scroll compressor (pictured behind the support rail)
2. Coaxial coil
3. Control panel
4. Plastic drain pan
5. Compressor isolation
6. Condensate piping
7. Blower and ECM motor
8. Painted steel cabinet
9. Lift-out service access panels (top and bottom, removed)
10. Two inch filter frame with MERV13 pleated air filters
11. ORB control (display panel located on outside access panel)

Figure 2-1 The features of a geothermal heat pump. With so many manufacturers out there, it is important to know the quality and dependability of the product you are recommending. (*Geofinity*.)

Compressor

Typically, two types of compressors are found in heat-pump equipment. They are reciprocating and scroll compressors. Scroll compressors are very quiet but make most of the noise during shutdown. Also, if the scroll compressor is a two-stage compressor, it may be noisier in the first stage than in the second stage. Many manufacturers offer a sound blanket over the compressor in the ultraquiet package.

We are entering into the age of direct-current (dc) inverted equipment. The compressors in these heat pumps are driven by direct current. This type of equipment has been introduced by manufacturers such as Trane, WaterFurnace and ClimateMaster and carries energy-efficiency ratings (EERs) in the high 40s. Much of this equipment has not been released and tested at this point. Further study will be done on this in future editions.

Fan Type

The industry has gone from single-speed fans to electrically commutated motor (ECM) fans. The energy savings from using variable-speed fan motors cannot be understated. Humidity control is improved, and overall comfort levels are improved because of reduced sound levels, reduced convection, and increased humidity control.

As more and more manufacturers get into the GHP manufacturing business, you also will see more and more heat pumps coming out with single- or three-speed fan motors, single-speed compressors, electromechanical controls versus electronic boards, and anything else that can cut and save costs on the equipment. These are the items that separate the premium equipment from the substandard equipment, and they all should be considered when purchasing or specifying a GHP.

Drain-Pan Construction

Drain-pan construction is one of the most important considerations in a GHP because drain pans tend to fail before any other part of the equipment. Plastic or stainless-steel drain pans will last much longer than galvanized drain pans. Drain-pan hose connections are also important. Many manufacturers use clear vinyl hoses, which allow for a clear view of the P-trap and the debris that may be inside the drain line.

Valve Options

Another consideration is the valving and connection options. Most premium brands of GHP equipment will have brass swivel connectors onto which the geothermal condenser water lines can be easily connected without tools. In addition, premium equipment will have the option of installing internal valves and flow restrictors. In this way, the geothermal installation is tidied up and simplified, with most of the controls, valves, restrictors, and specialties having been installed at the factory.

Domestic Hot-Water Options

Domestic hot-water options are available on most lines of GHP equipment. However, you will find that many lines of equipment do not offer a standard domestic hot-water circuit integrated into the GHP. In the opinion of the lead author, this is a mistake because the contractor will not control the domestic hot-water circulating pump properly. With a factory-installed pump and a proper electronic control board, the circulating pump can be controlled in such a way that it will operate within the parameters that the manufacturer has set. For example, you can choose to cycle the pump off at 150 to 125°F, you can choose to disable the pump and can choose to operate it at a lower or higher temperature depending on the situation. There are also situations in which the home owner may choose to disable domestic hot water because it's the middle of winter and he needs all the heated water available for heating his home or business.

Integrated Pump Kits

Many manufacturers offer optional domestic hot-water (DHW) pump kits that are integrated into the GHP equipment (Fig. 2-2). These options often include so-called smart pumps. A smart pump operates not only at variable speeds depending on the ΔT, or difference in temperature of the condenser water loop, but they are also now able to monitor the flow in gallons per minute, which enables the pump to report the total energy that is being extracted or returned to the earth (this will be covered in more detail a little later on). This is the means by which GHPs have come to be considered as renewable-energy equipment under current legislation. With new models of GHPs having the condenser water circulating pumps integrated into the cabinet, and with the ability to monitor actual British thermal unit (Btu) displacement, much of the guesswork has been taken out of the hands of engineers and contractors.

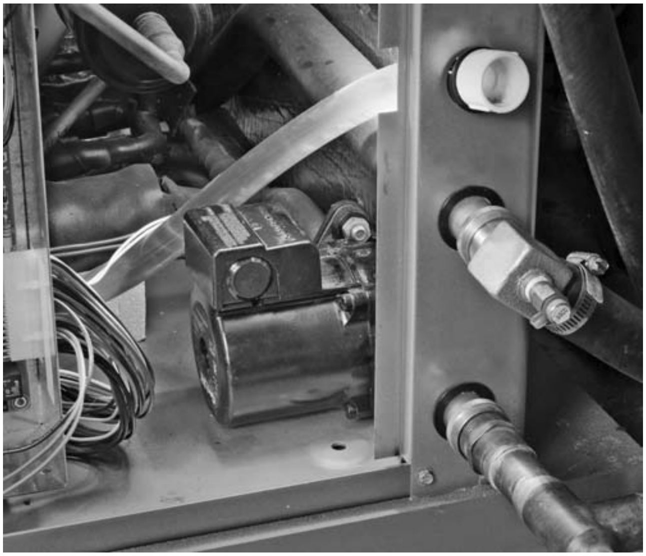


Figure 2-2 Anytime you can integrate factory-installed options into the packaged equipment, you will reduce field mistakes. Additionally, factory-installed pumps, valves, and controls have been proven to reduce energy consumption over field-installed hydronic specialties. (*WaterFurnace*.)

Legislation is coming into the industry that requires electric utility companies to start accepting GHPs as renewable-energy technologies. Because GHPs reduce electrical demand, fundamentally the same as generating renewable energy, the power companies must have a means of actually "reading the meter." Manufacturers and control companies are producing equipment that displays a meter reading of saved energy in kilowatthours compared with a baseline seasonal energy efficiency ratio (SEER) of 13 or a similar minimum standard.

Taco Hydronics, using the electronic iWorX platform, can provide the equipment-monitoring needs for this type of application. Geofinity manufacturing, using its new ORB platform, has the ability to monitor EER coefficient of performance (COP) in real time and data logging with astonishing accuracy. Geofinity was purchased by Modine Manufacturing in the first part of 2012.

Chapter 9 in this book will have more information on GHP specific controls, such as Taco's iWorX platform and the Geofinity ORB.

Flow Restrictors

Many people in the industry, including the lead author, like to see contractors and engineers keep things as simple as possible for each particular application. The lead author has seen the application of higher-efficiency pieces of equipment using multiple stages on which the proper hydronic specialties such as flow restrictors were not installed.

With a two-stage piece of equipment, it is necessary for the water flow to be set to two different rates. Just because a particular manufacturer does not offer integrated flow restrictors for its equipment does not mean that contractors and engineers will

Figure 2-3 Flow restrictors and valves are essential to good system performance. Much energy and resources are wasted when fluid systems are not controlled properly. If possible, use factory-installed specialties. (*WaterFurnace*.)

necessarily install modulating valves and flow restrictors on the outside of the equipment (although this should happen). When proper specialties such as flow restrictors are not installed, the equipment continues to consume a greater volume of water than necessary. Too high of a water flow can also invite water velocity erosion conditions. This is a waste of pumping energy, especially in the first or lower-capacity stage of operation. Depending on the thermostat calibration and setting, the system may stay in the first stage almost continually throughout the entire day, consuming much more pumping power and, in some cases, water than needed. Many professionals in geothermal HVAC technologies find that the efficiency of multiple-stage and variable-frequency-driven, and dc inverter equipment is in question when actually the design of the whole system is deficient (Fig. 2-3).

Solenoid and Proportional Valves

Numerous solenoids or automatic valves are available for controlling fluid delivery to GHP equipment. Among the most popular GHP control valves is the Taco geothermal valve, shown in Fig. 2-4. As with any hydronic system, there are many concerns related to fluid delivery. Volume, or gallons per minute, was just covered; now a word about water hammer and the elimination thereof.

Most of the time, GHPs are installed within the conditioned space. Under such conditions, noise can be a considerable issue. Using a slow-open/slow-close valve that eliminates water hammer and reduces or eliminates water noise through the orifice is of supreme importance.

Some Other Specialties

Various other items are included in certain manufacturers' heat pumps. For example, to keep compressor noise and vibration down, the compressor may be mounted on specialized patented isolation platforms within the unit. Manufacturers often will trap the condensate internally in a drain pan of the heat pump. If the engineer or contractor is not aware of this, this can cause some problems on the installation with regard to double trapping or in not installing a trap at all because the contractor thinks that the equipment is internally trapped.

Most manufacturers use CXM solid-state controls or something similar, in which many of the settings are executed via several dip switches (Fig. 2-5).

Figure 2-4 The Taco orange-top geothermal valve has been a favorite for decades. Taco valves and pumps are regularly factory-installed equipment standards and options. (*Taco*.)

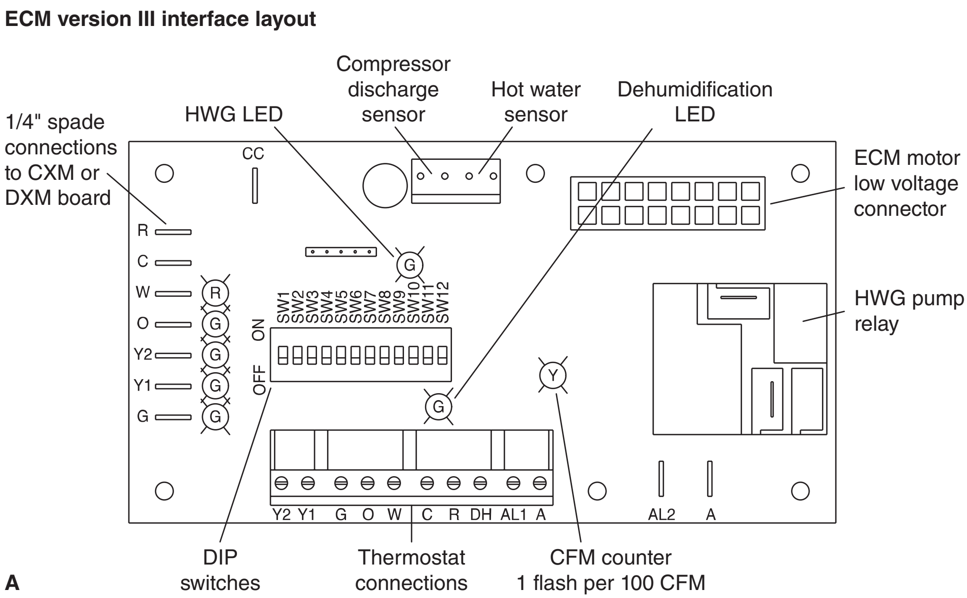
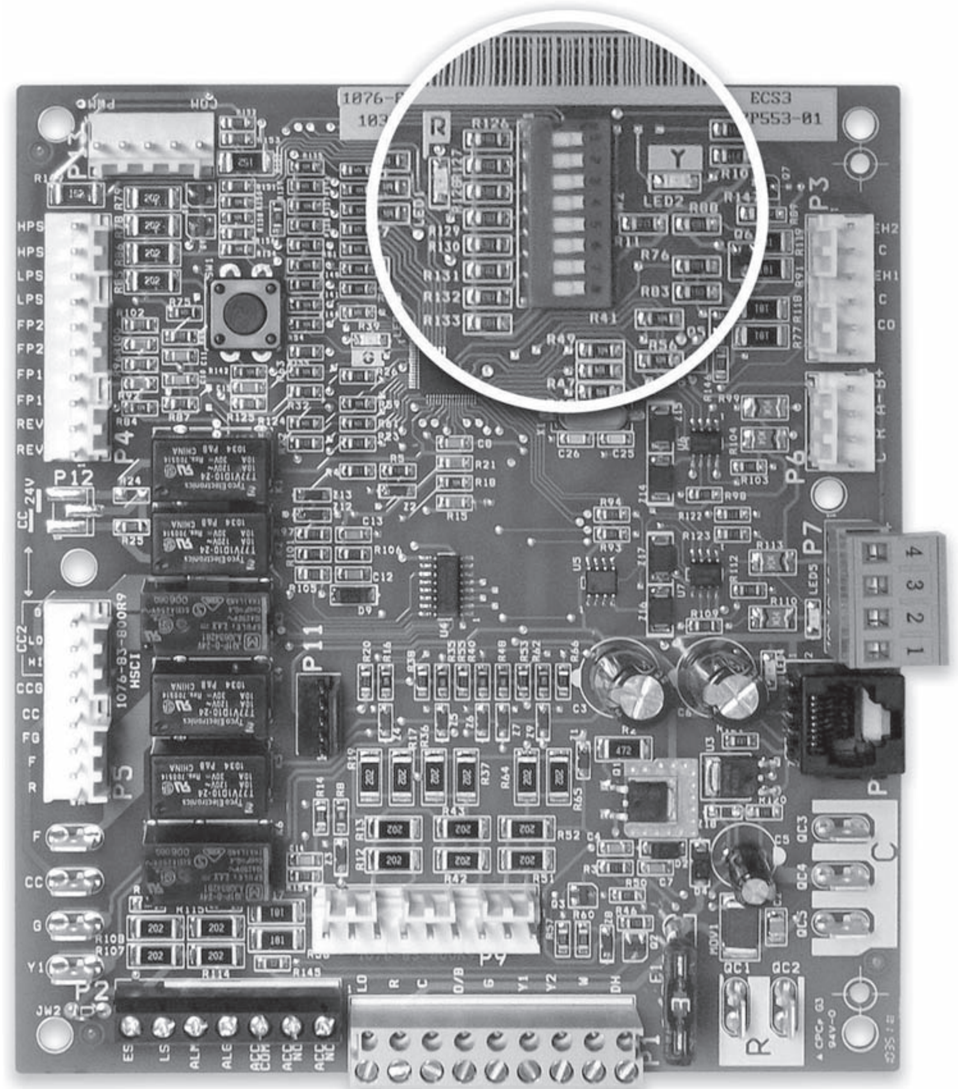


Figure 2-5 Dip switches must be set to correlate with the controls and circumstances in each and every situation. It is important that the engineer/designer stipulate the dip-switch settings for the field contractor installing the system. It is not hyperbole to say that 80 percent of all multistage ECM GHPs have not been set properly. This is an unfortunate waste of energy and resources. (*WaterFurnace and ClimateMaster.*)



B

Figure 2-5 (*Continued*)

Filters can be either integrated into the GHP equipment or field-engineered into return-air plenums or return-air grills. Often an additional filtration system is added, such as a Honeywell electronic product.

Superefficient DC Systems

In his first book, *Geothermal HVAC: Green Heating and Cooling*, the lead author had a small section entitled, "Superefficient DC HVAC." The section began like this:

"Okay, we have geothermal heat pumps that now achieve energy efficiency ratings of 30. Can we really go higher? I'm glad you asked because I have another story about that." The section went on to talk about the lead author's father's electronics shop, full of gadgets, motors, and wires. The lead author explained that among the jumble was a powerful alternating-current (ac) to direct-current (dc) rectifier about the size of a 20-in TV. On this rectifier was a myriad of potentiometers, dials, and switches. To a 10-year-old boy, this was fascinating. The lead author then issued a warning to all children and pets about electronic devices of any kind and rescued himself from any entanglements with People for the Ethical Treatment of Animals (PETA).

The section went on to talk about how it is that the lead author was able to figure out a lot about the limitations of alternating current. To make it simple, he explained a little bit about how ac works and then compared that with the dc devices powered by batteries, as well as photovoltaic and fuel cells. He pointed out that it's easy to vary the voltage on a dc device and a little more difficult to do so on an ac device. On ac it's difficult to vary the frequency rather than the voltage itself.

There is a type of motor called a *universal motor* or an *ac/dc motor* that will run on ac or dc (usually the dc voltage required is lower than the ac voltage required). These motors are popular for tool applications because they also happen to be very powerful for their size and weight. A typical 15-V universal motor will run just as well on about 30 V dc.

The lead author was fascinated with the capability of these motors when used with dc. He found that he could drop the speed down to about 25 percent or less of its ac rated speed and run it right up to nearly twice the speed that it would run on the rated voltage for ac.

So here was the point of that section: The lead author stated that the world would be seeing air conditioners that use the same type of technology. They'll be quieter, they'll have variable-speed compressors and fan motors, and they will come with all the bells and whistles you can want. Imagine having only two residential sizes from which to choose. Temperature variations will be gone because the unit will run most of the time at exactly the speed it needs to run to keep the home or business at exactly the temperature desired. And the great part is the efficiency. The lead author said that these devices were going to be in the 40 EER range or better for a seasonal average.

Well, that was in 2010. ClimateMaster has just introduced the ultraefficient Trilogy 40 series. These systems use a patent-pending technology that provides an annual EER of 40 or better. What's even more amazing is that at groundwater test conditions, the EER approaches 50. WaterFurnace has introduced the 7 Series line, and Bosch and Trane are introducing a similar line of equipment.

Ideally, this type of system will operate continually during the times when either heating or cooling is needed in the structure. Much like the cruise control on a car, it will operate at exactly the speed and capacity needed at that time.

To be sure, many people have wondered about this type of system because they have been in buildings that had temperature swings of two or more degrees. Once again much like the cruise control in a car, this is a much better design to modulate using a PID loop and either a variable-frequency drive or dc-driven motors to use just the right amount of energy to operate the compressor, pumps, and fans (Fig. 2-6).

FIGURE 2-6 Variable-speed compressor and an ECM variable fan motor are the heart of the superefficient variable-speed GHPs being introduced in 2012–2013. (*WaterFurnace*.)

Equipment Orientation

When speaking of equipment orientation, among the most important applications is the water-to-air heat pump. Among the choices you will have with regard to airflow are

1. Right return or left return
2. Bottom discharge or top discharge
3. Access panel location
4. Electrical box location
5. Geothermal/plumbing location

Although these are just a few of the options (Fig. 2-7), they give you a good idea of the infinite number of configurations from which you can choose for GHPs.

Beyond this, the number of things from which you might choose to specify a piece of equipment, includes the following options:

1. Refrigerant type
2. Microprocessor
3. Fan motor
4. Water valves
5. Thermostatic expansion valve (TXV)
6. Compressor isolation
7. Field-convertible option
8. Condensate overflow
9. Cupronickel exchanger

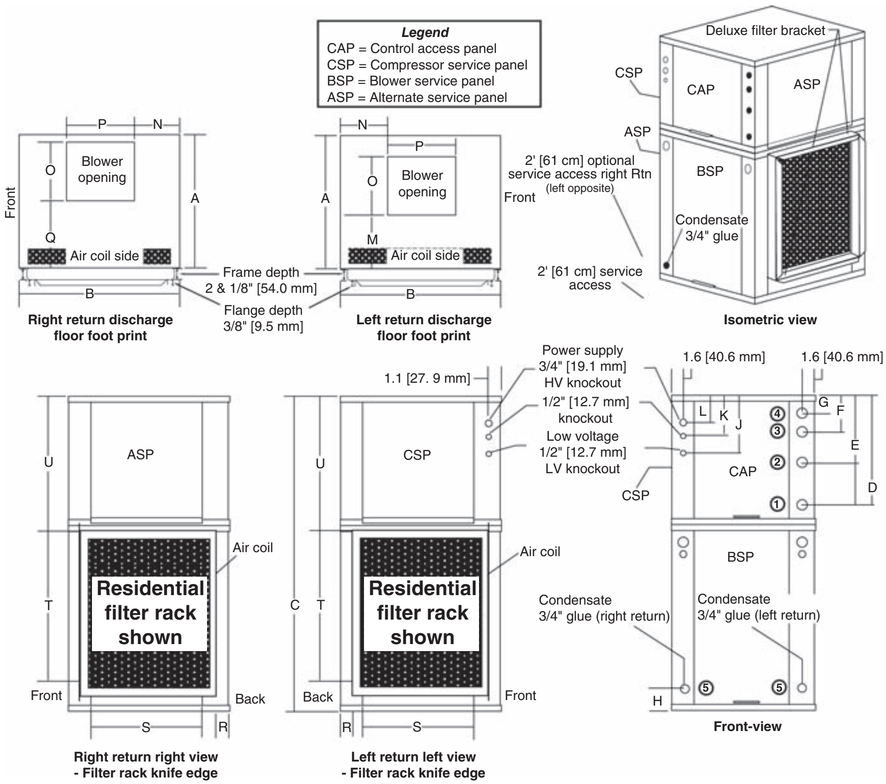


Figure 2-7 These are the orientation options for a vertical water-to-air GHP. This is just the beginning of the selections you will make for the geothermal equipment you integrate into each project. (*ClimateMaster*.)

10. Autoflow water regulation
11. Internal secondary pump
12. Coated Evaporator
13. Internal safety disconnect
14. Reheat for dehumidification

There are many more options than just these listed and depicted (Fig. 2-8).

Direct-Expansion Geothermal Heat Pump

Direct-expansion (DX) GHPs were covered previously and will be covered further here in this chapter. The basic premise of a DX GHP is that rather than being a water-source heat pump (i.e., a heat pump that uses water as the exchange medium), the DX GHP engages the use of the refrigerant lines directly in the earth for the process of geothermal exchange.

UNIT FEATURES

Product Series	Standard Features															Factory Installed Options															
	EarthPure® (HFC-410A) Refrigerant	Microprocessor CXM Controls *	iGate™ Advanced Control	ECM Fan Motor	Extended Range Capable Refrigerant Circuit (20°F to 120°F)	Copper Water Coil **	Modulating Water Valve ‡	TXV	Dual Level Compressor Vibration Isolation	Field Convertible Discharge (Horizontal Units)	Multiple Access Panels for Installation and Service Ease	Scroll Compressors	Factory Installed Hanger Brackets (Horizontal Units)	Remote Reset at Thermostat	Condensate Overflow Protection	Cupro-Nickel Coil **	High Static Blower	UltraQuiet (Mute) Package	Extended Entering Water Temperature Insulation ***	Auto-Flow Water Regulation	Two-Way Control Valve	Downflow Configuration	Desuperheater Coil	DDC Controller	DXM Controller *	Coated Air Coil	Internal Secondary Pump	ECM Fan Motor	ClimaDry® Reheat	Internal Service Disconnect	vFlow™ Internal Variable Water Flow
Tranquility® 30 Two-Stage (TT)	•	•		•	•	•		•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•		•	•	
Tranquility® 20 Single-Stage (TS)	•	•			•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Tranquility® High Efficiency (TR)	•	•			•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•		•		
Tranquility® 16 Compact (TC)	•	•			•	•		•	•	•	•	•	•	•	•	•	•	•	•					•	•	•					
Tranquility® High Efficiency Two-Stage (TZ)	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•				•	•		•	•				•
Tranquility® 22 Compact Two-Stage (TY)	•		•	•	•	•		•	•	•	•	•	•	•	•	•		•	•					•		•					
Tranquility® Vertical Stack (TRM)	•	•			•	•		•	•			•		•	•	•		•	•	•	•			•	•	•	•	•		•	
Tranquility® Console (TRC)	•	•			•	•		•						•	•	•		•	•	•	•			•	•	•	•			•	
Tranquility® Compact Belt Drive (TC)	•	•			•	•		•	•	•	•	•	•	•	•	•	•	•	•					•	•	•					
Tranquility® Large (TL)	•	•			•	•		•			•	•		•	•	•	•	•	•	•	•			•	•	•	•		•		
Tranquility® Water-to-Water (TMW)	•	•			•	•		•	•		•	•		•		•		•	•				•	•	•						
Rooftop (TRE)	•	•			•	•		•	•		•	•		•	•	•	•		•	•	•	•		•	•	•	•		•		
Rooftop (TRT)	•		•		•	•		•	•		•	•		•	•	•	•		•	•	•	•		•	•	•	•		•		
Rx Energy Recovery Ventilator (ERV)					•						•																				
Vertical Dedicated Outdoor Air (TOV)	•				•	•		•			•	•						•	†					•		•					
Horizontal Dedicated Outdoor Air (TOH)	•				•	•		•			•	•					•		†			•		•		•					

Figure 2-8 There is an abundance of options and accessories available to make your job easier as a designer/engineer/contractor. Take the time to know the project for which you are designing, and choose the right options. (*ClimateMaster*.)

The premise seems solid, and most engineers would argue that there is a step in the heat-exchange process that is eliminated through the use of refrigerant piping directly in the earth. This same argument is used to some degree in the promotion of variable-refrigerant-volume systems. However, the lead author has had experience with these systems leaking refrigerant, and although R410a is an environmentally friendly refrigerant, it is also an expensive refrigerant, and like any other refrigerant, it displaces oxygen.

These two issues are both prohibitive in many situations. The first situation the lead author would like to address is that of the expense of the refrigerant. An average 5-ton DX GHP will need 600 ft of copper tubing in the ground. This is accomplished by drilling a 300-ft hole, inserting the tubes with a bend at the bottom, and grouting the hole back up to the top. Such systems can require hundreds of pounds of refrigerant. Refrigerant R410a costs about $6 a pound in wholesale. It's not uncommon for a system to have more than $1000 worth of refrigerant contained within the piping system (Fig. 2-9).

The second issue involves finding the leak, which can be especially disconcerting if it is underground. In addition to these concerns, loss of refrigerant oil volume is a difficult thing to ascertain, causing a degree of uncertainty.

In addition to the cost of the refrigerant and the difficulties related to leakage, refrigerant is a heavy gas that can cause displacement of oxygen and result in suffocation. This obviously is not a concern outside in the open air, but it becomes a concern inside a building at the air handler. The lead author would not be surprised if you asked why would be it any more of a concern than a standard split system, of which many millions are installed. The answer once again goes to the volume of refrigerant in a geothermal DX GHP system versus a standard DX system. A standard DX system may have

Figure 2-9 This direct-exchange GHP system, installed in Kissimmee, Florida, uses a copper exchanger and contains refrigerant that provides the heat exchange necessary for the cooling and heating of the residences in the development. Although the condenser is placed outside, it also could be placed inside the structure because it requires no condenser fan ventilation. (*EggGeothermal*.)

10 to 30 pounds of refrigerant within the piping. A geothermal DX system may have many hundreds of pounds of refrigerant within the piping. This being the case, if the evaporator coils or the air-handler unit leaks inside the building, there is may be enough refrigerant to displace the oxygen in the dwelling or business.

A close business associate of the lead author tells the story of working on just such a system (meaning a DX refrigerant system) in which, during a part change, refrigerant was released. Normally, in this type of situation, there is not enough refrigerant in the system to displace the oxygen in the average room. In this particular situation, the engineer and his coworker were overcome within seconds. Somehow the fire alarm was set off, which woke the engineer up, and he was able to drag his coworker to safety. A designer should refer the ASHRAE Safety Standard 15 for refrigerant safety Requirements.

It is a fundamental belief that a factory-sealed self-contained heat pump or air-conditioning system is going to be the most dependable piece of equipment around. Using water or antifreeze as a medium for heat exchange, whether in the building or in the earth, is a much simpler and safer approach.

Commercial Chillers, Geothermal-Sourced

Many engineers prefer chilled-water systems. There are many reasons for this, not the least of which is that fan coils have fewer parts to fail than GHP equipment and greater capacity control. There are several different ways to adapt chilled-water/heated-water systems. The first and most common is through the use of a

Water-to-water heat pumps | Chiller plant

FIGURE 2-10 A common sight to most HVAC professionals is that of a central plant chiller depicted here. These chillers can be reverse cycle, allowing them to form the job and/or cooling the structure through chilled/heated hydronic lines to the various fan coils in the building. (*EggGeothermal and WaterFurnace*.)

geothermal-sourced central chiller, as depicted in Fig. 2-10. Normally, in such situations, as in any HVAC application requiring some degree of redundancy, the system will have at least two chillers rated for about 60 or 70 percent of the system's full load capacity. The purpose of this is simply to reduce the possibility of the building being completely down and in need of cooling or heating.

It is important to note at this point that although it is relatively uncommon, chillers can operate reverse cycle, or as a heat pump. Normally, a chilled-water system is hooked in with a cooling tower, as shown in Fig. 2-11.

In this situation, the heating mode can be achieved only through implementation and use of a boiler. This is so because a cooling tower is designed only to cool the condenser water for the chiller. It has no source of heat when the building is in need of heat and the outside temperatures are approaching freezing.

When this same chiller employs a geothermal or earth-coupled source, the same source that provides a heat sink is also the source that will provide heat. Remember, the temperature of the earth is between 37 and 76°F. This is plenty of heat for any reasonable application in this source of water.

In much the same way, rather than a single, larger chiller, a bank of smaller chillers can be manifolded together. In Fig. 2-10, you can see several 30-ton water-to-water chillers providing hundred tons of cooling and heating capacity. Among the benefits are high efficiency ratings and supreme redundancy capabilities. It is highly unlikely that more than one or two of these systems would go down or suffer mechanical problems on any given day. Undoubtedly the capacity loss would not even be felt by the building being served.

Variable-Refrigerant-Volume Systems

Variable-refrigerant-volume (VRV) systems are intended to provide the same versatility as a chilled-water system, in that they typically have one compressor, or heart of the system, and many fan coils or final air-delivery devices. Variable-refrigerant-volume systems and hydronic/chilled-water systems are similar in that they use a liquid

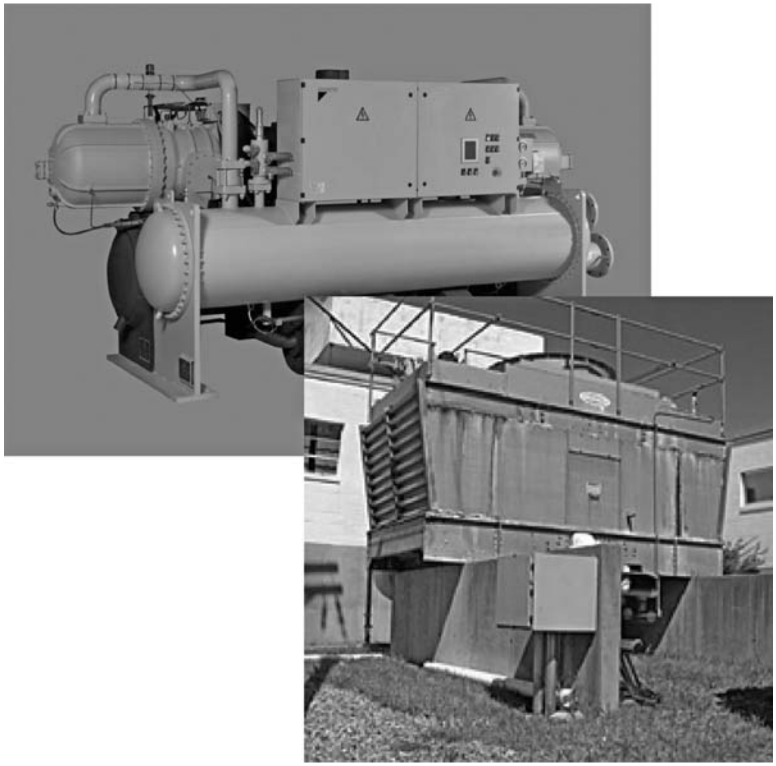


Figure 2-11 Typically, a chiller is paired with an evaporative cooling tower such as this. When a cooling tower is used, there is necessarily a boiler to provide a heating source for the hydronic system. Geothermal source options can eliminate the need for a boiler in the HVAC system. (*EggGeothermal*.)

medium to move Btu around a building to do the job of cooling and heating. However, there are significant differences.

The primary difference between a chilled-water system and a VRV system, besides the medium of heat transfer (water versus chemical refrigerants), lies in some of the challenges involved in the phase change of the refrigerant liquid. While the chilled-water system maintains a liquid state throughout the entire process circuit, a VRV system uses phase changes to perform its work, just like a DX air-conditioning or heating system. The difficulties surrounding this in the past have involved controlling the volume of refrigerant at varying loads to prevent compressor damage and overloading.

A refrigerant evaporator or condenser coil is designed to evaporate or condense a specific volume of refrigerant at a specific temperature and rate. If too much or too little refrigerant is supplied to any individual coil, it will not operate properly; it will freeze up, overheat, overcool, or starve. Often systems experience a life cycle of about 6 to 10 years, far below the life cycle of the products of most geothermal manufacturers such as WaterFurnace, ClimateMaster, Geofinity, Bosch, Spectrum, Trane and others.

Figure 2-12 shows that a VRV system can be adaptable and favorable to larger structures with lots of zones. In addition, less refrigerant needs to be delivered to the

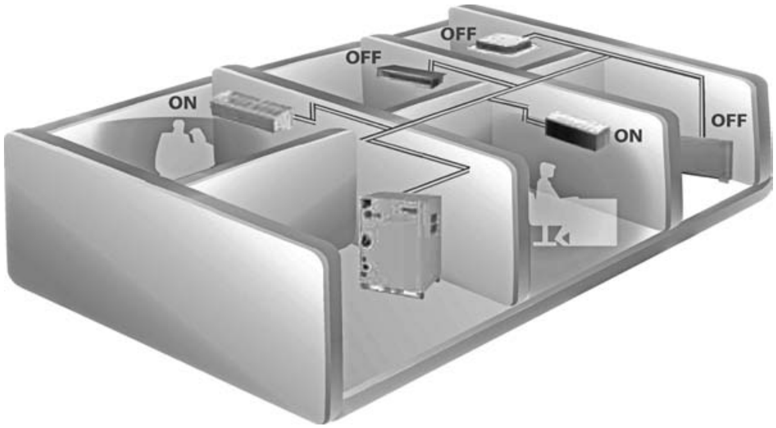


Figure 2-12 A variable-refrigerant-volume system has diversity in serving buildings with multiple loads. Such systems can be effectively geothermal-sourced. However, they show no improvement over standard hydronic systems increasing complexity. (*Daikon*.)

building overall when only a couple of zones need cooling or heating versus the full load, which would result in the need for full-capacity operation.

This is accomplished by using a VRV compressor with smart controls to anticipate the need for more or less capacity. Some of the pluses for the system include very small and lightweight evaporators (fan coils) that can fit just about anywhere such the cassette-style unit shown in Fig. 2-13 that can be installed in a ceiling. It is important to note that this style of evaporator also can be purchased for just about any GHP system but seems to be more prevalent in VRV systems. Many professional believe that caution should be exercised when considering VRV systems. Replacement parts are often very hard to come by, and the equipment becomes obsolete within a shorter period of time.

Summary

There are positives and negatives to every type of geothermal system mentioned in this chapter. Some of the issues are outlined below:

1. First cost
2. Complexity
3. Redundancy
4. Safety
5. Operation and maintenance
6. Energy efficiency

As you work your way through this book, it will become more apparent and easier to discern the importance of each of the issues mentioned. Although it may seem that each situation has a perfect answer, you'll find that there are many right answers. It will become your responsibility not just to choose a good solution or even a better solution but to choose the *best* solution.

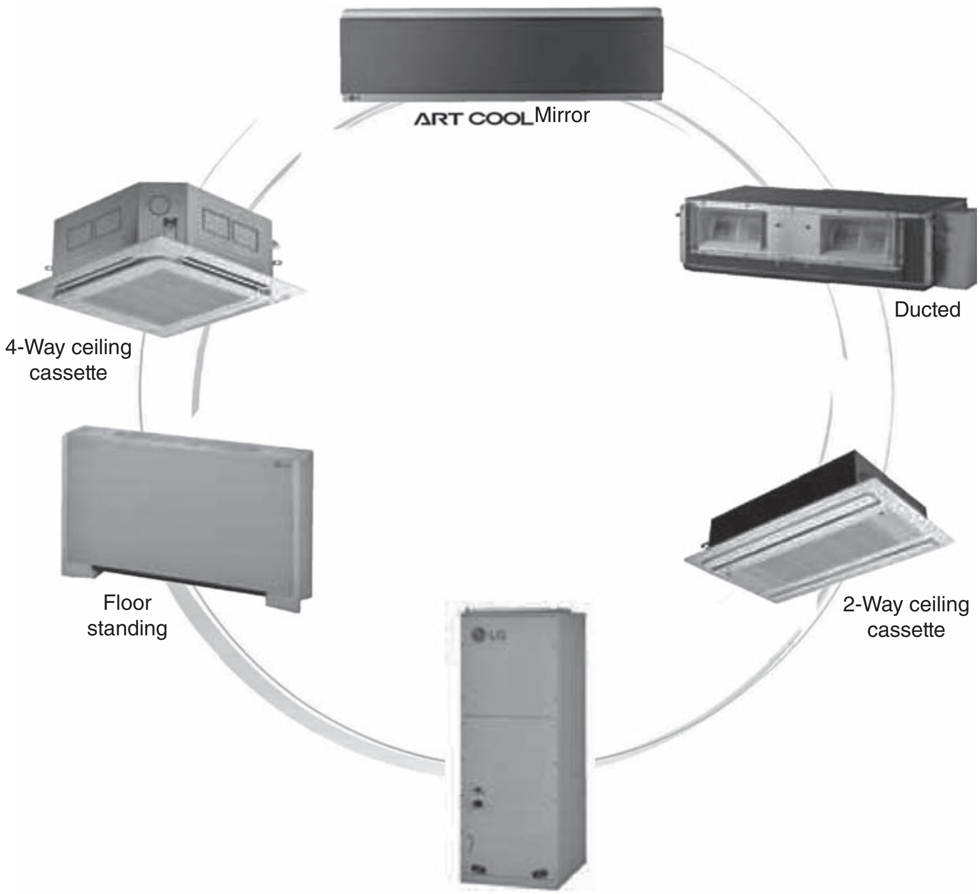


Figure 2-13 In buildings with limited space, there are several evaporator options that may be considered. The same configurations are available for hydronic/geothermal applications. (*Daikon*.)

Engineers sometimes become so wrapped up in the desire of their clients to find the least expensive solution that they forgo the best solution. About 15 years ago, the lead author lost the opportunity to contract an entire shopping center for a customer. This came after he installed a "good" HVAC system in one of the customer's retail stores. After the walk-through, which confirmed the more than ample quality of the installation, the owner asked if there was a better product available, efficiency-wise. When he was informed that there was a better product available for about 80 percent more, he was bitterly disappointed that that option was not presented to him at the point at which he could've made the decision. The customer never used the lead author's services again.

Always, always offer what you believe to be the best product at the best price. You can always value-engineer down from that point.

Review Questions

1. Of the following items, which would *not* be a consideration applicable for specifying a piece of geothermal HVAC equipment?
   a. Equipment first cost
   b. Energy efficiency
   c. Operation and maintenance cost
   d. The country in which it was manufactured
2. When specifying a geothermal HVAC system to a potential client, which of the following is the *least important* item to consider?
   a. The best product available
   b. The simplest design
   c. Operation and maintenance costs after installation
   d. The least expensive system possible
3. When upgrading a building with a cooling tower to a geothermal source,
   a. the boiler size must be increased.
   b. pipe sizing must be changed to the water-source equipment.
   c. condenser-water temperatures typically will increase.
   d. efficiency and longevity will increase.
4. Variable-refrigerant-volume systems with a geothermal source
   a. operate at lower efficiency ratings than condenser-water systems.
   b. can operate very effectively at high efficiency ratings.
   c. may use chilled water as a heat-exchange medium.
   d. are never considered.
5. Direct expansion geothermal heat pumps
   a. use a copper geothermal exchanger deposited directly into the earth/soil.
   b. are not available for pool-heating options.
   c. use less refrigerant than their water-source counterparts.
   d. cannot be used commercially.
6. Application of a central-plant chiller to a geothermal source
   a. is typically more efficient than a series of geothermal heat pumps.
   b. reduces the need for piping insulation.
   c. should be considered with reverse-cycle operation for heating.
   d. still must have a cooling tower applied.
7. The operation of fully variable dc geothermal heat pumps
   a. reduces the number of models needed capacity-wise.
   b. eliminates the need for ductwork.
   c. will operate fine on a standard thermostat.
   d. must be installed outside the structure.
8. The use of integrated pump kits in manufacturer's equipment
   a. increases the cost of the equipment installation.
   b. makes the use of domestic hot-water generators difficult.
   c. helps utilities and legislatures monitor actual Btu displacement.
   d. adds a component of complexity that is not desired.

9. Selection of the appropriate solenoid valve
   a. can reduce pumping energy consumption.
   b. can increase energy efficiency.
   c. reduces equipment noise.
   d. results in all the above.
10. According to the AHRI,
   a. geothermal closed-loop applications have a higher EER.
   b. geothermal groundwater applications do not qualify for Energy Star.
   c. geothermal groundwater systems have a higher coefficient of performance (COP).
   d. geothermal cooling should not be considered.
11. Condensate drain-pan construction
   a. is a low priority for consideration on GHP equipment.
   b. should be stainless steel or plastic or other corrosion proof material.
   c. should not use clear hose connections.
   d. involves all the above.
12. Geothermal heat pump sound levels
   a. are of little importance because the equipment goes in the mechanical room.
   b. are always higher than their fans—only counterparts.
   c. are important to consider in each and every case.
   d. may be in the range of 50 dB.
13. Manufacturers of GHPs must
   a. ensure that their equipment meets federal Energy Star ratings.
   b. be rated by the AHRI.
   c. produce products that are all about the same quality.
   d. none of the above.

CHAPTER 3

Variations in Earth Coupling

As we delve into this chapter on variations in earth coupling, you should keep an open mind to the limitless possibilities (Fig. 3-1). Whatever you can conceive, it will likely be touched on in some way in this chapter. The purpose of this particular chapter is to open our collective minds to the infinite combinations of possibilities when earth coupling geothermal systems. Intermingled with this you will find a healthy dose of cautionary situations. It seems that the problem that is pressing most on the industry at this time is the need to move on from past mistakes, but with an open mind.

Three popular earth-coupling methods are most commonly employed throughout the geothermal industry (Fig. 3-2). All three options take advantage of the virtually limitless renewable energy that the earth provides. Each of these methods has advantages and disadvantages; they are discussed in the following sections, and no one method is superior to another. The designer must always consider the local site geology and the annual heating and cooling ratios.

To best understand these options, first consider the general approach to taking energy *from* or returning energy *to* the earth. During the winter months, we extract stored solar energy that resides in the earth. Approximately 50 percent of the solar energy that strikes the earth is stored in the waters of the earth, either open waters or waters trapped between earth particles. In the summer, the relatively cool earth serves as a convenient sink for the excess energy from our homes and buildings. In winter, the relative warm earth and rock provide a stable, relatively warm energy source.

Closed loops depend on an intermediate piped antifreeze solution between the earth and geothermal heat pump circulating to and from the earth exchanging energy. In winter, a cold-return antifreeze solution will make the earth *energy* flow *toward* the well bore, warming the solution. The opposite energy flow occurs in the summer. Nothing physically moves in the earth only molecule-to-molecule *conductive* energy transfers.

Standing columns depends on well water flowing between the earth and the geothermal heat pump to transfer conductive energy in rock. This method is designed as conductive heat transfer but also is designed to periodically augment the energy transfer by physically moving small amounts of stable earth-temperature water into the bore hole. This stable-temperature water is typically located only 40 to 50 ft away from the bore. Whereas the standing-column well is designed around *conductive* energy transfer, it also takes advantage of the *advective* energy transfer (see below), the best of both close and open earth-coupling methods.

Open-to-reinjection earth coupling methods simply take advantage of the stable groundwater temperatures throughout rock fractures or in porous earth and depend solely on the *physical movement of the water* flow into the borehole. High-yield wells and

Figure 3-1 Prepare to be immersed in the wide and varied ways to tap into the earth's stable temperature for the purpose of heating and cooling. (*David Hoffman*.)

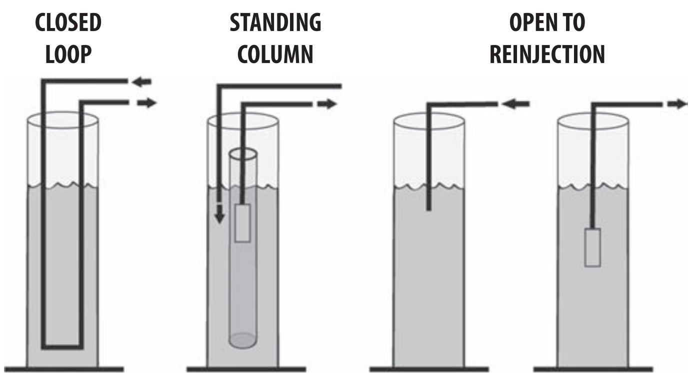


Figure 3-2 The three main methods of earth-energy heat transfer are closed loop, standing columns, and open to reinjection.

a responsible method of returning the uncontaminated water to the earth are required. This method is also known as a *doublet* earth coupling. This flow is known as an *advective* energy flow, physically moving through the soil and rock fractures.

Let's take a more comprehensive and comparative look at each of these three basic methods and, where appropriate, look at some of their variations. All three options—closed loop, standing column, and open reinjection—take advantage of the virtually limitless renewable energy that the earth provides. Each of these three methods has advantages and disadvantages, and they are discussed in this and subsequent chapters.

To best understand these options; first consider the general approach to taking energy *from* or returning energy *to* the earth. During the winter months, we extract stored solar energy that resides in the earth. Approximately 50 percent of the solar energy that strikes the earth is stored in the waters of the earth. In the summer, the relatively cool earth serves as a convenient heat sink for the excess energy from our homes and buildings.

Closed loops, either horizontal or vertical (as shown in Fig. 3-3), depend on an antifreeze solution in plastic piping returned to the earth to exchange energy. The average northern-tier earth temperature is 50°F—in winter, a cold 30°F return antifreeze solution will make the earth energy flow *toward* the well bore (*conductive flow*), warming the solution.

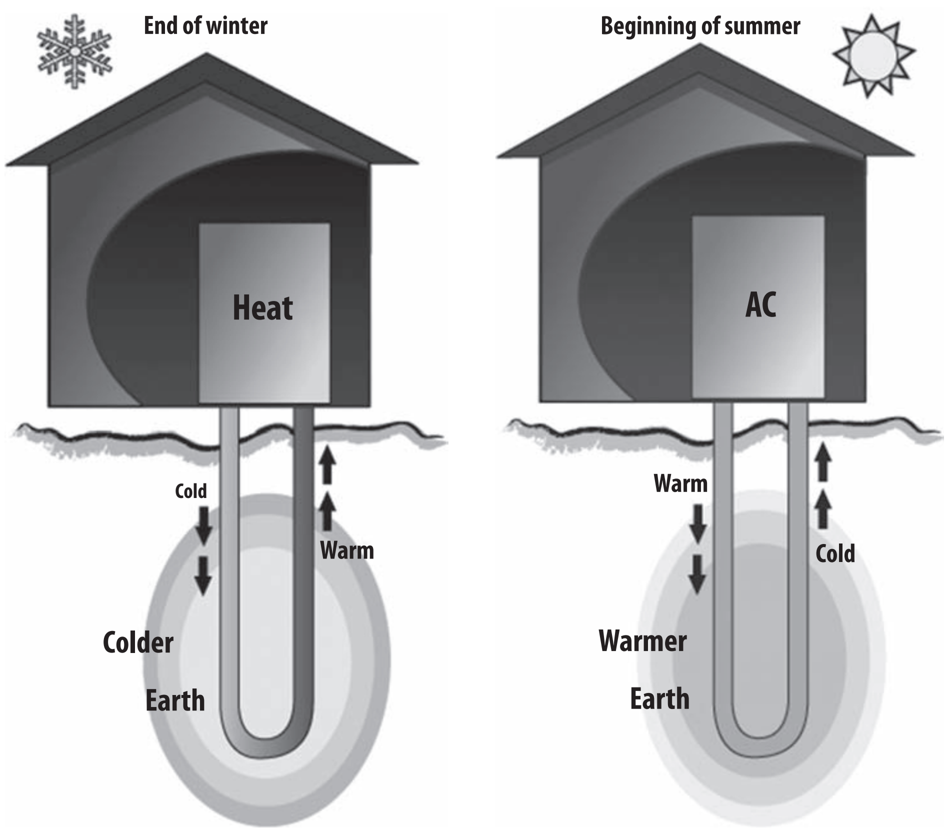


Figure 3-3 Closed loop: Heat is transferred to and from the earth to the heat pump. Closed-loop systems uses conductive heat transfer. (*Sarah Cheney*.)

The opposite energy flow occurs in the summer. Note here that energy moves from molecule to molecule; nothing physically moves in the earth, although there are many different types of closed-loop applications.

- Vertical
- Horizontal
- Pond loop

In this chapter we will focus only on vertical systems as they apply to closed-loop systems. These are generally accepted as the most effective and efficient systems in the closed-loop realm. Chapter 5 will further describe and expand on closed-loop designs and applications.

Pond-loop systems are a variant of closed-loop systems because the piping is placed directly into surface bodies of water such as ponds, rivers, lakes, and oceans. These can be installed in many creative ways and in many fashions with a number of different materials. As with all closed-loop systems, it is highly recommended that a material be used that will not biodegrade. The most commonly accepted material is high-density polyethylene tubing/piping, although applications with water moving over the heat-exchanger pipes may not be acceptable.

Standing columns likewise take advantage of the conductive heat transfer but also augment their energy-transfer capability simply by moving small amounts of stable earth-temperature (50°F) water; this is *advective* flow (Fig. 3-4). This stable-temperature water is typically located only 40 to 50 ft away from the bore. Northern-tier earth temperatures are in the 48 to 53°F range. Midcontinent loop temperatures enjoy 53 to 65°F

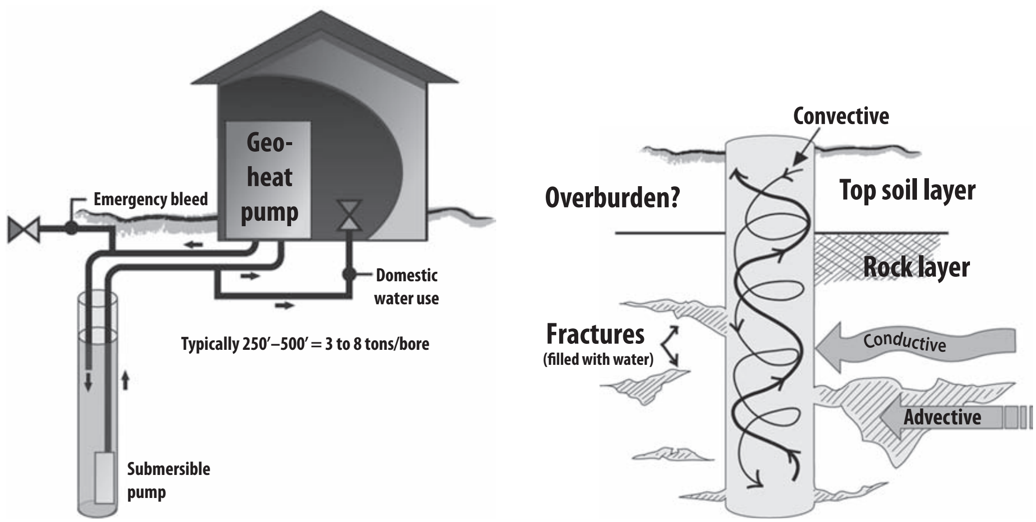


Figure 3-4 Standing-column wells use conductive and advective heat transfer. In a standing-column well system, 60 to 80 ft/ton of borehole is typically required with a 10 percent periodic bleed. A bleed line is favorable. (*Sarah Cheney*.)

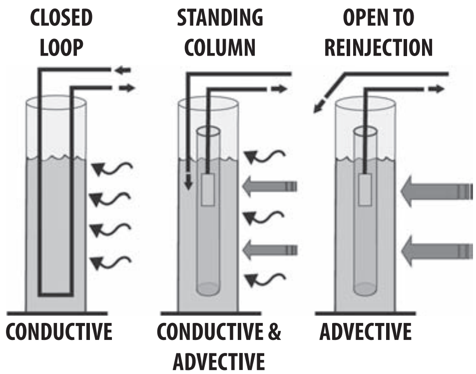


FIGURE 3-5 Open-to-reinjection systems use advective heat transfer.

average earth temperatures year round. Southern-tier earth temperatures are as low as 65 to 73°F and can have summer peaks of over 80°F.

Open-to-reinjection earth-coupling methods simply take advantage of the stable groundwater temperatures within rock fractures or in porous earth and depend solely on an *advective* flow into the borehole. High-yield wells and a responsible method of returning the water to the earth are required. This method is also known as a *doublet* earth coupling. Note here that the energy actually and physically moves with the movement of the water through rock fractures and between grains of sand—an important distinction between *conductive* and *advective* energy transfer (Fig. 3-5).

As geothermal heat pump (GHP) applications grow, each of these generalized methods has developed variants. The geothermal industry recognizes evaluation by a third-party organization. These methods are available through the established heating, ventilation, and air-conditioning (HVAC) infrastructure in the United States and internationally. The International Standards Organization (ISO) has taken responsibility for evaluating GHPs in its ISO Standard 13256. Previously, the Air-Conditioning, heating and Refrigeration Institute (AHRI) in the United States had that responsibility. Today, ISO and ARI are overlapping, with ISO taking the lead.

Approximately 50 percent or all U.S. GHP installations are closed-loop systems, with the other 50 percent being open and standing-column systems. As noted earlier, the majority of the closed-loop system are in areas where the bedrock is deeper than 250 ft from the surface.

Efficiency

Closed-loop systems are designed around 32°F entering water temperature (EWT) in winter (with antifreeze solution) and 77°F in summer. The lead author only condones food-grade propylene glycol as the antifreeze solution of choice. The standing-column winter temperature is designed around a minimum of 45°F EWT in winter and 60°F in summer for residential and 70°F for commercial. Open/recycling systems

A comparison of the three different methods is summarized in this table:

	Open Well(s)	Standing Column Well	Closed Loop
Efficiency	1	2	3
First Cost	1	2	3
Geology	3	2	2
Maintenance	2	2	2
Regulatory	3	2–3	1
Thermal Stability	1	1	2

Figure 3-6 In this comparison matrix you can see how the three general types of geothermal earth-coupling systems compare when taking into consideration efficiency, first cost, geology, maintenance, regulatory restrictions, and thermal stability. The lower number (1) represents most favorable. (*Water Energy Distributors*.)

take constant-temperature water (e.g., 50°F in New England) from the earth, reducing the return water temperature typically by 8°F in winter and increasing 10°F in summer. Because the source/sink water temperature remains unchanged throughout the year, this provides the highest efficiency of the three methods. Higher earth temperatures and resulting EWTs result in the best baseline performance for open-to-reinjection wells (Fig. 3-6).

Third-party efficiency evaluations have been performed by the Air-Conditioning and Refrigeration Institute (ARI 325 and 330) and more recently by the ISO. ISO Standard 13256 is somewhat more conservative than the more dated ARI standards. From the ISO 13256 rating in Fig. 3-7 it is clear a closed-loop system with winter EWTs of 32°F and summer EWTs of 77°F has the least relative efficiency of the three methods. Keep in mind that all GHP applications will still be more efficient than any fossil fuel–based system for heating and cooling. The well water at 50°F in winter and 59°F in summer is the most efficient of the three options, and a standing-column well falls between the two ends of the earth-coupling spectrum. The standing-column well benefits from the lack of thermal resistance of the closed-loop

Test Condition Comparison Table		**Ground Water (Well)**	**Ground Loop (Closed)**
	WLHP	GWHP	GLHP
Cooling Entering air temperature - DB/WB °F [°C] Entering water temperature - °F [°C] Fluid flow rate	80.6/66.2 [27/19] 86 [30] *	80.6/66.2 [27/19] 59 [15] *	80.6/66.2 [27/19] 77 [25] *
Heating Entering air temperature - DB/WB °F [°C] Entering water temperature - °F [°C] Fluid flow rate	68 [20] 68 [20] *	68 [20] 50 [10] *	68 [20] 32 [0] *

Figure 3-7 ISO-13256 chart for ClimateMaster Model TT units. Third-party evaluations of GHPs are performed by the ISO. (*ClimateMaster*.)

system's high-density polyethylene (HDPE) pipe and the ability to drill a deeper borehole without employing deep pipe-insertion methods.

First Cost

Estimated first costs for the *outside* portion of an earth-coupling system are typical and fluctuate relatively as material prices and location change. Note that these typical costs relate to *tons*—a ton is a nominal 12,000 Btu/h. The average 1800- to 2500-ft^2 home is typically in the 3- to 5-ton range. These relative installation costs are based on the outside or earth-coupling portion of the GHP system. Costs listed (in the following paragraph) are for the northeastern United States and more reflect the rock-dominated geology and wage scales of that area. Outside portions listed are for the earth boring, pumping, piping, and controls.

Closed-loop costs, including costs for antifreeze and loop charge and purge, are in the range of $4200 to $4800 per ton. Closed-loop systems are the most costly because loop pipe must be procured and the bore depths are typically 160 to 225 linear feet of bore per ton for a heating-dominated geothermal application (vertical application). For a cooling-dominated application, typical of a very large home or commercial building, bore depths are in the range of 220 to 280 linear feet of bore per ton.

Horizontal (including the Slinky), straight horizontal, and pond applications typically require 1000 to 1500 ft or more of pipe per ton and are highly dependent on annual earth moisture content. Lack of moisture content in the soil can increase the length of pipe per ton by a factor of 2 or more

A closed-loop system must use HDPE pipe. For a typical project, that HDPE cost is approximately equivalent to the cost of the heat pump The closed-loop GHP may be derated by ½ ton because of the wider diverse design temperatures, and thus the next-larger heat pump may be required to meet design specifications.

Standing-column wells have cost in the range of $2200 to $2800 per ton for residential applications. This includes a *porter* shroud for a commercial standing-column well, a bore shroud (if used) for the well pump, controls and offset piping, riser, and drop piping. The use of a *dual-purpose well* can positively affect first cost because the well can provide for both needs at a small differential cost. Various states have widely varying requirements for these dual-purpose wells.

The open/reinjection method is best designed for areas where there is abundant near-surface water. Wells are not deep, and pumping is achieved with modest pumping costs. If employed, return wells are generally similar to supply wells, with shallow depths but slightly larger, as well as at relatively low costs compared with other well types. An open-to-reinjection system typically costs between $1000 and $1350 per ton for the outside portion of the GHP system.

Geology

Within any geographic area, it is expected that the geology may vary from surface-exposed bedrock to bedrock that is over 1000 to 1400 ft from the surface. Other areas have unconsolidated (no rock) earth that is very porous (permeable). Each of these earth types has widely variable heat-transfer characteristics, and each must be known to design a successful GHP system. The change from surface bedrock to deep earth can be observed within a few hundred feet. For example, the lead author has (this refers to Carl Orio) noted the difference between surface bedrock in New York City and deep bedrock (>1000 ft) to the east in Brooklyn, only a few hundred horizontal feet away.

Standing-column wells are the most common in areas with near-surface bedrock and are employed in approximately 80 percent of the geothermal wells in the Northeast. Approximately 62 percent of the United States has similar near-surface bed rock.

Open wells are often used in *unconsolidated* aquifers (i.e., loose gravel and sand) and require steel or plastic casing to maintain borehole integrity. Casing typically is required in overburden and terminal moraine (where the glacier stopped)—southwest Massachusetts, Cape Cod, Long Island, and Brooklyn are examples of deep moraine. The Ogallala aquifer in the central great plains is also a good example of water containment. This aquifer is best traced by the wide shore of the Mississippi River, providing abundant groundwater to the U.S. plains states from western Texas to South Dakota.

Maintenance

Each borehole must be treated with respect, whether a closed-loop, standing-column, or open-to-reinjection bore. Each of the three methods should check the liquids every 1½ to 2 years. Groundwater in a bore must be free of foreign matter and should be tested at least every two years. Open-well systems are tested for flow rates, pressures, and changes in water chemistry. Closed-loop systems also should be checked every two years for acidification of the antifreeze, other chemical changes, variations in antifreeze concentration, and growth of inadvertent bacteria. Of note, some closed-loop systems inadvertently charged with iron bacteria–laden water have experienced nearly complete blockage.

Open-well and standing-column well systems are often employed in conjunction with domestic water systems and should be maintained in a sterile state at all times. Any open-well system, whether used for a heat pump or only domestic water, should be free of harmful bacteria (e.g., fecal coliform) and should be checked periodically. Iron bacterial (e.g., *Gallionella*) is not harmful to humans and is often human-induced. This iron bacterium causes "red-brown" deposits in sinks, toilet bowls, and pipes. If the deposits are not controlled, pipes eventually can become occluded. Groundwater GHP heat exchangers are not affected because they are made of copper-nickel alloy and are heated well above bacterial-killing temperatures (>130°F) during air-conditioning periods.

Closed-loop systems can develop oxygen entrainment and can react with the antifreeze solutions and their additives to develop an acid concentration. Such systems are easily checked with litmus paper or other pH evaluation methods. Closed-loop systems must be maintained in a sterile condition. A bacteria colony can thrive in a warm summer loop. Some closed-loop systems have automatic makeup-water devices in the event that the loop should develop a leak. These systems must be inspected periodically for proper antifreeze concentration and pH (acid activity). Some states limit the employment of automatic makeup devices so as to inhibit the accidental and continuous injection of antifreeze into surrounding soil should a leak occur.

Regulatory Requirements

Closed-loop designs are relatively new, only being listed and evaluated by the ARI since 1988 (ARI 330). Most states are now starting to develop regulations for these systems, with some states still having no regulations relating to this earth-coupling method. Typical regulatory requirements include certification of loop installers, abandonment-plan filings, listing of antifreeze solution compounds (including additives), and mapping of loop fields.

Open-to-reinjection systems responsibly return the water to the environment via surface water on the owner's property. Each state and, in some cases, many towns and cities have widely variable regulations and guidelines. Many standing-column systems have regulations that parallel those of open-well systems, with the exception of diversion regulations. Standing-column well systems are classified as Class V "noncontact cooling water" type 5A67 or 5A7 systems, a nonpolluting category. The typical and most common standing-column well will have 90 percent less diversion of water from the well, so they are regarded more favorably in some jurisdictions. Closed-loop systems are the least regulated, although some states have deemed closed-loop systems to be earth polluting, that is, changing the temperature of the earth. Many states regulate the use of harmful or poisonous antifreeze solutions in closed-loop systems.

Open-to-reinjection systems have been in use in the United States for over 70 years and, as a result, have been the most regulated. The lead author's oldest knowledge is of a geothermal well water system in New Haven, CT, installed in 1938. Another geothermal well system in a church in Tampa, FL, installed in 1921, was only recently upgraded to new equipment. For open-to-reinjection and standing-column well systems, federal and related state regulations involve permitting of water withdrawal and responsible return of the water to the earth. Other regulations may apply to excessive withdrawal, return to navigable streams or rivers, and other activities that may affect water supply or quality. If a responsible surface-water return to the earth is not available, a diffusion or reinjection well is drilled to return the water back into the earth. Wells are typically 6 in in diameter. These wells are often also used for domestic and/or irrigation water and are built to domestic water-well standards.

Thermal Stability

Undersized or unbalanced heating and cooling earth-coupling designs that do not model annual effects on the earth are prone to thermal runaway, where earth temperatures do not remain within the optimal or safe-operation entering-water temperatures for a GHP. An example of a well-documented runaway closed-loop project is an approximately 450-ton college in New Jersey. The closed-loop system temperatures were increasing at the rate of 1°C each year. Supplemental cooling was added, and the system stabilized.

As noted previously, open-to-reinjection and standing-column well systems can employ far-field stable-water temperatures to refresh borehole temperatures. Unexpected, unbalanced, or excessive energy loads from the building can be easily mitigated by removing water, bleeding or overflow, from the borehole, creating a depressive water-level cone around the bore. This cone of depression induces a free flow of stable-temperature water into the bore. This far-field water is at the average earth temperature and restabilizes the bore water temperature.

Open-to-reinjection systems are by definition thermally stable over a multiple-year period because the groundwater employed is at a constant temperature. Standing-column well systems change the earth's temperature in a cylindrical shape around the well column on an annual basis. The thermal effect is typically depleted 40 to 50 ft from the borehole column. Bleed and transfer efficiencies have shown in the field evaluations that Earth temperature change can be inhibited.

Proper design must recognize the geologic thermal characteristics, relative heating and cooling loads, and adequate spacing of multiple standing-column wells. A standing-column well can be up to 2000 ft deep and develop 30 to 43 tons of capacity. A 350- to 400-ft-deep well with dual-purpose rock bore and domestic water use can develop approximately 5 tons of heat transfer with little or no bleed. A bleed circuit (valve and temperature sensor) is relatively inexpensive and is always recommended in the circuit.

Close-loop systems do not have the ability to bleed or otherwise introduce fresh temperature-stabilized water into the loop bores to restabilize the earth temperature surrounding the plastic loops. As such, closed-loop systems thus are the most sensitive to annual thermal effects and unexpected or unspecified variations in design criteria. Absolute annual earth moisture minimums must be considered and will have an impact on responsible closed-loop designs. Field tests have shown long-term earth-temperature increases in commercial installations, often termed *thermal creep* or *thermal failure*.

Designing Geothermal Heat-Pump Systems

As GHP applications grow in popularity, each of these generalized methods has developed variants. This section reviews the industry-validated methods evaluated by third-party agencies. These methods are available through the established HVAC infrastructure in the United States and internationally. The ISO has the responsibility to evaluate GHPs in ISO Standard 13256. Previously, the ARI had that responsibility.

First, there are mathematical models based on Kelvin's circulation theorem for the design of closed-loop systems that seem, by outward appearances, to have been working well for at least 30 years. These systems involve the use of a certain length of pipe and its surface area in the ground per ton, provided that the ground has enough thermal conductivity (which is discussed in detail in Chaps. 4, 5, and 7). A number of variations exist that make a difference in the actual length of pipe needed per ton of building requirement for a certain application, and all these variations are taken into consideration. However, these systems are not taken very seriously by all designers because a number of systems have been installed under a "rule of thumb" criterion that has little or no margin of safety. This can be likened to many different things that we take for granted in our lives. We can remember when cars were considered ready for the junkyard after 50,000 miles and people mocking efforts to increase fuel efficiency and reduce smog. The cars of today are much more complex. But I think that we all agree that today's cars are highly dependable, fuel-efficient, and very clean burning. They also cost less in adjusted dollars because of the economy of scale and the automation of production we now enjoy. Anyone who has driven across the United States, especially via Interstate I-10, can appreciate the vastness of the state of Texas. Usually there is a second hotel stay in San Antonio as you cross the country from San Diego, CA, to Orlando, FL. In doing so one cannot help but think about how clean the air is in our big cities. If not for the advances made to our automobiles, this would not be so.

Many people have uncles and grandpas who love to talk about the "good ol' days" when things were simpler. It is easy to imagine: "Give me my 1969 Chevy Camaro with a

350-cubic-inch engine and some 95 octane gasoline, a four-barrel carburetor, and some Hooker headers," like the lead author's old buddy David Stephens used to say. He'd go on to talk about how there were no complex controls or vacuum hoses and the fact that he could fix or rebuild the thing in his sleep. He was right about simpler; cars certainly were that. *Everything* was a simpler. However, as Billy Joel sang, "the good old days weren't always good, and tomorrow ain't as bad as it seems." Well sung, Billy. You're very much right. You can keep the smog and emissions, low fuel economy, and breakdowns. The lead author will take what we've got now, and it's truly getting better all the time.

Please allow another digression to further make the point. At the age of 11, the lead author borrowed a book from the Barstow, CA, public library on car engines and used the knowledge gained in a short time to pull the engine out of his grandmother's 1964 Dodge station wagon and rebuilt the thing. He didn't need any special tools more than a chain hoist, a set of sockets, a torque wrench, and a timing light. That simply is not going to happen with today's cars. The engines are too complex, and the tools are very specialized. As a matter of fact, the lead author had to take his 2008 Chevy HHR into the dealer to replace the headlight simply because the entire fender undercarriage had to be disassembled to allow access to the headlight. The lead author considers himself pretty hands-on, but after a 1-hour attempt using the manual that came with the car (yes, he actually read the manual), he gave up. The point here is that we are in an age where things have become increasingly specialized, and for good reason. We are living better, cleaner, more abundant lives. Such is the evolution of the geothermal HVAC field. The lead author has an old acquaintance whose description of the formula for closed-loop engineering in the early 1980s was quite simple: "Bring a roll of pipe per ton out to the job, put it in the ground, and don't bring any back." Please don't take his words literally, but you get the idea. Today's GHP is twice or more efficient, and the extra efficiency comes from significantly improved earth-to-heat-pump energy transfer. Higher efficiencies put greater loads on the earth—old rules of thumb don't "fly."

With regard to the engineering of the ground loop, things are being done differently now. Just to say that the load for a building is 10 tons cooling and 160,000 Btu/h heating is no longer good enough. We need to know how many hours of cooling and how many hours of heating are needed each day and in each season. We need to know how much energy the earth can provide and absorb in any given situation. We need to understand load imbalance, bin data, and what challenges can surface in every different situation. The lead author still hears many contractors say that they just use 500 to 1000 ft of pipe per ton depending on the type of loop, whether horizontal, vertical, or water-immersed (lake or pond loop), and build the header for equal fluid flow through the loop using standard procedures, usually reverse return.

Lessons Learned from Geothermal Projects

The Sussex County, Delaware, Emergency Operations Center (EOC) at the time of this writing was about 4 years old. In the early summer of 2011, the center was suffering incoming water temperatures approaching 100°F. The facility engineer, Steve Hudson, knew that if the temperature reached 105°F, the geothermal heat pumps would shut down and render the mission-critical building inoperable (Fig. 3-8).

"I knew that we had to get the problem fixed, and there was no time for the blame game," said Steve. He and his trusted assistant, David Wootten, went right to work looking for answers. The closed-loop geothermal cooling system was suffering incoming

Figure 3-8 Sussex County, Delaware, Emergency Operations Center is a case study of something that was (or seemed to be) designed well, but the issues mentioned in the text were not known or considered or otherwise ignored.

water temperatures approaching 100°F. They knew that if the temperature hit 105°F, the entire operation, and millions of dollars of computer equipment, would be in jeopardy. The county commissioners approved an emergency budget to get a cooling tower put in. What about the geothermal system? A cooling tower would make the geothermal system a high-maintenance, water-consuming HVAC system. The geothermal system had failed after just four years. Why?

Hudson and Wootten didn't like it, so they looked a little further and found that there might be a better way. The Sussex geothermal design was like thousands before it—a series of wells are drilled into the earth, in this case 600 ft deep. Twin HDPE pipes connected at the bottom by a U bend were inserted deep into the hole, and the hole was backfilled or pumped full of a cement type of material called *grout* that hardens and seals the hole, providing a good bond between the earth and the pipe. In total, there were 24 holes to provide for a 110-ton cooling load.

The problem was that the Sussex County EOC, like so many other commercial buildings, needed cooling 24 hours a day, 7 days a week, even when the temperature outside was below freezing. So the heat from the building was pumped into the ground continuously for 4 years until—you guessed it—the ground could take no more (Fig. 3-9). Steve found that this was not an isolated case.

Hudson and Wootten gave the lead author a call, and he explained that this type of problem has been around for some time. He had first experienced such a problem in the early 1990s in the hot and humid climate of tropical Florida. He explained to Hudson and Wootten that in cooling-dominant locations such as occurred at the EOC, the earth suffers thermal retention and is unable to recover. However, there are ways to adapt these applications. Hudson had read part of Chap. 4 of the book *Geothermal HVAC: Green Heating and Cooling* (p. 73), where the lead author had given an example

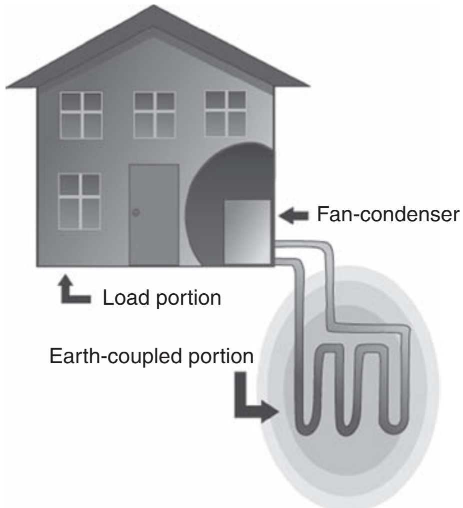


FIGURE 3-9 This graphic shows that the earth tends to retain heat when it is not given sufficient opportunity to dissipate. Unchecked, this spells doom to a closed-loop system.

of a contractor installing a geothermal system for a laser-crystal coatings facility. The facility mentioned in the chapter had need of a 230 MBtu/h cooling load. The contractor figured that because the system was for process cooling rather than comfort cooling, he should double the size to a roughly 480 MBtu/h system. How wrong he was! That was not nearly enough. The issue is the load factor in the closed-loop geothermal system software. The *load factor* is the portion of that season's space conditioning that is actually required. For example, during the northern-tier residential heating season, the heat pump may be calling for heat only 60 percent of the time. Conversely, a commercial building with many heating devices and people may be calling for heat only 35 percent of the time.

In the case of the EOC, the load would not increase, but the cooling hours would increase greatly. The system began to approach critical mass within the first year of operation. The incoming water temperature was above 105°F, and the system failed to do its job. Reading further into the aforementioned book, Hudson and Wootten found that there is a better way for cooling-dominant loads:

Properly engineered, geothermal systems can use a standing column or open loop, pump, and reinjection. In this method, groundwater is pumped through the heat pump and injected back into the aquifer from which it was pumped. Either of these two methods provide a "safety fallback" position should the earth coupling be taxed beyond its design. Both open-to-reinjection and standing-column wells can infuse nearby stable-temperature groundwater and compensate for unexpectedly higher heating or cooling loads.

When using a copper-nickel exchanger and water of proper quality, the aquifer water can be pumped directly through the heat pump's internal heat exchanger. An aquifer is a body of underground water, and its chemical and physical characteristics vary widely. Waters acceptable to the heat-pump's heat exchanger configuration are perfect for geothermal heat exchange.

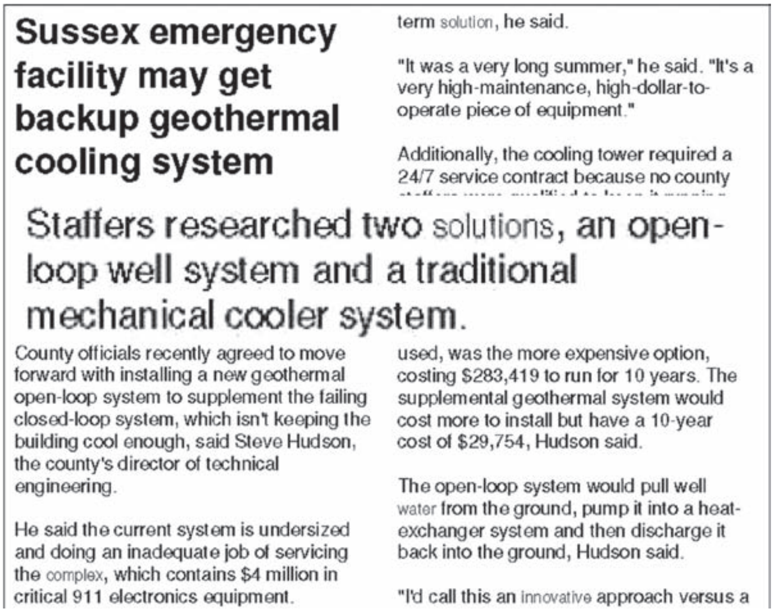
At this point, Hudson and Wootten knew that they had found the answer. But now they had the task of convincing the county commissioners that they could keep their geothermal system but that they needed to spend money to engineer it properly. Steve said to the lead author at one point, "I don't know. It's going to be a monumental task to convince our commissioners that we should spend a quarter of a million dollars and put in a geothermal system *fix* our geothermal system."

Hat's off to you, Mr. Hudson (Fig. 3-10). Six months later, he pulled it off! Fast forward to Friday, January 13, 2012 at 10 A.M. In the conference room at the Sussex County EOC, there are eight individuals in attendance. Among those in attendance are Steve Hudson, David Wootten, Sussex County Engineer Michael Izzo, the lead author, a handful of county commissioners and employees, and David Hoffman of Gipe Engineering. David Hoffman's firm has designed more than 600 geothermal systems for everything from homes to high schools. But he's not too sure what to make of the lead author . . . yet. Two hours later, the lead author and Hoffman were like long-lost family, enjoying lunch and some good stories about the early days of geothermal.

"It's time we start engineering these systems right for each application!" said Hoffman to the lead author. There was no argument from the lead author.

"The fact is, a properly engineered pump and reinjection geothermal system will cost one-third that of a closed-loop system; it will use almost no space, and the performance will improve," said the lead author.

Figure 3-10 Sussex County Emergency Operations Center Director of Technical Engineering, Steve Hudson, stands out front of the Sussex EOC with geothermal consultant Jay Egg (the lead author).



Sussex emergency facility may get backup geothermal cooling system

term solution, he said.

"It was a very long summer," he said. "It's a very high-maintenance, high-dollar-to-operate piece of equipment."

Additionally, the cooling tower required a 24/7 service contract because no county

Staffers researched two solutions, an open-loop well system and a traditional mechanical cooler system.

County officials recently agreed to move forward with installing a new geothermal open-loop system to supplement the failing closed-loop system, which isn't keeping the building cool enough, said Steve Hudson, the county's director of technical engineering.

He said the current system is undersized and doing an inadequate job of servicing the complex, which contains $4 million in critical 911 electronics equipment.

used, was the more expensive option, costing $283,419 to run for 10 years. The supplemental geothermal system would cost more to install but have a 10-year cost of $29,754, Hudson said.

The open-loop system would pull well water from the ground, pump it into a heat-exchanger system and then discharge it back into the ground, Hudson said.

"I'd call this an innovative approach versus a

Figure 3-11 Sussex made the bold decision to stick with it, unlike so many others that drop back to standard cooling towers or other air-conditioning solutions.

The summary of this case study is available on the website associated with this textbook. Sussex County now has a triple-redundant system operating in harmony with the ground loop, the open loop, and all the variables that are needed to ensure uninterrupted operation for the *mission-critical* facility (Fig. 3-11).

If you ask Hoffman now, he thinks the days of closed-loop geothermal systems are numbered. "These guys have gone from $1500 a hole to $3000 a hole. Carl Orio notes that in the northern tier, closed loops are approaching $5000 per ton. I hope they've been saving their money because they're not getting any more of mine."

The lead author has been going around the country listening to stories of woe from people who have abandoned expensive geothermal loop fields because they have "worn out." Balderdash!

Lend Lease

Joe Potter of Lend Lease, one of the world's largest integrated project-management firms, is right there with the lead author and Hoffman. "I think this is the way of the future, and the future is right now," says Potter.

Lend Lease supported the lead author's first book. "We've been sustainable since before people knew what *sustainable* meant," Potter said. "To us, this is just business as usual."

Lend Lease's Washington, DC, office has shown interest in geothermal open-loop systems. "This design will save schools and taxpayers millions of dollars. I'm glad to see this improvement in system design" said Potter.

In seeking to apply only the greatest geothermal innovations available, Potter and the lead author were not about to settle only with their chosen open-loop system design.

Figure 3-12 (*A*) Lend Lease advertisement. Lend Lease, among world's largest construction management firms, is firmly committed to sustainable technology such as geothermal HVAC systems. The company teamed up with Egg Geothermal to take the $81 million Pinellas Safety Complex geothermal in 2012. (*B*) Pinellas Safety Complex

Figure 3-12 (*Continued*)

They have recently taken notice of the newest advancement in GHP equipment technology. Geofinity Manufacturing—winner of the prestigious Innovation Award in the category of Building Automation at the AHR 2012 Expo—sits squarely in their sights to become their preferred geothermal equipment supplier for residential single-family project development (Fig. 3-13). The Geofinity product line features the ORB heat-pump controller. The ORB is a

Figure 3-13 AHRI Award for building automation products such as the ORB controller from Geofinity. Geofinity is revolutionizing the industry by providing the tools needed to determine instant and cumulative energy-efficiency ratings (EER). This is indispensable information that can be used in conjunction with current legislative work that treats geothermal heat pumps as renewable-energy-generating equipment.

patent-pending fully integrated equipment intelligence system offering complete operating, monitoring, control, and diagnostics capabilities. It performs the functionalities of a total system management and reporting platform, providing real-time data trending and analysis, whether on site or via e-mail or website information transfer (more on this in Chaps. 12 and 13).

New Hampshire Nursing Home

The 243,00-ft^2 Merrimack County Nursing Home in Boscawen, NH, is a great example of a large and successful 615-ton standing-column well geothermal project installed in 2008 (Fig. 3-14). This 290-bed facility with 425 employees demanded a 615-ton heating-dominant load. Well water is delivered directly to each of the 326 ClimateMaster geothermal heat pumps with copper-nickel heat exchangers; no plate-frame heat exchanger was required. The GHPs service client rooms (most rooms have two beds). Rather than a large central heating and cooling system, the multiple 2- to 3-ton separate heat pumps were selected to prevent migration of contagions. Each heat pump has a separate wall-mounted thermostat for maximum client comfort and control.

The mechanical room in the facility is only 1400 ft^2, or about 0.6 percent of the total building area, a geothermal advantage often overlooked in commercial buildings. Sixteen large (10-8-6) standing-column wells designed by Carl Orio and his team at Water Energy, Inc., serve the heat-pump load with no supplemental electric heat. The original earth-coupling system was designed around a 10 percent advective on-command bleed. Had that bleed overflowed into the nearby Merrimack River, a more complex permitting would have been required. The system was then designed around a 5 percent on-command bleed. Fortunately, there has been enough natural aquifer movement that no bleed has ever been required, and the well/earth temperatures have consistently remained

Figure 3-14 Merrimack County Nursing Home, a 243,000-ft^2 facility in New Hampshire.

within design limits of 50 to 70°F. The well fields were designed by Water Energy Design, and mechanical engineering by McFarland-Johnson Company. The standing-column well contractor was Skillings and Sons, and the completed costs for the outdoor well field, pumps, and offset piping was under $2000 per ton. The well field was broken into two linear arrays of eight standing-column wells located in the grassy area between upper and lower parking lots. "The nursing home is the largest geothermal project in the Northeast, and it taught us many lessons," said Carl Orio of Water Energy. Such a project depends greatly on the well contractor having all the necessary equipment and skill to drill deep boreholes. There are about six well contractors in the Northeast, some with over 30 years of commercial standing-column well experience and knowledge. The submersible well pumps are all controlled with energy-saving variable-frequency drives (VFDs). Any VFD, whether on a geothermal well pump or a modern exercise machine, generates "dirty" electrical signals, and these must be treated with respect (more on this in Chap. 7).

All well water was delivered directly to each of the four floors with no intermediate plate-frame heat exchanger required. Orio notes that the only need for a plate-frame, or intermediate well water, heat exchanger is in applications where the building is more than approximately 10 stories high. In such applications, one gains more in pumping-head energy savings than lost with the inefficiencies of a plate-frame heat-exchanger transfer process.

Whether servicing an emergency operations center as in Sussex County, DE, a summer home, a nursing home or hospital, or a good old American high school filled with 2000+ kids, geothermal heating and cooling clearly remain the most cost-efficient and environmentally responsible HVAC solution available in the world today.

Smart Controls

Rick Cox, president of Geofinity, stated, "Smart thermostats and building automation systems claim that they control and monitor equipment; however, without the integration of such 'intelligence' actually being built directly into the equipment, absolute confidence in system performance and optimization is impossible—the ORB is the answer. With this technology, we have revolutionized the future path of industry by demonstrating the critical need to design and manufacture HVAC equipment that possesses internal intelligent controls located directly within the systems."

"It is a highly informative and beneficial technological advancement for the consumer—the ORB provides real-time calculation of kW/h consumption, COP, EER, and CO_2 emissions. This ensures that an end user will always know that the system is operating at the highest performance and efficiency possible. With off-site real-time comprehensive troubleshooting information being immediately provided directly to the contractor via e-mail transmission to their smart phone or tablet of choice, the home owner is ensured significant savings in terms of equipment servicing costs. These enhanced reporting tools offer the contractor the advantage of "tool-free equipment troubleshooting" and an inherent ability to call the end user to notify them of a service requirement even before they realize they have a problem. This reduces travel time—the typical need for multiple site visits to diagnose and repair equipment is eliminated—and moreover, a service technician will be able to arrive to site with the necessary parts and tools in hand to solve any conditions that could arise. This combination of unparalleled system features results in significant financial benefit and real peace of mind," added Sean Piekaar, national sales manager for Geofinity.

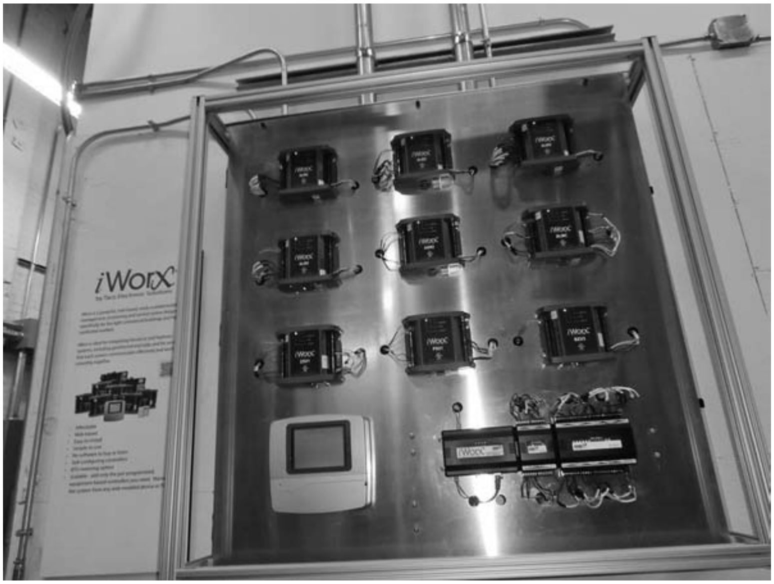


Figure 3-15 TACO iWorX. Larger commercial control systems such as the iWorX by Taco Electronics are revolutionizing the industry and answering the needs of forward-thinkers everywhere, enhancing the performance of industry standards such as Johnson Controls, Andover, etc. (*EggGeothermal*.)

The ability to measure and record energy used and saved by geothermal systems is rapidly becoming a major requirement in the United States. As of this writing, many states have and many more are adopting energy-savings incentives. A more common method is to credit or pay on renewable-energy credits (RECs). Much more about these new and exciting energy incentives will be discussed in Chap. 15.

For geothermal installations located in larger commercial and institutional projects, the iWorX control system by Taco Electronics is the ultimate building-automation solution (Fig. 3-15). The iWorX platform and master communication modules can do for an entire building full of any and all varieties of heating and cooling equipment, pumps, valves, and external controllers what the ORB by Geofinity readily offers individual residential applications.

Outside the Heat-Pump Box

Chris Integlia, executive vice president of Thermal Automatic Corporation (Taco, Inc.) in Cranston, RI, recently sent a geothermal proposal to the lead author for review. This will serve as an *object lesson* on the need for *you*, the up and coming engineers and architects of this country and the world, to protect the geothermal HVAC industry at large. The GHP system must be treated as a whole, not just as a heat pump or a ground coupling or a control device—the whole must be planned and integrated simultaneously.

Henry Ford is remembered as the pioneer auto maker and manufacturing genius. A friend of one the coauthors (Orio) recently gave him a stack of newspapers from his great grandmother's attic, printed in the early 1920s. These papers were replete with

DATE:
FEBRUARY 13, 2012

PROJECT TYPE:
GSHP System; New Construction

NEWPORT GEOTHERMAL LLC
www.NewportGeo.com

PROJECT: [redacted]
LOCATION: [redacted]

SCOPE OF WORK:
Provide and Install a geothermal heating and cooling system per drawings drawn by Peter Hess Design Build, LLC dated 12/22/11. The items included in this proposal are included below.

EQUIPMENT:
- Provide and install two (1) Water-to-Water Geothermal Heat Pump as noted below with all related piping and controls.
- Provide and install air-handlers for air-conditioning and heating on the second floor, and air-conditioning on the first floor.
- Provide and install source piping from the exterior of the building to the ground source heat pumps.
- Provide and install tubing in concrete for radiant for an area of approximately 800 square feet on the first floor. Tubing will be stapled/clipped to foam board installed over the plywood.
- Provide and install radiant tubing over approximately 2400 square feet of living space using Uponor QuikTrak radiant panels. The wood panels will be installed over the plywood subfloor.
- Additional work required due to conflicts on site related to structure or architectural elements that obstruct or prohibit the installation of the mechanical system as drawn in the documents provided may result in a Change Order.

AIR DISTRIBUTION SYSTEM:
- Sheet Metal ductwork will be installed to meet State Mechanical Code with flex duct limited to 6 feet.
- Supply and return diffusors will be install in each room per drawings. Ceiling and wall registers will be Hart & Cooley white painted aluminum. Floor registers will be Hart & Cooley, color brown.
- Provide and install (1) Energy Recovery Ventilation unit.

EARTH CONNECTION
- Execute manual-j load analysis to determine the heat loss/gain of the existing building sizing the system to the dominant load (typically heating in New England).
- Provide and Install and appropriately sized vertical vertical open-loop standing-column well.
- All excavation will be by the General Contractor.
- Slurry pits to contain the drillings will be required. It is typically required that an excavator/back-hoe be on site in the event that additional pits are required during the drilling process. If additional water removal is required by a third party pumping contractor, the cost for this will be billed at $195/1000 gallons and handled through a change order.

DOMESTIC WATER SYSTEM:
- First Floor: Bathroom: (1)Toilet, (1)Sink; Kitchen: Sink, Dishwasher, ice-maker supply; Laundry: (1) Washing machine
- Second Floor: (1) Toilets, (2)Sink Faucets, (1) Tub/Shower (no hand-held shower), (1) Shower Control (no hand-held shower or body sprays); (1) Washing Machine, (1) Secondary Drain with copper pan for washing machine, (1) Laundry Sink
- Misc: Exterior: (2) Frost-Free 10" Silcocks; Outdoor Shower: (1) s96-2 Symmons Valve, trim, shower arm and head will be supplied.
- Recirculation line from the furthest fixture back the water heater only. (i.e. one second floor bathroom).
- All domestic water supply lines will be PEX and all waster and venting lines will be PVC.
- Provide and install (1) Caleffi Solar Domestic Hot Water System with high-efficiency electric back-up.
- All fixtures will be supplied by the Owner/GC. We will provide and install chrome Brasstech shutoffs for all faucets and toilets.

Page 1 of 2

Figure 3-16 This is what appears to be a rather thorough contractor estimate to provide an upgrade to geothermal heating and cooling for a home. Read on to see some of the items that should be considered to ensure a smooth job.

TAX CREDITS:
- Newport Geothermal, LLC will supply the required proof from the manufacturer that the equipment installed meets the requirements set forth by the Federal Government and is Energy Star certified for the installation.
- It is the clients responsibility to coordinate all required paperwork with their own accountant and/or tax preparer.

Payment Milestones-1

Milestone	#	Tasks	Amount
Project Start	1	Project Downpayment	**$14,883**
Drilling Payment	2	Upon Completion of the drilling	**$9,180**
Mechanical Start	3	Upon Delivery of the Equipment	**$27,116**
Mechanical Partial	4	10 Days after the Start of the Mechanical Installation	**$18,806**
Mechanical Rough	5	Upon Completion of the Rough Inspection	**$27,295**
Finish	6	Within 5 days after the start of the system	**$3,336**
		Total Project Cost	**$100,617**

PAYMENT CONDITIONS & NOTES:

(i). Payments are due as noted above. (ii) Additional work will be billed separately from this agreement. (iii) All payments should be made within 5 days, failure to meet these terms may result in a stop work order. (iv) 1.5% Per Month will be added on overdue accounts (18% annually). (v) Retainage expressly not allowed under the terms of this agreement.

A. Indemnification: The GEOTHERMAL CONTRACTOR will indemnify the Owner against all claims, demands, and liability for damages for death or bodily injury to persons and for damage to property arising as a result of work directly related to this contract. However, this indemnity will not extend to any loss, damage, or expense arising out of the sole negligence or willful misconduct of the CLIENT or the CLIENT's agents, servants, or independent Contractors.

B. System Start-Up: THE GEOTHERMAL SYSTEM IS NOT TO HEAT OR COOL THE BUILDING DURING CONSTRUCTION; Construction dust will damage the fan coil units and void the warranty of the entire system. The builder should make provisions to install covers on all duct openings, supply and returns, to eliminate the possibility of construction debris, dust and the like of entering the system. It is the CLIENT's responsibility to protect the supplies and returns – please budget accordingly.

C. Finish Conditions: We are assuming that the existing walls to be R-19, all ceilings to be R-38, and the first floor system insulated to a minimum of R-30. All ductwork must be within the building envelope, which means the insulation in the attic must go over the ductwork or significant efficiency losses may be experiences by the homeowners.

D. Change Orders: Additional work will be billed whereby total man-hours at the rate of $75 per/man hour shall be added to the cost of materials plus other expenses such as subcontractor costs plus 15%.

E. Warranty: In addition to the GEOTHERMAL Heat Pump manufacturers' warranty, the GEOTHERMAL CONTRACTOR hereby warrants all other materials and labor provided by the GEOTHERMAL CONTRACTOR for this project for a period of one year.

F. Notice to Owner: Failure of the contractor to pay those supplying materials or services to complete this contract can result in the filing of a mechanics lien on the property which is the subject of the contract pursuant to State of Rhode Island GL 5-56-18 and the Rhode Island Mechanics Lien Act Chapter 28 Title 34. To avoid this result, you may ask the GEOTHERMAL CONTRACTOR for "Lien Waivers" from all persons supplying materials or services to complete this contract.

By:______________________________, Hazard Stewart, Manager, Newport Geothermal, LLC

Owner's Signature: ______________________________ Date:__________

Printed Name: ______________________________

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Figure 3-16 (*Continued*)

NEWPORT GEOTHERMAL LLC
www.NewportGeo.com

GSHP Design Report

Project:
Prepared: 13-Feb-2012

Prepared By:

Designed with loopLink by Geo-Connections, Inc

Figure 3-16 (*Continued*)

Newport Geothermal, LLC

13-Feb-2012

RE: GSHP System Design Report for 37 Ferry Lane - Open Loop

System Loads

System Loads or Peak Loads are calculated based on a variety of details for an individual residence. Assumed occupancy levels, the number of appliances operating, the number of doors & windows and the tightness of the construction all contribute to the amount of energy required to maintain the thermostat set points given the historical extreme weather conditions in your area.

The peak loads used in this report were provided as listed in the following table.

1 kBtu/hr = 1,000 Btu/hr

Zone	Total Heating Load (kBtu/hr)	Total Cooling Load (kBtu/hr)	Zone SHF
First & Second Floors	60.00	43.00	0.900
Total	60.00	43.00	

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Figure 3-16 (*Continued*)

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Equipment Schedule

Based on the provided loads, the recommended heat pump schedule for this system is as follows:

High Cap.
Low Cap.

1 kBtu/hr = 1,000 Btu/hr

Zone	GSHP	QTY	Heat [1] Cap. (kBtu/hr)	Cool [1] Cap. (kBtu/hr)	Water [2] Flow (GPM)	Air [3] Flow (CFM)
First & Second Floors	ClimateMaster - TMW060 (ELT-100/50)	1	66.50	62.40	15.0	
			0.00	0.00		
High Capacity Totals			66.50	62.40	15.0	
Low Capacity Totals			0.00	0.00	-	

1. All capacities shown are total.
2. For water-to-water equipment, source and load water flows are assumed equal.
3. Air flow rates are reported on a per heat pump basis. For total air flow in a zone, multiply the reported air flow by quantity.

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Figure 3-16 *(Continued)*

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First & Second Floors

Zone Details

The peak loads for each individual zone are used to calculate the total amount of heating & cooling capacity required for a space based on the set points and the climate data for your area.

Peak Heating Load	60,000 Btu/hr	Peak Cooling Load	43,000 Btu/hr
Heating Set Point	70 °F	Cooling Set Point	75 °F
		Space SHF	0.900

GSHP Selection

The ground source heat pump below has been selected to maintain comfortable heating & cooling for this zone.

Manufacturer ClimateMaster

Model TMW060 (ELT-100/50)

Heat Pump Type Water to Water Capacity Single # Heat Pumps 1

Installed Capacity Check

The installed capacity check describes the efficiency and total heating/cooling capacity of the selected ground source heat pump system. This information is used to ensure proper sizing of equipment based on the load represented by this zone.

Heating		Cooling	
Heating Capacity	66,500 Btu/hr	Total Cooling Capacity	62,400 Btu/hr
% Sizing	110.8%	Sensible Cooling Capacity	46,800 Btu/hr
Installed COP	4.27	% Oversizing	20.9%
Balance Point Temp.	0.5 °F	Installed EER	27.49

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Figure 3-16 (*Continued*)

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First & Second Floors

Zone Operating Summary

The Zone Operating Summary describes equipment runtime and the total annual power consumption for the GSHP operating in this zone.

Heating

High Capacity Runtime 1,750 hrs
Supplemental Runtime 6 hrs
Dual Fuel Runtime 0 hrs

Heat Pump Energy Use 7,982 kWh
Pumping Energy Use 518 kWh
Supplemental Energy Use 8 kWh
Dual Fuel Energy Use 0 kWh

Cooling

High Capacity Runtime 579 hrs

Heat Pump Energy Use 1,315 kWh
Pumping Energy Use 171 kWh

GSHP Operating Cost Breakdown for Zone Name

Based on the annual power consumption of the system and the price per kilowatt hour in your area the estimated cost to maintain the set points for this zone are as follows:

Heating

HP Operating Cost $1,077.59
Supplemental Operating Cost $1.20
Dual Fuel Operating Cost $0.00
Pumping Cost $69.97

Total Cost $1,148.77

Cooling

HP Operating Cost $177.56
Pumping Cost $23.16

Total Cost $200.72

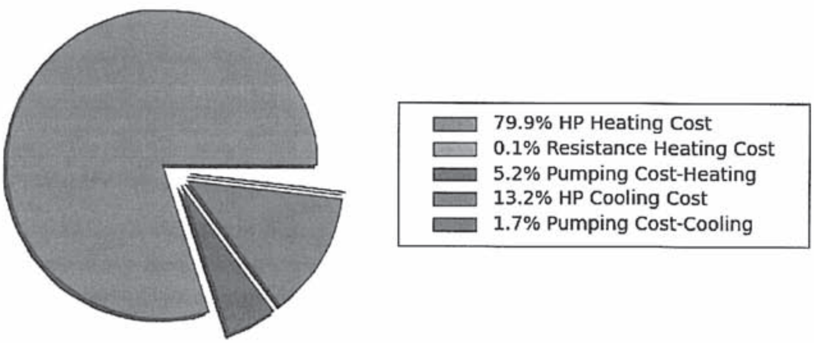

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Figure 3-16 (*Continued*)

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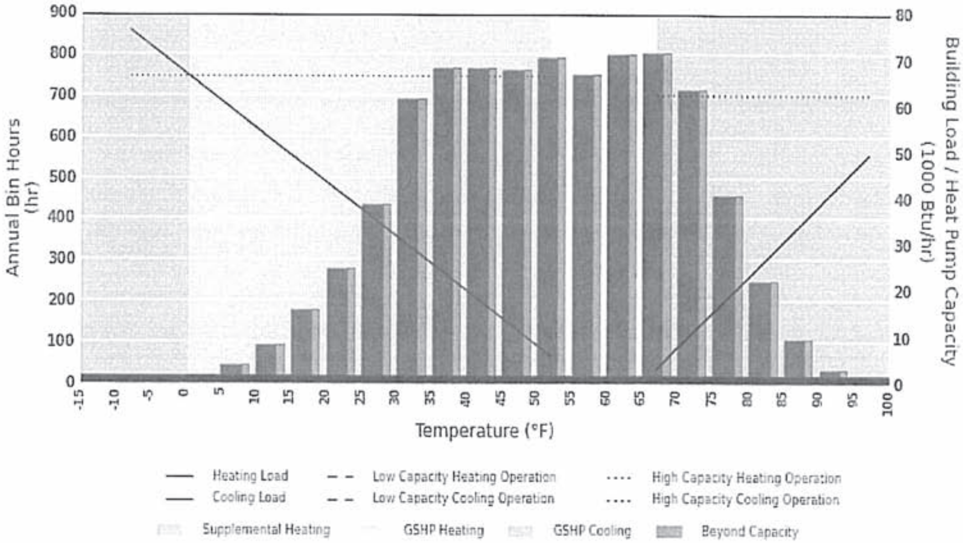
Back-Up System Details

Supplemental System Details

Supplemental systems operate at the same time as the geothermal heat pump and provide additional heat when the space load is greater than the system capacity.

Supplemental System Type Electric Resistance COP 1.0

Zone Load and Operating Profile



Heating		Cooling	
High Capacity Runtime	1,750 hr	High Capacity Runtime	579 hr
Supplemental Runtime	6 hr		

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Figure 3-16 (*Continued*)

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Energy Prices

Standard Electric Rate	0.135 $/kWh	Natural Gas Rate	1.200 $/ccf
ASHP Electric Rate	0.135 $/kWh	Propane Rate	2.790 $/gal
GSHP Electric Rate	0.135 $/kWh	Fuel Oil Rate	2.790 $/gal

Energy Price Inflation Rates

The following inflation rates are applied to long term economic analyses to give a more realistic evaluation of the long-term cost benefits of using GSHP.

Electricity	2.000%	Propane	4.000%
Natural Gas	4.000%	Fuel Oil	8.000%

Equipment Efficiencies

The following efficiencies are for air systems, hot water generation efficiencies can be found on the hot water generation page.

NOTE: GSHP efficiencies shown below are system wide averages which include pumping and applicable resistance energy. Efficiencies for individual GSHP zones can be found on the zone pages.

Heating

GSHP (COP_{AVG})	3.79
Electric Resistance (COP_H)	1.00
ASHP (HSPF)	6.00
Natural Gas (AFUE)	85.00%
Propane (AFUE)	90.00%
Fuel Oil (AFUE)	75.00%

Cooling

GSHP (EER_{AVG})	22.75
A/C (SEER)	16.00
ASHP (SEER)	15.00

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Figure 3-16 (*Continued*)

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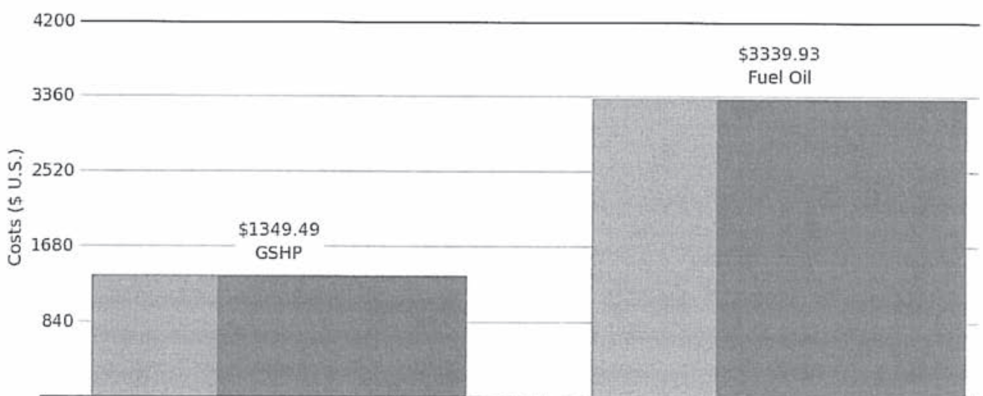
Economics: Operating Cost Summary

Actual costs and savings may vary from those reported. The methods of calculation and the data used are designed to approximate the total cost and savings of the GSHP system based on the weather conditions for an average year in your area. Additionally, the assumed rates of inflation and the unit prices for energy are subject to change according to the economy and your energy provider.

Annual Operating Cost by Technology



System Type	Heating	Cooling	Total	vs. GSHP
Ground Source Heat Pump (GSHP)	$1,148.77	$200.72	$1,349.49	———
Fuel Oil	$3,054.56	$285.37	$3,339.93	$1,990.44

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Figure 3-16 (*Continued*)

Newport Geothermal, LLC

Economics: Operating Cost Summary

Annual CO2 Emissions by Technology

Geothermal heat pumps generate NO DIRECT EMISSIONS however, even "green" heating and cooling technologies like GSHPs produce "upstream" carbon emissions. The amount of these emissions depends on the power generation method in your area.

In areas where the primary power generation technology is nuclear, hydroelectric, wind turbine or solar, the upstream carbon emissions are minimal. However, the majority of the power in the United States is generated by coal fired power plants which emit a relatively higher volume of CO_2.

The emissions shown in the graph below are adjusted based on the mix of power generation methods in your region. Note that for natural gas, propane and fuel oil, only the point of use carbon emissions from the combustion of the fuel is considered not the upstream emissions resulting from their production.

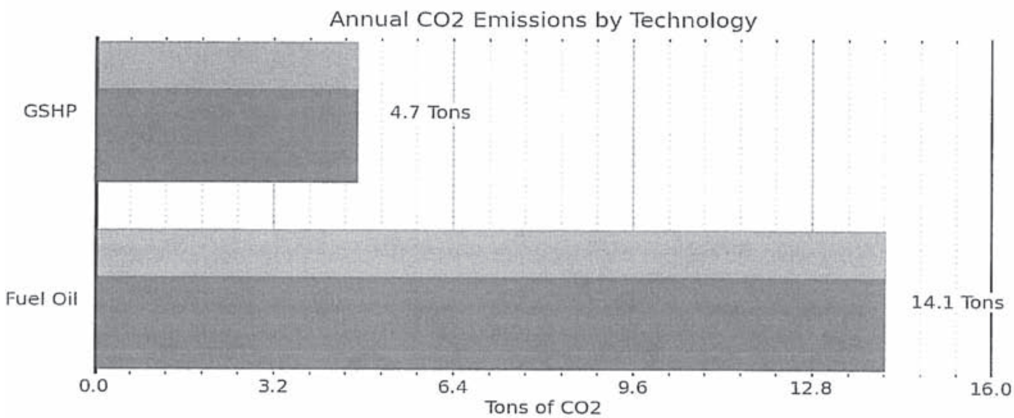

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FIGURE 3-16 (*Continued*)

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Economics: Cost of Ownership

Actual costs and savings may vary from those reported. The methods of calculation and the data used are designed to approximate the total cost and savings of the GSHP system based on the weather conditions for an average year in your area.

Conventional vs. GSHP

Based on the details of your loan(s), a reasonable operating cost comparison between a properly sized and installed GSHP system and a conventional system may be made.

	Fuel Oil w/ A/C	GSHP
Installation Cost	$29,750.00	$56,978.00
Incentives	$0.00	$17,093.00
Actual Cost	$29,750.00	$39,885.00
Loan Amount	$29,750.00	$39,885.00
Loan Interest Rate	8.000%	8.000%
Loan Term	30 years	30 years
Down Payment	$0.00	$0.00
Monthly Payment (P&I only)	$218.29	$292.66

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Figure 3-16 (*Continued*)

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Economics: Cost of Ownership

Simple Payback

GSHP Install Cost	$39,885.00	−	Conventional Install Cost	$29,750.00
Conventional Operating Cost	$3,339.93	−	GSHP Operating Cost	$1,349.49

⇒ $10,135.00 / $1,990.44 = Simple Payback Period 5.1 years

Short Term Savings

Monthly Operating Savings

Conventional Op. Cost	$278.33
− GSHP Op. Cost	$112.46
Monthly Op. Savings	$165.87

Difference in Monthly Payment

Payment w/ GSHP	$292.66
− Payment w/ Conv.	$218.29
Incremental Payment	$74.37

Monthly Operating Savings $165.87 − Incremental Payment $74.37

= Monthly Savings w/ GSHP $91.50

Monthly Savings w/ GSHP $91.50 × 12 = Annual Savings w/ GSHP $1,098.00

30 Year Savings

Fuel Oil w/ A/C

Adjusted Install Price	$78,586.19
+ Adjusted Op. Cost	$378,357.88
Ownership Cost	$456,944.07

GSHP

Adjusted Install Price	$105,358.32
+ Adjusted Op. Cost	$54,746.22
Ownership Cost	$160,104.54

Conventional Ownership Cost $456,944.07 − GSHP Ownership Cost $160,104.54

= 30 Year Savings $296,839.53

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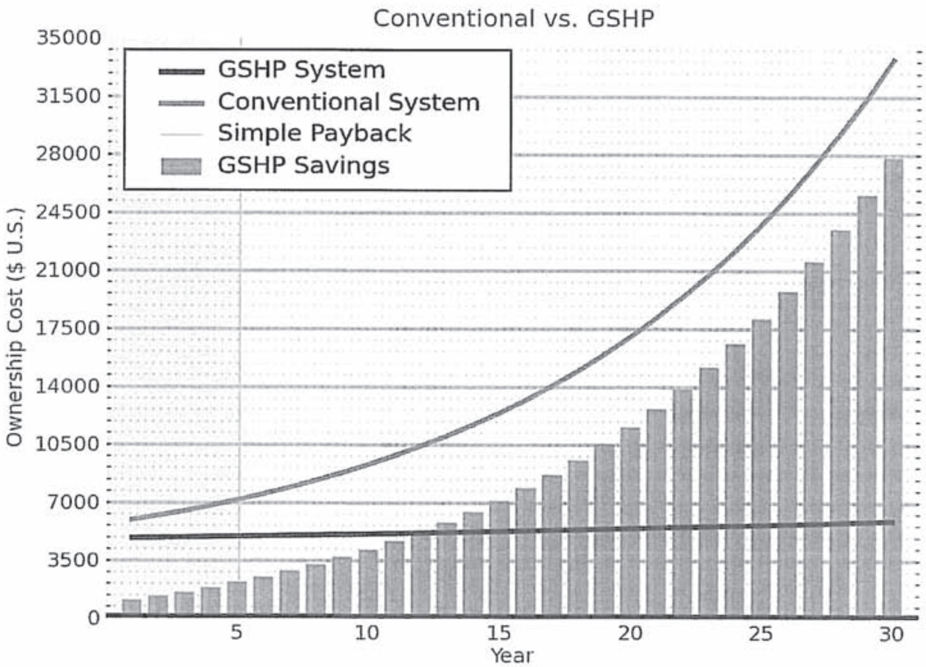
Figure 3-16 (*Continued*)

Newport Geothermal, LLC

Economics: Cost of Ownership

Cost of Ownership: Conventional vs. GSHP

The cost of ownership is a sum of operating costs and loan payments over the estimated 30 year life of a GSHP system including initial costs and fuel inflation rates. The figures represented in the graph below and the following tables assume that both systems are running at their peak efficiency throughout the full 30 year span.



(401) 608-6566
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Figure 3-16 (*Continued*)

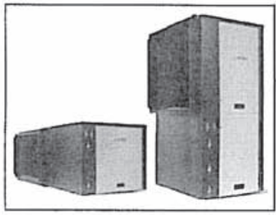
30 Year Cost of Ownership Table

	Ground Source Heat Pump (GSHP)			Fuel Oil w/ A/C		
Year	Purchase Price +	Operating Cost =	Ownership Cost	Purchase Price +	Operating Cost =	Ownership Cost
1	$3,511.92	$1,349.49	$4,861.41	$2,619.48	$3,339.93	$5,959.41
2	$3,511.92	$1,376.48	$4,888.40	$2,619.48	$3,607.12	$6,226.60
3	$3,511.92	$1,404.01	$4,915.93	$2,619.48	$3,895.69	$6,515.17
4	$3,511.92	$1,432.09	$4,944.01	$2,619.48	$4,207.35	$6,826.83
5	$3,511.92	$1,460.73	$4,972.65	$2,619.48	$4,543.94	$7,163.42
6	$3,511.92	$1,489.95	$5,001.87	$2,619.48	$4,907.45	$7,526.93
7	$3,511.92	$1,519.74	$5,031.66	$2,619.48	$5,300.05	$7,919.53
8	$3,511.92	$1,550.14	$5,062.06	$2,619.48	$5,724.05	$8,343.53
9	$3,511.92	$1,581.14	$5,093.06	$2,619.48	$6,181.98	$8,801.46
10	$3,511.92	$1,612.77	$5,124.69	$2,619.48	$6,676.54	$9,296.02
11	$3,511.92	$1,645.02	$5,156.94	$2,619.48	$7,210.66	$9,830.14
12	$3,511.92	$1,677.92	$5,189.84	$2,619.48	$7,787.51	$10,406.99
13	$3,511.92	$1,711.48	$5,223.40	$2,619.48	$8,410.51	$11,029.99
14	$3,511.92	$1,745.71	$5,257.63	$2,619.48	$9,083.35	$11,702.83
15	$3,511.92	$1,780.62	$5,292.54	$2,619.48	$9,810.02	$12,429.50
16	$3,511.92	$1,816.24	$5,328.16	$2,619.48	$10,594.82	$13,214.30
17	$3,511.92	$1,852.56	$5,364.48	$2,619.48	$11,442.41	$14,061.89
18	$3,511.92	$1,889.61	$5,401.53	$2,619.48	$12,357.80	$14,977.28
19	$3,511.92	$1,927.40	$5,439.32	$2,619.48	$13,346.43	$15,965.91
20	$3,511.92	$1,965.95	$5,477.87	$2,619.48	$14,414.14	$17,033.62
21	$3,511.92	$2,005.27	$5,517.19	$2,619.48	$15,567.27	$18,186.75
22	$3,511.92	$2,045.38	$5,557.30	$2,619.48	$16,812.65	$19,432.13
23	$3,511.92	$2,086.28	$5,598.20	$2,619.48	$18,157.66	$20,777.14
24	$3,511.92	$2,128.01	$5,639.93	$2,619.48	$19,610.28	$22,229.76
25	$3,511.92	$2,170.57	$5,682.49	$2,619.48	$21,179.10	$23,798.58
26	$3,511.92	$2,213.98	$5,725.90	$2,619.48	$22,873.43	$25,492.91
27	$3,511.92	$2,258.26	$5,770.18	$2,619.48	$24,703.30	$27,322.78
28	$3,511.92	$2,303.43	$5,815.35	$2,619.48	$26,679.57	$29,299.05
29	$3,511.92	$2,349.49	$5,861.41	$2,619.48	$28,813.93	$31,433.41
30	$3,511.92	$2,396.48	$5,908.40	$2,619.48	$31,119.05	$33,738.53
	Total Cost Over 30 Years		$160,103.82	Total Cost Over 30 Years		$456,942.40

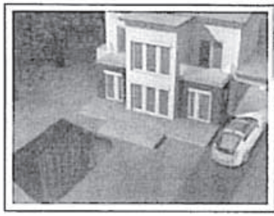
13 of 13

Figure 3-16 (*Continued*)

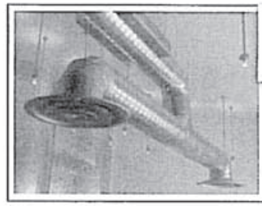
GEOTHERMAL HEATING & COOLING SYSTEM + DOMESTIC PLUMBING



Water-to-WATER GSHP



OPEN-LOOP FIELD



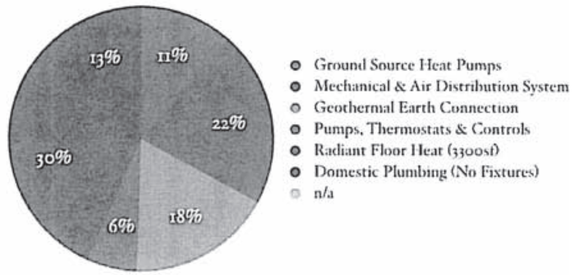
FORCED AIR SYSTEM

System Breakdown

Zone	Width (AVG)	Length (AVG)	Total	Include	Notes
First Floor Zone 1 & 2	1	3300	5.5	☑	Air & Radiant
Second Floor - Zone 3	1	550	0.9	☑	Air Only
	0	0	0.0	☐	
	0	0	0.0	☐	
			Tons	6	

Budget

Description	Cost	Qty	Total Cost	%
Ground Source Heat Pumps	$11,405	5	$11,405	11%
Mechanical & Air Distribution System	$21,688	1	$21,688	22%
Geothermal Earth Connection	$17,710	1	$17,710	18%
Pumps, Thermostats & Controls	$6,175	1	$6,175	6%
Radiant Floor Heat (3300sf)	$30,200	1	$30,200	30%
Domestic Plumbing (No Fixtures)	$13,439	1	$13,439	13%
n/a	$0	1	$0	0%
	System Cost		$100,617	



Payment Milestones

Milestone	#	Tasks	Amount
Project Start	1	Project Downpayment	$14,883
Drilling Payment	2	Upon Completion of the drilling	$9,180
Mechanical Start	3	Upon Delivery of the Equipment	$27,116
Mechanical Partial	4	10 Days after the Start of the Mechanical Installation	$18,806
Mechanical Rough	5	Upon Completion of the Rough Inspection	$27,295
Finish	6	Within 5 days after the start of the system	$3,336
		Total Project Cost	$100,617

NEWPORT GEOTHERMAL LLC
www.NewportGeo.com

Figure 3-16 (*Continued*)

half-page ads for automobiles, the "new transportation." Other than the Ford, none of the automobiles are on the market or, in many cases, even remembered today. It is easy to miss Ford's greatest contribution to the auto industry—a profound understanding of the industry as a whole. The coauthor (Orio) notes that the "Ford Institute" taught not only the auto's composition and its repair equipment but also fuel, lubrication, roads, bridges, insurance, financing, its place in the family, and its place in the United States. This is the same challenge that the geothermal industry must face today.

Chris Integlia sent an e-mail to the lead author asking him to review a geothermal quote for a residential application in Rhode Island. Chris asked for special feedback and insight into

1. Financial analysis or payback period
2. Lack of design drawings—piping and/or well drawings
3. Lack of reference to controls and/or sequence of operations

Let's take a few minutes to review the proposal and think about what you would expect to see on such a document, given Chris's questions to the lead author. At first glance, the proposal is indeed professional in appearance. The first two pages are a summary of the equipment going into the project: two water-to-water heat pumps with all related piping and controls, two air handlers, some piping for connections, some Pex tubing for radiant on foam board over plywood, and a note about the likelihood of change orders for the unseen things.

These two pages go on to say, like so many "canned specs," that the ductwork will go in according the state mechanical code, and some identity is given to the registers by brand and color. The earth coupling is identified as a vertical open-loop standing-column well. The only mention of anything to do with the sizing is contained in the statement, "Execute a manual J-load analysis to determine the heat loss/gain of the existing building to the dominant load (which typically would be heating-dominant in New England).

There is a mention that the home owner needs to work with his own accountant to get the tax credits, and then the six-tiered payment schedule is set forth (Fig. 3-17).

The home owner has no recourse with regard to the geothermal source because no claim made as to what it will be designed to do. The water temperature, water quantity, expected depth, construction parameters, construction materials, codes, and compliance are all rather vague at best. There are so many wrong ways to do this type of a well that the lead author will not confuse the issue by attempting to cover all these wrongs.

The lack of piping detail and associated drawings leaves too much to chance. A drawing of the piping, together with the components with which it will be integrated, will serve to allow a healthy discussion of the degree of reliability and functionality for which the consumer is willing to pay. As engineering professionals, it is incumbent on us to give our customers the very best available. Let them decide if they want a finished product of lesser value. You would be wise to determine in advance the lowest standard to which you will affix your reputation because, make no mistake, you will have to live with the product you design, and that can be more costly than you can possibly imagine. Let's look at an example.

Specify the Best, and Let the Customer Decide

A good friend and bishop of the church with which the lead author engaged in much good business on a commercial level asked him to provide a proposal for an air-conditioning system in the game room of his newly acquired home. This home was large,

Tax credits:

– Newport geothermal, LLC will supply the required proof from the manufacturer that the equipment installed meets the requirements set forth by the Federal Government and is Energy Star certified for the installation.

– It is the clients responsibility to coordinate all required paperwork with their own accountant and/or tax preparer.

Payment milestones - I

Milestone	#	Tasks	Amount
Project start	1	Project dawnpayment	**$14,883**
Drilling payment	2	Upon completion of the drilling	**$9,180**
Mechanical start	3	Upon delivery of the equipment	**$27,116**
Mechanical partial	4	10 days after the start of the mechanical installation	**$18,806**
Mechanical rough	5	Upon completion of the rough inspection	**$27,295**
Finish	6	Within 5 days after the start of the system	**$3,336**
		Total project cost	**$100,617**

Figure 3-17 Here is a mention that the home owner needs to work with his own accountant to get the tax credits, and then the six-tiered payment schedule is set forth.

perhaps 20,000 ft^2. Like many homes that have the finest of bathroom fixtures, marble tile, and chandeliers, the HVAC system was what the industry calls "builder grade." *Builder grade* is a construction-friendly term used to denote the lowest possible cost and standard with which a contractor may pass by the codes of the local building department.

The lead author knew his friend to be a shrewd businessman and inclined toward saving money on his commercial ventures, which is to say that he generally preferred the least expensive options for his HVAC needs. This was reflected in the lead author's proposal to him for the game room upstairs; the lead author proposed a builder-grade 2-ton split system. It wasn't until a month or so later when the lead author saw the man that he thought again of the project. He inquired when the man was going to have the lead author's company do the work. The man's answer cut the lead author to the quick. "I had another air-conditioning company do the work. They proposed a system more than four times the price, rated for 16 SEER with a two-speed compressor and many extras, including zone dampers. I simply figured that you must not be qualified to install such a system or else you would have proposed it."

Ouch! What a lesson to learn. We should always propose the best solution for our customer's request. Let's not let anyone else fall victim to such an oversight. It is always easier to say, "I was proposing the best, what I would use if I had the choice. You may feel free to negotiate a better value for your circumstances or needs at any time. Here are your choices." And then, of course, make the case for the "value-engineered" items.

In the construction trades, many people get a chuckle when faced with "value engineering." Loosely translated, it means to get the price down but make it look and perform the same because they can't afford it at the current cost.

Now back to the lack of piping detail on the proposal. If the customer sees exactly what he is getting, he must then also understand the degree to which the system will affect his life in every way. He will know where the service points are located and how much time will be needed for periodic maintenance.

Figure 3-18 As you add hydronic equipment to improve system performance, there is need to properly control and anticipate situations. We need not reinvent the wheel here; companies such as iWorX Electronic Solutions have provided the systems we need to get the system designed properly.

In the case of this proposal, a plate and frame exchanger (PFHX) should be offered to protect the equipment because the water quality for this application was aggressive.

Let's take the time here to further expand on the use of flat-plate heat exchangers or the use of factory-installed copper-nickel heat exchangers. It is important to note that a flat-plate heat exchanger with a 3°F *approach temperature* causes a small reduction in heat-pump efficiency but is substantially more costly overall for the system. A quality copper-nickel (90/10 percent alloy) heat exchanger, available from any of the major manufacturers, will tolerate almost any quality of water, including seawater. Copper-nickel heat exchangers have been used on ocean-going ships for many years. The issue lies with control of electrolysis (which will be discussed further later on) and with water velocity.

Plate and frame heat exchangers are needed when well-water quality does not meet primary drinking standards (health or state water quality requirements). A PFHX with a 10°F approach temperature is small and relatively inexpensive, but it changes the well-water temperature entering the heat pump by 10°F lower in the winter and warmer in the summer. This affects the cost and efficiency of the system. Each and every situation must be carefully evaluated for water quality, cost, and efficiency.

A PFHX is a valuable addition to the design of a high-rise geothermal building when employed with standing-column well or open-to-reinjection well earth coupling. While there is a loss in efficiency with the PFHX approach temperature differential, there is a gain in system efficiency when the building is approximately 10 stories high. The PFHX provides a closed secondary loop from the surface to the highest GHPs. The closed loop merely requires circulation, with less pump pressure and energy required. The 10-story building is an approximate height, based on typical conditions, where the added well pumping costs can be offset by the lower cost of a closed circulation loop.

This then leads to a discussion of the need for pump control. In these times, there are few instances where variable pump control should not be used. Fundamentally, this will allow for full control of the loop and well temperatures, which, in turn, has a direct correlation with the efficiency of the heat-pump equipment and its ability to control the environment. Items such as humidity and air-exchanger fouling can be controlled by proper implementation of pump and fan speed controls.

The controls for a geothermal system are a point of great importance to the authors of this book for many reasons. It is their experience that fewer than 20 percent of geothermal systems, especially two-speed high-efficiency geothermal systems, are installed properly. Figure 3-19 shows a two-speed geothermal system.

Most often you will find the system installed with either a two-stage thermostat that is programmed to one stage (because that is the factory default) or a thermostat that is programmed properly but the heat pump is not set up to operate as a two-stage heat pump. Even if the thermostat and heat pump are set to operate on two stages, the question still remains, Is the number 1 stage set on the thermostat actually the number 1 stage on the unit, or is it number 2? After all this is confirmed, the pumps that operate the geothermal flow for the system constitute the next set of variables.

The pump station and a closed-loop application should be at least a two-pump assembly, with one pump correlating with each stage of operation. This is so often backwards, in that two pumps run on first stage, and vice versa. It would be better to have a pump on a variable-frequency drive with individual flow setting water valves for the stages.

In the case of a pump and reinjection system with a plate and frame exchanger, it's common to see the pumps running on a pressure switch with a drawdown pressure tank. This system isolates the inside equipment and exchanger from the problems associated with water quality of the well but still leaves much to chance with regard to staging of the system. These systems must be properly temperature controlled. More will be covered on this in Chap. 12 on controls.

Proper control of the well pump is an issue in that there are several ways to do this. Most often, however, one finds that the well pump is turned "on full" whenever the heat pump is running, as are the condenser pumps. This wastes energy.

All the pumps should be on variable-speed controllers, which operate based on the needs of the heat pumps as in Fig. 3-20. The ORB platform from Geofinity does just this.

FIGURE 3-19 A two-speed high-efficiency geothermal system with electronically controlled motor two-speed compressor. Today's geothermal heat-pump equipment needs smart controllers. With the introduction of direct-current (dc) inverter-driven variable-speed equipment, this is more important now than ever. (*Geofinity*.)

This will be covered in depth in Chaps. 12 and 13. For an idea of what the lead author is speaking about, please read on.

Figure 3-21 is a chart derived from a manufacture's specifications that lists the different EERs and coefficients of performance (COPs) for a water-to-air GHP at different water temperatures. You can see from this chart that at 32°F and 50°F (the ISO Design standards for closed loop versus groundwater) the COP increases from about 4.1 to about 5.1. If you correlate the difference in the water temperatures, it seems perhaps obvious that a warmer incoming water temperature would result in a lower EER, and indeed, it does. In the heating mode, however, the higher incoming water temperature results in a higher COP.

The lead author would ask you to venture a guess as to the answers to the following questions:

1. If you use variable-speed pumps and slow down the flow of water, thus saving pumping energy, how much will the temperature of the water be increased?
2. What will that do to the EER of the heat pump?
3. At what point is the best overall EER achieved?
4. How will that be determined under the differing conditions?

If this seems like a lot to take in, don't worry yet. More on this will be covered in Chaps. 12 and 13. For now, it is important just to realize that there is so much more to geothermal HVAC and hydronics applications than the industry has been able to teach thus far.

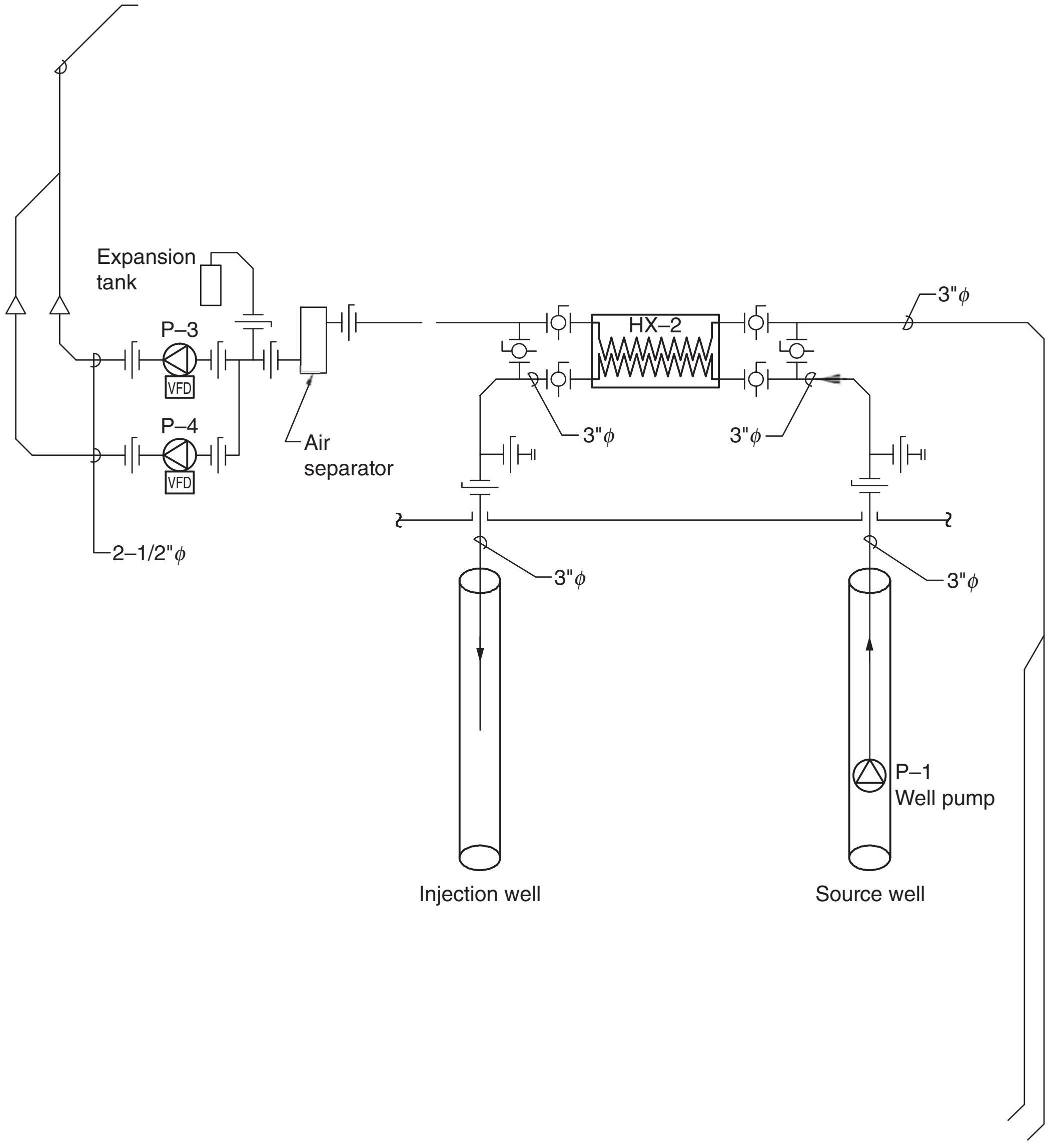


FIGURE 3-20 Rather than operating the pumps on pressure switches and thermostats, variable-frequency drives and proportional-integral-derivative controller (PID) loops are integrated into the control system to provide precise, and seamless control. Compare this with the cruise control on your car.

In its simplest form, many don't think further than the lead author did as a 10-year-old boy. This was during the energy crisis of the 1970s. It seemed that the fuel lines were never-ending, and the press was on us continually to save energy. The lead author had plenty of time to ask his father about energy efficiency and associated philosophies and theories during those hours in the gas lines in the sweltering Mojave Desert of California. To the lead author, it seemed as though it would be illogical to assume any difference

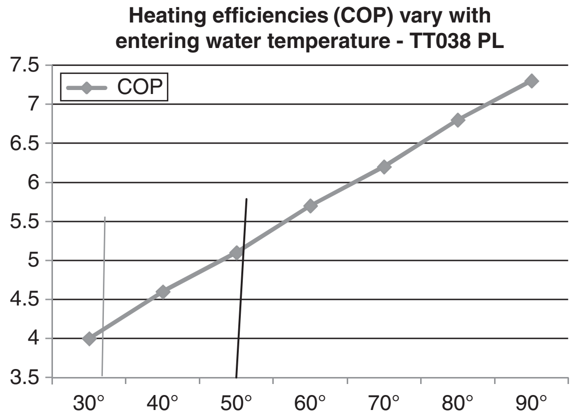


Figure 3-21 This chart depicts how varying water temperatures affect energy-efficiency ratings (EERs). (*ClimateMaster*.)

between driving at 45 miles per hour or driving 90 miles per hour. The rationale was simple in his mind: If you drive slower, the engine would use less gas per hour, but you would drive fewer miles per hour. If you drive faster, the engine would use more gas per hour, and you would drive more miles per hour. What the lead author's father explained—and one would imagine that many of you now know—is that there are other factors working on the vehicle's fuel economy that the lead author had not considered. In this case, the primary factor was the wind resistance. The lead author's father said that in fact the best efficiency in miles per gallon was at about 35 miles per hour. You may remember or have studied that for a period of time, the United States dropped the speed limit to 55 mi/h, primarily to increase the fuel economy of the country as a whole. Now an entire new dynamic could be applied that has to do with economics in a myriad of ways (e.g., lost productivity, etc). What the lead author wishes to convey here is that we may have lost much more in productivity than what we gained by the increased fuel savings.

You will eventually see that there is a better way to control all the components in your geothermal HVAC systems. Although it is important to understand why, the controls do the hard work of learning and adjusting. The most important thing you can do is size the pumps and piping properly, set them up for variable-speed capacity, and run fully integrated and cost-effective controls.

Do Geothermal Systems Wear Out?

During a recent control summit at the Taco iWorX facility in Cranston, RI, some colleagues and the lead author were having lunch at a local restaurant (Figs. 3-21 through 3-24). As we are having lunch, the lead author started a conversation about the thermal retention issues that he had experienced in the Southeast over the years. To his amazement, this wasn't a singular regional concern. He had suspected this after reading an article on renewable energy a couple of years before. Scott Sklar from the Stella Group in Washington, DC, had called Don Ellis from ClimateMaster because he had received several queries about geothermal systems wearing out after about 10 years.

Figure 3-22 Engineers are discovering more and more often that closed-loop systems fail in cooling-dominant situations.

Figure 3-23 Mike Albertson, of WaterFurnace International, and Carl Orio, coauthor and chairman of Water Energy Distributors, discuss geothermal HVAC technologies at Taco in Cranston, RI.

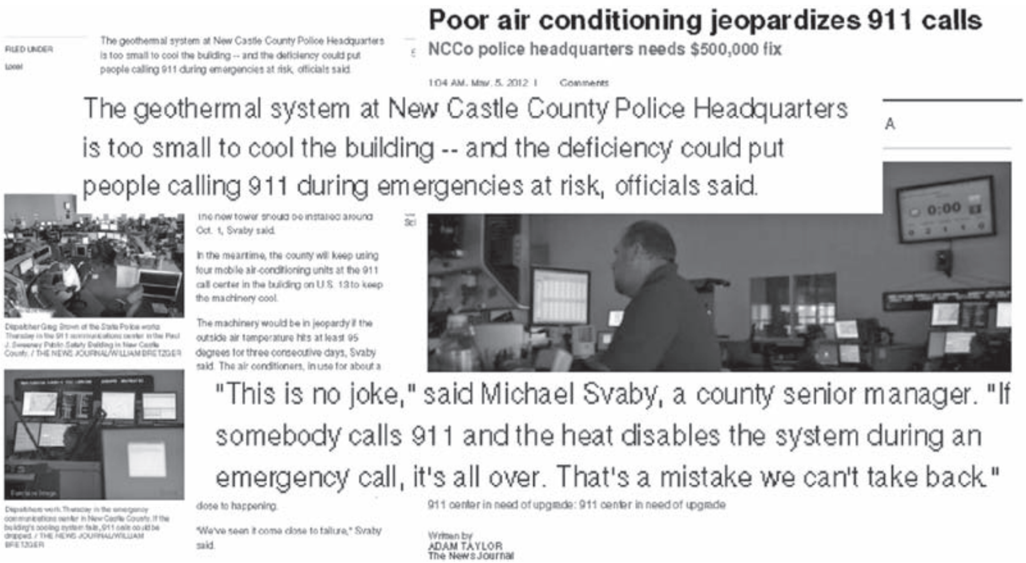
Figure 3-24 Coauthor Greg Cunniff, Kristy Egg, and Brian Payne are among others discussing geothermal HVAC applications and issues over lunch.

The lead author had found in Florida that closed-loop systems engineered to the specifications of the International Ground Source Heat Pump Association (IGSHPA) guidelines had been failing in four or five years. As he and his friends continued the discussion, the engineers sitting around the table began to share stories of woe about geothermal loops failing and/or being abandoned after 10 or 12 years all over the North American continent. Specifically, these were typically commercial buildings with a cooling-dominant load because of the high internal heat gains.

Based on the lead author's very unscientific approach in this case, it was easy to see that thermal retention (aka *temperature creep*) had become a serious concern for geothermal systems. As of the writing of this book, the lead author is involved in no less than a half dozen geothermal remediation issues, specifically with government buildings around the country. And that is all that the lead author can say at this time.

Many, many more systems are being abandoned at a rapid pace because of thermal retention problems. Up to the present, there have been no manual or engineering guidelines to stay the errant guidelines that show closed-loop technology as the primary method of handling all geothermal systems, whether cooling- or heating-dominant. So let the lead author make this clear: Cooling-dominant systems must be open-loop systems, or accept the high cost of fully sized loops or inefficient/high maintenance augmentation.

In the story of the geothermal failure of New Castle, Delaware, EOC, it was evident that as of the beginning of May 2012, yet another geothermal system was struggling with the issue of heat retention. The county had no plan of which it was certain, and it was getting ready to spend an additional half-million dollars to fix the problem. The lead author estimates that 20 to 50 faulty systems go unreported for every one that is reported. At the very end of that news story (Fig. 3-25), you will find some sad words that really could've been prevented. At least three or four of the county officials are quoted as



Poor air conditioning jeopardizes 911 calls

NCCo police headquarters needs $500,000 fix

1:04 AM, May 5, 2012 | Comments

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Local

The geothermal system at New Castle County Police Headquarters is too small to cool the building -- and the deficiency could put people calling 911 during emergencies at risk, officials said.

The geothermal system at New Castle County Police Headquarters is too small to cool the building -- and the deficiency could put people calling 911 during emergencies at risk, officials said.

Dispatcher Greg Brown of the State Police works Thursday in the 911 communications center in the Paul J. Sweeney Public Safety Building in New Castle County. / THE NEWS JOURNAL/WILLIAM BRETZGER

The new tower should be installed around Oct. 1, Svaby said.

In the meantime, the county will keep using four mobile air-conditioning units at the 911 call center in the building on U.S. 13 to keep the machinery cool.

The machinery would be in jeopardy if the outside air temperature hits at least 95 degrees for three consecutive days, Svaby said. The air conditioners, in use for about a

"This is no joke," said Michael Svaby, a county senior manager. "If somebody calls 911 and the heat disables the system during an emergency call, it's all over. That's a mistake we can't take back."

Dispatchers work Thursday in the emergency communications center in New Castle County. If the building's cooling system fails, 911 calls could be dropped. / THE NEWS JOURNAL/WILLIAM BRETZGER

close to happening.

"We've seen it come close to failure," Svaby said.

911 center in need of upgrade: 911 center in need of upgrade

Written by
ADAM TAYLOR
The News Journal

Figure 3-25 The Newcastle, Delaware, Emergency Operations Center (EOC) experienced the same situation as the Sussex EOC. Geothermal HVAC systems are favored for EOCs because they allow removal of all equipment from the harsh outdoor environment, placing it indoors where it is typically safer, especially during emergency weather. This does the counties and cities no good if the systems cannot stay operational.

saying that they do not have confidence in geothermal systems. With this type of publicity, it is unlikely that New Castle will ever consider a geothermal system again, at least in the near future.

So what are we doing about thermal retention/creep or cooling-dominant modes in the geothermal industry? In the article shown in Fig. 3-26, you will be enlightened as to a concern posed by a consumer regarding geothermal loops wearing out. The underlying problem here is posed by the consumer as follows: "I have never heard of that before. Scientifically, that doesn't make any sense to me."

As you can see in the article, Scott Sklar says, "None of the residential systems these companies have installed have this kind of saturation problem." The article goes on to say during an interview with Dan Ellis, president of ClimateMaster, that this issue of thermal retention is confronted only in larger commercial systems with a dense ground heat-exchanger array, unbalanced seasonal loads, and poor design. He continues that in these situations the center of the ground-coupled heat-exchanger array begins to act as thermal storage. This is a well-known design aspect that good design software addresses. The software looks out over long periods to allow for any impact. The size of the heat exchanger is adjusted to keep within the design parameters over that long time period. Alternatively, the load and balance involved supplemental heat rejection in many other ways.

Once again, the lead author must state that closed-loop geothermal systems should not be applied to cooling-dominant loads. Hybrid systems, such as those that use a cooling tower or an air-source fluid cooler, are a waste of money and resources in the lead author's opinion. He will endeavor to explain why this is later on.

ASK ANGIE

Ask Angie: Heat and drought can challenge geothermal units

Published: August 10, 2012

By Angie Hicks — Angieslist.com

Dear Angie: I have a ground-source geothermal heating and cooling system. This summer, we've endured a significant drought and heat wave in our area, and I've noticed that our geothermal system has not been cooling our home as effectively it normally does. I know the unit relies on steady ground temperatures to dissipate heat. Could the dry ground and extreme temperatures be affecting the performance of the system? **—Cathy H., Carmel, Ind.**

Answer: Unfortunately, some homeowners with geothermal systems are experiencing problems with the units not sufficiently cooling their homes. The dry ground and high temperatures definitely are affecting how well some units perform.

Ground-source geothermal units use an underground loop system to bring heat from the earth into the home during the winter and pull heat from the home back into the earth during summer. Loops can be buried vertically or horizontally, depending on the type of soil, the size of the yard and other factors. Systems with horizontal loops seem to be affected more by the dry conditions because they're not buried as deep as vertical systems. The ground needs to be moist and cool for the system to operate as it should.

Obviously, that's been a major problem in parts of the United States this summer with the lack of rain and the unusually high temperatures at night, when the ground is normally able to cool off.

"The dry ground and high temperatures definitely are affecting how well some units perform... units use an underground loop system to bring heat from the earth into the home and pull heat from the home back into the Earth during summer... that's been a major problem this summer with the lack of rain and high temperatures..."

Figure 3-26 As if to answer whether or not the problem of heat retention is isolated only to commercial applications as the previous story suggested, this article shows conclusively that thermal retention in residential geothermal closed systems is also an issue.

Even in residential systems, which are generally considered to be safer for closed-loop applications, one can see more and more issues cropping up. And then in the "Ask Angie" article, the subject was "heat and drought can challenge geothermal units (on closed loops)." In the article, dated August 10, 2012, the consumer statement is that she's noticed that her geothermal system was not cooling her home as effectively as it normally did. Angie replies that some home owners with geothermal systems are experiencing problems with the units not cooling their homes sufficiently. The dry ground and high temperatures are definitely affecting how well some units perform and must be considered when designing geothermal HVAC systems.

The article might as well stop there because many contractors have experienced the same situation decade after decade. This is a problem that needs to be addressed by not making any more of the same mistakes.

When you add the complexity of an air-source system or cooling tower, you're adding all the headaches of a basic HVAC system to the efficiency of a geothermal HVAC system. Indeed, this actually adds to the possibility of more failures and potentially reduces efficiency significantly. It is very easy to supplement a short-looped system with a properly engineered open-loop system.

At this point, it should be clear that closed-loop applications for commercial loads and imbalanced loads should be carefully scrutinized. The lead author would go so far as to say that they should be weighed carefully against the cost and efficiency of a standing-column well system or an open-loop system.

Back in 2006, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' (ASHRAE) Geothermal Research Committee prompted a study to examine the long-term earth-temperature effects of a 200-ton standing-column well system in Massachusetts (*ASHRAE Transactions* QC-06-006). After a 10-year period, the results for the standing-column well system showed *no change* in average annual mean earth temperature. The standing-column well's design for 100 percent of the dominant earth load and the periodic bleed provided the desired earth-temperature stabilization.

Hydronic Geothermal?

What are the advantages of hydronic systems as opposed to forced-air systems? The large family of GHPs includes not only water-to-air heat pumps that produce heated and cooled air but also water-to-water heat pumps that produce heated or chilled water. Let's take a look at the delivery of the geothermal energy. Past studies by the U.S. Department of Energy (DOE) have indicated that as much as 90 percent of the GHP shortfalls inside a residence and, to a lesser extent, in commercial buildings has been attributed to poor in-building distribution.

In the book *Geothermal HVAC: Green Heating and Cooling*, the lead author uses the illustrations reproduced here as Fig. 3-27 for the purpose of explaining the advantages of hydronic versus forced-air cooling. In these illustrations you can see that capturing waste heat for use in other areas of the structure is all but impossible with forced-air systems. Use of the condenser-water loop as with geothermal systems opens the door for considerable opportunities for heat claim often known as *load shedding* and *load sharing*.

Additionally, the space saved by using hydronic systems cannot be understated. Water carries 32 times the energy of forced air in the same area. Heat transfer through conduction rather than convection is more efficient as well.

There was a time when energy was cheap. Whether it was gasoline, fuel oil, propane, or electricity, it made no sense, fiscally speaking, to introduce energy-conservation measures into the marketplace. This is not the case now. The lead author remembers during the energy crisis of the 1980s the diesel-powered VW Rabbit that claimed a fuel efficiency of 50 mi/gal. Just as soon as that was introduced and the energy crisis went away, the age of sport utility vehicles (SUVs) began.

Along with SUVs came huge homes with electrical resistance or gas heating, saunas and spas, heated pools, and every other luxury conceivable. Progress is good, and the lead author likes to see people enjoying more luxury. However, he looks at the cost of energy as a means by which one can become more responsible.

In 1987, the lead author was able to put his hands on his very first heat-pump water heater. The interesting thing about this 120-gallon heat-pump water heater installed in the back room of a Wendy's restaurant was that the lead author had been able to rationalize the high cost not because of hot-water savings but as a result of additional cooling for the back room where the potatoes were baked and other cooking occurred. It seemed that this particular room was always a bit hotter than the rest of the restaurant.

So, as you can see in Fig. 3-28, the heat-pump water heater was using the heat essentially from the energy radiated from the oven and the steam and radiated energy from the chili kettles to heat the domestic hot water for the restaurant. When this was presented to the bean counters for Wendy's, the only consideration at the time that

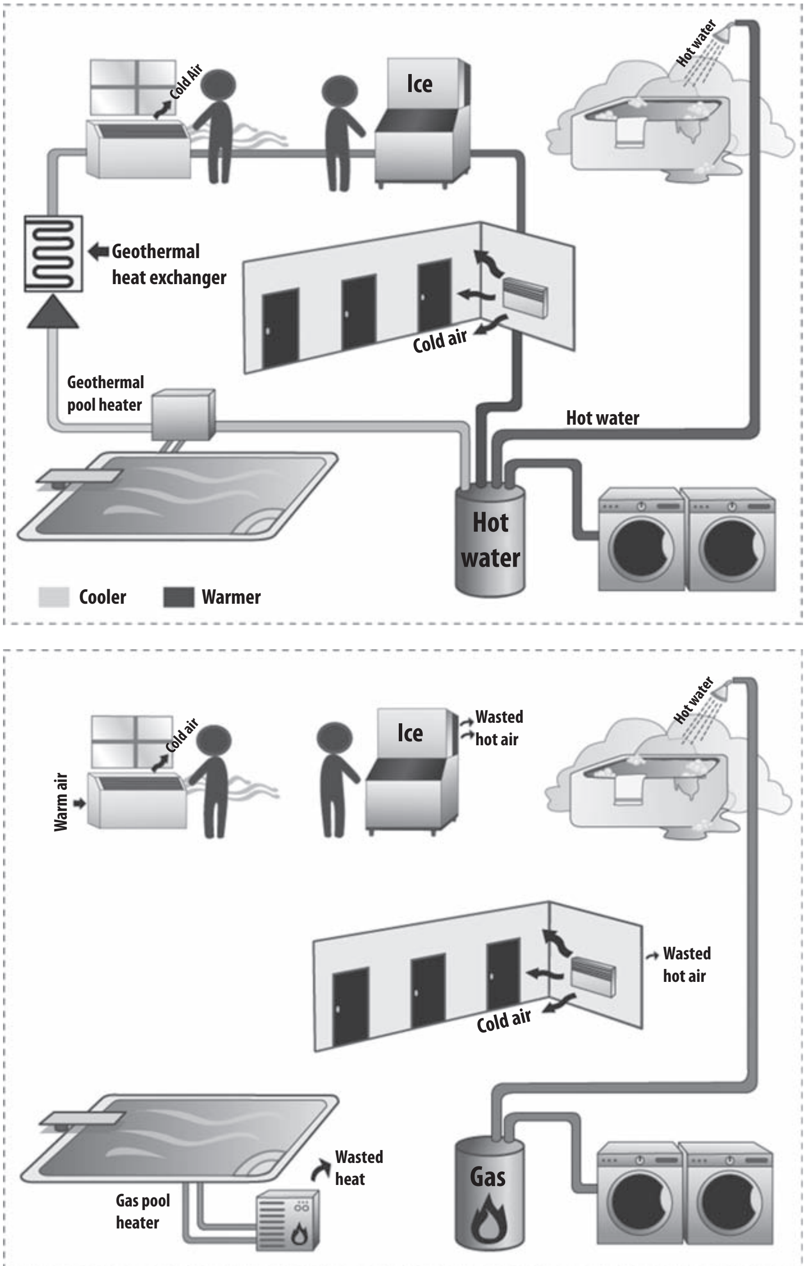

Figure 3-27 Using hydronic base systems, the combination of opportunities to load shed and load share is virtually unlimited. This simply cannot be done effectively with air-source applications.

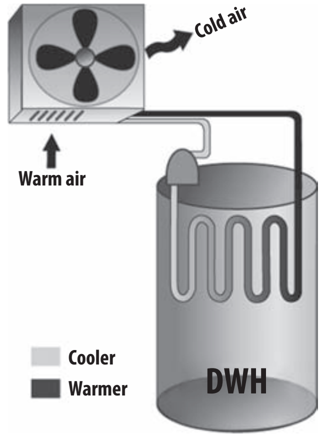

FIGURE 3-28 As in the case of the lead author's first heat-pump water heater installation in a Wendy's restaurant in 1988, comfort and convenience are normally the number one consideration for renewably sustainable technologies such as geothermal HVAC systems. The reason the owners chose this heat-pump water heater was that the more hot water was needed in the back room, the more air conditioning would be produced. Subsequently, the lead author has found repeatedly that trying to sell this technology based on the merits of energy efficiency fails. It must be sold on the merits of comfort, longevity, and dependability.

interested them was the additional cooling for the back room. Indeed, it did provide quite a bit of cooling for the back room. But what everyone failed to see was the incredible reduction in energy consumption at this restaurant compared with many others in the system. That year the company had opened a couple of other restaurants without heat-pump water heaters that had similar sales records and similar footprints, but they used almost $600 per month more electricity and still did not have as comfortable an environment in the back room as did the one with the heat-pump water heater.

Now, to go back the depiction of load shedding and load sharing from the case for the hotel. Imagine how much could be saved in your particular installation or design if you pumped all the heat rejected from your room air conditioners, your common-area air conditioners, your 100 percent outdoor-air air conditioners, and your ice machines into the domestic hot-water system, pool heating, and hot tubs.

The possibilities here are endless, but they all begin with the use of hydronic systems to facilitate load shedding and load sharing.

Agricultural Geothermal Applications

Animals

Geothermal applications in the agricultural sector are growing by leaps and bounds. In the book *Geothermal HVAC: Green Heating and Cooling*, the lead author discussed the increased production of both dairy cows and pigs by cooling down their environment just 10°F. Cooling the ground directly under the stalls in which they are housed places these animals in a much more favorable environment and increases production in all areas. This cooling can be accomplished by running coils of pipe underneath the stalls that absorbed the heat from the animal either through their hooves or, when they're lying down, through their skin.

How many times have you seen your favorite dog curled up on the cool concrete of the garage floor or the coolest part of the tile in your home? Just like your dog, animals love to have the heat absorbed from their bodies on a hot day through the medium of a cool concrete slab, cool tile, or an earthen surface. A heated radiant floor in the winter gives a whole new meaning to comfort for you and a four-legged friend.

Here's another one—and geothermal can provide an energy "pinch"—involving using both cold and hot outputs of a water-to-water GHP: Consider a commercial egg farm and the processing, cleaning, and storing of the eggs. How could a GHP ever be of any value? It can. A chicken's egg is at 103°F when laid. That egg must be cleaned with water that is over 130°F and then cooled to less than 40°F. A water-to-water GHP with entering well water at approximately 50°F can have water leaving the heat pump with R410a refrigerant at 130°F on its condenser side and 40°F on its evaporator side. With proper water-flow balancing and storage, both the inflows and outflows of the system can be added when using the flexibility of the GHP to produce a COP of 6.0 to 7.0. Both sides of the heat pump provide the needed temperatures for egg production—hence the "pinch."

Fruits and Vegetables

Did you know that most of the fruits and vegetables sold in Europe are actually grown in greenhouses in Denmark and surrounding areas? The medium the farmers use for heating when the weather is just too chilly to grow the next crop is geothermal heating. Now it's happening in the United States. Sometime in early 2011, the lead author was contacted by a company planning to install geothermal air conditioning in a 1,200,000-ft^2 greenhouse to be built in Ocala, FL. The owners had determined that geothermal cooling was needed to keep the tomato plants at a median temperature of about 72 to 78°F. Apparently, this temperature increases production almost threefold compared with the typical 90 to 95°F temperature experienced for many months of the year in Florida. Actually, temperatures in the 90s all but eliminate the production of many types of fruits and vegetables, something that the lead author was told during the process of assisting engineering of this geothermal HVAC system.

Additionally, CO_2 control can enhance the growth for some plans by a factor of 2. This is another advantage to geothermal applications because the greenhouse itself can be cooled during summer operation. The controlled CO_2 levels and the warm water available from the condenser side of the heat pump can enhance plant growth substantially.

This just barely scratches the surface of what can be done with geothermal HVAC technology in agricultural applications. The beauty of this is that these two examples provide students with an opportunity to let their minds ponder the nearly limitless potential for geothermal applications beyond just human comfort.

Dual-Purpose Wells: Geothermal and Domestic

With regard to cost savings, the cost versus energy savings achieved by dual-purpose geothermal wells is the most impressive. Dual-purpose wells employ the same water for a standing column as is used for domestic needs. The water quality must meet all federal, state, or local sanitation standards, and the system must be carefully designed.

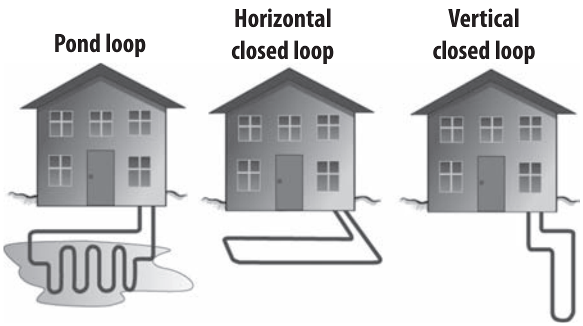

Figure 3-29 Several different types of closed-loop systems can be employed. The most common is the vertical closed-loop system. In vertical closed-loop systems, typically 150 to 230 linear feet of borehole per ton is needed. The cost per ton ranges from $3200 to $4400 for the outside portion of rock-bore closed-loop systems, including piping and antifreeze solutions. (*Sarah Cheney*.)

Domestic daily water use for cooking, drinking, and washing creates an advective water flow from far-field temperature-stable water, providing standing column and open-to-reinjection well temperature stabilization.

The Water Energy main offices in Hampstead, New Hampshire, an 8000-ft^2 office building (16 tons), has a single 1100-ft standing-column well. This system requires no bleed because daily domestic water use provides all the temperature stabilization needed to keep the standing-column well temperature within a 45 to 65°F range. Typically, this facility's GHPs heat up the surrounding earth in the summer, and this "stored" energy is typically available each year until Thanksgiving or mid-December, when the well temperature reaches the mean earth temperature of 50°F. The facility also sees a corresponding efficiency enhancement of a low entering-water temperature in the spring when first calls for air conditioning occur.

Closed-loop systems use HDPE pipe buried horizontally or vertically (Fig.3-29). The nonbiodegradable pipe is filled with an antifreeze solution, allowing lower solution temperatures to reach the heat pump. Temperatures can be well below freezing, generating the need for an antifreeze solution rather than pure water to prevent freezing in the heat pump, heat exchangers, or piping. Because the plastic piping creates another heat-transfer barrier, earth water solution temperatures must be lower in the winter and higher in the summer for effective energy transfer.

The Riversdale Museum Standing-Column Well Installation

Among the different types of geothermal earth coupling is the standing-column well (Fig. 3-30). A standing-column well is configured in which water is either drawn from the bottom and reinjected at the top or drawn from the top and reinjected at the bottom. Often this can be reversed through valving, or multiple valves on the surface of the well.

Carl Orio, coauthor of this book and patriarch of Water Energy Systems, has been a pioneer in standing-column well design. During the writing of this book, Carl and the lead author have conferred often on the need for proper training in more ways than one. The lead author had the opportunity to tour the Riversdale Museum in Delaware. Use of standing-column well technology there really paid off for the client. The wells are only able to produce perhaps 5 gal/min of water, but because of the better thermal conductivity of the borehole compared with a closed-loop system, the facility gets about

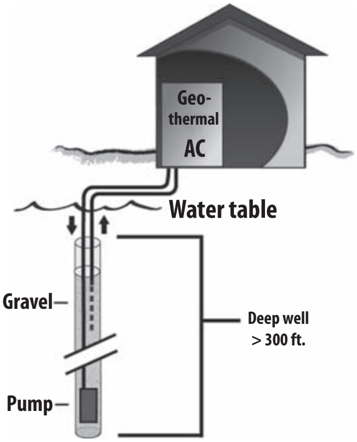

FIGURE 3-30 There are wells that do not produce sufficient water volume to facilitate the flows and pressures required for the heating and cooling loads placed on a geothermal system. In such situations, standing-column wells may very well fit the bill. (*EggGeothermal*.)

FIGURE 3-31 This is the actual 1500-ft-deep standing-column well installed at the Riversdale Museum in Delaware, along with some of the equipment and piping installed in the service the structure. If this were a closed-loop well, it would provide about 6 tons of heating and cooling capacity. Instead, the capacity is about five times that. (*EggGeothermal*.)

five times the heat transfer from the same size borehole as with a closed-loop system. In this case, the standing-column well was drilled to a depth of 1500 ft. Water is drawn from very deep in the well.

There are many considerations in constructing a standing-column well. For example, the entire length of the permeable zone in a standing-column well could be screened, allowing free flow of water from the aquifer to carry heat to and from the suction point of the well and carrying heat to and from the injection point of the well. In the case of the museum, a Porter shroud had not been installed. This caused short-circuiting of the supply and injection water and resulted in the need to reopen the well for installation of pipe for separate the permeable zones.

Since installation of the Porter shroud, the museum has operated well, according to the curator. He stated that he is very happy with the geothermal system and would recommend installation of such a system to anyone.

YWCA in Canton, Ohio, Switches Over from Closed Loop to Open Loop by Yoder Geothermal

Yoder Geothermal, Inc., a prominent geothermal HVAC contractor in Ohio attended a webinar conducted by the National Ground Water Association in 2011. In that webinar, representatives from EggGeothermal discussed open-loop technology with regard to PFHX usage and piqued the interest of Tim Yoder. Yoder had a geothermal application in which the soil was causing drilling problems and increasing the cost of the project substantially. Having just attended the National Ground Water Association webinar, Tim made the suggestion to go with an open-loop system on an plate-frame heat exchanger.

During an interview in May 2012, Tim said that the 100-ton system in the YWCA had an electrical consumption budget of about $54,000 per month. The system was operating at a monthly range of $10,000 to $15,000 per month. Jim Sloan, with Finney Refrigeration, worked with Yoder to put the system together. Engineer Josh Staley has become a believer in the system after seeing the increased performance compared with a closed-loop system.

On proposing the open-loop alternative to the owner, the concept was approved. This saved the facility $600,000 in installation costs and has improved system efficiency by about 37 percent compared with other similar installations on closed loops. The YWCA building in Canton, Ohio, is a geothermal application using vertical water-source heat pumps in resident rooms and horizontal heat pumps in common areas that serve the 60,000-ft^2 facility.

There are two 100-ton water-to-water heat exchangers that are completely redundant for backup and service without interruption (Fig. 3-33). No glycol is used in the main loop, protecting the groundwater in case of heat-exchanger failure. A small amount of glycol is in secondary circuits in the water-to-water heat pumps that serve the three energy-recovery ventilators for freeze protection.

Two Hydrotherm KN-6 boilers provide emergency backup heat in case of well pump failure (Fig. 3-34). These were installed early in the project and were to be the main source of heat because of budgetary restrictions, along with a cooling tower. Because of the opportunity to use an open-loop system as opposed to a closed-loop geothermal system, these boilers became unnecessary and now serve as backup. The planned cooling tower was never built.

A variable-frequency drive controls the well pump based on main-loop temperature and allows the pump to shut off if the loop is between 48 and 67°F. A separate variable-frequency drive controls the loop pumps based on the main-loop pressure (Fig. 3-35). If one pump should fail, the drive will ramp up the second pump to maintain proper pressure. Both drives are based on supply water after the balancing valve. The boiler temperature sensor is in the return-water line in case the loop temperature drops too low in heating mode.

Figure 3-32 This YWCA facility, originally slated to go closed loop, is serviced by a pump and reinjection geothermal HVAC system. (*Yoder Geothermal*.)

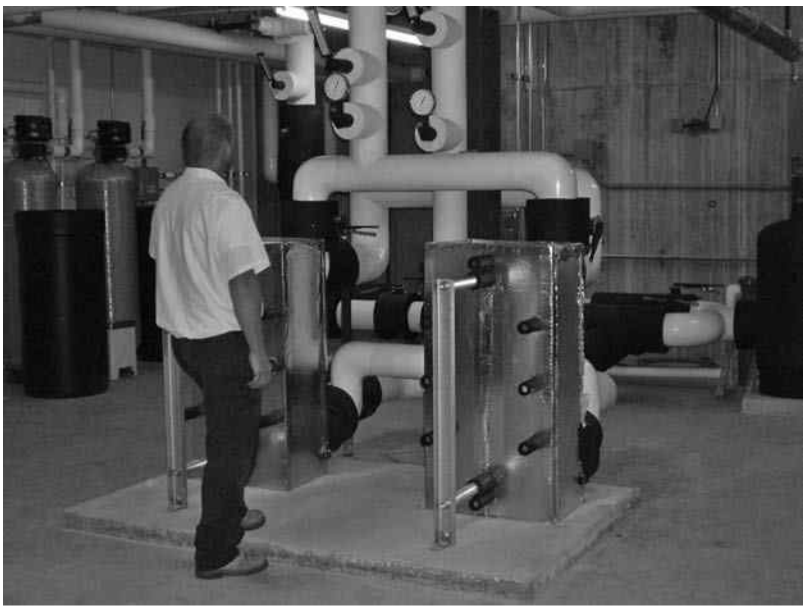

Figure 3-33 These two 100-ton plate and frame exchangers protect all the equipment in the building, effectively exchanging heat. (*Yoder Geothermal*.)

FIGURE 3-34 These two boilers will set idle for a long time because a geothermal source provides heating as well as cooling. (*Yoder Geothermal*.)

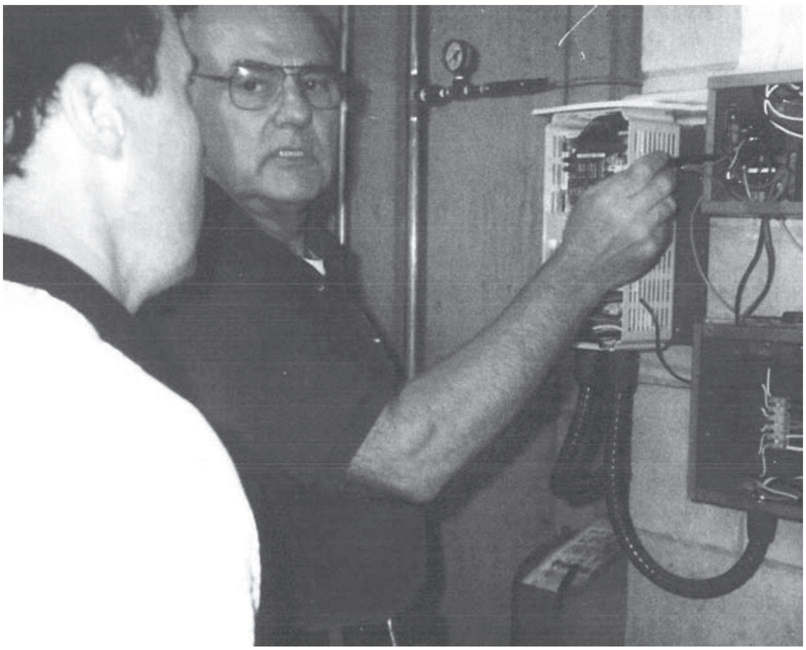

FIGURE 3-35 This is one of the variable-frequency drives that controls the circulating pumps and well pumps. (*Water Energy*.)

This building has a floor below the city sewer level, and all basement floor drains are small sump pumps. The well pump can pump in excess of 300 gal/min. If a pipe were to break, the 12-ft basement would take about 61 hours to fill up, but long before that it would break down the mechanical room wall and flood the elevator pit. Not long after that it would submerge the main electrical panels and actually shut itself off, but why wait? A floor water sensor was installed to interrupt the pump circuit if water gets about a half an inch deep (Fig. 3-36).

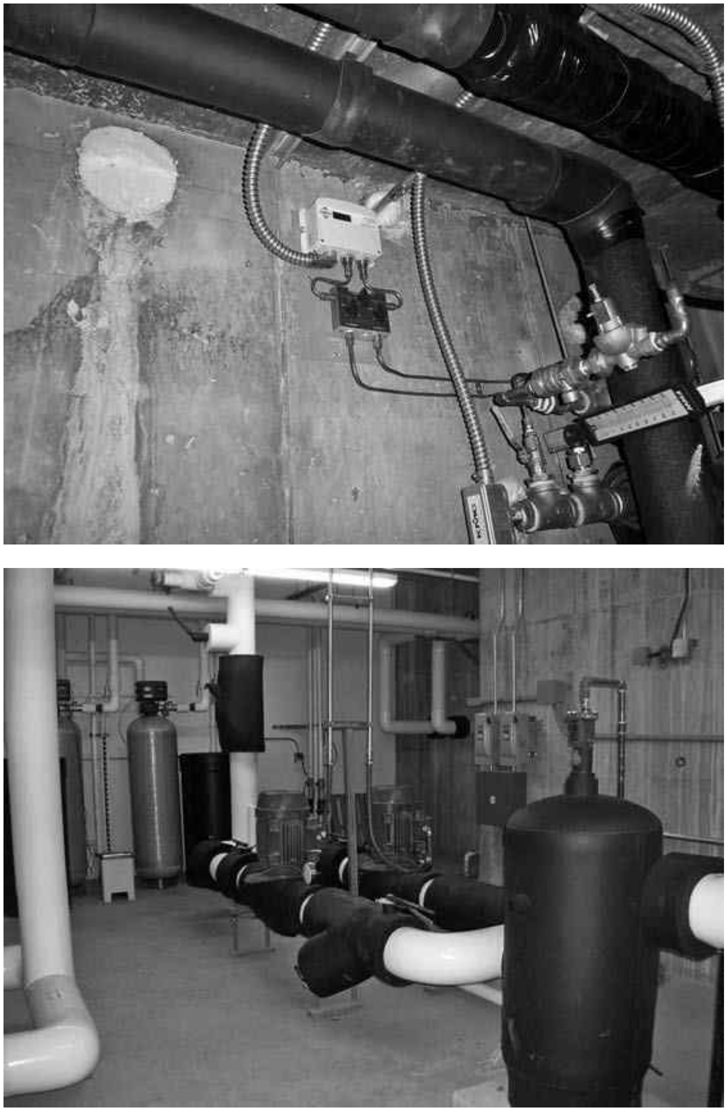

Figure 3-36 Circulating-pump piping and expansion tank for the building. The differential pressure controller in the first picture is used to determine the speed necessary for the variable-frequency drives on the condenser-water circuit in the second picture.

The biggest anticipated system downtime would be well pump failure. The driller indicated that he could change the pump in 12 hours, but it might take weeks to get a pump, so we supplied a spare as part of the project (Fig. 3-37).

Using a good piece of equipment with a good warranty and strong factory support are instrumental in facilitating a flawless geothermal HVAC system. (Spectrum Equipment LLC) (Fig. 3-38).

Figure 3-37 Redundancy is attained through an on-site spare deep-well pump.

Figure 3-38 Equipment such as this pair of water to air geothermal heat pumps from Spectrum Equipment up to create a flawless geothermal HVAC system.

Review Questions

1. Variable-frequency drives (VFDs) and PID loops are likened to
   a. amplitude modulation.
   b. the cruise control on an automobile.
   c. radio transmitters.
   d. motor speed control on exercise tread mills.
2. The energy-efficiency rating from ARI is different from the actual EER, which depends on
   a. circulation-pump efficiency.
   b. compressor staging.
   c. water flow.
   d. all the above.
3. In observation of the performance of new geothermal HVAC systems, it is believed that ______ could be installed in a manner that would allow better performance.
   a. 20 percent
   b. 50 percent
   c. 80 percent
   d. 10 percent
4. Geothermal HVAC systems installed in commercial applications that are cooling-dominant have a greater chance of failing than those with balanced loads. Most owners faced with this problem
   a. litigate against the engineer.
   b. add more loop field.
   c. install a cooling tower.
   d. abandon the geothermal system for a standard air-cooled system.
5. Tax advantages for geothermal HVAC systems from the federal government include
   a. covering the well drilling costs.
   b. federal tax credits.
   c. tax write-offs for photovoltaics that power geothermal.
   d. upgraded insulation.
6. When specifying equipment and systems for geothermal HVAC customers, we should
   a. attempt to provide the least-expensive system possible.
   b. provide the best product possible regardless of price.
   c. provide the best product possible depending on what we think the customer can afford.
   d. provide every possible combination of specifications.
7. The specification of a plate and frame exchanger is designed to
   a. increase the cost and profit of the project.
   b. protect the equipment from fouling when using poor-water quality.
   c. provide improved heat transfer.
   d. act in place of a hydraulic separator.

8. The use of hydronic systems over forced-air systems increases effectiveness and efficiency by
   a. reducing the area needed for ductwork.
   b. moving more Btus to less space.
   c. opening opportunities for load sharing.
   d. all the above.
9. Standing-column geothermal wells can be distinguished by
   a. at least four boreholes per job.
   b. a single borehole into which the supply and return lines enter.
   c. a column that rises about 20 ft above grade.
   d. an above-ground pump that serves the well point.
10. Open systems, commonly referred to as pump and reinjection or pump and regeneration systems,
   a. can reduce construction costs significantly.
   b. work great in bedrock where there is little water.
   c. expend much energy for pumping.
   d. increase drilling costs significantly.
11. Pump and regeneration systems
   a. work in every application.
   b. are best applied where a sufficient aquifer is present.
   c. are less efficient than closed-loop systems in cooling-dominant climates.
   d. are not dependable.
12. Vertical closed-loop geothermal HVAC applications
   a. use ¾-in HDPE exclusively.
   b. are among the most popular closed-loop systems installed.
   c. require an abundant water source.
   d. require aeration.
13. Seasonal imbalance in heating and cooling loads in geothermal HVAC applications can lead to
   a. an imbalanced perspective.
   b. thermal retention in the loop field.
   c. the need for more equipment.
   d. failure of the drain field.
14. Geothermal heat pumps operate within a range of incoming water temperatures. These heat pumps typically will begin to fail once the incoming water temperature reaches
   a. 90°F.
   b. 30°F.
   c. 40°F.
   d. 105°F.
15. Cooling towers provide cooling for condenser water that has been heated during the refrigeration process. Some of the negatives of using a cooling tower include
   a. consumption of freshwater for evaporation and dilution.
   b. high mineral concentration requiring chemical treatment.
   c. mineral scaling of surfaces.
   d. all the above.

16. Power companies are required by law to obtain 20 percent of their energy from renewable-energy sources by the year 2020. Geothermal heat pumps are considered a renewable energy-generating source
    a. when they generate heat for domestic hot water.
    b. that extracts and rejects Btus to and from the earth.
    c. when attached to a generator.
    d. while consuming energy from a photovoltaic array.

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CHAPTER 4

Application of Earth Coupling with Regard to Site Conditions

There are quite a lot of items to consider when deciding what type of geothermal system will be most useful. This chapter focuses on earth coupling and overall site conditions.

The concern that the lead author hears most often, with the exception of cost factors, involves the surface area that will be required for a geothermal system. If this is a concern to a potential customer, know that there is always ways around limited land issues. If there is plenty of land, that opens up all the options.

Several different types of earth-coupling methods can be used. These include a few different closed-loop earth-coupled types, a few more types of surface water–coupled types, and a few variations in what is called *pump and reinjection earth coupling*. In addition to these, there is also direct expansion and some more basic types of ground coupling that will not be covered, including earth-coupled air ducts.

Closed-Loop Ground-Coupled Systems

Figure 4-1 shows several types of closed-loop systems, including horizontal single-pipe, two-pipe, slinky, and finally vertical systems.

Surface-Water Closed-Coupled Systems

Figure 4-2 shows a few different types of lake and ocean exchangers. The different ways that high-density polyethylene (HDPE) pipe can be used are as numerous as your imagination. Lake plate exchangers are a great way to take the guesswork out of doing a lake loop. They have good conduction characteristics and will have less exposure to damage because of the smaller surface area. However, HDPE will not fail due to corrosion-related issues, but the soft plastic can be damaged by boat a nchors, props, and the like, as can the plate exchangers.

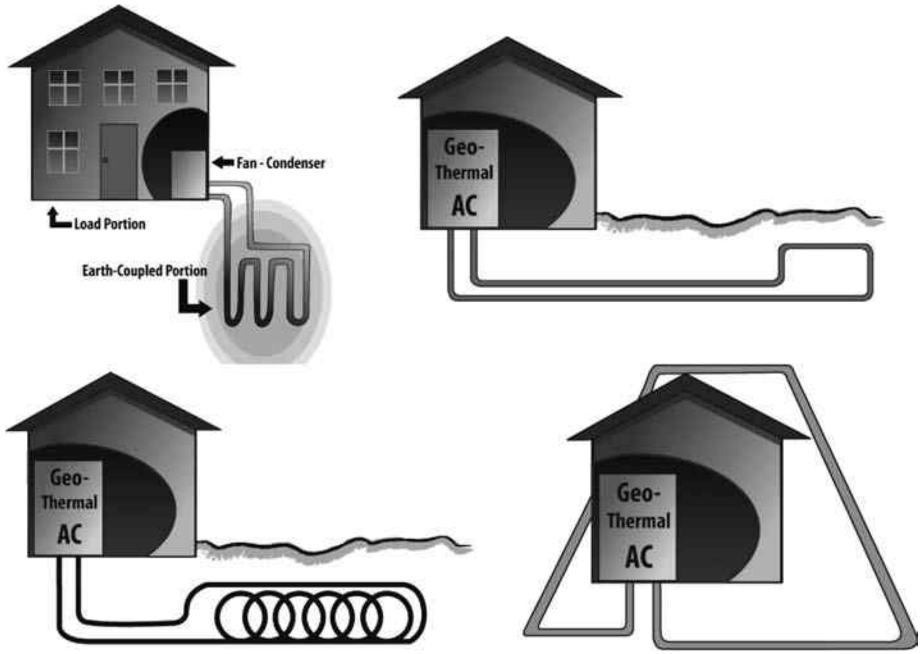


Figure 4-1 There are four main types of closed-loop ground-coupled systems: single pipe, dual pipe, slinky, and vertical borehole. Each of these types of loops will have a different length or heights to perform the same amount of heat absorption/rejection per ton. (*Sarah Cheney*.)

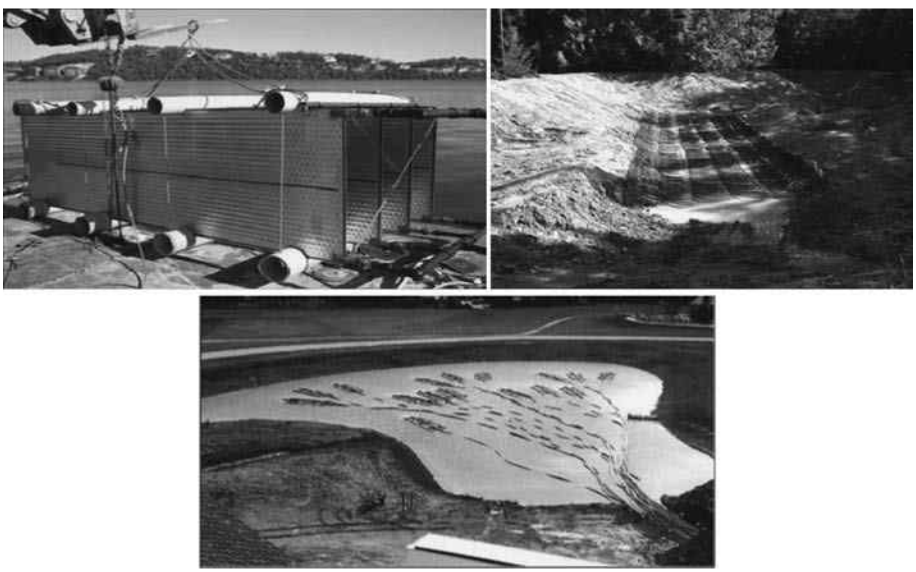


Figure 4-2 Surface-water closed-coupled systems, or pond loops as they are often called, can be assembled in several different ways using many different materials. Here you can see the use of some of these different methods and materials. (*AWEB Supply*.)

Pump and Reinjection Earth-Coupled Systems

Figure 4-3 shows the different types of pump and re-injection systems. There are some that discharge from a well to a surface-water location. This is not recommended because of aquifer depletion. Most jurisdictions do not allow this type of system.

Direct exchange with groundwater (no use of an intermediate exchanger) is a simple system. Water quality should be taken into consideration; otherwise, proper selection of equipment with regard to water quality will ensure long equipment life. When water quality or circumstances dictate, an intermediate exchanger should be selected. This isolates the heat pump equipment from the well water, and also allows load shedding/sharing (see chapter 13). A closed loop condenser-water circuit is created, and this condenser-water loop has heat either extracted from or added to the well source through the exchanger.

Direct-Expansion Geothermal Systems

Direct-expansion geothermal systems claim higher efficiency because of the reduction in linear feet of ground loop needed. This is primarily due to the following two reasons:

1. Higher conductivity of copper compared with HDPE
2. One less step of heat transfer (hence the term *direct expansion*)

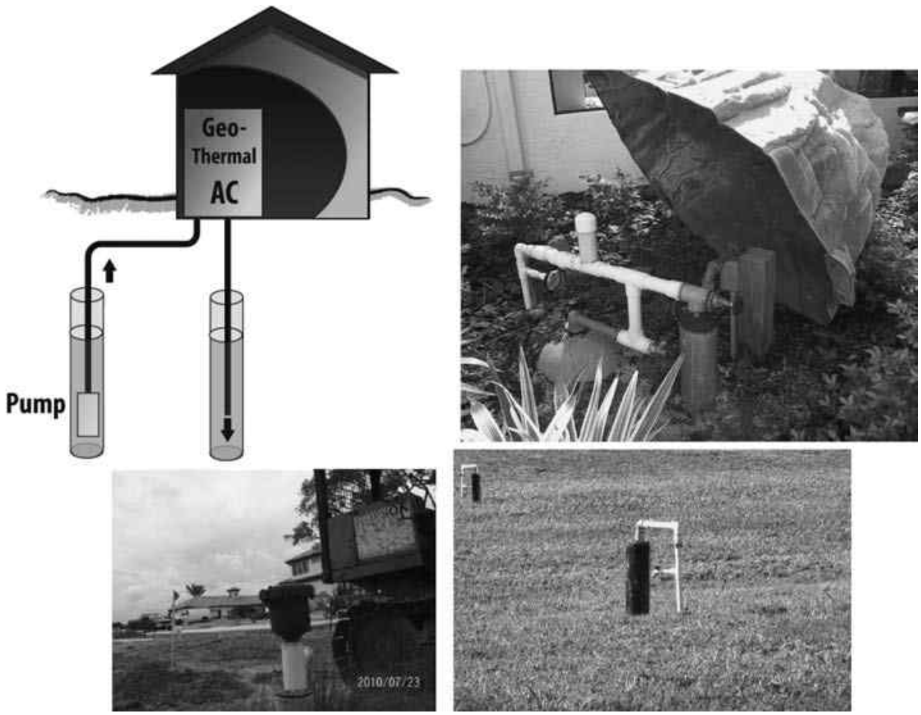


Figure 4-3 Pump and reinjection geothermal systems involve drilling to the aquifer and placing a pump either below the surface of the well water or on the surface, whichever the circumstances may require. These systems always will have at least two points, one for supply and one for injection of the water. Here you can see the different well points and some of the ways they can be constructed and/or hidden. (*Photographs: EggGeothermal; Artwork: Sarah Cheney*.)

These systems use refrigerant in the piping that is inserted into the earth. Excavation is reduced (Fig. 4-4).

In areas with acidic soils, the copper lines can be at an increased risk of corrosion. Some installers recommend against this type of plan in such locations, although it is possible to shield the pipes. This can be accomplished with a plastic sleeve. Ironically, though, plastic reduces the thermal conductivity of the copper to some degree.

An important note along the lines of direct-expansion systems has to do with the mechanics of the heat pump. A heat pump uses more refrigerant in certain phases of operation than in other phases of operation. This is normally remedied by using a receiver or a tank that is integrated into the system to hold the excess refrigerant. Because direct-expansion (DX) geothermal systems use a considerable amount of copper tubing, by which they gain their high efficiency rating, a much larger refrigerant receiver is required than in standard systems. This is not a problem unless the system develops a refrigerant leak. The good news is that R410a refrigerant is relatively benign.

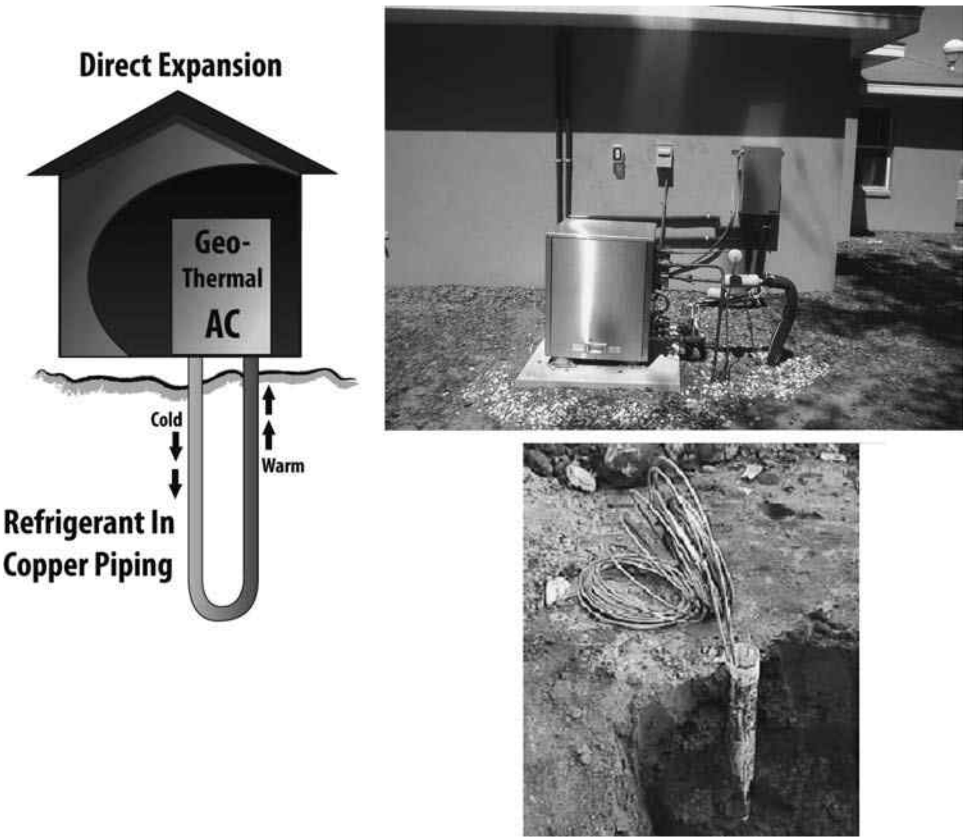


Figure 4-4 Direct-exchange geothermal systems use copper refrigerant pipe placed directly in contact with the material in the borehole or trench. Shown here are the basic construction and actual DX condenser unit, in which you can see the copper lines entering the earth. Also shown is construction of the well. (*EggGeothermal*.)

If it is accidentally released into the ground, there should be no lasting environmental effect because the refrigerant evaporates, according to the Material Safety Data Sheet. As with any system, good installation and service practices should be followed to minimize leaks.

Many contracting companies have determined that direct exchange is not actually a viable alternative to geothermal because of the failure of the copper in the ground (owing to low pH levels) and because of the high volume of refrigerant needed to fill the system. Sometimes hundreds of pounds of refrigerant R410a are needed in a DX system, resulting in high cost for refrigerant replacement in the event of a leak.

Some of the items to be considered in the process of determining earth and site conditions are included in the following questions:

1. How much land is available?
2. Is there a body of water nearby?
3. What is the heating and cooling load?
4. Is the load heating- or cooling-dominant?
5. By what factors is the load heating- and cooling-dominant?

These questions are important to the engineer in the evaluation of the earth and site conditions for a geothermal system. If there is too high a cooling load, fundamentally, no amount of earth loop will be enough to permanently provide a heat sink for the building loads (more on this later).*

Types of Earth and Related Conductivity

If a closed-loop system is selected, a thermal conductivity test likely will be needed. This also may be true with a large standing-column well system, which also may need a yield test for water volume. If there is precedence data, a copy of the lithology Orwell report should be obtained and evaluated. Thermal conductivity tests require specialized equipment and certification from the appropriate agency.

It is best to use an agency that is proficient in doing thermal conductivity tests. Geothermal heating, ventilation, and air-conditioning (HVAC) technology is becoming such an advanced technology that there are several specialized areas within the field that should be left to experts in those particular tasks. For example, it is not recommended that an HVAC company become a well-drilling company because it will not have the history or experience to understand the topology of a particular area and will waste a lot of time and capital trying to become proficient drillers.

The difficult part in evaluating a project's potential for installation of a geothermal HVAC system is determining the size of the closed-loop field. One of the major components in making this determination is the soil's thermal conductivity (Figs. 4-5 and 4-6).

*"Analysis of Energy, Environmental and Life Cycle Cost Reduction Potential of Ground Source Heat Pump (GSHP) in Hot and Humid Climates," DOE Award Number: DE-EE0002802. Sponsor: U.S. Department of Energy; primary investigator: Yong Tao, University of North Texas (formerly with Florida International University); co-primary investigator: Yimin Zhu, Florida International University; partners: ClimateMaster Geothermal Heat-Pump Systems, Florida Power & Light Company, Oak Ridge National Laboratory, Gulf Power Company, and EggGeothermal Air Conditioning and Pool Heating.

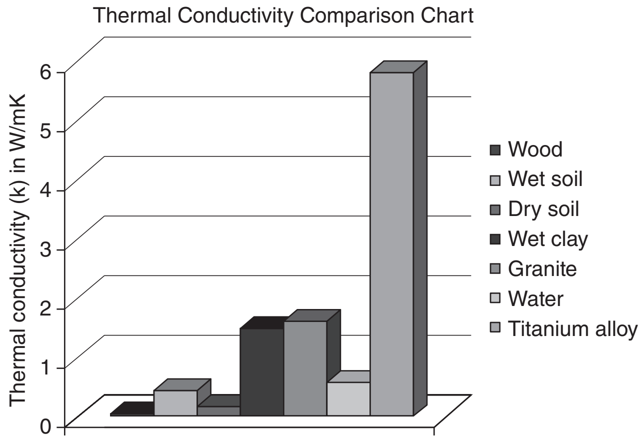


Figure 4-5 This chart indicates the thermal conductivity of many common materials with which we work. For reference, titanium alloy is shown at the right of the scale. The different conductivity levels of various types of soil illustrate that the links of closed-loop piping can vary drastically. (*Sarah Cheney*.)

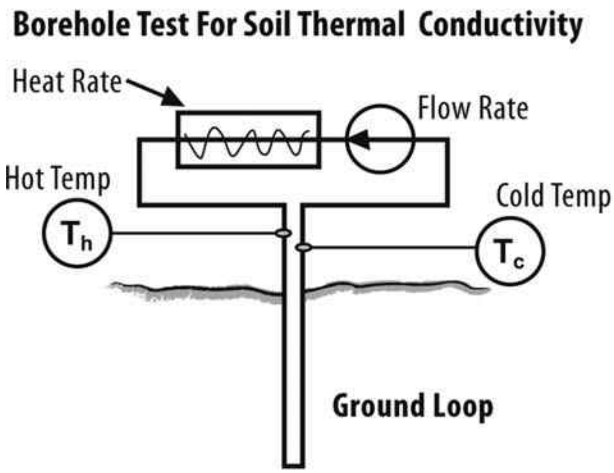


Figure 4-6 Thermal conductivity testing can involve heating fluid that is pumped into the ground, as shown here. Calculations based on gallons per minute and difference in temperature over a period of time provide the necessary data to determine the thermal characteristics of the earth in which the loop will be placed. (*Sarah Cheney*.)

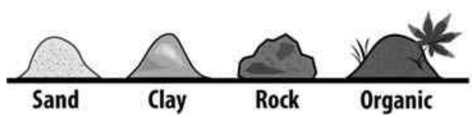


Figure 4-7 Different types of earth show different thermal conductivity characteristics. (*Sarah Cheney*.)

It is therefore necessary to conduct a geothermal conductivity test. It is incumbent on the designer of the ground-loop exchanger to see that this is done effectively and correctly. The different types of soil differ in thermal conductivity, there can be quite a difference in the cost of a closed-loop system based on the thermal conductivity of the soil in which it is to be located. (See Chap. 5 for more details on thermal conductivity.)

Designing the Closed-Loop Heat Exchanger

Closed-loop heat exchangers can be arranged in a number of ways. What has to be considered first is the area in which the exchanger will be placed.

1. What are some of the potential obstacles?
2. What will be done with the land after the loop is installed?
3. What is the potential of damage later on?

Open Fields/Schools

In applications where there is a football or soccer field available, you'll find plenty of space under most circumstances in which to place the heat exchangers (Fig. 4-8). Schools are a great application in most of North America for closed-loop systems. This is so because there is relatively little load in the summer due to summer vacation. If there was a long cooling season, we would likely see more problems with this arrangement.

Under Parking Lots

A geothermal exchanger under a parking lot is a good application as long as the thermal conductivity of the ground does not depend on rainfall and the associated saturation of the ground. The situations in which this likely would be favorable include dry and arid climates, granite/rock, or areas with high aquifer levels (Fig. 4-9).

Under Buildings

When considering applications under building and under parking lots, soil compaction can be an issue. Obviously, if the building requires the driving of peers or pilings, this must be carefully coordinated so as to prevent damage to the ground-loop exchanger.

Front or Back Yards

A common site for geothermal installations is the front or side yard of a residential structure. This is a nominally invasive procedure with no lasting effects under most circumstances (Fig. 4-10). The case cannot be overstated for informing the owners/customers that this is a messy job. Under most conditions, the drilling will be done within a week.

Rights-of-Way and Under Streets

In municipal applications involving district cooling and heating systems, rights-of-way are an excellent opportunity for locating heat exchangers and condenser water piping from a geothermal source.

Figure 4-8 It is evident in these before and after photos of the geothermal loop field placed in the courtyard of Washington College that there will be little chance for damage of the loops by future activity. (*David Hoffman*.)

Figure 4-9 Placing a geothermal closed-loop exchanger under a parking lot works especially well with the lithology is mostly rock. (*David Hoffman*.)

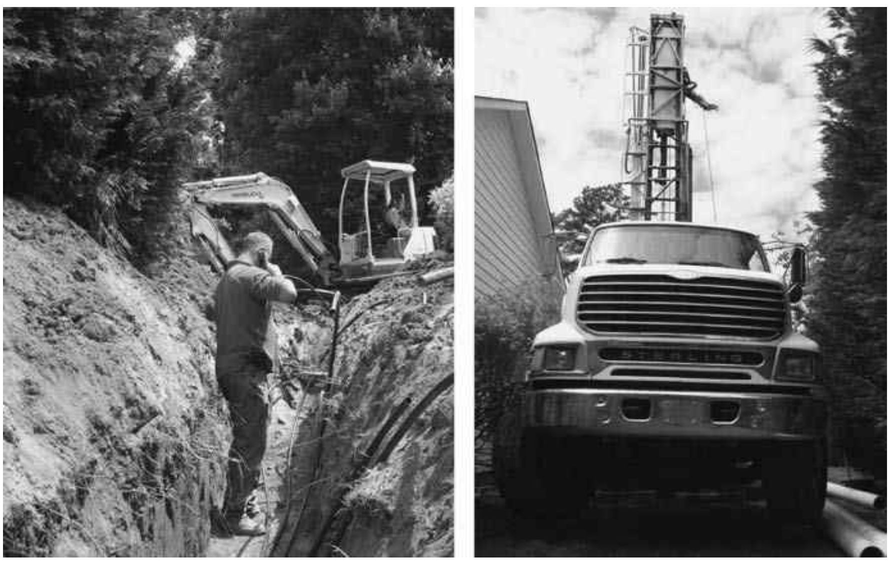


Figure 4-10 As seen here, drilling can be rather invasive. Logistically, it is important to make sure that the equipment needed to perform the job can gain access. Once the driller is done, the landscaping is replaced, and everything is back to normal. (*EggGeothermal*.)

Common Areas/Golf Courses/Parks

Master-planned communities are an excellent opportunity for use of golf courses and common areas for geothermal installations.

As of 2012, there are very few engineers who have solid experience in geothermal HVAC applications. This book will be a step toward educating an upcoming generation of engineers in the specialty of geothermal HVAC technologies. As such, it is important to understand the process by which a geothermal HVAC system is typically brought to fruition: Typically, an owner decides that geothermal HVAC technologies may be right for him or her. At this point, he or she will ask an architect, contractor, and/or engineering firm to facilitate the design. The architect or engineering firm hires a geothermal consultant. This team then comes together to provide a well-thought-out geothermal HVAC system for the structure on which they are working. In this way, there is a team of experts all checking each other's progress and preventing problems. The geothermal consultant typically is someone who has been in the field for quite some time who has a great overview or bird's-eye view, if you will, of the technology. The engineering firm is typically a forward-thinking firm that can listen and learn as the consultant feeds it information and the owner adds information about his or her needs. The consultant can be a former manufacturer's rep, a former contractor, a nonpracticing engineer, or someone who has graduated from the "school of hard knocks." The important thing is that he or she will have the background to be able to see problems before they arise (Fig. 4-11).

Figure 4-11 It takes cooperation to make a geothermal project work. Here we see county commissioners, county engineers, private engineers, and the consultant on a project. (*EggGeothermal*.)

Bid Specifications for Drilling

Most mechanical firms and HVAC firms do not have the capability or the desire to tackle the drilling portion of a geothermal HVAC application. The lead author believes that tackling the drilling portion as an in-house entity is a foolish notion unless you acquire the entire drilling firm, including its employees.

Well drilling and geothermal looping, as it is called, are a highly specialized skill set. This is not something that you want to tackle with anything less than at least a generation or two of experience behind you. It is very hard work and encompasses more variables than just about any other entity involved in geothermal HVAC construction.

The lead author worked as a well driller for two days. This was at the age of 18, just before he joined the Navy. It was perhaps the hardest two days of labor he ever performed. During that time, he dropped something of which he cannot remember the name down the hole, causing the drilling foreman working beside him to threaten to cripple his body and send him down the hole after it. The scary thing is that the lead author truly thought that the foreman was going to do that, and he spent the rest of the day in fear for his life.

So, if we are not going to get into the well-drilling or geothermal looping business, how do we control what our subcontractors do? The answer is with a very good set of bid specifications. As a mechanical contractor with 25 years of experience with well drillers, the lead author can tell you that Forrest Gump was right with a slight variation: Well drillers are like a box of chocolates; you never know what you're going to get. The only protection in this situation is—yes, you got it—a solid bid specification.

And you're in luck because Fig. 4-12 shows just what a good well driller's bid specification looks like.

As you can see in the figure, the specification is several pages of very detailed data to ensure that not only is the well drilled and cased properly but also that the proper flow ratings, drawdown, well pump head, and so on are achieved. Often the lead author has been privy to a job that had an unspecific bid specification and then ended up with the wrong well pump, the wrong casing size, the wrong casing type, the wrong well depth, the wrong VFD, and the wrong well distance separation.

This particular well-drilling specification is not designed to cover all situations. That's what you do or have an engineering firm do—designate the different parameters under which you may be subjected.

Cooling Towers

There is a terrific market out there: cooling-tower upgrades/elimination (Fig. 4-13). When you consider what a cooling tower actually is designed to do, it's clear that a cooling tower is a piece of equipment used to cool down condenser water to a temperature lower than the dry-bulb temperature using evaporative cooling.

The inherent problems with cooling towers are all the result of dealing with evaporative cooling (Fig. 4-14). Some of these problems include

1. High water usage because of evaporation
2. High water usage due to blow-down
3. High mineral concentration as a result of evaporation

SECTION 23 65 10 WELL DRILLING

SECTION 1 - GENERAL REQUIREMENTS

1.1 SCOPE OF WORK SUMMARY

A. All permits associated with the installation of the proposed wells.

B. All associated drilling equipment, piping materials and installation labor.

C. Management of soils and drill cuttings generated during drilling activities.

D. Installation of two (2) 12-inch diameter Schedule 40 PVC supply wells (18-inch outer casing).

E. Installation of one (1) 12-inch diameter Schedule 40 PVC injection well (18-inch outer casing)

F. Installation of three (3) 2-inch diameter Schedule 40 PVC monitoring wells (6-inch outer casing).

G. Cleanup and resurfacing of work areas.

1.2 GOVERNING AUTHORITIES AND REFERENCES

A. Florida Administrative Code, Chapters 62-532, 62-528.

B. Florida Statutes, Chapter 40D-3.

C. Southwest Florida Water Management District (SWFWMD).

D. Florida Department of Environmental Protection (FDEP).

E. TBRWC.

1.3 WELL DRILLER'S QUALIFICATIONS

A. The successful bidder shall meet all the requirements of the Southwest Florida Water Management District Water Well Contractor licensing program, and possess an active license with the district.

1.4 PERMITTING

A. The Contractor is responsible for acquiring all permits unless noted otherwise in this scope of work. Permit(s) shall be obtained prior to installing the recovery, injection, and monitoring wells. The Contractor shall complete permit applications for SWFWMD, FDEP, and TBRWC. Client shall be provided a copy of all permits/licenses prior to mobilization for well installations and a copy of all permits/licenses will be maintained on site by the Contractor. Note, a water use permit from FDEP must be obtained prior to obtaining a well construction permit from SWFWMD.

B. Permitting and well construction activities shall comply with Chapter 62-532 of the FAC, Chapter 62-528 FAC, and Chapter 40D-3 of the Florida Statutes (FS).

Figure 4-12 An engineering specification for drilling geothermal wells, especially where lithology is unknown, can be a lengthy document. Words cost little compared to missed items, however. (*Engineering Matrix*.)

C. Well completion reports for injection well to be submitted to Owner and FDEP within 2 days. Within thirty days of installation, well completion reports shall be submitted to the permitting authority. Copies of the completion reports must be submitted to the client prior to invoicing.

D. Oversight Personnel (What is the responsibility of oversight personnel??): A

minimum two-person oversight, that includes a competent Florida licensed Professional Geologist, will be required for the drilling event. Note, drilling oversight will be provided by others.

1.5 GENERAL SPECIFICATIONS AND BACKGROUND / PROJECT DESCRIPTION ???

A. Waste Disposal

1. Waste disposal methods will be based on selected drilling method. Drilling mud and/drill cuttings generated during well installation activities will either be re-used onsite during other construction activities or properly disposed off by the contractor at a Florida approved soil disposal landfill facility. Note, proper disposal at an approved disposal facility will require a pre-burn sample to be collected and analyzed for TCLP benzene and the 4 RCRA metals at a minimum. See Attachment B. Drill cuttings may also be disposed onsite in a mud hole to be dug onsite by contractor. This option requires prior client and property owner approval.

2. Contractor should include costs for all three options as separate line items in their bid submittal.

3. The Contractor will provide a copy of all waste manifests and bills of lading for materials, including asphalt, concrete, and soil, transported off site within 15 days of removal from site.

SECTION 2 - SITE WORK

2.1 PIPING SYSTEMS

A. The piping layout is detailed in the attached Figures and is summarized below. Changes in pipe diameter, class, or material are not to be made without approval of the Oversight Personnel and client.

1. Supply Well Construction:

a. Two supply wells shall be installed. For bidding purposes, assume both wells shall be installed to a total depth of 250 feet below land surface (bis). The final depth shall be a field decision based on the depths at which a favorable lithology is encountered during drilling as determined by the Oversight Personnel.

b. Each supply well shall be double-cased into the confining clay layer. The outer casing shall be constructed of 18-inch diameter Schedule 40 PVC or steel casing. For bidding purposes, assume 120 feet of outer casing.

c. The supply wells shall be constructed of 12-inch diameter Schedule 40 PVC solid riser with an open bottom.

Figure 4-12 (*Continued*)

d. The well annulus shall be backfilled with neat cement grout to the surface.

e. A site plan showing the proposed well locations is included as Figure 1. A supply well construction diagram is included as Figure 2. Following installation, the supply wells will be developed via over-pumping until clear of visible fines as determined by the Oversight Personnel.

2. Injection Well Construction:

a. One injection well shall be installed to a total depth of 250 feet bis. The final depth shall be a field decision by the Oversight Personnel based on the lithology encountered during drilling.

b. The injection well shall be double-cased into the confining clay layer. The outer casing shall be constructed of 18-inch diameter Schedule 40 steel casing or Schedule 40 PVC casing. For bidding purposes, assume 120 feet of outer casing.

c. The injection well shall be constructed of 12-inch diameter Schedule 40 PVC solid riser with an open bottom. The well annulus shall be backfilled with neat cement grout to the surface.

d. Following installation, the injection well shall be developed via over-pumping until clear of visible fines as determined by the Oversight Personnel.

e. A site plan showing the proposed well location is included as Figure 1. An injection well construction diagram is included as Figure 3. Contractor shall submit copies of well completion reports within 2 days of well installation per Chapter 62-528 FAC.

3. Monitoring Well Construction:

a. Three monitoring/observation wells shall be installed. The monitoring wells shall be installed to a total depth not to exceed 250 feet below land surface (bis). The monitoring wells will be constructed of 2-inch diameter solid schedule 40 PVC casing flush threaded to ten feet of 2-inch diameter 0.010- inch slotted schedule 40 PVC well screen. The wells will be double-cased into the confining clay layer. The outer casing will be constructed of 6-inch diameter Schedule 40 PVC solid riser.

b. For bidding purposes, assume 60 feet of outer casing. The well annulus shall be backfilled with 20/30 silica sand pack to two above the screen interval, followed by two feet of 30/65 fine silica sand seal, followed by cement grout to the surface.

c. The wells shall be finished flush to grade with an 8-inch protective steel manhole and two feet by two feet square concrete pads.

d. Following installation, the monitoring wells shall be developed via over- pumping until clear of visible fines as determined by Oversight Personnel. A site plan showing the proposed well locations is included as Figure 1. A.

Monitoring/observation well construction diagram is included as Figure 4.

4. Site Restoration:

Figure 4-12 (*Continued*)

a. The Contractor is responsible to restore site to match or exceed pre-existing conditions, including equipment and materials staging areas.

b. The Contractor shall not cut or injure any trees on which the work is to be done without approval by the oversight personnel. Vegetation (grass or shrubs) shall be restored with similar materials if damaged during installation activities.

c. Contractor shall replace all existing structures that are damaged or removed during the well installations. The Contractor is responsible for repair or replacement of any material damaged during installation activities at no additional cost to the Owner.

d. Contractor shall be responsible for removing any temporary facilities installed for completion of field activities and for the restoration of the site to its condition prior to construction activities.

2.2 ADDITIONAL CONTRACTOR REQUIREMENTS

A. The requirements of this specification shall include:

1. Mobilization and demobilization efforts.

2. This specification calls for no electrical, water, sewer, or discharge facilities. The Contractor shall assume the findings would be drummed or trucked and disposed of by the Contractor as part of this specification. Contractor to stipulate means on Bid Form.

3. The Contractor shall stipulate on the Bid Form any services required to complete the drilling that are not listed in this specification.

SECTION 3 - SPECIAL CONSTRUCTION

3.1 DRILLING

A. Pre-construction Meeting

A pre-construction meeting will be held prior to initiating well installation activities with all appropriate oversight, Contractor, and Owner Personnel. The meeting is intended to identify and specify project work flow and logistics including the following:

1. Proposed work scope, methodology, and calendar schedule.

2. Identify routine site activities such as equipment traffic flow, high volume traffic times, and pedestrian pathways.

3. Work hours.

4. Site specific requirements, including traffic control measures/plan, health and safety issues and site security.

5. Equipment staging area(s).

Figure 4-12 (*Continued*)

6. Materials staging area(s).

7. Excavated material stock pile area(s).

8. Coordination of piping installation activities.

9. Inspection/confirmation of the proper operation of all existing lighting, signage, sprinkler, and other facility systems/equipment; and documentation of pre- construction conditions.

10. Permit status review.

B. Drilling:

1. The proposed wells shall be installed utilizing the applicable industry drilling methods. Air rotary, mud rotary and reverse air circulation are acceptable drilling methods. Well casings, pipes, and all materials shall be new and free of defects. Soil samples shall be collected using a split spoon at five foot intervals to the depth where the outer casing will be set.

2. Once the outer casing is set, split spoon samples shall continue to be collected at ten foot intervals to the total depth of the wells.

3. The Oversight Personnel will describe and document the soils according to the USCS, equivalent to ASTM D2488. Documented observations of the soil samples shall consist of, at a minimum, sample depth, lithology, color, and degree of sample saturation. Soil samples shall be obtained from each formation penetrated during drilling activities.

4. After reaching the monitor wells target depth, well completion procedures shall commence. Following well development activities, depth to water, and temperature readings will also be documented by the field Oversight Personnel.

5. Only water from a potable source shall be used during all well installation activities.

C. Field Changes:

1. Owner authorized Oversight Personnel shall be on site for the project duration to verify compliance with the drawings and specifications. No deviation from this SOW shall be permitted without prior approval. Work that will result in additional cost to the Owner shall not be conducted without written notice from the Contractor and written approval by Owner. No change orders will be issued for activities not previously approved by Owner. The Oversight Personnel shall have authority to approve minor scope changes or procedures. The General Contractor shall approve all major modifications through a formal written change order procedure.

2. For bidding purposes, a full day of work is considered to be 10 hours. Contractor's prices and work should also be based on a 10-hour day. The total number of days to complete the project shall be actual work days (Monday through Friday, not calendar days).

Figure 4-12 (*Continued*)

3. Change orders for delays caused by weather, equipment malfunctions, and coordination with subcontractors or material supply vendors will not be accepted.

4. The Lump Sum Bid shall not be revised due to delays or as agreed upon by the Oversight Personnel and General Contractor.

5. If additional time is necessary, the Contractor must provide justification to the General Contractor. The Contractor is expected to provide a responsible bid that enables the safe, successful, and cost-effective product in a timely manner utilizing best industry practices.

SECTION 4- MECHANICAL
4.1 DRAWINGS

A. Well Construction drawings have been prepared to illustrate the required work as indicated

below.

1. Figure 1 Drilling Site Plan

2. Figure 2 Supply Well Detail

3. Figure 3 Injection Well Detail

4. Figure 4 Monitoring Well Details

Any deviation from this SOW must be clearly indicated in writing and/or drawing in the final proposal. The successful Contractor will provide a safe cost-effective product that meets or exceeds best management and engineering practices.

*** END OF SECTION 23 65 10***

Figure 4-12 (*Continued*)

4. High maintenance needs
5. High chemical usage
6. High failure rate of the equipment

Because of these problems many facility managers are forced into considering air-cooled systems. The consulting engineering firm Engineering Matrix, located in Largo, FL, has faced much of this over the past couple of decades. President Stan Newton said that "due to problems with cooling towers, many of the educational clients have gone to air-cooled equipment." Too bad, because air-cooled units have an innate efficiency of about 1.2 kW/ton, whereas a water-cooled system has an innate efficiency of around 0.85 kW/ton. This equates to big dollars on a 300-ton air-cooled system running 50 percent of the year:

Air-cooled system energy cost per year:	$164,400
Water-cooled system cost per year:	$116,500
Energy cost savings per year with a water-cooled system:	$47,900

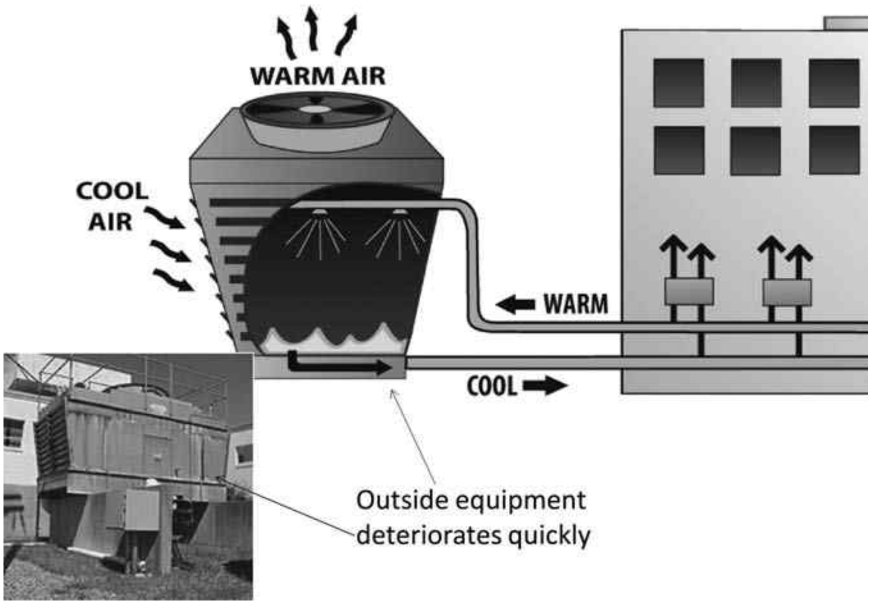


FIGURE 4-13 The cutting-edge market for cooling-tower replacement/elimination through the use of earth coupling. (*Photograph: EggGeothermal; artwork: Sarah Cheney*.)

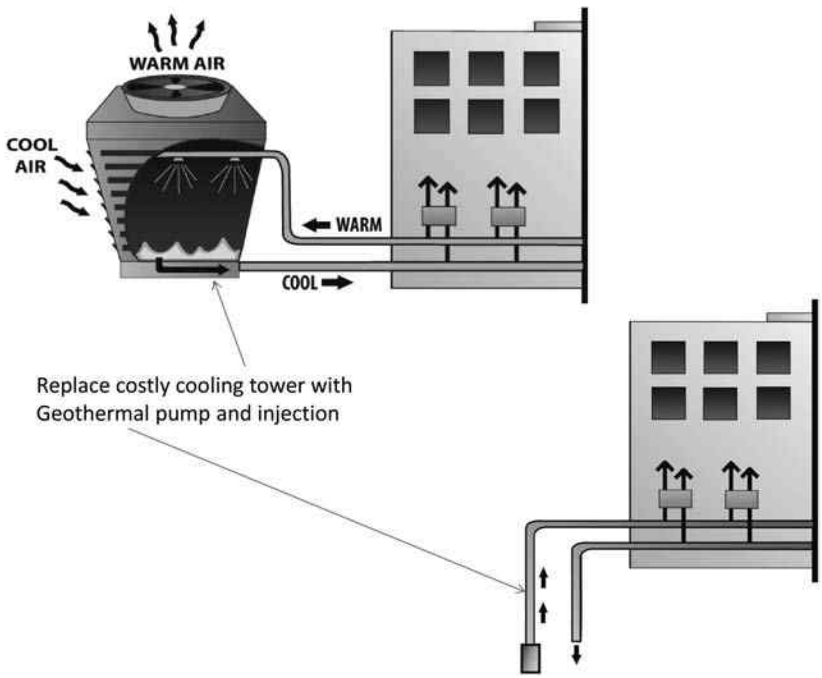


FIGURE 4-14 Cooling towers operate using the principle of the evaporative cooling on the condenser water loop. Cooling towers suffer significant degrees of aging and mineral deposits that contribute to their rather short life and high degree of required maintenance. (*Sarah Cheney*.)

This low-maintenance model has been ingrained in many of the school districts to the point where they default to the air-cooled option. This is understandable when the water-cooled system adds a maintenance headache, but this will go away with the geothermal option.

As more school districts and public entities become familiar with the upgrade and replacement to geothermal cooling towers, we will begin to see many more geothermal systems applied in commercial applications. Not only are they more efficient, longer lasting, and sustainable, but they also allow for additional space outside the building. This is so because the cooling-tower location has been freed up. In a recent meeting, this was the primary reason for the owner's consideration of geothermal—simply to free up space outside for an expansion.

More on Geothermal versus Evaporative Cooling Towers

The preceding discussion provides some idea of the incredible savings available by switching from a cooling tower to geothermal cooling (and heating). But this is a worst-case scenario; even in Florida, the state with the warmest well water in the country, the temperature of the groundwater (i.e., the geothermal exchange medium) is 72°F. When the temperature outside is 92 to 95°F and the relative humidity is high, the best you will be able to do with geothermal often is to achieve a condenser water exchange at 85 to 90°F with direct non–aggressive water. Even with a marginally good plate and frame exchanger with an approach of say 5 or 6°F, you can attain to a condenser water temperature of under 80°F. With this in mind, the preceding water-cooled comparison can be even better than an almost $50,000 per year savings. And the bonus is that switching from a cooling tower to the geothermal option also can eliminate your boiler.

Most cooling towers are placed on buildings that either have a chiller or a series of water-cooled air conditioners. Either way, a chiller is a heat sink and not a heat source. With this basic scenario, a boiler must be installed wherever there is a heating season, except in the case of geothermal applications.

When a cooling tower is eliminated because the facility has upgraded to a geothermal source with a plate and frame exchanger, not only has the facility gained a permanent and superior heat sink, but it also has gained a heat source. Take a moment to think about this: The heat sink becomes the water that is pulled from the ground and reinjected into the earth. The temperature of this water in the continental United States is between 40 and 75°F. This is also a wonderfully effective heat source. Whether the facility is using a chiller or individual water-source air conditioners and heat pumps, the need for a boiler is eliminated.

With closed-loop applications, as in the case of the YWCA in Ohio pictured in Fig. 4-15, a boiler is often still installed because there is a chance that the capacity of the closed loop will be overrun. In the case of an open-loop geothermal source, boilers truly can be eliminated, as can the need for a supplemental cooling tower.

It is true that if the chiller is not a heat-pump chiller, you will need to keep the boiler until the chiller is upgraded or an additional one is installed. The same is true with water-sourced air conditioners; if they are not heat pumps, you typically will need to keep whatever heat source they're using until they are upgraded to heat pumps. Most facilities that have individual water-sourced air conditioners have heat pumps already. In a few cases, they may be air conditioners with electric resistance heat strips. Either way, the geothermal heat source is made available.

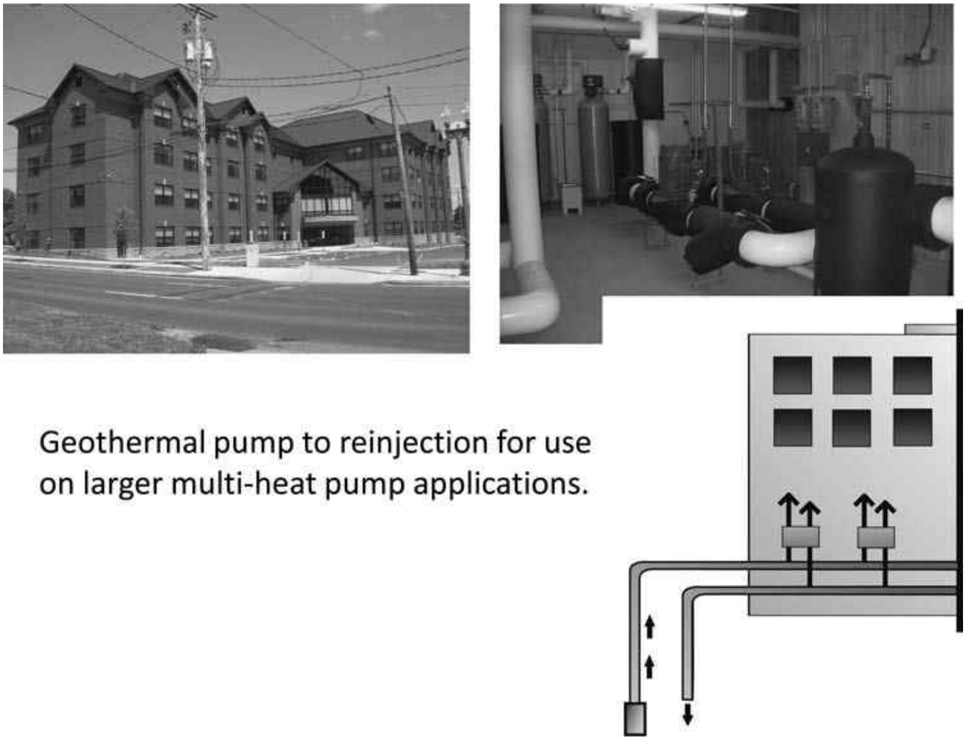


Figure 4-15 This YWCA facility in Ohio went open loop instead of closed loop. As a result, the facility needs no boilers or cooling towers (*Photographs: Yoder Geothermal; artwork: Sarah Cheney*.)

As for the chillers, it's unlikely that a chiller has a reversing option unless it's been specially ordered as such.

The question may be asked about the footprint needed and other construction concerns of upgrading from a cooling tower to geothermal heat-exchange system. The answer is simple and beautiful: You only need an area large enough to put a plate and frame exchanger (which may be set in the current mechanical room or on or near the footprint of the existing cooling tower) and a borehole of less than 3 ft diameter for the supply well. Additionally, you will need to go a predetermined distance away from the supply well and install or drill an injection well. With elimination of the cooling tower, there is normally plenty of room for a geothermal heat-exchange system.

Much like the residential and commercial new construction markets, the retrofit market for geothermal systems where cooling towers are concerned is a stimulus opportunity of large proportions. As engineers and mechanical professionals, you will run into questions about "heating up the aquifer or heating up the earth." This is simply not something about which you should be concerned when utilizing an open to reinjection Earth coupling method. Aquifers vary dramatically from region to region and from state to state, but there is one common thread that the lead author has seen to all aquifers, whether they are stagnant, flowing, or ocean-fed. An aquifer typically covers a large enough area that heat-transfer issues (i.e., heating up the aquifer) are about as likely as heating up the earth's atmosphere from the heat discharged from cooling towers.

Figure 4-16 Chillers can be designed to be reverse cycle, just as a heat pump has a reverse cycle. In this case, the chiller can provide heated water, similar to a boiler, at a coefficient of performance (COP) approaching 5.0. (*Trane*.)

The lead author recalls a situation in the Arab Emirates in which he was to use an aquifer that was more than 1000 ft deep. This is called the *Jurassic Aquifer* and is considered a nonreplenishable aquifer. The region had given permits for farming and had tapped into this aquifer and dropped the level considerably over a decade. The reason for the drop in water level is obvious, as indicated by the name of the aquifer. As a result, permits for pumping water were restricted or revoked. However, sustainable use of the aquifer as a heat sink, wherein all the water pumped out was reinjected back into the aquifer a few degrees warmer, is readily acceptable. The aquifer actually was rather large and covered many hundreds of square miles. With a heat sink that large, you can see that the aquifer is perfect as a sustainable earth-coupling medium for the purpose of cooling (and heating) buildings of all types.

This is why geothermal or geoexchange, properly engineered, is so very sustainable. In *Geothermal HVAC: Green Heating and Cooling* (p. 102), the lead author says

> Beyond these, there are countless other opportunities in commercial applications. Cooling towers, which currently got the rooftops of skyscrapers and occupy valuable ground space for school complexes, can be eliminated. The consequences of this single upgrade are many. Billions of gallons of freshwater are evaporated into the air, and millions of dollars are spent on chemicals to control water-quality improvement and scalene calcification of the surface of the cooling tower and associated heat exchangers. The primary

purpose of the cooling tower is to take condenser water and cool it down to a usable temperature for the refrigeration and air-conditioning equipment it services. They are loud and require endless maintenance, repair, and replacement. By pumping and reinjected groundwater, instead of using the evaporative cooling effect of a cooling tower, water waste will be all but eliminated, and the efficiency of the refrigeration equipment will increase, saving substantial amounts of energy.

Geothermal Case Studies

Remediation of Failed Geothermal Systems

In June 2011, training was being conducted in the offices of a geothermal contractor in New Port Richey, FL. Representatives from Thermal Automatic Corporation (TACO), iWorX Controls Division, were training employees of Egg Systems on the installation and programming of the iWorX control system. Tom Polanski and Roger Michaud were the trainers. On about the third day of training, a newspaper headline was brought to the attention of the lead author right there in the conference room. The headline read, "Sussex Geothermal System Failing After Only Four Years." The article went on to state that the geothermal system for the Sussex County, Delaware, Emergency Operations Center was suffering from incoming condenser-water temperatures of over 105°F. In the article, reference was made to the county commissioners and those in charge of the project not knowing on whom they should lay the blame. One thing was certain: The system was failing because the geothermal ground loop was not big enough to handle all the heat rejection from the facility.

The lead author was traveling home from a meeting in Orlando (at the time he resided in Hudson, FL) when he received a cellular call from Delaware. The man on the other end of the phone identified himself as Steve Hudson, facilities engineer for Sussex County. Recalling the news article from the month before, the lead author discussed with Steve his ideas to remediate the failing geothermal system at the Sussex County Emergency Operations Center. He indicated that he was anxious to help Steve, and they began a dialogue.

Steve listened intently as the lead author explained that a properly engineered geothermal system in a cooling-dominant situation, such was the case in Sussex County, DE, would not suffer any degree of thermal retention or incoming water temperatures above normal. He went on to explain to Steve that the situation could be remediated for perhaps less than it would cost to install a cooling tower and provide the facility with a degree of redundancy, perhaps even triple redundancy. This would be very favorable to a mission-critical building such this facility. After listening to the lead author's spiel, Steve said that he would arrange a remote conference for the county commissioners to attend sometime in July.

In July, the conference went well, and the commissioners agreed to talk further with the lead author about remediating the project. In subsequent conversations, the commissioners stated clearly that although it was evident that the system could be remediated to better than new, it was unlikely that the county would approve "repairing a geothermal system with a geothermal system."

At some point the commissioners began to warm up to the idea of an open-loop geothermal system and decided to entertain an agreement to retain EggGeothermal as their geothermal HVAC consultant on the project. After reviewing several consulting engineering firms and consulting a geothermal professional, it was decided to retain Gipe Engineering as the consulting engineer for the project design.

In January 2012, the Sussex County engineers met with Gipe Engineering and EggGeothermal to award contracts and begin the facility remediation. This was a productive meeting in which Gipe Engineering and EggGeothermal formed a mutually beneficial bond that has continued to further the good cause of geothermal air conditioning in the region and around the country.

Just a few months later, in April 2012, a news report was brought to the attention of EggGeothermal by Steve Hudson. The article stated that New Castle County, DE, had a three-year-old emergency operations center with a geothermal HVAC system that failed. In this case, the emergency operations center and the police station had installed five temporary air conditioners to supplement the failing geothermal system. Steve gave EggGeothermal contact information for the lead engineer at Newcastle. Michael Svaby, in turn, called the lead author and asked him for an opportunity to fix the New Castle facility with him.

The geothermal system for New Castle was designed by a different engineering firm than the one that designed the Sussex County facility. This clearly indicates the possibility that engineering standards for cooling-dominant modes may be at fault. A meeting was set for New Castle County, and Michael Svaby, engineering director for the county, left the meeting determined to make certain that all future geothermal projects were done with an open-loop system such as that in Sussex County. Unfortunately, progress toward remediating the project using a cooling tower was past the point of no return, meaning that they had to stick with the cooling tower for the current remediation.

Figure 4-17 shows a of a news report a quote within the body of the text indicating the high cost of cooling tower operation and providing a comparison with geothermal.

Direct-Expansion Geothermal HVAC Systems

Direct-expansion geothermal HVAC systems are those in which copper tubing containing refrigerant is used directly in the ground as the heat exchanger (Fig. 4-18).

The argument for direct expansion is obvious. A DX system is only one generation of heat transfer. Most geothermal systems use a water-based fluid in the ground heat exchanger. This fluid is pumped through the ground, absorbing or rejecting heat and returning into the geothermal heat pump or other similar equipment, where it then enters a water-to-refrigerant exchanger that provides the necessary thermal exchange to the refrigerant inside equipment (Fig. 4-19).

Based on the simple laws of thermodynamics, it would make sense that two stages of heat exchange would use more energy or leave more efficiency to be desired than a one-stage change. In theory, this is true, but in practice, there are still some questions.

The lead author shall attempt here to address a few of the concerns aired by engineers who have used/designed DX geothermal systems. Among these concerns are

1. The high volume of refrigerant needed for an earth-coupled exchanger.
2. The corrosion of copper in direct contact or proximity with soil.
3. Refrigerant oil return from the earth-coupled heat exchanger.
4. Oxygen-displacement hazard in the facility due to the large volume of refrigerant in the system.
5. Soil/aquifer contamination due to refrigerant leak.

Sussex emergency facility may get backup geothermal cooling system

Problems with the cooling system at the 3-year-old, $13 million Sussex County Emergency Operations Center will require an additional $350,000 to fix.

County officials recently agreed to move forward with installing a new geothermal open-loop system to supplement the failing closed-loop system, which isn't keeping the building cool enough, said Steve Hudson, the county's director of technical engineering.

He said the current system is undersized and doing an inadequate job of servicing the complex, which contains $4 million in critical 911 electronics equipment.

"When we lose airconditioning in the middle of July, we have to have a backup system to go to," Hudson said. "Two hours without air conditioning is all we have until electronics start shutting down."

Officials are consulting with county legal staff on the issue of who is responsible for the cooling problems and what can be done, said County Engineer Mike Izzo.

The county rented a portable cooling tower over the summer, but that's not a long-term solution, he said.

"It was a very long summer," he said. "It's a very high-maintenance, high-dollar-to-operate piece of equipment."

Additionally, the cooling tower required a 24/7 service contract because no county staffers were qualified to keep it running.

Staffers researched two solutions, an open-loop well system and a traditional mechanical cooler system.

The mechanical cooler, though more widely used, was the more expensive option, costing $283,419 to run for 10 years. The supplemental geothermal system would cost more to install but have a 10-year cost of $29,754, Hudson said.

The open-loop system would pull well water from the ground, pump it into a heat-exchanger system and then discharge it back into the ground, Hudson said.

Figure 4-17 As you can see in this news clipping, Sussex County's engineer did the math. This would qualify as the proverbial no-brainer. (*News excerpt: The News Journal*.)

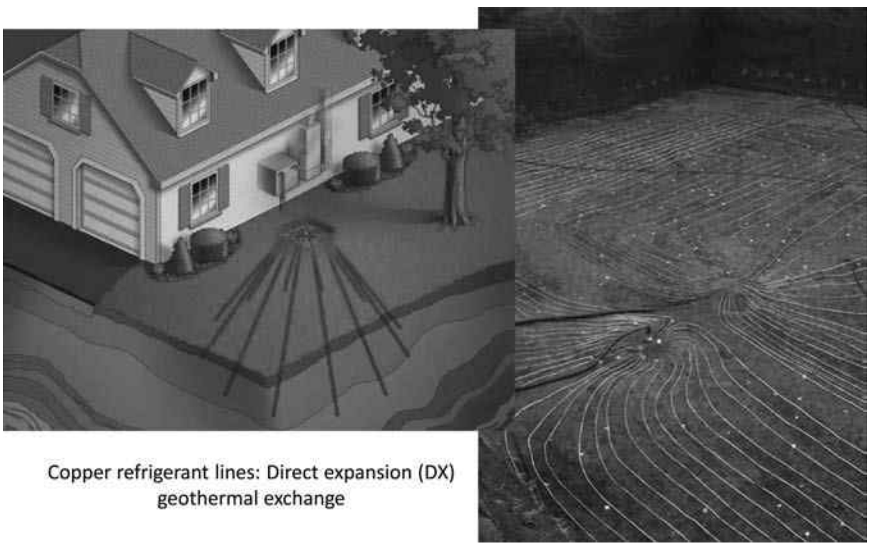


Figure 4-18 As mentioned previously, direct-expansion (DX) systems use direct contact of the copper with the soil from which the energy is being transferred. Although this eliminates one generation of heat transfer, it opens the door to some other potential issues. (*Illustration: Earth Link Direct Exchange*.)

Figure 4-19 Elegant and simple. A unitary geothermal heat pump contains all the necessary components to provide domestic hot-water heating and air-conditioning, as well as in some cases pool or spa heating. This is the essence of simplicity—load-sharing, load-shedding sustainable and effective design. (*Jacobs Heating*.)

SAFETY DATA SHEET according to Regulation (EU) No. 1907/2006

DuPont™ SUVA® 410A Refrigerant

Version 2.3
Revision Date 17.07.2007 Ref. 130000000570

ACCIDENTAL RELEASE MEASURES

Personal precautions	:	Evacuate personnel to safe areas. Ventilate the area. Refer to protective measures listed in sections 7 and 8.
Environmental precautions	:	Should not be released into the environment.
Methods for cleaning up	:	Evaporates.

Figure 4-20 In this Material Safety Data Sheet (MSDS) for R410a, it is evident that the refrigerant is nontoxic and its cleanup method is described by one word: *evaporates*. (*DuPont*.)

For DX geothermal system, the volume of refrigerant can be three to five times that in a standard DX heat pump or more compared with a package geothermal heat pump. An average 5-ton geothermal heat pump may have 4 or 5 lb of refrigerant in it. An average 5-ton standard heat pump (nongeothermal) may have 11 to 15 pounds of refrigerant. A DX geothermal heat pump using an earth-coupled DX heat exchanger may have 50 lb or more of refrigerant. This is so because refrigerant is contained in the entire condenser portion, which in the cooling mode is that portion of the exchanger in the earth. This can be several hundred feet of condenser line.

Copper is a great conductor, but incidents of copper failing when placed in soil are by nature quite higher than HDPE. Whether due to electrolysis, pH levels, or any other type of contamination, it matters not. Copper is more likely to fail at some point in time, and that point in time will be earlier than plastic or HDPE under the same conditions.

Refrigerant oil tends to migrate to be the lowest point in a refrigeration system. As you refer back to Fig. 4-4, you'll see that the lowest point is deep in the borehole for the exchanger. It is evident that most of the refrigerant oil normally would be trapped in the earth-coupled exchanger. Through clever engineering, this problem has been mostly eliminated.

Oxygen displacement by refrigerant can be a serious concern. Refrigerant is heavier than air and displaces oxygen just as water in a pool displaces oxygen from the pool. In a home, if the air-handler coil were to spring a leak, the refrigerant from the system would leak into the home. Not to worry; this happens quite often with no dangerous results. The reason why you don't hear of this causing health problems is that the average unitary geothermal heat pump system holds only about 3 to 10 lb of refrigerant. The entire refrigerant charge would only fill a few inches of heavy gas (not liquid) above the floor of the home in which it is installed. So, unless someone is lying face down in exactly the right place on the floor, this is not a problem. However, if you multiply the amount of refrigerant by a factor of 10, this becomes a potential problem.

*Wei Ruan and William Travis Horton, "Literature Review on the Calculation of Vertical Ground Heat Exchangers for Geothermal Heat-Pump Systems." Presented at the International High Performance Buildings Conference, Purdue University, Washington DC, 2010, Paper 45; available at http://docs.lib.purdue.edu/ihpbc/45

Just as a person will drown if underwater in a pool for too long, a person may be asphyxiated in environments such as just described. In such cases, it is important to use the appropriate alarms to warn occupants of refrigerant leak.

With R410a, as indicated in Fig. 4-20, there is little fear of contamination of the earth or groundwater.

Review Questions

1. Among the advantages of replacing a cooling tower with a geothermal source is
   a. elimination of fresh-air equipment.
   b. addition of an ozone-generating system.
   c. elimination of boilers.
   d. increased gray-water usage.
2. Among the options that can be found on a geothermal heat pump is
   a. a teapot warmer.
   b. a potable-water chiller.
   c. a pool/spa heater.
   d. an ozonating filter.
3. Direct-expansion geothermal heat pumps are called such because
   a. they allow direct expansion of refrigerant into the air stream.
   b. they're expandable to fit any size from 2 to 5 tons.
   c. the refrigerant runs through the earth heat exchanger.
   d. of the expansion of the piping in the exchanger.
4. Of the four types of generally known closed-loop ground-coupled systems, which of the following is *not* included?
   a. Slinky style
   b. Etch-a-Sketch style
   c. Vertical
   d. Two-pipe horizontal
5. Soil thermal conductivity depends on the makeup of the earth being tested. Which of the following is *least likely* to increase conductivity?
   a. Silt and loam
   b. Hydration
   c. Bentonite
   d. Granite
6. Thermal conductivity testing of a borehole involves circulating fluid through pipe in the borehole. The instruments then measure the gallons per minute and the
   a. specific gravity.
   b. ambient air temperature.
   c. thermal conductivity of the piping material.
   d. difference in temperature of the fluid in and out.
7. Among the factors in deciding the location of the closed-loop field for a geothermal system, which of the following is *not* considered?
   a. Elevation
   b. Proximity to the building
   c. Right-of-way
   d. The hole

8. Cooling towers provide evaporative cooling for condenser water loops feeding
   a. geothermal loop fields.
   b. water-source heat pumps.
   c. fire-control systems.
   d. HVAC control panels.
9. Switching from a cooling tower to a geothermal option can eliminate the
   a. need for chemical treatment.
   b. freshwater loss due to evaporation.
   c. condenser water loop.
   d. plant engineer.
10. A geothermal pump and regeneration system
    a. uses less closed-loop piping then a slinky.
    b. has at least four boreholes.
    c. generates about half the electricity needed to run it.
    d. basically eliminates thermal retention/gain.
11. A close-coupled surface-water system
    a. pumps lake water directly through the exchangers.
    b. is very close to the body of water.
    c. uses closed-loop piping within the body of water.
    d. is more expensive than ground loops.
12. A good thermal conductivity tests will contain the following data *except* for
    a. the loop-drilling log test.
    b. the estimated soil diffusivity.
    c. the conductivity of the closed-loop piping.
    e. the lithology at differing depths throughout the bore.

CHAPTER 5

Closed-Loop Earth Coupling and Fusion

Closed-loop earth coupling involves the placement of piping [usually high-density polyethylene (HDPE)] directly into the earth or a body of surface water to achieve an efficient earth energy transfer. Over the last 35 or 40 years, there've been many improvements and innovations in the design and application of closed-loop systems. Many will be mentioned in this chapter. Only the application of closed-loop systems using HDPE pipe and associated fusion techniques will be discussed in detail.

Other types of closed-loop applications will be mentioned, and references to the associated engineering technologies and applications will be provided. This is so because there are, at the time of this writing, insufficient data to provide proper engineering and technical endorsement of other closed-loop technologies.

Among the most important factors to remember with closed-loop earth coupling is this: Closed-loop earth coupling must be applied with caution. This is so because, although the earth is able to absorb and dissipate tremendous amounts of energy, extraction or thermal retention can occur when loads are imbalanced. By imbalanced loads, what the authors mean to say is that if there are significantly greater cooling or heating hours in a building, traditional loop design may not be able to provide an economically attractive solution.

In each of these cases, it is important to understand that there is always a suitable solution as far as the authors of this book have been able to observe. The solutions are covered in the various chapters of this book, and it is important that due diligence is done in the engineering of each geothermal heating, ventilation, and air-conditioning (HVAC) application undertaken.

There are three generally accepted types of closed-loop applications that will be addressed herein (Fig. 5-1). They are

1. Horizontal ground loop
2. Vertical ground loop
3. Surface-water system (pond or lake loop)

Each of these types of ground loops has its strong points and weak points.

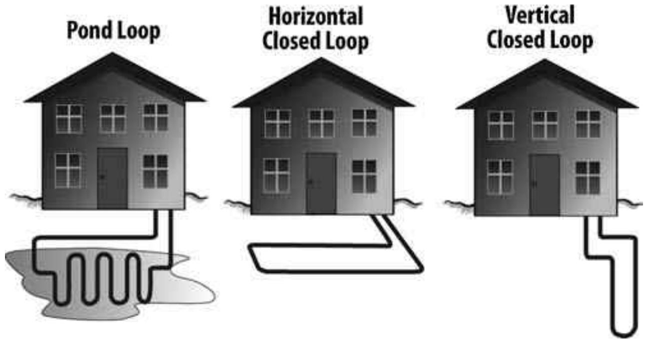


Figure 5-1 The three types of closed-loop systems are horizontal, vertical, and surface water. (*Sarah Cheney*.)

Horizontal Ground Loop

This type of ground loop is used when a project has plenty of land area for the heat exchanger. Trenching and excavation typically are rather extensive with a horizontal ground loop; thus the designer must be careful to represent this to the owner.

There are several different designs for horizontal ground loops (Fig. 5-2). Among these are

1. Single-pipe systems
2. Two- and four-pipe systems
3. Slinky-type systems
4. Matt-loop systems

The trenches, or excavations, are typically 3 to 6 ft below mean ground level. Trench length depends on the type of geothermal loop but can vary greatly. The typical area needed per ton is approximately 1000 to 1500 ft^2.

Horizontal ground loops are often considered first because they do not require vertical drilling, and vertical drilling is relatively expensive. Horizontal ground loops typically need a considerably greater length of heat exchanger per ton than vertical ground loops or pond loops.

Surface-water exchangers also may use a type of plate exchanger placed directly in the body of water. These exchangers are typically more efficient in heat transfer because they are made of a more conductive metal such as stainless or copper-nickel. When addressing the issue of heat transfer, the choices of a plate heat exchanger is often favored over pipe such as high-density polyethylene (HDPE).

Vertical Ground Loop

Vertical ground loops are best suited for geothermal projects for which land is at a premium, retrofit projects, or where landscaping, irrigation, and the like are better left relatively undisturbed. Most often, vertical systems use vertical boreholes into which pipes

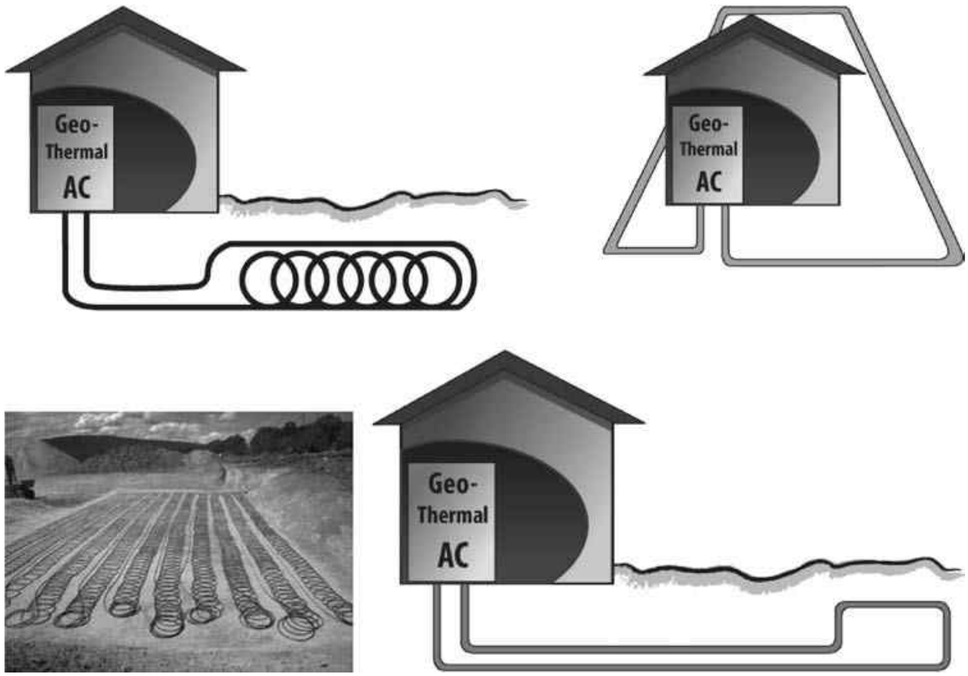


FIGURE 5-2 Several types of horizontal ground loops can be considered, each requiring a different set of engineering criteria. (*Artwork: Sarah Cheney; photograph: Geofinity*.)

connected by a U-bend at the bottom are inserted (Fig. 5-3). The void around the HDPE pipes is filled with grout material, typically a bentonite clay or a clay-sand mixture. The grout material provides support for the piping, protects the piping, and enhances the heat transfer between the pipe and the earth surrounding it.

Borehole lengths typically range from 90 to 450 ft. The piping normally is ¾- to 1¼-in inside-diameter (ID) HDPE. Pipe sizing matters a great deal when it comes to pumping power. A pump is needed to circulate the fluid through the ground loop into the equipment. It may seem like a small matter, but pump power is a significant factor in the overall efficiency of a geothermal HVAC system. The shorter the run of pipe and the more parallel loops piped to headers, the better is the pumping factor. Thus many designers have gone to 1-in pipe for the main heat exchanger because of increased surface area and heat transfer and reduced pumping power. However, there is an upper limit on pipe sizing because turbulent flow (Reynolds number > 2500) must be maintained in the HDPE pipe to ensure energy transfer.

Surface-Water Systems

Surface-water systems are the most favorable of the closed-loop technologies, particularly in areas of the Midwest and the South. This is so because there is relatively little disturbance of the earth, with the exception of some trenching to and from the body of water that is to be used as the source and sink for heat transfer.

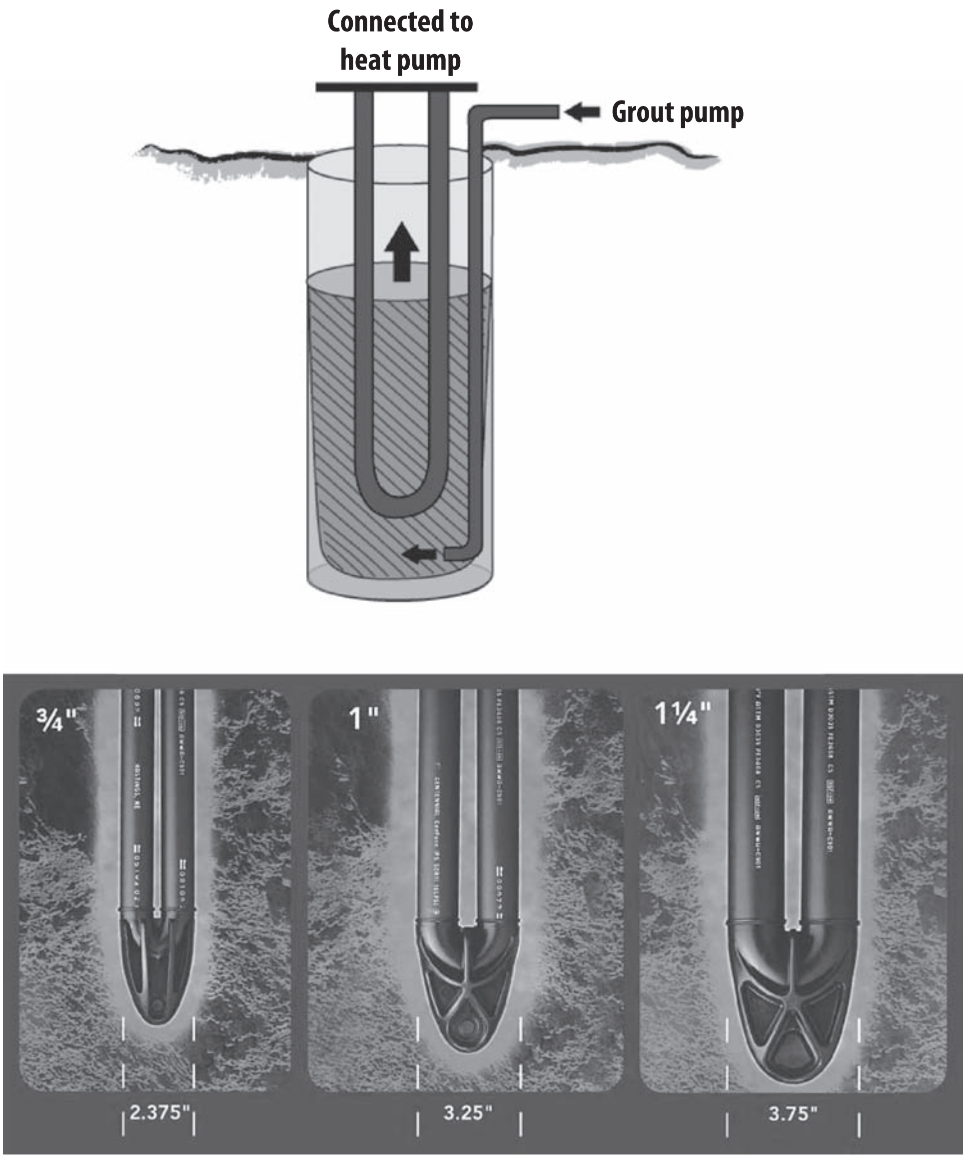


Figure 5-3 A vertical loop is typically constructed of pipes connected at the bottom by a U-bend connection. The void is filled with the grout material to enhance heat transfer. (*Artwork: Sarah Cheney; U-bend depiction: Centennial Plastics*.)

Among the choices that must be made for implementing a surface-water system for closed-loop application are the following:

- Physical characteristics of the body of water (i.e., surface area and depth)
- Traffic and egress (If there is a lot of boat traffic or the area is used for other purposes, these activities may disturb the heat-exchanger array.)
- Type of heat exchanger to be used
- Water quality (i.e., corrosive nature)

Although they are not all covered here, three main types of heat exchangers can be placed in the water:

- An HDPE array
- A lake plate exchanger
- Other engineered material (e.g., copper-nickel or stainless steel)

An HDPE array is a very common surface-water exchanger. This is so simple because engineering precedents are easily accessible for the heat-transfer capabilities of HDPE and a body of water as applied to geothermal HVAC systems. These applications are easily adaptable to the different and varying needs of various projects.

A lake plate exchanger is a good choice larger systems because these exchangers can be engineered for each application and are not as unruly in look or application as an HDPE array can be.

Some of the things to be aware of when designing surface-water systems for geothermal HVAC applications include

- Variable levels of the body of water (e.g., drought and tidal conditions)
- Hazards (e.g., boat traffic, egress, and fishing)
- Seasonal fluctuations in temperature

Bodies of water, such as lakes and tidal canals, fluctuate in temperature surprisingly close to the ambient temperature. In studies conducted in tropical climates, it was found that the fluctuation in water temperature at one location can be as much is 50°F or more per year. For example, it is not uncommon for a lake in Florida to fluctuate from 41 to 94°F depending on the season.

Likewise, the temperatures of tidal canals, harbors, and bays connected to the oceans can fluctuate significantly by season. In the Gulf of Mexico, the temperature ranges from 54 to 87°F seasonally. In northern climates, the water at the bottom of a relatively deep, unmixed lake or pond will always be 39.2°F (4°C). Water is a peculiar compound as it is most dense at that temperature. This is why the lighter water freezes from the top down in a lake or pond rather than from the bottom up.

Any way you look at it, the use of water as a heat sink/source is better than air within reason. Water transfers heat 24 times faster than air with the same given area of heat transfer.

The Invention of Standardized Geothermal HVAC

In the 1970s and 1980s, geothermal HVAC engineering was entering into more mainstream acceptance. Prior to that time, heat exchange using the earth had been practiced, but it had been engineered for each individual application most of the time. The two biggest problems with the engineering of a geothermal heat-exchanger system were water quantity and water quality.

Industry representatives got together and earnestly searched for a way to standardize geothermal HVAC applications. There was one type of earth coupling that seem to work in all situations—at least where heating was the dominant load.

As mentioned previously, there are at least four dominant methods of earth coupling. They include

1. Geothermal water wells
2. Standing-column wells
3. Closed-loop wells (or arrays)
4. Surface-water exchange (either direct or close-coupled)

When you look at these choices for geothermal exchange, two of them depend on a full water supply—geothermal water wells and surface-water exchange (lake or pond). The standing-column well is not so dependent on water quality, water yield, or need for reinjection. However, conditions must be right for a standing-column well to work. Fortunately, conditions are right in approximately 65 percent of the continental United States. Unfortunately, that leaves 35 percent of the country having to make another choice.

With closed-loop technology, theoretically it does not matter whether there is lots of water, no water, rock, sand, or any other soil type within a given set of parameters. This is so because closed-loop systems do not depend on water quantity/quality. Once the loop is sized properly and filled with a treated antifreeze solution, theoretically, the geothermal operation could continue with little further service or concern.

Fundamentally, all of this is true. However, the authors have run into some barriers or roadblocks, as it were. The authors have found that a point of diminishing returns is reached with regard to the earth's ability to absorb heating- and cooling-dominant loads. A list of some of the items that have been discovered over the past two decades that limit the use of closed-loop technology includes

1. Imbalanced loads (bin data)
2. Soil-saturation changes (moisture content of soil)
3. Cooling-dominant loads
4. Commercial applications

Each application must be carefully considered. After determining whether a closed-loop system will work in an application, a financial analysis should be completed. Most of the time, closed-loop systems are more attractive in smaller applications. They tend to become more expensive as the tonnage increases because the number of holes needed per refrigeration ton does not change, whereas the number of holes for wells per ton can be reduced with an increase in air-conditioning capacity. This is so because a water well can be drilled to a larger diameter and accommodate as large a pump as necessary to address the air-conditioning and heating capacity of the system.

Closed-Loop Design Considerations

Whenever a closed-loop geothermal system is considered, the following criteria must be evaluated:

1. Land available and soil type
2. Thermal conductivity characteristics of the soil 365 days a year
3. Heat-exchanger type (e.g., vertical loops, Slinky, horizontal two-pipe, four-pipe, etc.)
4. Heat-exchanger design (i.e., number of parallel circuits, header orientation, pumping power needed)
5. Pipe joining methods

Once these items have been determined, construction of the geothermal heat exchanger can begin. The industry has accepted the use of HDPE as a standard for in-ground heat exchangers for geothermal HVAC and other applications. HDPE has a proven record of reliability, ease of connection, abrasion resistance, handling compliance, and other desirable characteristics that compensate for a relatively low thermal conductivity. As a result of this, unless otherwise specified, everything mentioned in this chapter will be focused on the use of HDPE piping.

Thermal Conductivity Testing and Evaluation

Thermal conductivity testing is normally done for large closed-loop projects and a 10 to 20 percent reduction in bore length may be achieved by experienced and certified agencies. Typically, thermal conductivity is performed by drilling a sample borehole in a given piece of earth, inserting a quantity of HDPE piping in the same manner as the geothermal exchanger would be constructed, circulating water through the piping while adding a predetermined amount of heat via an electric or fossil fuel–driven heating element, and recording the results. The laws of reciprocity allow heat to be extracted from the earth using much the same constants and curves as obtained from the results of the test over a given period. This proves the earth's ability to absorb and/or reject heat under given conditions. Figure 5-4 provides an example.

Thermal conductivity is shown in $k = \text{Btu}/(\text{h} \times \text{ft} \times °\text{F})$. Figure 5-5 shows the thermal conductivities of differing types of soils and materials:

These tests are called *formation thermal conductivity tests*. In addition to the thermal conductivity, these tests also can and should report the formation thermal diffusivity. This is determined by the undisturbed formation temperature from the returning water during the first half-hour of circulation prior to the start of heating.

The heat capacity for the boring should be calculated from an average of specific heat density values, as indicated in *Ground Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*, by Kavanaugh, S. P. and Rafferty, S. (New York: American Society of Heating, Refrigeration and Air-Conditioning Engineers, 1997). In addition, it's advisable to use Table 3 of the *Soil and Rock Classification for the Design of Ground Coupled Heat-Pump Systems Field Manual* (Stillwater, OK: International Ground Source Heat Pump Association).

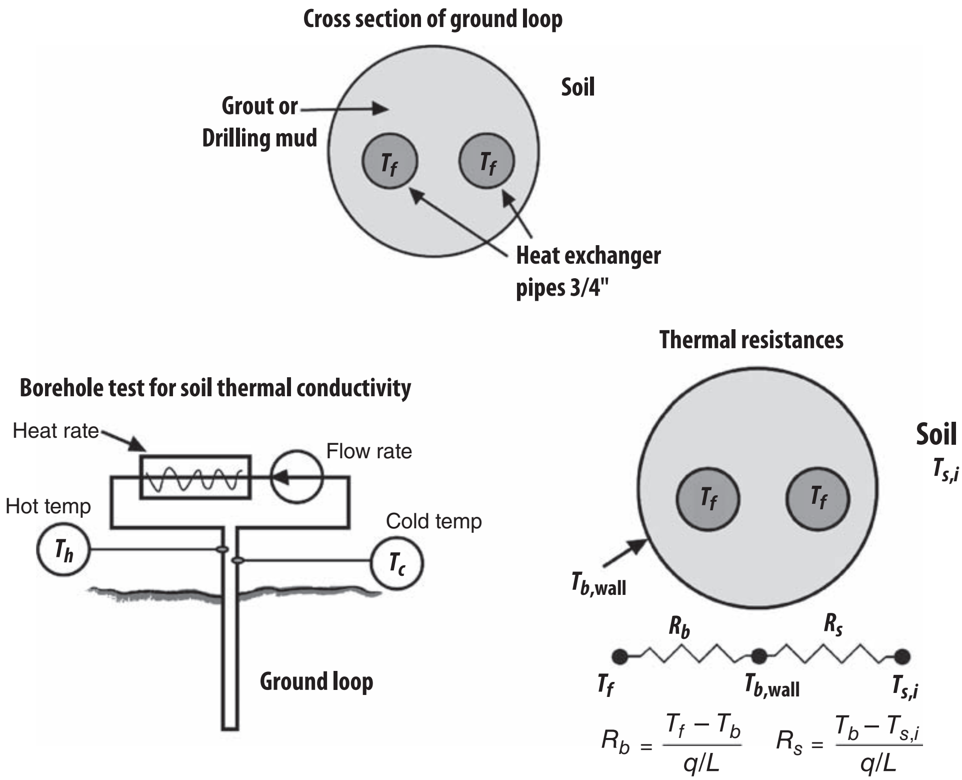


Figure 5-4 Refer to Fig. 5-3 for a cross section of a vertical ground loop. The thermal bond of the HDPE to the grout and to the soil has a direct relationship on the ability to transfer heat. Typically, in a thermal conductivity test, flow rates and heat rate are known, and by calculating the difference in temperature between the ingoing and outgoing pipes, one can determine the soil's capacity for thermal conductivity.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has published a set of standards for doing thermal conductivity testing (*Handbook of HVAC Applications*. New York: ASHRAE, 2011, Chap. 34). The following is a list of recommended procedures:

1. *Test duration.* A minimum test duration of 36 hours is required. It would be preferable to provide a test of 48 hours.
2. *Power quality.* The standard deviation for power should be less than or equal to 1.5 percent of the power, and the average with maximum power variation should be less than or equal to 10 percent of the power supply. The best simulation of the expected peak loads on the U-bends, the heat flux rate per foot of borehole gap, should be 51 to 85 Btu/h or 15 to 25 W, respectively.
3. *Temperature measurement of the undisturbed formation.* Undisturbed formation temperatures are to be determined by circulating water through the loop for approximately ½ hour before heating is begun and tabulating the stabilized loop return temperatures.

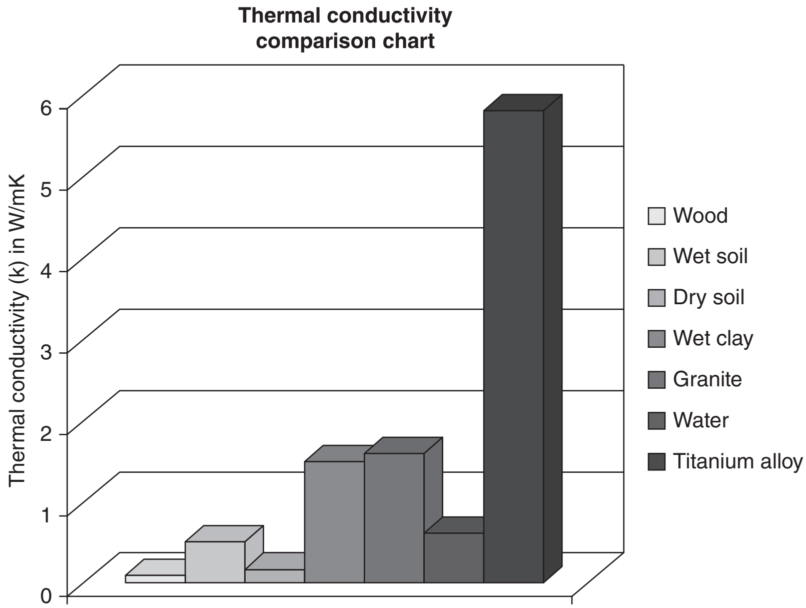


FIGURE 5-5 Thermal conductivity values *k* of differing types of soils and materials. For comparison, the chart shows that most materials have a thermal conductivity *k* of about 1 or less. Titanium alloy, for reference has a *k* value above 5.

4. *Procedures for the installation of test loops.* The target borehole diameter should be a minimum of 4.5 in, not to exceed 6 in. The bore annulus should be uniformly grouted from the bottom up using a "tremie" tube/pipe to avoid bridging and voids in the borehole.
5. *Time between installation of the loop and testing.* It is recommended that the loop be installed a full 3 days prior to testing.

During the thermal conductivity testing, water is heated at a uniform rate and then circulated through the ground loop. Heat is rejected to the ground to simulate cooling-load operations. The water temperatures to and from the ground loop, water flow rate, and electrical power consumption are measured and recorded prior to heating and throughout the duration of the test.

The best data-analysis methodology is probably the line-source method. In this method, an infinitely thin constant heat source in a homogeneous medium is used. Formation thermal conductivity (FTC) of the medium is derived from the slope of this line:

$$\text{FTC} = \frac{Q/L}{4\pi \times \text{slope}}$$

where Q/L is the rate of heating per length of the borehole and the slope is the slope of the temperature versus ln(time).

Real-world deviations from the line-source model result in nonlinear temperature-ln(time) plots, especially during the early heating times. After about 12 hours, the heating curve becomes approximately linear with ln(time). The slope is used to derive the conductivity of the formation beyond the effects of the near-well bore deviations from the idealized line-source model.

It is important to note that the thermal conductivity and thermal diffusivity describe how efficiently, how quickly, and how far heat is dissipated away from the well bore once it gets to the formation (beyond the bentonite and into the undisturbed earth). Even more important, *this is only half the information needed to characterize the thermal performance of a geothermal well*. The other piece of information needed is a measure of the difficulty of transferring heat from the ground loop to the formation. This is described by the *borehole thermal resistivity* (BTR).

In order to determine BTR, the difference between the average loop temperature and the temperature at the margin of the borehole divided by the heat flux per foot is calculated:

$$\text{BTR} = \frac{T_{\text{loop}} - T_{\text{bore\_edge}}}{Q/L}$$

A higher BTR value reflects a greater resistance to the flow of heat from the ground loop to the wall of the borehole. These two parameters are used to characterize the thermal performance of a geothermal well.

A fairly effective BTR can be derived using the preceding equation and the line-source model temperature at the borehole radius. Real-world deviations between the actual well bore and near-well bore conditions are reflected in the BTR. Formation thermal conductivity and the effective BTR need to be computed together from the test data. Together they describe the borehole performance under the test conditions. In summary, these test conditions are designed to approximate full-load cooling.

It is important to understand these processes for thermal conductivity and diffusivity testing. It is not as important to be able to do these tests yourself. Understanding the results of these tests is important and will become the basis for closed-loop design.

Design of the Heat-Exchanger Loop

The ground loop has several factors that can affect long-term performance. Among these factors are

1. The thermal conductivity of the earth
2. The grout/fill material
3. The integrity of the grout (quality of application)
4. The type of heat exchanger
5. Vertical separation
6. The length of the bore

The term *length of the bore* refers to borehole in a vertical heat-exchanger system. Without exception, a borehole for vertical heat exchanger will have two times the length of the bore in actual pipe. This is so because two pipes to the U-bend placed at the bottom are inserted into the borehole. The length of the bore is one of the primary factors that affects ground-loop performance and ultimately geothermal heat-pump performance.

In addition, commercial systems, owing to high internal heat gains, tend to be cooling-dominant, even in cold northern climates. Thus the required link for the cooling mode tends to dominate loop length. This is especially true in southern climates, where the length of the loop can quickly reach a point of diminishing returns while not having sufficient heat-dissipation capacity to avoid thermal creep.

Thermal creep is the term used to identify a condition in which the ground-loop exchanger is extracting or rejecting more heat than the surrounding earth can dissipate or absorb. This is often also referred to as *thermal retention* in a cooling-dominant situation.

The basis for design of the heat exchanger or loop field is the thermal conductivity test. At this point, if the thermal conductivity test is correct, the length of the borehole needed can be determined. A thermal conductivity test may come back with numbers similar to the following:

Average formation thermal conductivity = 1.60 Btu/(h × ft × °F)

Formation thermal diffusivity = 1.22 ft^2/day

Undisturbed formation temperature = 70.2°F

Estimated average heat capacity = 29.7 Btu/h/ft^3

The most important piece of information that comes from the report on thermal conductivity is the average formation thermal conductivity.

Bin Data and Degree Days

In the lead author's first book, on page 198, he presented a short discussion on degree days, which are the basis for calculating energy efficiency. In addition, the relative humidity plays a role. This is the reason why the weather patterns need to be separated into individual distinct groups, or *bins* (Fig. 5-6). This is important for determining the capacity of a ground heat exchanger. You'll notice that the ability of the earth to absorb heat involves a quantity of heat, a time, and the temperature factor. When any of these is surpassed for an extended period of time, thermal creep is the result.

Degree days (DDs) are a measure of heating or cooling. A *degree day* is technically an integral part of a function of time and temperature. Degree days are defined relative to an appropriate base temperature (typically 60 or 65°F), which is the outside temperature that would require no conditioning. One popular approximation method is to take the average temperature on a day and subtract that from the base temperature. If the value is less than or equal to 0, that day is rated as 0 DD. Two DDs can be added over periods of time to provide an estimate of seasonal heating needs. For example, the DDs in the heating season in New York City average 5050, whereas they are 19,990 for Barrow, AL. This means that a home of similar size and design would require roughly four times the energy to heat in Barrow versus New York. In contrast, Los Angeles has a DD rating of 2020.

In many situations, cooling of a building is needed even when the temperature outside is below freezing. Please review the case of the Sussex County Emergency Operations Center (EOC) in Chap. 4 of this book. The geothermal cooling system for that facility reached an incoming temperature of 105°F in only 4 years. Sussex County

Dry Bulb with MCHR			Humidity Ratio with MCDB		
DB (F)	HR (gr/lb)	Hrs	HR (gr/lb)	DB (F)	Hrs
94 to 96	127.5	6	145 to 150	84.9	1
92 to 94	120.6	35	140 to 145	86.8	6
90 to 92	113.5	97	135 to 140	84.6	29
88 to 90	108.1	172	130 to 135	82.9	89
86 to 88	106.1	247	125 to 130	83.3	234
84 to 86	106.8	317	120 to 125	80.8	442
82 to 84	104.6	274	115 to 120	79.3	552
80 to 82	104.9	325	110 to 115	78	484
78 to 80	103.8	384	105 to 110	76.2	358
76 to 78	105.3	382	100 to 105	75.3	342
74 to 76	103.6	548	95 to 100	73.3	416
			90 to 95	74.3	322
			85 to 90	72.8	426
			80 to 85	70	425
			75 to 80	67.9	423

Figure 5-6 Bin data include the separation of temperature and relative humidity into distinct groups or bins to aid in energy calculations.

has an average winter temperature of 34°F, but the EOC has so much internal heat gain that it needs cooling, even when the temperature is below freezing outside.

In that chapter, the heating degree days were a measure of how much heating was needed in degrees and for how long in days the outside air temperature was below (or above in the case of cooling) a certain level/temperature. The lead author has had situations in which a client has questioned the cooling efficiency of a system when the savings were not what was expected. Here is an example:

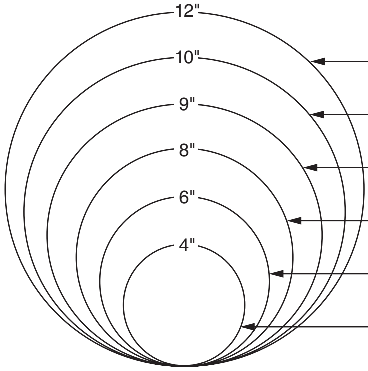
- The DDs for Tampa, FL, in March 2011 were 162; in March 2012, they were 273.
- The electric usage was 3636 kWh in 2011 and 3512 kWh in 2012.
- 3636/162 = 22.4 kWh per degree day in 2011.
- 3512/273 = 12.86 kWh per degree day in 2012.
- This is a *reduction of almost 43 percent in energy consumption*.

This exercise is a real-life example of why a firm grasp on degree-day data is important for real-life calculations.

Header Design

The length of pipe required for a given ground-loop heat exchanger often can be measured in miles rather than feet. Such heat exchangers should not be in series. A thousand feet or more of pipe in series will increase the pumping power requirements out of proportion with breaking up the circuits into parallel. Just as a four-lane highway can reduce congestion compared with a two- lane highway, one can get more water through the same number of feet with less pump power when parallel or decoupled secondary circuits are used.

Comparison of Pipe Cross Section



PIPE DIAMETER	GPM-l/Mn	Sq.IN IN CM^3
12" 30.48 cm	2800/10,598 1750/6,624	113"/729.07
10" 25.4 cm	1963/7,431 1226/4,641	78.5"/506.45
9" 22.86 cm	1588/6,011 992/3,755	63.5"/409.67
8" 20.32 cm	1250/4,732 781/2,957	50"/322.58
6" 15.24 cm	700/2,650 438/1,658	28"/180.64
4" 10.16 cm	313/1,185 195/738	12.5"/80.64

Figure 5-7 Pumping power is increased as the length of pipe is increased. Parallel or decoupled secondary circuits provide a reduction in pumping power.

Much of this will be covered in the hydronic chapters in this book (Chaps. 9, 10, 11, and 13). Header design historically has been reverse return in order to ensure equal flow through all the circuits. Using a pipe sizing chart, one can see how much water can flow through each piece of pipe per length (Fig. 5-7).

In a reverse-return piping system, the header size is increased as the circuits are added on. In a decoupled system, a hydraulic separator is used, and the individual circuits are operated as called for. This type of system gives complete control of the system ground loop to the control system (Fig. 5-8).

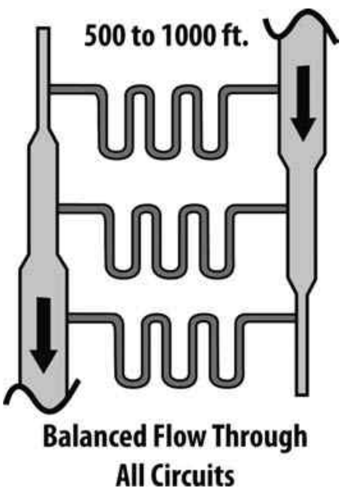


Figure 5-8 Methods of providing parallel circuits vary as in this example of reverse-return and decoupled secondary circuits (see Fig. 6-10 for an example of a hydraulic separator and Chap. 13 for more details on decoupled secondary circuits).

Design of the Geothermal System Including the Heat-Exchanger Field

Without exception, a trusted program for the calculations should be used for this section. The lead author has had numerous requests to state certain no-nos for this particular subject. This will be done after some of the basics have been covered.

Two of these programs are called *CLGS* and *GeoDesigner*. Most geothermal heat-pump (GHP) manufacturers have programs available to calculate the parameters for designing geothermal heat-exchanger loops and the associated equipment and systems (Fig. 5-9). In addition, special thanks go out to Dr. Stephen Kavanaugh and Prof. Kevin Rafferty for their significant work in the field of geothermal heat-exchanger design and pumping power. Much of the information in the remainder of

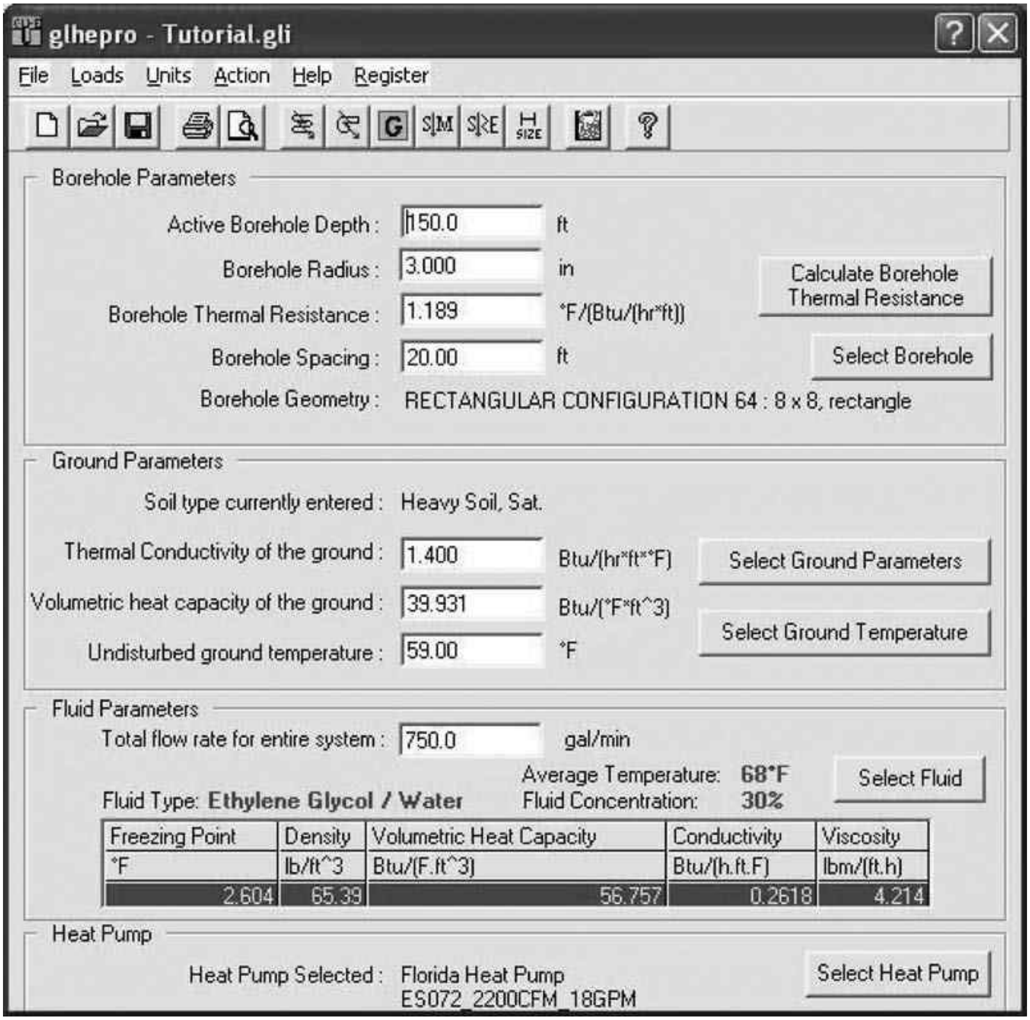


Figure 5-9 Use of geothermal heat-exchanger design software is recommended.

this chapter is derived from their work. Even David Hoffman, whose writings appear toward the end of this chapter, give Dr. Kavanaugh significant accolades for his dedication to the industry.

Over the past 30 years, there has been much argument about the potential for closed-loop systems to wear out. The term *wear out* is not appropriate, but it is used in the media quite often. The real issue here is more accurately described as *thermal saturation*, *thermal creep*, or something of the sort. Whatever you call it, it is a situation in which the ground-source heat-pump loop field becomes too cold or, more often, too hot to continue to provide adequate exchange based on the capabilities of the GHP equipment to which it is connected. Geothermal heat-pump equipment will operate down to 25°F and up to 105°F entering-water/fluid temperature (EWT).

The moisture content of the earth in which the heat exchanger is installed has a great effect on thermal conductivity. In the case of drought, when the loop field becomes less saturated, temperatures can increase drastically. For example, the heat rejection required to cause a 1 percent reduction in ground moisture is approximately the same as that needed to raise the ground temperature to 30°F.

Much of the issue surrounding this has to do with improper load calculations for the building. With few exceptions, thermal creep is a result of buildings with imbalanced loads, that is, cooling- or heating-dominant loads. Just because a building is cooling-dominant does not mean that a closed-loop system will not work. A properly sized ground-source heat exchanger will work in every situation.

The question is simply this: What is the cost of a properly sized ground-source heat exchanger for the building in question versus the cost of a groundwater open-to-reinjection or standing-column well for the building in question?

Tropical climates are cooling-dominant, so much so that it is easier to say that they have no heating load. Some cold climates have no cooling load, so they would be considered heating-dominant. It is interesting to note, however, that most commercial buildings are cooling-dominant because they have significant internal heat gains and need cooling capacity even when the outside temperature is very low indeed. Careful consideration of domestic water-heating needs with a water-to-water GHP can mitigate this unbalance to some degree.

This section will not address the breakeven point (between close-loops and groundwater heat exchangers) but focuses instead on proper construction of closed-loop ground-source heat pumps. For more information on this, please refer to earlier sections on bin data and DDs.

Many of the parameters and choices that have to be made include

1. Availability of land
2. Soil type and conditions (rock, sand, etc.)
3. Depth to water (saturation)
4. Obstructions (e.g., trees, structures, etc.)
5. Pump sizing
6. Heat-exchanger matrix (see layout example in Fig. 6-10)

A standard geothermal ground-loop system typically will have a series of vertically bored holes interconnected in a series-parallel fashion (Fig. 5-10). The parameters that should be considered for energy-efficient design include

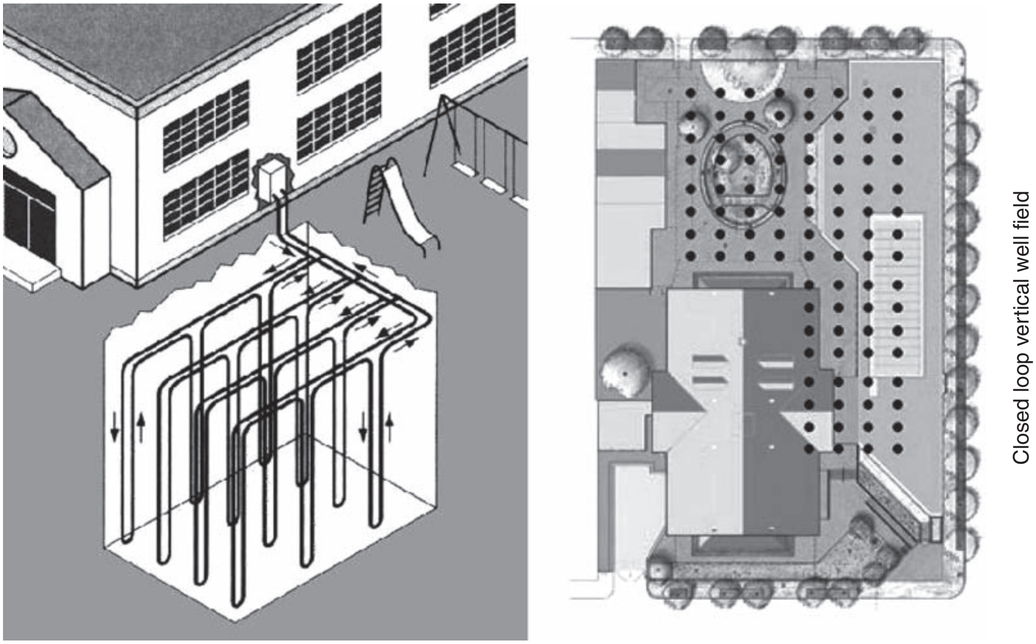


Figure 5-10 Layout of geothermal well fields can be as wide and varied as the real estate in which they are installed.

1. Exchanger pipe size (and header design)
2. Borehole size (diameter)
3. Borehole spacing
4. Length of borehole per ton
5. Pumping power (ground loop, including header design)

Each of these items will be considered in order.

1. Exchanger Pipe Size

At the beginning of the 1980s, ¾-in HDPE pipe was used most commonly for construction of in-ground heat exchangers. This was true because, for the cost per linear foot and the Btus absorbed, it seemed to be a more economical choice. However, pumping power becomes a real issue in larger systems. Not that it is not an issue in smaller systems, it is just such a small factor sometimes that the choice to go with smaller piping is given.

Although each and every commercial geothermal installation should be individually designed, generally, 1- and 1.25-in pipe is used most commonly for vertical borehole insertion. The increased surface areas, in combination with the reduced pumping power needed, is the major factor here. With this advice comes the warning: Larger diameter, while reducing pump power, can result in the flow reverting to a laminar Reynolds number with substantial loss of heat transfer, particularly with a Reynolds number lower than 2500.

2. Borehole Size

Borehole sizes range from 4 in diameter and up. The primary function of the size of the borehole is to allow sufficient room for HDPE pipe insertion. Therefore, if the pipe is large and the borehole is vertical, borehole would need to be as large as 5 or even 6 in in diameter In addition, the use of grout against the pipe can thermally enhance the surface area and heat exchange compared with the surrounding soil. In such cases, a larger borehole allows a larger square footage of effective contact area for the pipe. This information is based on the thermal conductivity test.

3. Borehole Spacing

A significant amount of data has been generated regarding borehole spacing. Thermal communication between boreholes can cause thermal creep, either warmer or colder (Fig. 5-11).

Vertical boreholes have been spaced at 15 ft and even closer at 10 ft on center in past decades. It has been suggested that vertical borehole spacing of 20 ft or more provides the safest distance to prevent borehole-to-borehole interference resulting in thermal saturation or thermal creep, particularly on deeper (over 300-ft) boreholes.

Recent tests indicate that commercial buildings with properly designed loop systems can operate very efficiently even after 15 to 20 years or more. However, poor design and

Figure 5-11 Thermal communication between boreholes can be a significant issue. In the illustration, the effect of rejected heat overlaps between the boreholes or the vertical piping, and compounding thermal saturation.

thermal creep also have resulted in remarkable declines in the efficiency ratings of some of these systems. The information is not conclusive, but it suggests that building loads play a significant role in the favorable operation of the ground-source loop.

Borehole spacings of less than 15 ft experience high ground-loop temperatures during extended periods of drought and longer seasons with higher outdoor temperatures. Ground-source heat-pump systems with loop temperatures below 90°F are able to regularly attain Energy Star ratings above 92. In systems where loop temperatures are above 95°F, the Energy Star rating averages 53.

4. Length of Borehole per Ton

Bear in mind that when one speaks of the length of a borehole per ton, the pipe length is doubled because there is a down pipe and an up pipe connected with a U-bend at the bottom (Fig. 5-12).

Although you will find commercial systems installed with as little as 130 ft of borehole per ton, systems with a normalized length equal to or greater than 200 ft per ton of installed capacity account for 83 percent of the geothermal HVAC systems receiving an Energy Star designation above 90. Studies indicated that buildings with a normalized vertical bore length to floor area of between 0.4 and 0.6 ft/ft^2 accounted for 90 percent of those receiving an Energy Star designation. These figures must be carefully applied. Remember, these are *rationality checks*, not design criteria. Buildings with higher occupancy and higher internal heat gains may need much more cooling capacity than these figures indicate.

Building ventilation air rates significantly affect the thermal loads and energy efficiency of a building. Buildings with ventilation-air equipment allowing 20 ft^3/min per person or less frequently can attain an Energy Star designation. Buildings with ventilation-air capacity of 40 ft^3/min per person or less will have only a modest influence on building demand. For systems that require higher rates of building ventilation, careful design and diligent monitoring of operation and maintenance programs are necessary. Basically, do not overventilate zones that are not fully occupied. Although Chap. 12 addresses controls, it is important to note here that buildings that have individual controls for smaller zones or spaces account for 81 percent of those achieving an Energy Star designation.

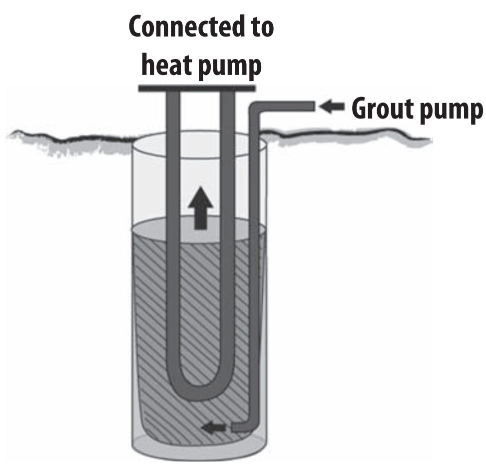


Figure 5-12 Borehole length × 2 = exchanger length.

5. Pumping Power for the Ground Loop

Dr. S. P. Kavanaugh states that geothermal systems with external pumping power of about 5 hp per 100 tons show the best efficiency. A maximum ground-loop pump power of 10 hp per 100 tons is suggested. The way to get to this figure is not always obvious. Modeling of the ground-source heat exchanger, a carefully controlled variable-frequency drive (VFD) or other control system, and a little patience and experience will get you there.

Often variable-speed pump drives are inoperable and save little energy. Please refer to Chap. 12 for further information on this subject. Measured differential loop temperatures indicate that most central loop pumps are significantly oversized, and variable-speed drives did not reduce flow at part of the load primarily because of bypassed controls and errors or omissions on the part of the programming.

Ground-Loop Guidelines

In conclusion, the following factors are a guideline, *not* design factors, for an efficient ground-source heat-pump system:

1. Exchanger pipe size (and header design): 1 to 1.25 in or greater
2. Borehole size (diameter): 4 in or greater
3. Borehole spacing: 20 ft or more
4. Length of borehole per ton or per square foot of building: 250 feet of borehole for each HVAC ton capacity or 0.4 ft^2 of building area per linear foot of borehole
5. Pumping power (ground loop, including header design): 5 to 10 hp per 100 tons

Of particular note: *Ground-source heat-pump buildings using a central one-pipe loop have performed well above average in studies*. Most of these buildings receive Energy Star designations. Central one-pipe-loop buildings offer significant energy-performance advantages over any other buildings noted. The sections and chapters in this book on hydronic design directly address these design issues and are included to provide the perfect combination of energy-efficient technologies.

Many studies have been performed on public schools. The authors of this book have found that public schools perform better in cooling-dominant situations than commercial buildings in general. Often a public school designed to the same criteria as a commercial building so far as the ground-source heat-pump ground loop is concerned show a significant advantage.

It has been suggested, and seems obvious, that schools generally do not have a heavy degree of summer traffic (summer vacation), significantly reducing the cooling load at a time when many commercial buildings suffer high incoming loop water temperatures. With the knowledge that a significant reduction in efficiency occurs above a loop temperature of 90°F, it stands to reason that considerable care should be taken in using closed-loop heat exchangers in hot and humid climates, where the earth temperatures are often in the range of 70°F and more. Keep in mind the standard International Standards Organization (ISO) rating is a 77°F entering-water temperature.

These guidelines provide a template by which you may compare your results after having used appropriate building-load calculations along with the appropriate loop design software.

Pipe Joining Method: Heat Fusion

The process of joining HDPE pipe is called *heat fusion*. Although this section will provide steps, pictures of incorrect joints, and other items, remember that this is a skill set that must be learned by hands-on experience and formal certification.

Again, there is one method of joining HDPE to HDPE: heat fusion. Unlike polyvinyl chloride (PVC) and some other plastics, solvents cannot be used to join HDPE. A characteristic of HDPE that makes it favorable for use as an in-earth heat exchanger is the abrasion resistance and nondegradable nature of the plastic.

The process of heat fusion is somewhat like metal welding in that the materials are joined at the molecular level but superior in that the process results in a permanent, monolithic fusion joint. HDPE pipe may be mechanically fastened to metal adapters for final connection to equipment, pumps, etc. This connection is heat-fused or compression-connected to a barbed connector much the same as a rubber garden hose is slipped over a barbed fitting and then held in place with a clamp. However, HDPE is much more rigid than rubber hose and should be heat-fused at the factory/manufacturing level or by a qualified technician.

HDPE has many different types of fittings, including reducers, 90-degree bends, bushings, saddles, etc. Figure 5-13 illustrates the heat fusion of HDPE pipe using either socket or butt fusion.

The butt fusion technique consists of heating the squared ends of two pipes, a pipe and a fitting, or two fittings by holding them against a heated plate, removing the plate when the proper melt is obtained, promptly bringing the ends together, and allowing the joint to cool while maintaining the appropriate applied force for the piping used. Surface preparation is of utmost importance here. A mechanical facing tool is used in this process (Fig. 5-14).

Saddle fusion is the technique used to apply a fitting to the outside of a contiguous length of HDPE pipe (Fig. 5-15). This technique involves melting the matching

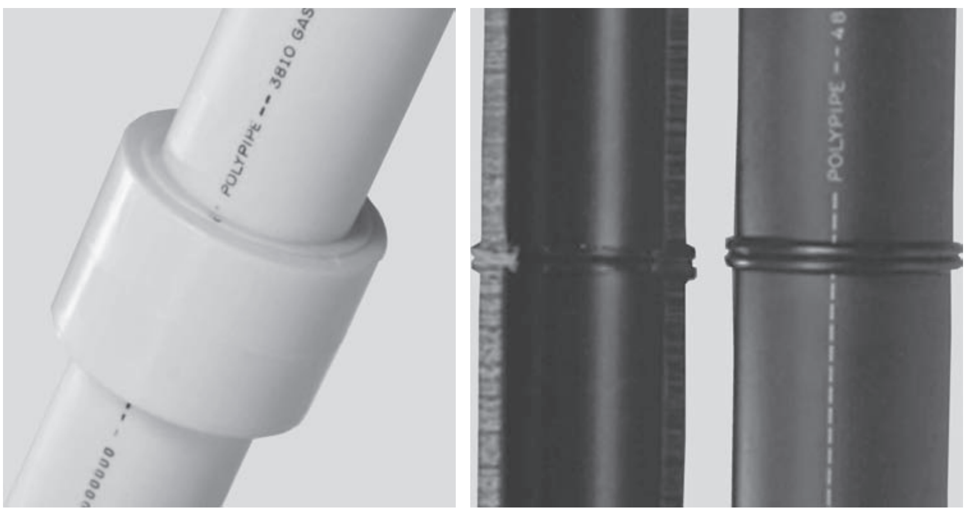


Figure 5-13 Heat fusion is the way to bond HDPE. The two processes of joining include butt fusion and socket fusion.

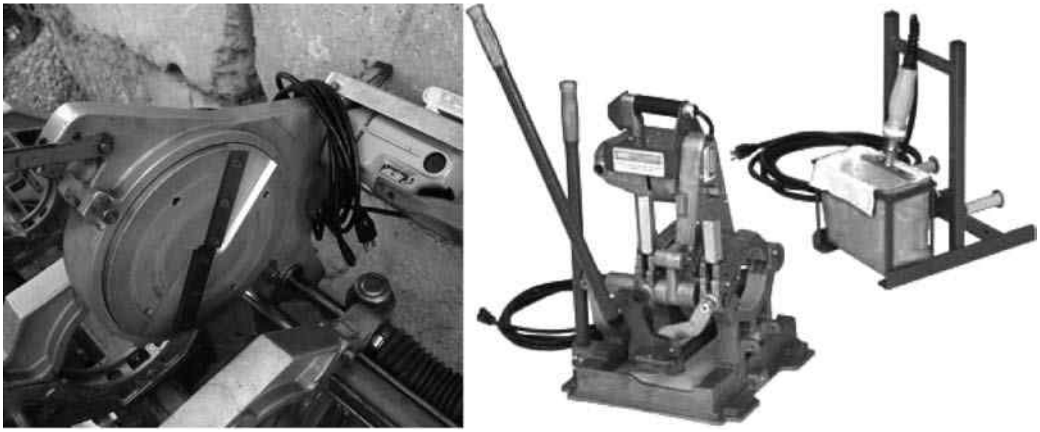


Figure 5-14 A mechanical facing tool prepares the ends to be joined by butt fusion.

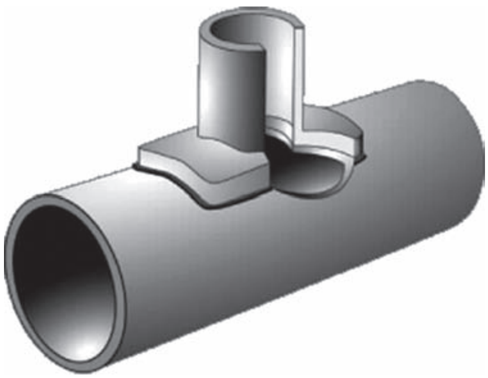


Figure 5-15 Saddle fusion involves attaching a fitting to the side of a contiguous length of pipe.

curved surface of the base of a saddle fusion fitting while at the same time melting a matching pattern on the surface of the pipe. The two melted surfaces are then brought together, and the joint is allowed to cool while maintaining the appropriate applied force. Once cooled, the passage to the fused pipe is drilled out. Usually, drilled fittings are visually marked.

The socket-fusion technique involves simultaneously heating the outside surface of the pipe and the inside of a socket fitting, which is sized to be smaller than the smallest outside diameter of the pipe. After the proper melt has been applied at each base to be mated, the two pieces are joined by inserting one component into the other. The fusion is formed at the intersection resulting from the interference fit. The melts from the two components are fused together as the joint cools.

There are many things to watch for during inclement weather when fusing HDPE pipe. In addition, HDPE has reduced impact resistance when subjected to subfreezing conditions. Additional care must be exercised while handling the pipe in cold weather.

Especially in windy conditions, the fusion operation should be shielded to avoid excess heat loss from wind chill. The heating tool also should be stored in an insulated container to prevent heat loss. All surfaces must be clean and dry when performing a fusion.

About 20 years ago, an industry trainer, Mr. C. R. Douthitt, told the lead author a story about a fusion piping crew that was experiencing failures in its fusion joints. The joints looked proper with regard to melt and penetration. The fitters seemed to be following correct procedures. But, for some reason, stress tests on the piping still revealed joints that were popping apart.

In this case, it was discovered that one of the crew members not involved in the fusion process had been using the fusion heating iron during lunch each day to warm his food. Much of the time, oil and other contaminants from the food inhibited the ability of the HDPE to form good fusion joints. When this was discovered, the guilty party maintained his innocence by showing how, with a nice dry napkin, he had polished the surface of the heating iron. As you might imagine, this did about as much good as seasoning a new frying pan, and just integrated the oils further into the nonstick surface (Fig. 5-16).

The authors recommend that you contact your preferred supplier of HDPE pipe if you wish to have further training on fusion techniques. This section will suffice for our purposes; it is important to understand the fusion process.

The authors would like to thank David Hoffman of Gipe Engineers for much of the input here. Mr. Hoffman is a professional engineer with extensive experience in closed-loop design. He, like much of the industry, thanks Dr. S. P. Kavanaugh for much of the engineering knowledge gained in the design of geothermal HVAC systems. With permission from Mr. Hoffman, we include a summarized excerpt of his letter to the lead author.

Figure 5-16 A fusion heating iron. The surface is coated with a nonstick Teflon material. Any oils or foreign debris will prevent a good fusion bond if present on the surface.

A Comment from a Geothermal Expert in Switzerland

Nicolas de Varreux, Director of Mack Drillers, has the following to say regarding closed-loop engineering:

> Here in Switzerland, it [closed-loop exchanger design engineering] matters so much that certain local government agencies have banned the use of glycol antifreeze in vertical loops. Temperatures in the loops never go below 5°C, even in the coldest part of winter.
>
> This decision was taken both to avoid soil contamination in case of leaks (even though we only use biodegradable glycol) and also to guarantee the use of the loop system for over 50 years. Because, as you know, if you keep taking more energy than the soil can give, you end up freezing the ground around your loop year-round, causing the system to stop working properly altogether.

Review Questions

1. In cold temperatures, care must be taken during the heat-fusion process for HDPE by
   a. sheltering the fusion iron from rain and wind.
   b. keeping the butt ends of the pipe warm to fusion.
   c. shielding electrical components from frozen condensation.
   d. driving the temperature of the fusion iron higher to compensate for the cold.
2. In sizing circulation pumps for geothermal HVAC systems, a good benchmark for maximum pump sizing is
   a. 5 to 10 hp per 100 tons of cooling capacity.
   b. 100 kW of power per 10 tons of cooling capacity.
   c. 220 ft of head for 10 tons of cooling capacity.
   d. 1 hp per 10 vertical ground loops.
3. The purpose of borehole spacing is to prevent thermal communication between the loops. A good guideline is to keep boreholes
   a. less than 300 ft deep.
   b. 15 ft apart one from another.
   c. 20 ft apart for a each ton of cooling capacity.
   d. 20 ft apart.
4. Degree-day data are used in conjunction with bin data to
   a. calculate the necessary ground-loop heat-exchanger capacity.
   b. calculate energy consumption.
   c. provide the number of cooling hours.
   d. provide all the above.
5. The three basic types of closed ground loops are called
   a. horizontal, vertical, and surface water.
   b. lake loop, Slinky, and two-pipe.
   c. standing column, vertical, and pond loop.
   d. opened reinjection, standing column, and closed loop.

6. The most common and effective type of closed ground loop is
   a. the Slinky ground loop.
   b. the surface-water ground loop.
   c. the vertical ground loop.
   d. the standing-column well.
7. The phenomenon in which rate of heat being rejected to the earth is higher than the earth's ability to dissipate is called
   a. thermal creep.
   b. thermal retention.
   c. load imbalance.
   d. all the above.
8. The different types of heat exchangers placed in water include
   a. evaporative fountains.
   b. convective loops.
   c. lake plate exchangers.
   d. all the above.
9. Geothermal HVAC surface-water closed-loop systems typically experience
   a. trouble-free operation.
   b. high seasonal temperature swings.
   c. potential hazards (e.g., boat traffic, fishing, etc.).
   d. all the above.
10. High-density polyethylene (HDPE) is by far the most common heat exchanger used for closed-loop geothermal applications today because of its
    a. high thermal conductivity.
    b. longevity and flexibility.
    c. laminar-flow characteristics.
    d. buoyancy.
11. Thermal conductivity testing of a borehole for a geothermal HVAC system provides the geothermal designer with
    a. the heat-absorption capacity of the earth and Btus/(h × ft × °F).
    b. the gallons per minute capacity of the column.
    c. the overburden above bedrock.
    d. the rejection capability of the piping in Btus/(h × ft × °F).
12. Grout/fill material has a profound influence on the performance of a vertical closed-loop exchanger
    a. because grout is the material through which the heat is transferred to the earth.
    b. because the quality of application results in voids.
    c. because the grout supports the piping in the borehole.
    d. because of all the above.
13. In a vertical borehole geothermal heat exchanger, a good rule of thumb is to expect calculations to result in
    a. 700 ft of pipe per ton.
    b. 250 ft of borehole per ton.
    c. at least 1000 ft of pipe per ton.
    d. 130 ft of borehole per ton.

CHAPTER 6

Plate-Frame Heat Exchanger: When Is It Needed?

It is commonly thought that a plate and frame heat exchanger or a brazed-plate heat exchanger is needed to protect water-to-refrigerant coaxial exchangers in geothermal heat pumps (GHPs) and similar equipment. This can be shown to be a fallacy much of the time.

Frequently, what causes a factory-mounted coaxial water-to-refrigerant heat exchanger to fail is electrolysis. It has become abundantly clear that the results of electrolysis have been mistaken for erosion and corrosion of factory-mounted heat exchangers over the past few decades.

There are several good reasons to install a plate and frame heat exchanger. However, installation of such an exchanger simply to protect a factory-mounted water-to-refrigerant coaxial heat exchanger without regard to the information contained herein is a mistake.

A plate-frame heat exchanger (PFHX) provides segregation between two different fluids used to transfer energy (Fig. 6-1). It can be a definite advantage or an unnecessary cost and complexity; and as with selecting a closed-loop, standing-column well, or open-to-reinjection GHP system, it depends on the demands of the application.

As a general rule, it is a good idea to specify a cupronickel exchanger in a geothermal heat pump if the determination is to use well water directly through the heat pump. When using a plate and frame exchanger, copper heat exchangers and heat pumps will be sufficient.

What Is a Plate-Frame Heat Exchanger?

Two basic types of FPHXs are common:

- Plate and frame heat exchanger (Fig. 6-2)
- Brazed-plate heat exchanger (Fig. 6-3)

Electrolysis versus Chemical/Abrasive Wear and Corrosion

A combination of erosion and electrolysis can lead to rapid deterioration of pipe or heat-exchanger integrity. Erosion of any pipe can be caused by high velocities through the pipe and typically occurs at minor obstructions such as a solder drip, a ding in the pipe, or even the union of a male-to-female solder joint. The presence of a single solder drip has been shown to increase a water velocity of 6 ft/s to a turbulent eddy of over 200 ft/s (Fig. 6-4).

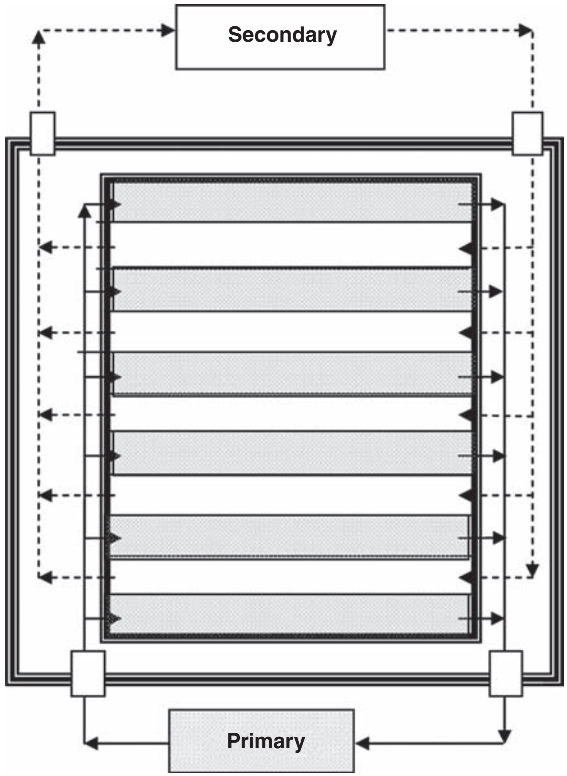


Figure 6-1 A flat-plate heat exchanger (FPHX) provides a primary and a secondary fluid loop. Each fluid is completely separated from the adjacent loop; The heat/energy exchange is made through a series of parallel thin metal plates. The PFHX is usually composed of a multiple stack of thin stainless-steel or titanium plates. Every other plate contains the opposing fluid loop, usually flowing in the opposite direction for maximum heat transfer. (*Water Energy Distributors*.)

Such a high a velocity will create a *velocity-erosion site*. Velocity erosion can go undetected for years, or it can be exacerbated by another demon—electrolysis.

Electrolysis Conditions

Electrolysis can occur in any water or conductive fluid and can cause a charge buildup at a sharp point (such as a lightening rod). If the charge concentration then passes from the metal edge into the water stream, it is possible that the sharp edge can become a *sacrificial anode*. Keep in mind that copper oxide is an electrical rectifier, so a direct-current (dc) component can essentially plate away that sharp edge. As the edge gets plated away, it creates a new sharp sacrificial anode surface, resulting in a self-degrading condition (Fig. 6-5).

Three conditions must exist for an electron seeking its ground potential and causing electrolytic corrosion. These conditions are not unique to GHPs but can occur in any installation with

- A high-resistance electrical ground
- Conductive water or fluid retuning to earth potential (i.e., ground)
- A 115-V device

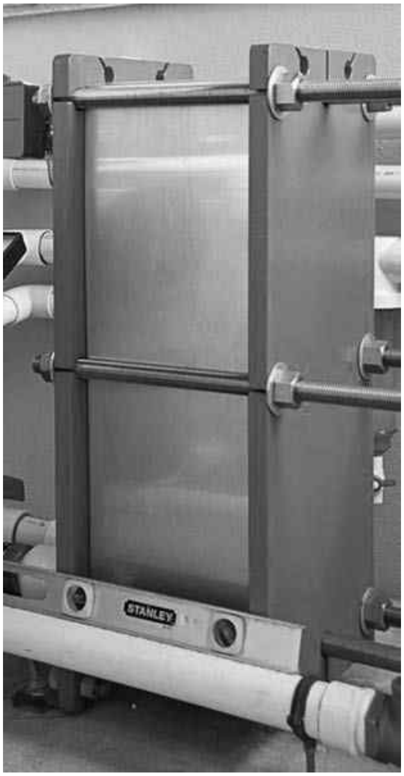


Figure 6-2 This configuration is common for large heat-exchange applications. Note that the plates are bonded by large pressure bolts. The integrity of the plates is ensured by either gaskets or a bonding glue between plates. Cleaning of these heat exchangers is possible (as discussed in the text). (*EggGeothermal*.)

Figure 6-3 Typical brazed-plate heat exchanger. A small and very compact size for heat exchange is one of the definitive advantage for this type of heat exchanger. This type of heat exchanger can be quite efficient when designed properly. Antifreeze and inhibited solutions and pure water with little or no minerals are common requirements. This type of heat exchanger cannot be easily cleaned mechanically. (*Water Energy Distributors*.)

High-resistance ground. The *National Electric Code* (*NEC*) requires (Sec. 250) a ground with a potential of less than 25 Ω. In the past, metal city or residential water piping provided that low-resistance electrical ground. Not so today with plastic piping, rubber (Fernco) couplings, and nonmetallic repairs.

Conductive water. Other than distilled water, water has some dissolved chemical compounds, and those that ionize in water provide an electrical path. Water conductivity is measured as micromhos per centimeter (μmho/cm), also known as a siemens. Sea water can be 30,000 to 50,000 μmho/cm, and natural well water is typically in the 100 to 600 μmho/cm range. We term water *brackish* at greater than 1000 to 2000 μmho/cm.

A 115-V device. A 115-V device such as a small pump, control, or like device derives its 115 V from one side of a 230-V line and a return to ground. If the return to ground

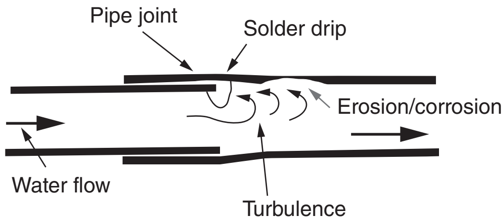


Figure 6-4 This figure shows how a solder drip can cause erosion/electrolysis in copper piping. (*Charles C. Roberts, Jr.*)

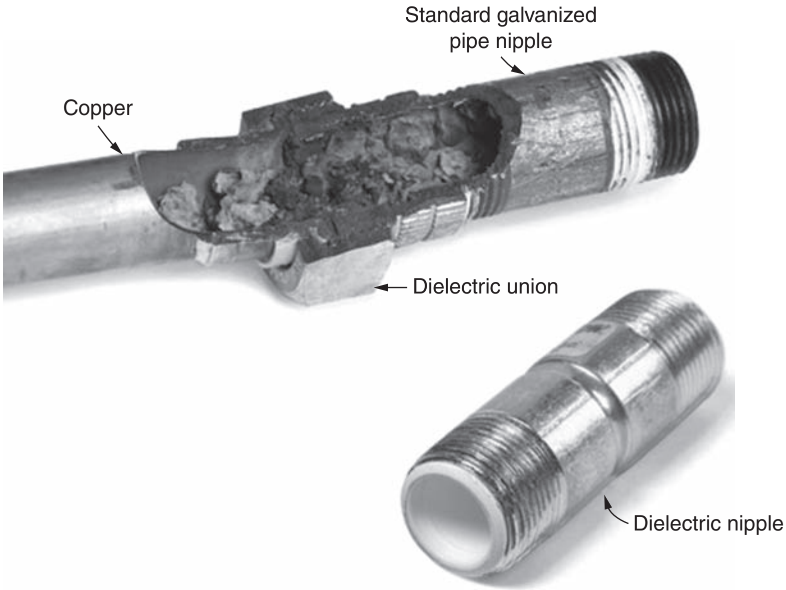


Figure 6-5 Electrolysis can occur even with measures such as dielectric unions. Much of the corrosion and deposits found in heat exchangers is the result of electrolysis rather than water quality. (*Family Handyman*.)

is of a lower resistance through water than the intended metal ground, the stage is set for electrolytic corrosion.

Check with the electrician who installed your dishwasher, clothes washer, or clothes dryer. He or she installed a fourth wire, an electrical ground, to ensure that the internal 115-V controls for those 230- clothes dryer devices did not have a lower-resistance path to ground.

No 115-V device should ever be used in any application, geothermal or otherwise, where there is the possibility of the neutral current being returned through the water-to-earth potential.

When Is a Plate Heat Exchanger Required?

While a PFHX separates well water or closed-loop antifreeze solutions, is it really needed? Often a case of "geojitters"—a lack of geothermal experience—creates a perceived need for all the design safety possible. The intent of an intermediate heat exchanger is to ensure separation of the natural well water or antifreeze solution from the GHP's heat exchanger and refrigeration circuit. Generalized design models often identify the use of plate heat exchangers to cover all global conditions. When one addresses these subjects, one must consider global contingencies that are out of the control of the designer and not generally addressed by generalized design models. This often adds unwarranted installation costs and results in reduced GHP efficiencies.

GHP manufacturers make their products available with copper-nickel heat exchangers, generally 709 Alloys. A 709 Alloy is 90 percent copper and 10 percent nickel with traces of chromium and iron additives. Copper-nickel alloy is used on ocean-going shipboard heat exchangers that use saltwater. Ships have been fabricated with copper-nickel hulls and have shown long lives.

Design Cost and Efficiency

When designing an FPHX, two very important factors must be considered because the two needs are diametrically opposed:

- What temperature differential from the primary to the second loop can be tolerated? Typical designs are from 3 to 10°F.
- What cost can the project tolerate? A 3°F approach temperature is significantly more costly than a 10°F approach temperature. The relationship is nonlinear and inverse.

A first consideration is the *approach temperature*, which is the temperature differential between the input of the FPHX primary loop and the output of the secondary loop. The approach temperature is selected by the designer as a tradeoff between efficiency and cost. A desirable 3°F approach carries a high price and occupies a lot of space, but it has a minimal impact on the temperature of the water entering the heat pump from a well or a closed loop. However, a 10°F approach could have to address the difference between 50°F well water and 40°F entering water into the heat pump, an attendant 8 to 12 percent decrease in efficiency.

Freezing Potential

Lower well or open-water design temperatures can have a significant risk. The difference between 40°F entering-water temperature and 32°F operating temperature with antifreeze solution is a loss of 15 to 23 percent efficiency in heat-pump operation. Without antifreeze, a thin plate surface can easily rupture. A ruptured plate(s), mixing refrigerant and water, will destroy the heat pump.

As an example, take a primary loop of 43°F earth-source water reduced by 10°F by the secondary antifreeze solution in heating mode. Eventually, the *water-side* heat exchanger will freeze as the antifreeze-loop temperature is depressed by cold-weather operation, whereas the *heat-pump* heat exchanger will not freeze the antifreeze solution in its secondary loop. The well water on the primary side of the heat exchanger *will freeze* and likely fracture the plate(s).

Cleaning

Both well water and antifreeze solutions can contain unwanted minerals, particulates, and/or biologic components that can create scale or biofouling of any heat exchanger (Fig. 6-6). A PFHX can be disassembled, cleaned, and reassembled, a relatively daunting task that may require assisted handling of the metal end plates and integrity of the thin exchange plates, and new gaskets and, if glued, solvents.

Of note, bacteria are killed by temperatures above 130°F. It is significant that all GHP heat exchangers have, when in the air-conditioning mode, refrigerant temperatures well above 130°F. Geothermal heat-pump heat exchangers are basically self-cleaning. Plate-frame heat exchangers are not self-cleaning.

Figure 6-6 Example of biofouling in a PFHX. An inadvertent injection of an iron bacteria (*Gallionella* and others) can allow bacteria to become established in a well-water system and to a lesser extent a closed-loop system. These bacteria are not harmful to humans but over a period of time (years) can occlude pipes. The bacteria can be controlled effectively by treatment by any competent well contractor or plumber. The iron bacteria should not be allowed to get established in any piping system, geothermal or otherwise. (*Water Energy Distributors*.)

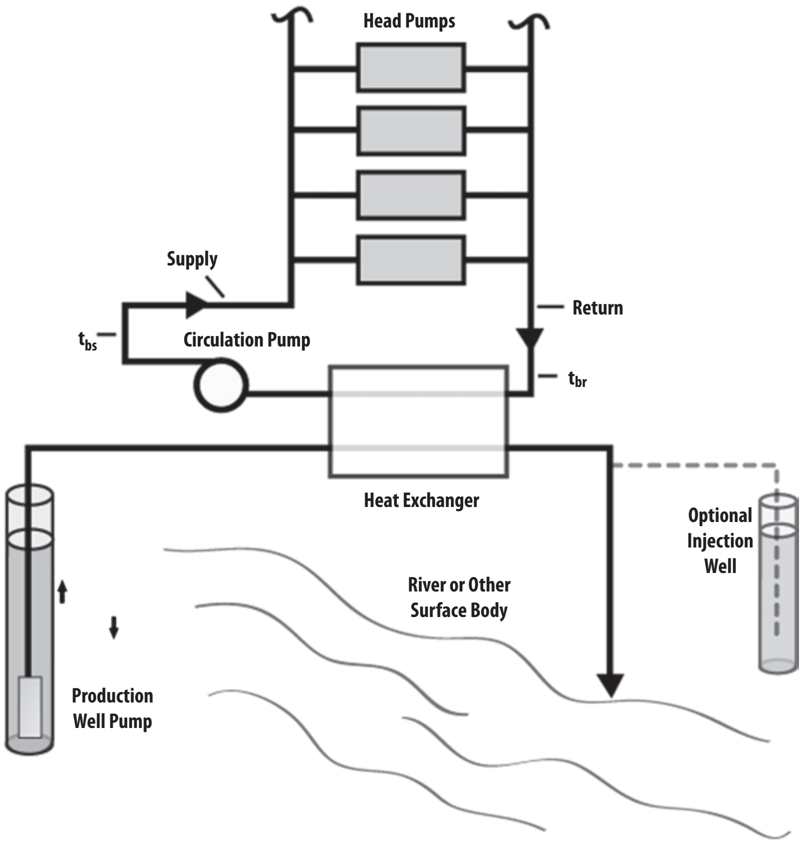


Figure 6-7 In high-rise buildings, a plate heat exchanger can effectively separate the pumping power of a submersible well pump from the high pumping power needed to lift water from the surface to the upper stories of the building. While a plate frame heat exchanger reduces the GHP winter and summer efficiencies by allowing greater variations in entering-water temperatures, the additional high-rise open-system pumping power savings can offset that efficiency loss. Modeling by Dr. Carl Johnson has shown that there is a breakeven point at approximately 10 stories. This is based on nominal heat-pump, plate heat-exchanger, and pumping efficiencies. (*Sarah Cheney*.)

Best Uses

There are at least three appropriate uses for PFHXs:

1. Separation of submersible well-pump power from a condenser water loop in high-rise buildings (Fig. 6-7)
2. Separation of the well-pump from the condenser water loop for thermal-advantage piping (load sharing/shifting) (Fig. 6-8)
3. Unusually abrasive, toxic, or objectionable geothermal sources, such as sewage or highly corrosive chemical fluids (Fig. 6-9)

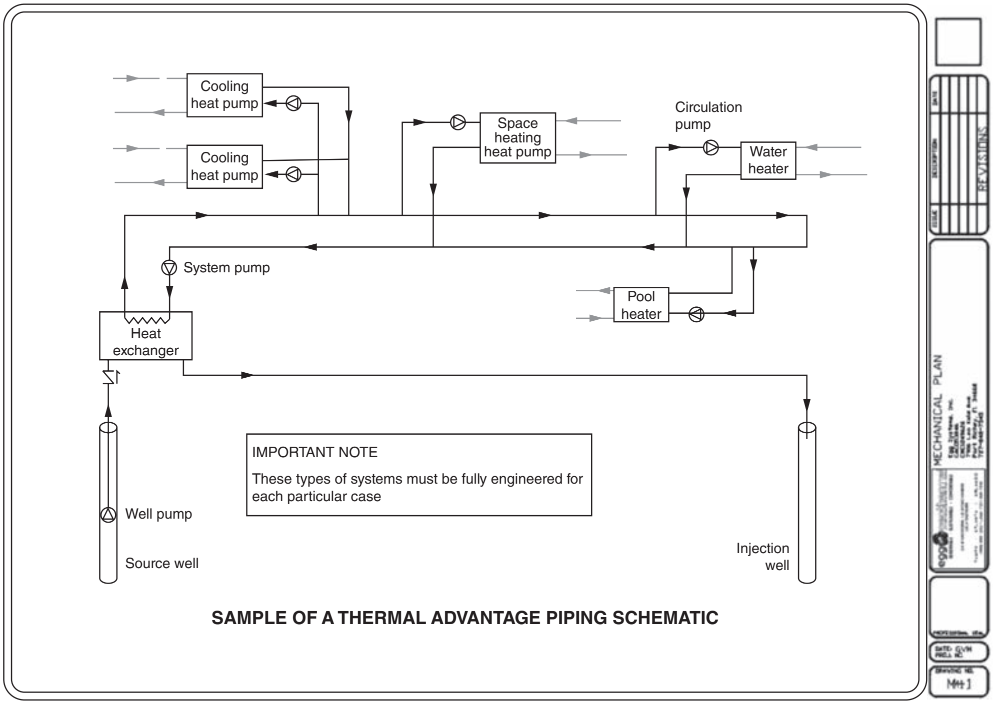


Figure 6-8 In thermal-advantage piping systems, there is an advantage to recirculating rejected condenser water into storage tanks or into large condenser water loops for use by other heat-pump equipment within the circuit. (*Guy Van Muellbrook*.)

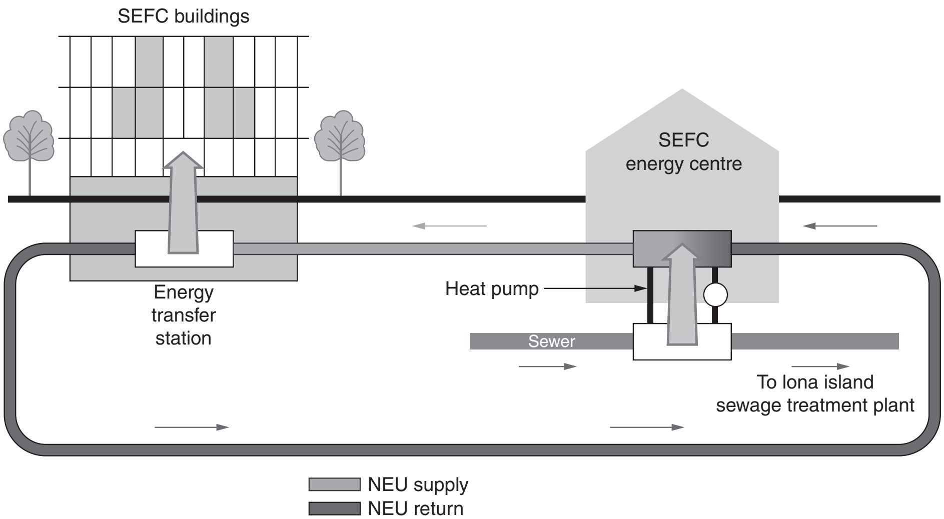


Figure 6-9 The use of sewage discharge as a geothermal heat source is becoming increasingly popular. In addition, there are many different possible scenarios for other heat reclamation from hazardous sources. (*SEFC*.)

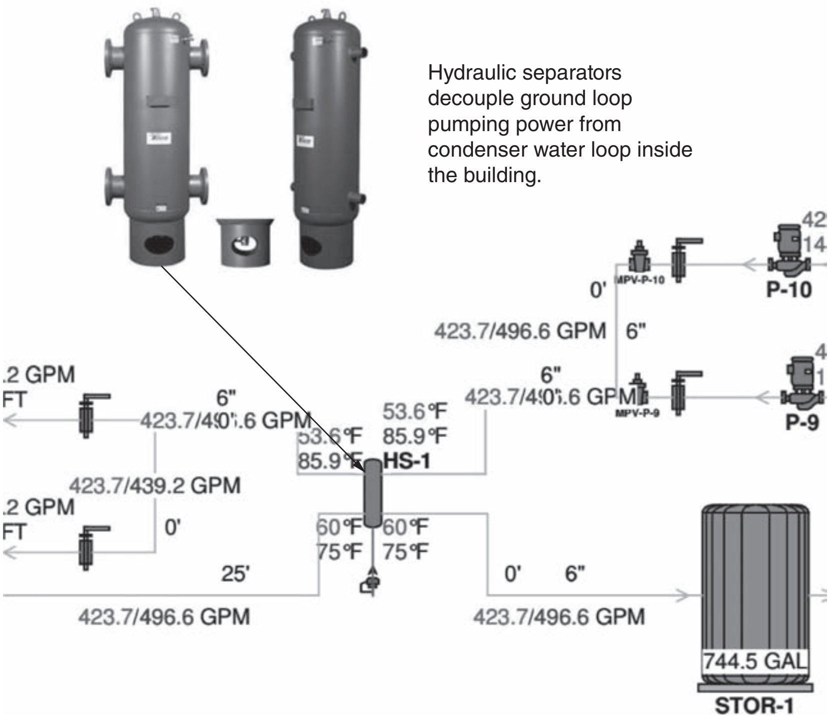


Figure 6-10 A hydraulic separator can be used in place of a heat exchanger in many situations. This is especially true when the designer wishes to separate geothermal ground-source pumping power from condenser water-loop pumping power. (*EggGeothermal*.)

Hydraulic Separators

A *hydraulic separator* acts as a dividing line for pumping power (Fig. 6-10). More will be said about hydraulic separators in Chap. 13. For now, it is important to understand that a hydraulic separator can be used to separate earth-coupled pumping power from the condenser water loop.

The performance of a hydraulic separator is much like the performance of a PFHX, except that the fluid is not separated by plates; thus there is no difference in temperature (approach) when both sets of pumps are in operation.

Review Questions

1. A hydraulic separator acts as a(n)
   a. vessel for thermal-advantage exchange.
   b. earth-coupled exchanger.
   c. shell and tube exchanger.
   d. dividing line for pumping power (decoupler).

2. A plate and frame heat exchanger is needed
   a. when electrolysis occurs between dissimilar metals.
   b. when segregation between two different fluids is desired.
   c. always to protect the equipment exchanger.
   d. to keep particulate matter out of the equipment.
3. Electrolysis can occur during which of the following condition(s)?
   a. At a sharp point in the fluid flow
   b. When the equipment is improperly grounded
   c. When the well casing is not bonded to the equipment
   d. All the above
4. Biologic fouling in a plate and frame heat exchanger is caused by
   a. temperatures below 130°F.
   b. introduction of lake water.
   c. lack of propylene glycol.
   d. ultraviolet radiation.
5. A 115-V device such as a small pump can cause electrolysis when
   a. the ground is used as a neutral.
   b. the pump derives its 115 V from one side of a 230-V line and returns to ground.
   c. it is plugged into a dedicated device under a 115-V convenience outlet.
   d. answers a and b

CHAPTER 7

Standing Column and Open Geothermal Systems

A standing-column well (SCW) is a collaboration of the best characteristics of an open- and a closed-loop earth-coupled geothermal heat pump (GHP) system. Those two methods represent the opposing extremes of earth-coupling methods employed by GHP system installations.

An open-well system has the advantages of the lowest first cost and the highest efficiency, but a large water yield from a surface- or groundwater well is often not possible. Even if it is possible, there may not be a reasonable way to get the water back into the environment. As installations become larger, the use of an open-well system may become less feasible because hundreds of gallons of yield and/or reinjection would be required.

A closed-loop system, either vertical or horizontal, represents the opposite end of the designer's options for a GHP system (Fig. 7-1). The closed loop can avoid some regulatory problems that may exist with groundwater that is contaminated, but a closed-loop system usually has the highest first cost. The closed loop is designed around Air-Conditioning and Refrigeration Institute (ARI) Standard 330/International Standards Organization (ISO) Standard 13256, with a winter entering-water temperature (EWT) with antifreeze of 32°F (0°C) and a high summer EWT of 77°F (25°C). Wide design temperatures result in lower efficiencies.

An SCW system provides the designer with a minimum of a 20 percent higher heat-pump efficiency and a smaller first cost than a closed-loop system. The SCW is slightly less efficient and has a higher first cost than an open system. When employed in areas with near-surface [~150 ft (40 m)] consolidated bedrock, an SCW has the advantage that its design can be unambiguous. What this means is that the designer can depend on the SCW to perform as good as or significantly better than either an open or a closed system design model. The cost of an SCW can often be accurately estimated and has a lower installation and operational costs when compared with a closed-loop Earth coupling system.

Where Does a Standing-Column Well Fit?

Figure 7-2 illustrates the lithology of the earth near Interstate I-95 in Virginia and reveals several opportunities and several restrictions. Although an open-loop GHP system is the most efficient and least costly to install, there really is no way to guarantee that there would be enough water flow in this Piedmont lithology. This means that either a

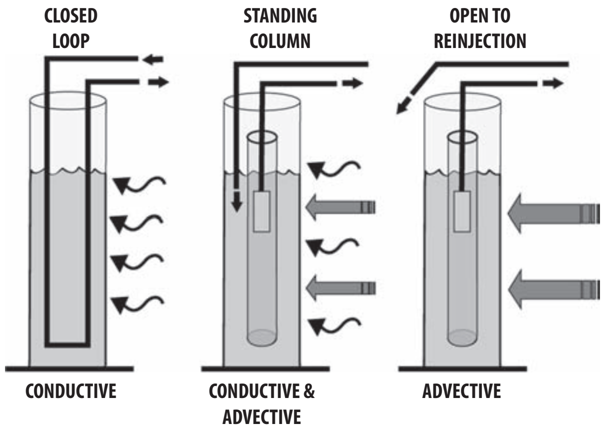


Figure 7-1 A standing-column well has some of the positive traits of both an open-well system and a closed-loop system. (*Sarah Cheney*.)

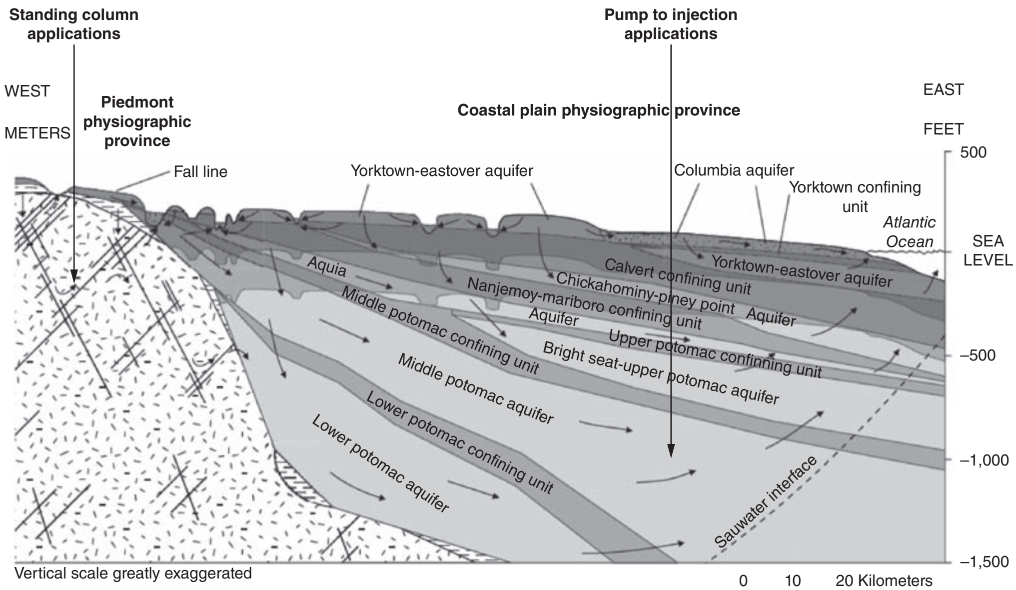


Figure 7-2 An open-loop system works in the coastal plain where water is plentiful, but not in the Piedmont, where water is found only in relatively small volumes in fractures of solid rock. A closed-loop system will work in both areas but is more expensive. An SCW system will work in both conditions and is less costly and more efficient than a closed-loop system.(*Virginia Water*.)

closed-loop or SCW system must be chosen for design. A SCW is both less costly to install and more efficient because of its use of more stable water temperature delivery to the GHPs. The SCW is best chosen for design as field observations during drilling of the first bore can point to conditions favorable to an open to reinjection or closed-loop system. In short, it is easier from move to a "center design" session to either extreme.

	Open Well(s)	Standing-Column Well	Closed Loop
Efficiency	1	2	3
First Cost	1	2	3
Geology	3	2	2
Maintenance	2	2	2
Regulatory	3	2-3	1
Thermal Stability	1	1	2

Note: On review of this matrix, it is obvious that there are advantages to each type of earth-coupling system. "1" is best or highest efficiency.
Source: Water Energy Distributors.

Table 7-1 Comparison Matrix for Geothermal Wells

In the coastal plain, water is plentiful. All three geothermal well types could work there, but in this case, an open-well system would be least costly and most efficient under most conditions. Note that in an SCW, a good base of rock with a modest amount of water in fractures provides the best installation scenario. Unconsolidated earth and the required casing of the well diminish the first cost effectiveness of an SCW.

A comparison of the three different methods is presented in Table 7-1.

Efficiency

As stated earlier, an open well with a constant temperature of 50°F (15°C) in northern tiers of the United States provides the highest efficiency and lowest first cost but is highly dependent on the geology of the site not only to provide a high volume of water but also to provide an adequate receptor for the large volumes of recycled water. Also, an SCW with a winter temperature of 42 to 45°F (6–7°C) and a summer temperature of 65°C (18°C) has a slightly lower efficiency. Closed-loop systems have the lowest comparative efficiencies. Still, all GHP systems are more cost efficient heating and cooling than fossil fuel-based systems.

First Cost

Typically, open wells are found in unconsolidated earth with highly permeable formations. These formations are generally near the surface, and the drilling of a short bore minimizes cost. A companion reinjection or diffusion well, if employed, is also comparatively inexpensive. SCWs are deeper and are employed only in rock formations. Contrary to intuition, a drilled well in unconsolidated earth is about twice as costly as a rock well. An unconsolidated-earth well requires a casing to maintain the integrity of the borehole; a rock bore hole does not require casing. Closed-loop systems in unconsolidated earth generally require two to three times deeper bore depths per British thermal unit (Btu) of heat transfer. The added cost of the high density polyethylene (HDPE) plastic pipe, more and shorter bores, liquid and air purging, and antifreeze solutions add to these closed loop costs. Shorter bores are required to allow ease of insertion of the HDPE pipe and avoid high pressure drops in the closed-loop piping. Perhaps the best use for closed-loop or no-bleed SCW geothermal piping is in smaller single-family homes with similar cooling and heating loads, which can take advantage of the thermal storage characteristics of the earth, and recognize a desired 250 foot minimum SCW bore depth.

Geology

An open well depends completely on the geology of the area, and without highly permeable soil or fractured rock, there is not enough water movement to provide reliable open-diffusion GHP operation. An SCW depends only on the existence of competent rock. Competent rock can be found near the surface in 60 to 65 percent of the continental United States. A closed-loop system is highly dependent on the amount of moisture in the soil and soil configuration and composition. Designed borehole length and resulting recirculation length can vary by a factor of 2 to 3 for the same heat-transfer capacity depending on the soil/earth configuration. In order to keep all large closed-loop designs within cost boundaries, larger projects often drill test bores. These test bores, further described in chapter 5, are then thermally evaluated to determine design factors before final designs are completed for the well field. Test bores for a SCW are designed and anticipated as the first SCW and test/first wells are not abandoned. The drilling of a test bore for a SCW may be used/anticipated as the first standing-column well to be drilled, and thus the cost associated with the test bore are not wasted.

Even under ideal geologic conditions, closed-loop systems require more land surface area than an SCW or an open earth-coupling system.

Maintenance

All three options should have periodic well/bore maintenance. Open and diffusion SCW systems must have flows and pump performance verified and be kept free of iron bacteria and other unwanted substances by annual assessment and remediation. Closed-loop systems should be checked periodically for pumping flow, fungi, iron bacteria, and acidification (loop pH) of the antifreeze solution.

Regulatory Issues

All three options must comply with varying federal, state, and local regulations. Open diffusing-well technology has been around longer and consequently is the most regulated typically. Although it is the most regulated of the three, the regulations are normally well established, and *thermal exchange wells* are defined as "a system composed of basic conventional water well and an injection well waters withdrawn, used for thermal exchange, and then returned to the same permeable zone from which they were removed."

As an example, a 2600 gal/min thermal exchange well permit was pulled by a developer in Florida on the Pinellas County Emergency Operations Center for its geothermal chiller. The total cost of the permit was $25 because the design involved a well-established technology. It is not uncommon for well drillers and even the water authorities themselves to be unaware of these statutes.

Large open-well systems likely will require discharge/diversion permits. Because the U.S. Environmental Protection Agency (EPA) regulations consider geothermal to be "beneficial," the granting of permits has not been draconian.

Standing-column wells are regulated by the same discharge/diversion requirements but at a significantly lower level because the overflow rates are about 10 times less, on average, and are our periodic, not continuous. SCWs are also considered to be regulated under Class V underground injection criteria (UIC), Type 5A6 or 5A7, depending on depth—the water being reinjected into the same bore must meet primary federal drinking quality standards. Salinity and dissolved solids are tolerated to relatively high levels. Fecal coliform bacteria and other defined primary health risks are not tolerated at any level.

Because closed-loop systems are relatively new, they are often less regulated. Some states require there to be a closure plan, by which the owner of a closed-loop system submits a plan to fill the loops with bentonite should the field be abandoned or fail. Some local agencies have registered concern over the amount of nonbiodegradable plastic inserted into the earth and the health effects of antifreeze solutions. Other states have decided that closed-loop systems are "polluters" because they change earth temperatures. In addition, in direct-exchange systems that use refrigerants flowing directly through the closed ground loop, typically corrosion in the copper pipe poses an additional obstacle to direct expansion closed-loop technology.

Thermal Stability

Both SCWs and open diffusion wells have the additional advantage of advective heat transfer. Advective heat transfer actually moves the stable earth temperature/energy from a distance away as groundwater is forced to move to the well bore by water withdrawal. The advective heat transfer can compensate for January or August weather conditions in excess of projected federal or state guidelines. Buildings that do not fully meet insulation or infiltration design specifications benefit from the periodic and automatic advective heat transfer to compensate. Because closed-loop heat transfer depends solely on conductive heat transfer, there is little that can be done to compensate for design shortfalls. Compensation by added heating or cooling loads will dictate the addition of closed loops or supplement heating or cooling devices. Fossil fuel-based or electric supplemental energy source or sink devices are typically less efficient than a GHP (Figs. 7-3 and 7-4).

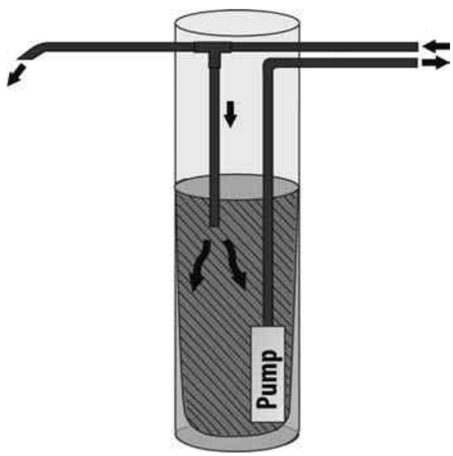


Figure 7-3 Water from the bottom of a deep bore is circulated to a GHP and returned to the top of the bore. In this manner, heat transfer occurs by three mechanisms: conductive, advective, and convective heat flow. (*Sarah Cheney*.)

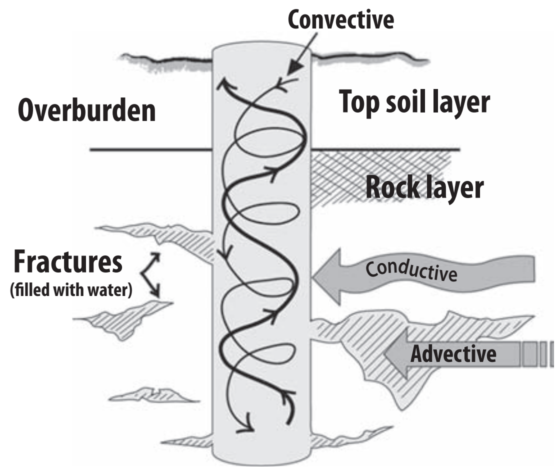


FIGURE 7-4 Heat transfer in an SCW takes advantage of conduction, convection, and advective heat transfer. (*Sarah Cheney*.)

Design of conductive heat transfer in the earth is well established and well modeled. Conductive heat transfer is the primary basis for SCW. The most popular method is based on the Kelvin line theorem (Kemler, E. N., *Heat Pump Applications*. New York: McGraw-Hill, 1958) and is mathematically identical to the math for a closed-loop installation. The Kelvin line theorem is the basis for all closed-loop conductive heat-transfer modeling for an SCW. It involves making the thermal resistance of the closed-loop pipe zero because that heat-exchange surface does not exist in an SCW. The Kelvin line theorem considers the factors listed in Table 7-2.

Advective heat transfer is effective and is the least-modeled method for heat transfer in or out of a geothermal bore. In its simplest form, the open well is 100 percent advective flow; the energy physically moves with the water. Removing water from the bore creates a flow of "fresh" water into the bore. That fresh water is at the same temperature as the far-field groundwater. By bringing even small amounts of water into the bore from the far field, the bore temperature can be increased dramatically in winter and decreased in summer. Temperatures of the bore rock and water can change by 4 to 6°F for a residential applications within 30 to 45 minutes. A commercial SCW will show a change in 45 to 60+ minutes—both examples varying with bore depth and pumping rate.

■ Thermal Conductivity
■ Thermal Diffusivity
■ Soil/Rock Density
■ Heat Exchange Surface Area
■ Approach Temperature

Source: Water Energy Distributors.

TABLE 7-2 Conductive Heat-Transfer Factors

The advective flow for an SCW is designed as a percentage of the total pumped flow based on 3 gal/min/ton of calculated load. Without pump testing, detailed geologic evaluation, or other more definitive information, the SCW is usually designed around an assumed flow that will allow a 10 percent advective exchange from the SCW. It must be noted that advective flow rates up to 30 percent bleed can greatly reduce SCW bore depth and size by as much as 55 to 65 percent. When an SCW is designed, bleed rates over 30 percent become less and less thermally beneficial for wells drilled to conductive depths. Advective flow is identified and then specified by the SCW designer after the actual first bore information is available. The preceding conductive and convective heat-transfer characteristics do not mandate verification. Advective flows and the resulting drawdown of the static water levels do require verification.

Convective heat transfer credits the SCW bore with heat transfer induced by warm water rising and colder water falling in the bore. Convective heat transfer is presently considered a performance bonus and is not usually computed. Studies at Oklahoma State University (Dr. J. Spitler et al. in ASHRAE RP-1119 R&D STUDIES APPLIED TO STANDING-COLUMN WELL DESIGN

ASHRAE 1119-RP, FINAL REPORT, July 2002
Jeffrey Spitler
Simon Rees
Zheng Deng
Andrew Chaisson
Oklahoma State University
School of Mechanical and Aerospace Engineering
Carl D. Orio
Carl N. Johnson
Water and Energy Systems Corporation

have indicated that the natural convection in a bore can contribute to an effective pumping that creates a beneficial advective effect.

The least complex SCW design is that employed for a residential application, depicted in Fig. 7-5. The residential SCW places a submersible well pump at the bottom of the bore and simply uses the surface of the rock bore for heat transfer to provide the three heat-transfer mechanisms. Note the use of the same bore for domestic purposes. This dual-use SCW method greatly reduces the cost of the earth coupling, and every ensuing day enhances the advective heat-transfer benefit for the domestics use. Careful selection of the piping material, construction methods, and design make the dual-use SCW practical and economical. Dual-use SCWs will be carefully examined by local health officials; having heat pump heat-exchanger Material Safety Data Sheets (MSDSs) and water-quality results available can speed up an official review.

Water Energy Distributor's 8,000-ft^2 building, in Hampstead, NH, using 16 tons for full heating and cooling requirements, employs a single 1100-ft SCW with no bleed. Daily domestic use of the well water provides an adequate bleed effect.

The 500-ft residential limit for well pump depth is a relatively arbitrary number. Below 500 ft and for larger commercial projects, it is advantageous, as shown in Fig. 7-6, to use a suction-line extension for the submersible pump. This tail pipe, also known as a *Porter shroud*, allows the installer to keep the pump near the top for ease of service and reduces the cost and size of the riser pipe and submersible power cable.

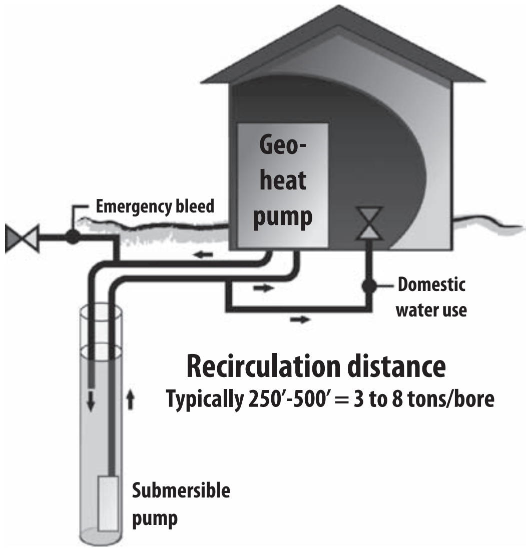


FIGURE 7-5 The residential SCW design is the least complex of all standing-column designs. (*Sarah Cheney*.)

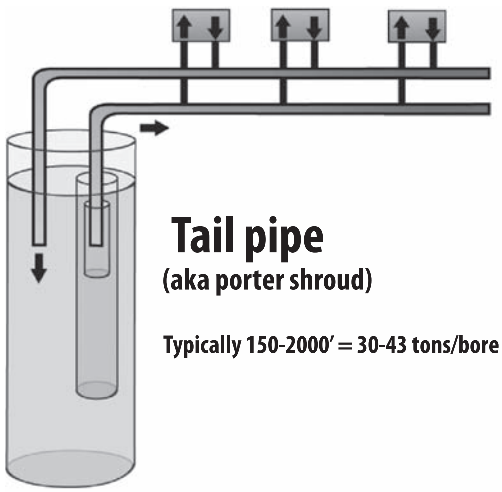


FIGURE 7-6 Large thermal loads require different SCW, as shown here with the use of a Porter shroud. (*Sarah Cheney*.)

As building loads become larger and larger, the bore must provide a greater surface area, and consequently, depth or bore diameter must be increased. In such situations, the submersible pump is located near the top of the bore, and the designer can depend on the more stable and slightly warmer water temperatures located at the bottom of the deep bore. The designer can expect ¼ to ¾°F for every 100 ft below 500 ft that the SCW goes.

The installer can depend on a shorter riser pipe, a shorter and smaller electrical cable, and ease of pump service (should service be required) with location of the pump near the top of the well. Reynolds number adjustments in the annulus can be increased above 2500 (turbulent flow) and achieved by variations in the bore-to-shroud ratio. Keep in mind that for the round trip from annulus to shroud to pump on the suction side of the pump, the pressure drop should not to exceed about a practical 20 ft at most.

The question is raised as to how large a bore might be beneficial. Larger diameters are not significantly better because the flow likely will become laminar (low Reynolds number). For anything definitive in a well diameter about 8 in, a competent engineer should run the Kelvin line theorem and give significant consideration to a point of diminishing returns.

As an example, going from a 6- to an 8-in bore diameter gives only about 15 to 25 percent enhanced heat transfer. A "commodity" SCWs has been 1500-ft depth with a 10 percent bleed because an , 8–6–4 (8″ casing, 6″ bore, 4″ shroud) SCW in medium- to high-density rock [thermal conductivity ≈ 1.4 Btu/(h · ft · °F)] can develop approximately 30 to 33 tons of heat exchange.

Designing a Standing-Column Well

Full building loads must drive all geothermal earth-coupling designs. The building side of the heat, the *inside*, either draws (winter) or sinks (summer) heat from or to the earth, called the *outside*. The terms *inside* and *outside* were coined by the ISO Standard 13256. They were chosen to eliminate the vestigial air-conditioner terms *condenser* and *evaporator*. The outside in the air-conditioning mode is appropriately the condenser. However, in winter-heating mode, it becomes the evaporator, a source of much past confusion. The connected heat-pump load is merely an energy-transfer device from the earth to the building. It must be noted that a cooling load on a Btu basis is a higher energy transfer than a heating Btu. The cooling load from a building additionally contains and must transfer the electrical motivational power (e.g., compressor and blower/pump power) to the earth. For a heating load, these electrical power factors are additive and reduce the energy-transfer requirement from the earth. Table 7-3 provides a logical series of first steps for a residential SCW design.

Competent bedrock provides the earth designer with a well that does not require casing. The cost of well casing is typically the same as the cost of drilling. A competent rock well does not require casing and consequently is about one-half the cost of a cased or screened earthen well. Finding deep overburden (earth) usually dictates the design of an open- or closed-loop earth coupling. Survey of the near-surface bedrock in the United States (*Geothermal Resource Council Transactions* 18, 1994) indicates that

● Competent bedrock within approximately 150-200 feet
● Rigid, Written & Accurate Loads
● Preliminary Design Specifications & Drawing (Bid)
● Monitor Test Well Information
● Final Specifications (Construction)

Table 7-3 Standing-Column Well Design Sequence

Residential	
Manual-J[3]	ACCA Wright Soft Corp
Commercial—Small	
Manual—N	ACCA Wright Soft Corp
Commercial—Large	
ASHRAE	F-17, 2009
DOE 2	US Department of Energy
Trace	Trane
HAP	Carrier
Enhanced EQuest	ClimateMaster

Source: Water Energy Distributors.

Table 7-4 Typical Load Programs

approximately 60 to 70 percent of the United States can cost-effectively employ the SCW earth-coupling method.

Determination of formal loads, both heating and cooling, is a *must* before any SCW or closed-loop or open-system design can be finalized. Estimated heating and cooling loads based on rules of thumb or other "guess" methods is unacceptable. Methods derived from American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) fundamentals must be employed. Table 7-4 lists several programs that have been employed successfully.

Designers of complete SCW systems must recognize heating and cooling loads *and* well-water flow requirements for the heat pump(s). Additionally, use of the geothermal well for domestic, irrigation, and other water needs must be considered. While many manufacturers offer GHP water flows as low as 1.5 gal/min per ton of connected load, the authors recommend designing around 3 gal/min per ton. For example, loss of 20 percent water flow due to installation vagaries would render a 1 gal/min per ton heat pump inoperative; a 3 gal/min per ton design would lose only 2 to 4 percent of its capacity!

Commercial loads requiring more than one SCW with a resulting in rectangular or large array well field with wells that may interfere with each other thermally must be analyzed on a month-by-month basis. Both total monthly loads and heating and cooling loads and peaks by month are required to use available analysis software effectively. Table 7-5 provides a logical series of first steps for a commercial SCW design.

The SCW designer must coordinate with the building heat-pump designer to determine the heating, ventilation, and air-conditioning (HVAC) designer's connected loads and load-factor profiles. Although the connected loads will not directly affect the SCW heat-transfer design, such loads must be defined to determine well-water pumping rates and consequent pump size and location within the bore. A prudent design flow rate is based on 3 gal/min per ton. Commercial loads often have an oversized connected load and a consequent pumping rate that is higher than the actual building heating or cooling load. The connected load must be specified to define required pumping rates and total dynamic pumping heads.

Earth Coupling Design Menu
Feasibility
Preliminary Requirements
Design Concept
Geology
Estimated Costs
Design
Rigid Design Requirements
Well Design & Specifications
Heat Pump Selections
System Schematic, No Inside Layouts (for MEP)
Outside Layouts
Installation
Sub Contractor Advice
Submittals, RFI's, Change Orders
Heat Pump Interfaces/controls
Operational Sequences & System Level Schematic
Punch List
Commissioning
Assist & Verify Operational Sequence
Distributor-Manufacturer Technical Interface
Assist Startup Documents

Source: Water Energy Distributors.

Table 7-5 Typical Steps in an SCW Commercial Design

Preliminary design specifications for either residential or commercial SCWs must specify and typically "schedule" the number, diameters, depth, and anticipated yields of wells. Additionally, the specification must address the possibility of very high flow rates, regulatory requirements, and the designation of the first well of a commercial multiwell field as the test well. Building load and connected loads provide the SCW designer with anticipated conductive heat-transfer design requirements, bleed requirements, and pumping requirements.

One question in determining the need for a bleed receptor is typically, "Where does your roof and driveway runoff go?" Another question might be, "What if it does not rain when bleed is necessary (e.g., very cold weather or summer cooling rain)?" The magnitude of the typical 10 percent bleed is about equivalent to site runoff on an annual basis.

The first (test) well verifies or modifies the geologic information researched by the designer. Large projects (e.g., 500 to 1000 tons) may require a test well before the final well contract is awarded. The SCW designer must be provided with rock types, depths of formation changes, depths of yields, and ambient static levels. Designs greater than 1000 tons demand a more distributed field and require more than one test well.

GLPRO 3.0	Oklahoma State University
Closed-Loop simulation	University of Alabama
Equest-GeoEnhanced	ClimateMaster

Source: Water Energy Distributors.

Table 7-6 Typical Thermal Pattern Evaluation Program

In all applications, the designer must specify the required bleed (periodic overflow), final well depth, and pumping rate for the well. High bleed (overflow) rates can reduce the depth and number of SCW bore holes by as much as a factor of 0.55 to 0.65, nearly a two-thirds reduction in *water recirculation distance*, which is defined as the distance between the submersible well pump and the end of the return drop pipe. The importance of timely assessment of the first borehole's characteristics can save a project substantial construction costs. The availability of a high bleed rate and its usefulness must be tempered by the availability of a responsible receptor for a higher flow and incident bleed rate. Design of a periodic 10 percent bleed typically results in periodic advective flow during the high peak period in January or midsummer. A 30 percent bleed may be translated into bleed in December, January, February, and March; the high bleed rates can result in a shortened bore or fewer SCWs. For example, a project in Hartford, CT, had planned for three 1500-ft boreholes with 10 percent bleed. Very high water yields from the first well allowed the design to be reduced to three 520-ft SCWs with 30 percent bleed. The 30 percent bleed was accepted as "cleansing water" in the city storm drains that inhibited the formation of debris dams.

In general, a linear array of SCWs with ideal spacing of 75 ft (20 m) or as close as 50 ft (15 m) requires no evaluation of interference between wells. The interference between multiple SCWs in a large field array must be evaluated. Programs to determine well-to-well interference patterns are listed in Table 7-6. Linear arrays in a well field have little effect on well-to-well thermal interference, but a well field with wells surrounding wells must be evaluated. This is true of an SCW field and even more of a closed-loop well field.

All three programs have been designed for an array of closed-loop boreholes. The *GLEPRO* program can best simulate an SCW and provide an assessment of the bleed effect. *GLEPRO* and *EQuest+* allow the input of a zero resistance or infinite conductance for a closed-loop pipe (which makes the thermal resistance of the closed- loop pipe disappear). Varying bleed rates create a varying virtual change in the thermal conductivity of a borehole. Both programs have the ability to change the thermal conductivity to levels associated with the designed bleed rate. Increasing the bleed rate can greatly increase the thermal conductivity coefficient, as defined in these models.

Standing-Column Wells in the Field

The geothermal market is growing. The evaluation for prequalification of well contractors who can successfully complete and understand a *total* geothermal system becomes a mandatory requirement (Fig. 7-7). Capacity of the drilling equipment and ability and

Figure 7-7 The evaluation of an SCW or open-to-reinjection well contractor is important. (*Water Energy Distributors*.)

geothermal knowledge of the driller must be critically evaluated. As discussed previously, using a comprehensive drilling specification has marked advantages.

- Capability of the rig
  - Pullback
  - Air compressor
- Capability of driller
  - Deep-bore experience
- Bore rods
  - Owns 1500 ft
- Handling of water
  - Temporary runoff

The capacity of the well rig must take into consideration the ability of the rig to lift a long train of well rods, say, 1500 to 2000 ft. Often a rig with a lower pullback or lift can compensate with the use of aluminum well rods—an expensive but valid compensation.

A typical commercial SCW can deliver 30 to 40 tons of earth coupling. An often overlooked question is, "Does the driller have 1500 ft of drill rod?" The average well rig will only have 700 ft of rod in its service magazine; this implies that the driller has a second truck with additional rods. Is this part of the driller's equipment inventory?

■ Stop Drilling, shorten the well specification, establish a higher bleed rate. (if allowed and permitted by contract)
■ Bring on-site a second compressor in series
■ Have an experienced driller that can “stay ahead” of the large water flow by various other methods
■ Drill continuously around the clock

Source: Water Energy Distributors.

TABLE 7-7 Very High Well Yield Construction Options

The typical well rig has an on-board 350-lb/in^2 air compressor. Various compressors provide volumes of air from typically 1200 to 1400 ft^3/min. The compressor pushes high-pressure air into the bottom of the bore via the hollow well rods. This air lifts water and drilling spoils up and out of the bore. Should the well yield high water flows, more and more of the compressor energy is employed to lift and stay ahead of the large mass of water. By physical laws; a 350-lb/in^2 compressor can only lift 808 ft (250 m) of water column. Table 7-7 lists the options available to a well contractor operating in high-yield bores.

A high-production well with a responsible method to return high-bleed-water rates to the earth can provide a significant cost reduction. The possibility of high bleed rates must be coordinated immediately with the project’s civil engineer. The civil engineer must determine where additional water is to be placed and whether any temporary or final regulatory requirements require revision in areas where high-yield wells are noted, the civil engineer should be notified to anticipate possible need for high bleed rates.

Temporary water discharge and spoils from a typical SCW make use of a temporary water/spoils pit. The pit is large enough to contain approximately 2 hours of water overflow. However, if the good fortune of a high-production well is encountered, the drilling spoils will not increase, but temporary drilling-water flows will be significantly larger.

Rural drilling typically will handle the high temporary flow rates and return of the water to the earth via temporary surface runoff or local surface bodies of water. Drilling in urban areas may require temporary discharge permits and/or other local permit requirements. Temporary discharge permits are not draconian but may require 1 to 2 weeks to be processed. In areas with or a history of high groundwater yields, the design specifications must include requirements to prepare for a temporary discharge permit application. This is also true of closed loop and open to recycle in Earth coupling. In areas where high water yield is encountered unexpectedly, regulatory agencies normally have an emergency exclusion permit. This permit is usually processed in hours and has sampling and other requirements similar to the temporary discharge permit process but is allowed for a shorter period of time (e.g., weeks rather than months).

During the drilling process, water and rock-cutting samples should be taken (Fig. 7-8). Rock samples are usually 3 to 4 oz (100–125 g) placed into small sealed plastic or fiber bags. Each bag is marked with the depth at which the sample was taken and any other appropriate information. Unless otherwise specified, the samples are to be taken at one-third and two-thirds depth and the bottom of the borehole and whenever changes in geologic formations are encountered. This is a requirement for large commercial projects and is included in the drilling bid specification.

Figure 7-8 The well driller will sample rock cuttings during the process of drilling. (*Water Energy Distributors*.)

Rock samples are analyzed to verify the geologist's initial estimates. In addition, rock samples have their density measured by simple displacement methods. Rock density and type are employed to verify the design conductivity and diffusivity coefficients [(IGSHPA) International Ground Source Heat Pump Association]. Typical rock densities fall between 150 and 200 lb/ft^3 (2,400–3,200 kg/m^3).

Water samples normally are taken after the well has been *developed*. A developed well has been pumped until the water is cleared of all discernible solids, color, and other suspended material. Water samples must be submitted to a state/federal water laboratory for an evaluation to primary federal drinking quality standards. These standards are relatively wide ranging, with relationships to aesthetics such as color, dissolved solids, and salts. The standards do not allow any primary health risks such as fecal coliform bacteria. The designer and owner should anticipate finding no fecal coliform in a well that has been sealed properly from surface water by a casing and has been drilled by a well crew that maintains clean tools and hands.

Well casing (Fig. 7-9) is used to segregate the surface waters from the pristine deep groundwaters. The casing also serves as a convenient method to support a pitless adapter used to hang a submersible well pump and return drop pipe.

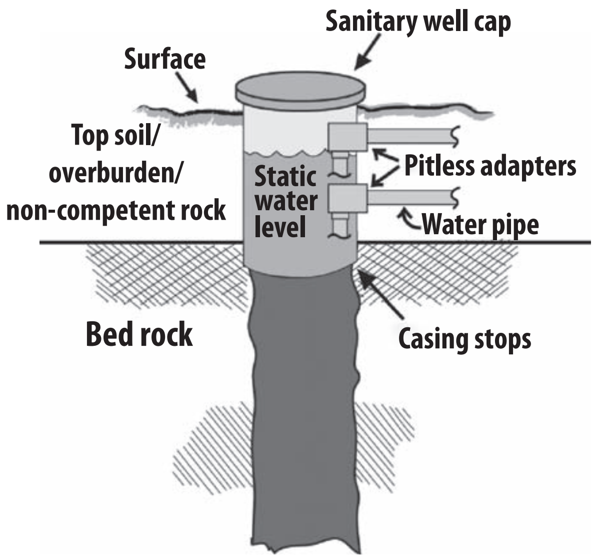


Figure 7-9 Typical casing configurations vary depending on the application. Thicker casing is used for commercial applications, whereas thinner (19 lb/ft) casing can be used in residential applications. (*Sarah Cheney.*)

The casing is steel at varying weights specified as pounds per linear foot. Residential and small- to medium-size commercial wells are designed around a 6-in rock bore and an 8-in casing. Small systems can tolerate casing at 19 lb/ft (~30 kg/m), and larger commercial systems can tolerate casing at 26 lb/ft (4 kg/m). In applications with water that has a high electrical conductivity, as defined by conductivities above 3,000 to 5,000 µmho/cm (siemens), PVC-80 casing is often employed. When polyvinyl chloride (PVC) casing is used, frequently with brackish or salty waters, a separate electrical ground must be installed into the water table. Seawater can have a conductivity of 30,000 to 50,000 µmho/cm. In all applications, the casing or the ground is the ideal electrical ground for the building and can provide added protection from electrolysis (see Fig. 7-15).

An inner sleeve, known as a *Porter shroud*, is inserted into deeper SCWs. The sleeve is typically 4-in PVC. A nominal 4-in submersible well pump is 3-5/8 in in diameter and fits into the Porter shroud. This configuration ensures a high water flow past the well pump motor with attendant water-cooling and lubrication. This most common configuration is known as an *8-6-4 SCW*—an 8-in (20-cm) casing and/or a borehole to below the maximum static water drawdown, a 6-in (15-cm) rock bore below that level to the bottom of the borehole, and a 4-in (10-cm) Porter shroud.

An SCW with pump rates higher than 100 to 120 gal/min (35–45 tons) and high lift requirements may require a larger-diameter pump and a consequent larger-diameter shroud and well—with attendant higher construction costs. Larger commercial wells may be configured as 10-8-6 or even 12-8-6.

The Porter shroud, as discussed earlier, provides a means to use deep temperature-stable and slightly warmer water from the bottom of the borehole without requiring the pump to be set at the bottom avoiding the cost of a 1500-ft riser pipe and long and

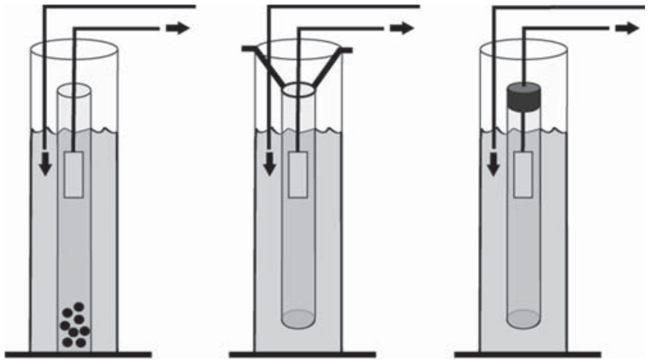


FIGURE 7-10 A Porter shroud, in which the well pump is installed to facilitate the draw of water from the bottom of the well, can be supported in any of the three ways. (*Sarah Cheney*.)

heavy-gauge submersible electrical cable. Typically, water temperatures will increase ¼ to ¾ in per 100 ft below 500 ft.

Various configurations of the shroud have been and still are used. Three of the most common supports are as shown in Fig. 7-10. The bottom-set configuration is allowed to freely sit on the bottom of the borehole. Because the shroud represents the suction side of the submersible pump, it must have a very low pressure drop. One-inch holes are cut from 20 to 60 ft above the bottom of the pipe for an 8-6-4 standard SCW design. The 20-ft bottom offset provides space for miscellaneous drilling debris. The top-supported shroud is hung by three or four stainless steel cables with stainless steel hooks over the top of the well casing. The bottom of the shroud must be well above any possible debris. Both of these methods have the advantage that pump service can be done without interfering with the shroud. The hub-supported method uses the well-pump riser pipe as a support for the shroud as well as the well pump. The hub-supported method, with a suitable breather vent, is often employed in a borehole with high static levels that could overflow the top of an open shroud. A overflow short circuit inhibits the benefit of the round-trip heat transfer.

In all cases, there must be no possibility that the static level of the well could allow water to flow over the top of the shroud, short-circuiting the heat transfer. Also, high static levels, typically 75 ft or less, could increase during pumping and invade the power-wire conduit. For this condition, the electrical conduit is sealed with Sealstic or a similar compound, and a stainless steel breather screen is installed in the well cap.

A representative pump test must be performed when the well is drilled. The well's static depth at an estimated maximum pumping rate and lift head for the well pump(s) must be determined. Factors to establish the well-pump design are set by the maximum pumping rate and the total dynamic lift head. Pump selection factors to determine total dynamic lift head (TDH) are

Bore lift head	At specified bleed rate
Heat pump	Flows and pressure drops
Pipe train	Riser, offset, and drop piping, piping, fittings, solids trapper, other sand trapper, and so on
Valves	Control, constant flow, and backpressure

A common commercial SCW is approximately 1,500 ft (450 m) deep and has an ideal yield of 10 to 15 gal/min (33–50 L/s) with little or no drawdown below its ambient static level. The typical bleed is 10 percent of the pumped flow. Assuming a 35-ton (120-kW) capacity of the well, the pumping rate would be in the 105 gal/min (350 L/s) range, and the TDH would be approximately 110 ft (35 m). These conditions, when combined with the dynamic lift in the building, may provide a requirement for a typical 5- to 20-hp submersible well pump. The 5-hp pump is the most common bid-specification pump for a 1,000- to 1,500-ft (20- to 30-ton) borehole. Bid specifications must recognize that final pump sizing is done only after the drilling of all wells in a well field is accomplished, and the well characteristics, including static drawdown at the bleed pumping rate, are known. Deeper statics and/or higher TDH may require 6-in pumps and larger casing, bore, and shroud (e.g., 10-8-6 SCW).

A submersible pump, as depicted in Fig. 7-11, starts with parallel torque and is retained in the center of the bore/shroud by one or more torque arrester(s). The arrestor ensures that the well pump assembly does not twist or have a horizontal movement

Figure 7-11 Submersible well pumps and motors are designed to fit neatly into the well bore casing or Porter shroud. (*Water Energy Distributors*.)

when the startup torque is applied. Twisting can break wires, loosen fittings, and cause the pump to impact the sides of the well bore. Large pumps, such as a 5-hp pumps, are often inserted into the bore with two torque arresters. In applications where the submersible pump is powered by a variable-frequency drive (VFD) and can be "soft started," a single arrestor maybe adequate.

The well pump is supported in the borehole by a *pitless adapter*, as shown in Fig. 7-12. The adapter is a unique device that allows a submersible pump to be changed out of service without digging a pit alongside the well casing in order to disconnect the riser-to-offset piping for service. In large installations, before the advent of the pitless adapter, this often involved expensive permanent pits, 6 to 8 ft in depth, with access and service requirements. The female part of the adapter is rigidly bolted or welded to a hole in the well casing side 4 to 6 ft below grade. The male part of the adapter is connected to the riser pipe, which, in turn, supports the submersible pump and its riser pipe. A temporary removal tool is inserted into the top of the male portion, and the entire riser pipe and pump assembly can be separated from the fixed female portion of the adapter and pulled to the surface.

The top of the well casing must be sealed with a sanitary-seal cap, as depicted in Fig. 7-13. This type cap assembly is needed to prevent the possibility of surface contamination of the bore as well as vandalism. The sanitary-seal assembly is in two pieces, composed of two steel rings and a matching cap. The lower ring is bolted or welded to the casing. The second ring and cap are placed on top of the lower ring. As the two steel rings are bolted together and tightened, a large rubber O-ring is compressed and expanded between the two steel rings, sealing the top of the well casing.

The well column must be allowed to "breathe" as the water column rises and falls with small annual changes or with the effects of pumping and returning water to the well. Keep in mind the water level inside the Porter shroud will retreat and the water in

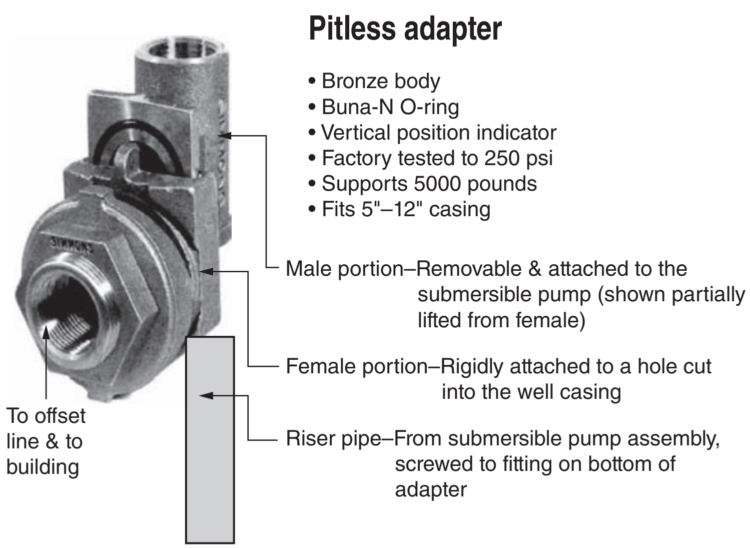


Figure 7-12 A pitless adapter provides for below-ground connection through the casing for the piping that supports and serves the submersible well pump assembly. (*Water Energy Distributors*.)

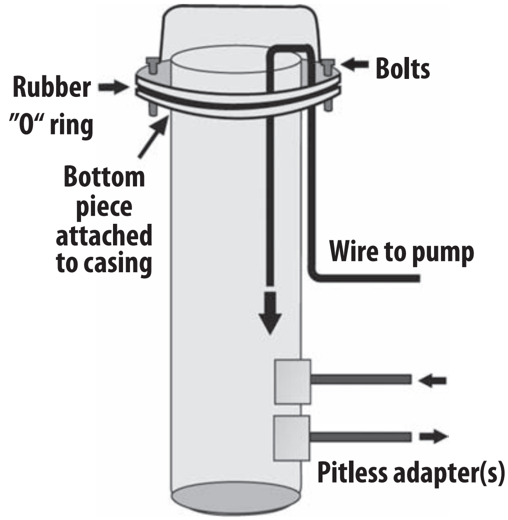


Figure 7-13 The top of the well casing must be sealed with a sanitary-seal cap to prevent the possibility of surface contamination and vandalism. (*Sarah Cheney*.)

the annulus will increase as the pump is operated. Casing venting is normally through the wire chase, where mechanical-room air is exchanged with well-column air. In cases where the well static is very high (near the surface), the wire chase is sealed, and the well bore is allowed to breathe through a stainless steel screen at a breather port on the sanitary seal. When using a breather port, care must be taken to ensure that surface water will not be allowed to invade the well bore.

Controls for the submersible pump are driven by the designated use of the SCW. As discussed later, all SCW are assumed to have well water compatible with copper-nickel heat-pump heat exchangers and that an intermediate plate-frame heat exchanger (PFHX) is not required.

Typical direct well-water and simple pressure-control options include the following:

1. A single well is used for a single heat pump. The controller simply can be a signal from the device calling the heat pump and simultaneously calling the well pump. Flows and pressures are preset and do not change.
2. Variable-frequency drives (VFDs) provide distinct advantages when multiple heat pumps, multiple wells, or multiple uses for the well(s) are part of the design. As flows and pressures change, the VFD automatically changes well pump speed and power required. Significant energy savings can be realized with the use of a VFD.

As discussed previously, the more water removed from a well column, the more the temperature will approach the far-field temperature. There is a distinct thermal and design advantage to a well(s) that has water withdrawn for other purposes. Taking advantage of the use of withdrawn water for domestic, irrigation, or other purposes presents the designer with a dilemma. The heat pump requires large volumes of water at relatively low pressure [e.g., 20 lb/in^2 (1.3 bar)] approximately 3,000 hours per year.

Domestic use is typically small amounts of water at high pressure [e.g., 50 lb/in^2 (3.3 bar)] approximately 600 to 800 hours per year. Irrigation requires high water flows at high pressure 200 to 300 hours per year. The practical design result is the use of a VFD well-pump control (Fig. 7-14).

Some states in the Northeast have approved dual-use wells. Some plumbing boards did not promote the dual-well method, and many town/city health officials suggested or denied their cost and energy-saving use. Recently, regulatory groups have approved dual-purpose wells based on the addition of a simple *backflow-preventer valve* on the line to the heat pump—separating a heat-pump heat exchanger perceived failure from dumping refrigerant into the domestic water line. Other states also allow this cost-saving method. A recent white paper on the economic benefit of a dual-purpose geothermal well based on actual geothermal history in a New England state estimated a historical savings to home owners in that state alone of $23 million, with a projected 5-year further savings of $49 million by use of dual – purpose SCW's.

The VFD package (Fig. 7-14) includes five necessary components:

- A VFD
- A line-power radiofrequency interference (RFI) filter
- A load-line reactor
- A ground plane
- Software program to be compatible with a submersible pump motor

Any VFD creates spurious electrical signals in the 100-kHz to 1-MHz range. Note that an AM radio band is also in this range. Exercise equipment as a stair climber, treadmill, and the like all have VFD drives. An RFI filter on the input power line and load side feed line greatly reduces the radiofrequency (RF) interference. An AM radio listener in the fringes of the AM coverage still may have interference from any VFD.

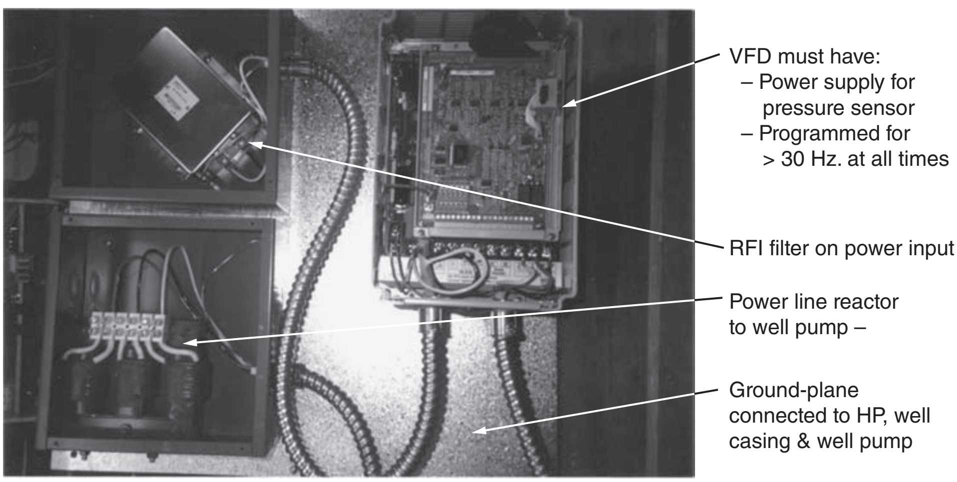


Figure 7-14 A variable-frequency drive (VFD) can save considerable energy on multiple GHP unit installations and serves to reduce wear and tear resulting from frequent starts and stops of the pump. (*Water Energy Distributors*.)

Because the VFD and the submersible well pump are far apart, usually 100 to 300 ft, a load line reactor is low-cost assurance that spurious standing electrical waves between the VFD and the motor winding are damped. Beyond 300 ft, the line-loss factors must be computed and may require upsizing power-line reactors. Without the dampening effect of the line reactor, standing-voltage waves in long power lines can become additive by a factor of 3 and break down motor windings and penetrate wire insulation. Absorption of the RF and standing waves is bled off through an electrical ground plane. The ground plane must be attached to the building ground and the steel well casing. The steel well casing, in many instances, is the lowest (best) ground for the building and geothermal system (Fig. 7-15).

Variable-frequency drive packages with multiple uses (e.g., domestic, irrigation, and heat pumps) are available with multi-pressure logic controls. Submersible well pumps must not be run at less than half speed (30 Hz). Water traveling past the lower motor assembly provides motor cooling and lubrication. Too slow a motor speed will not provide an adequate water flow for cooling. Poor cooling and lubrication result in reduced motor and pump reliability.

Should the heat-pump system or related water pipe components use an active neutral electrical return, such as when using 115 Vac within the heat-pump circuit, or associated piping the 115-V neutral returning to earth potential should not find the well water to be of less resistance than the intended building-earth ground. In this unwanted case, the electrons will seek lowest potential through the water column (see Fig. 7-15). Sufficient current flow and natural copper oxide rectification can create electrolysis within the heat pumps and/or related external piping. Whenever possible, earth ground the building and heat pumps via the steel well casing ground. A waterproof earth-bonding lug should be welded to the steel well casing. The lug is waterproofed to prevent dissimilar metal galvanic corrosion (see Fig. 7-14).

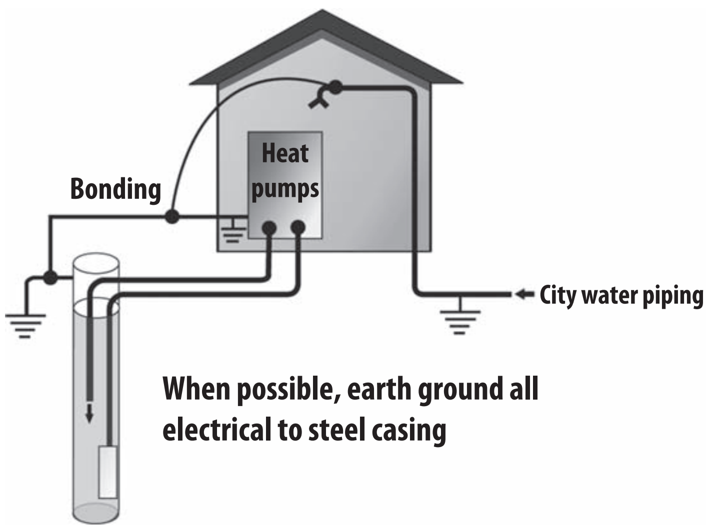


Figure 7-15 Securely bond the well casing to the heat pumps and the home piping system. This will prevent serious damage related to electrolysis. Do not count on the existing bonding unless you can verify it. (*Sarah Cheney*.)

Standing-Column Well Controls

Integration of the various controls in a GHP system emphasizes the requirement for a comprehensive system level of understanding. Parceling out pieces of the system to various subcontractors with no *one* overall system contractor being responsible for coordination is a recipe for project problems.

Typical GHP installations will be presented with pressurized water, design flows, and pressures. As in Fig. 7-16, the heat-pump control calls for an open and automatic motorized [M] water valve that allows water to flow at a constant rate set by an automatic flow-control valve [H]. Automatic flow-control valves allow the designer and installer to forego the costly water balance that otherwise would be required. Test ports are specified and installed at the input and output of the GHP. These ports are used to verify flow rates and temperatures. Major geothermal manufacturers provide tables of water-pressure drop at various flow rates through their heat exchangers.

Single-purpose well pumps (e.g., heat pump only) are operated for best efficiency with a capacitor run control (CRC). An optional CRC provides a run capacitor as well as the standard start capacitor for the submersible motor. For fully loaded motors, the CRC can provide an approximately 13 percent reduction in the kilowatt usage of a submersible motor at full load.

Geoexchange installations with multiple wells and/or multiple heat pumps on a common well manifold will benefit from VFDs. As mentioned earlier, the simple pressure logic provides significant energy-use improvements as well as ease of balance and operation. The VFD should remain a stand-alone control without interference or splitting of responsibility from a building management system (BMS). Monitoring of the well-water system and the performance of a VFD by the BMS is desirable and benefits the reliability of the entire geoexchange system.

Very large installations with multiple large (30- to 40-ton) heat pumps have been matched to a single 30- to 40-ton SCW. It should be noted that while this one-to-one well to heat pump is a convenient control simplification, temporary loss of a heat pump or its companion well results in a loss of the entire stage, unlike most common supply and return manifolds. For reliability purposes, a common supply and common return manifold with several wells and several heat pumps is a wise design.

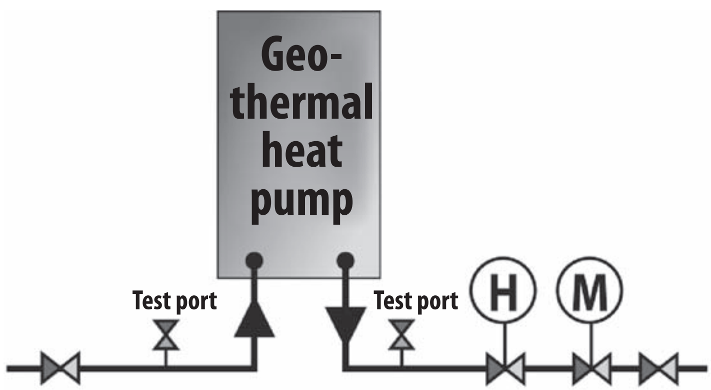


Figure 7-16 Several different controller strategies can be implemented on GHP applications.

Offset Piping Layout

Design of an SCW takes advantage of the more stable warmer winter and cooler summer temperatures. Maintaining temperature stability is desirable.

Figure 7-17 shows a good piping layout for a 200-ton installation with six SCWs. Note that the HDPE pipe is sufficiently competent to allow a maximum bend radius of approximately 26 times its diameter. In this case, the 3-in HDPE was bent with an approximate 6-ft radius. All underground fittings and splices were made with either a heat-fusion or heat-socket connection. Mechanical fitting and other connections are not permitted. Underground terminations in the building are usually fusion to National Pipe Thread (NPT) or flanges.

Electrofusion fittings have been employed in applications where there is limited space for the connections in the mechanical room. Electrobonding for HDPE piping (Fig. 7-18) is an expensive but sometimes necessary space-saving option. Electrofusion requires a computer-controlled fusion controller and clamping jigs. The controller is connected temporarily to the fitting and determines optimal time and temperature for the resistance elements buried in the plastic fitting itself.

The installation in the figure, the Hasting School in Massachusetts, has been evaluated by several organizations, including ASHRAE (*Transactions*, QC-06-006). The 72,000-ft^2 grammar school was retrofitted from electric resistance heat to geothermal heating and air conditioning in 1996. This 200-ton project has six SCWs designed for a 10 percent bleed rate. Its operating cost was projected and has achieved approximately 4.2 kW/ft^2 per year with a 10-year maintenance cost of \$0.085/ft^2 per year (including a sixth-year revision of the building's direct digital control system).

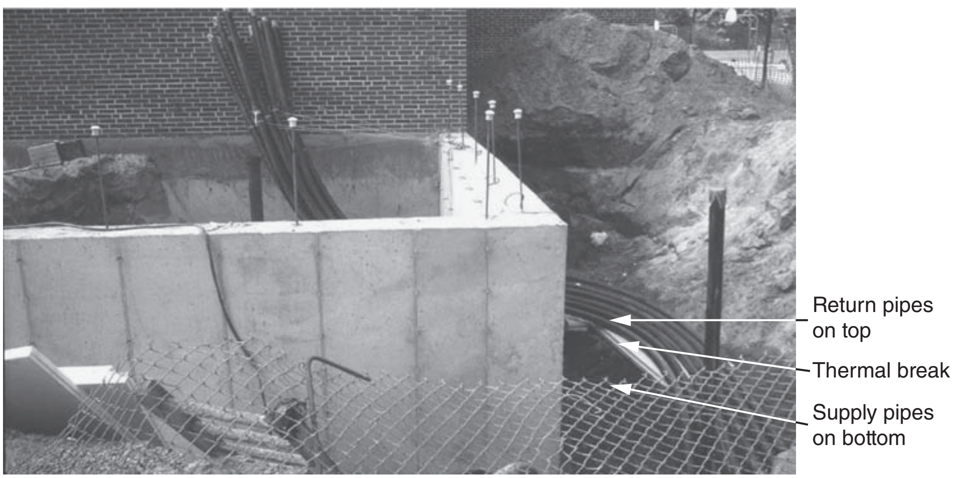


Figure 7-17 Use of HDPE or underground connections provides for worry-free installation, provided that accepted industry practices are followed. Note that the HDPE also exhibits a greater tolerance to wide variations in temperature. (*Water Energy Distributors*.)

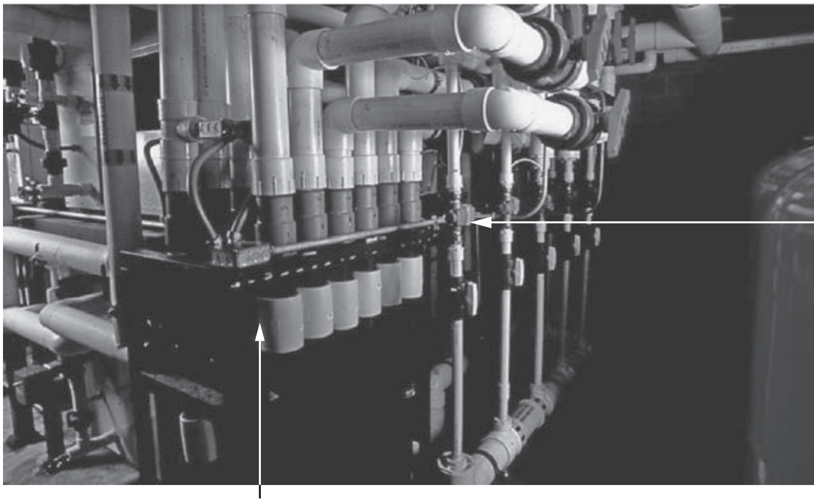


Figure 7-18 Electrofusion fittings can be used in applications where there is limited space. (*Water Energy Distributors*.)

Bleed Circuit

A bleed circuit (Fig. 7-19) is a mandatory requirement for any SCW, whether designed for a bleed-induced shorter bore or a "no bleed" deeper bore or multiple bores. The bleed provides the thermally powerful advective flow. Such periodic and automatically commanded flow ensures good performance of the SCW under extreme operational conditions while saving unnecessary bleed during less demanding times. An SCW can be designed for a no-bleed configuration, and only the rock surface provides the energy transfer with no dependence on the bleed function. A no-bleed SCW will require approximately twice the bore surface area of a 10 percent bleed SCW.

As shown in Fig. 7-19, a single temperature sensor is located on the input line to the heat pump(s) from the well. The sensor typically monitors the drop in temperature during critical winter operation. A similar or dual-channel sensor also could be employed to monitor the temperature during summer operation. During winter, with a well water temperature drop, a bleed operation is most critical because entering water temperatures below 40°F can result in temperatures leaving the heat pump(s) at less than 34°F. Low leaving water temperatures (LWT) can result in freezing in a typical heat exchanger. Always keep in mind that the freezing of water in a heat exchanger is related primarily to the temperature of the refrigerant on the opposing side of the heat pump, not the temperature of the water entering the heat exchanger. For example, too slow a water flow can result in a large depression in temperature—50°F water may be cooled to below 32°F if it is flowing at a rate of less than 1 gal/min. If the well-side design includes an intermediate heat exchanger and a below-32°F antifreeze solution on the heat pump side, the heat exchanger still can freeze on the well-water side with likely fracturing of the plate-frame

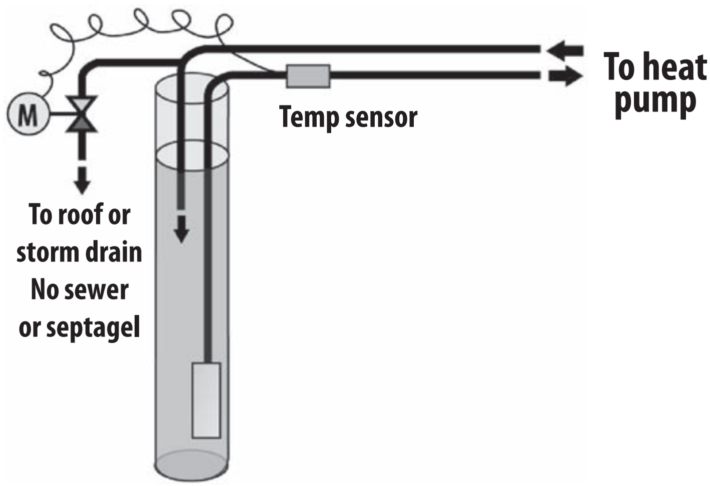


Figure 7-19 The bleed circuit rate is controlled by the supply-water temperature. Bleed increases significantly improving the automatic control of advective heat transfer within an SCW. (*Sarah Cheney*.)

heat exchanger plates. Depending on the configuration of the heat-pump heat exchangers, the best that can happen is a shutoff on low water temperature or low refrigerant pressure/temperature; the worst is freezing and burst of a freeze-intolerant heat exchanger, mixing water and refrigerant. A selection of water heat exchanges that can tolerate inadvertent light freezing is an important design and equipment selection requirement.

The bleed circuit provides an automatic assurance against freezing in the event the winter is colder than predicted, the rock/well is not as planned, and the building did not meet insulation/infiltration design standards. The bleed can equally compensate during extreme summer operation, particularly in commercial applications. A simple bleed option can replace an expensive supplemental cooling tower.

Water being returned to the bore cannot be allowed to free fall. Free-falling water entraps air, and can out–gas dissolved carbon dioxide. Entrapped air in the water reduces heat exchanger performance and out gassed carbon dioxide can promote scaling. A solid drop pipe (Fig. 7-20) below the level of the maximum static depth ensures that air will not be entrapped in the return-water path.

If the drop pipe contains more than 34 ft of water, a perfect vacuum is formed. When this condition occurs, a bleed cannot occur. Opening a bleed valve will simply suck air, and no bleed water will be discharged. All bleed designs must consider this suction effect. A simple drawdown test, as discussed earlier, provides the necessary information so that backpressure devices, if required, are inserted into the return pipe run to inhibit the vacuum effect.

Devices and measures to ensure bleed can range from simply providing a manual or automatic backpressure valve (see inset in Fig. 7-20) on the return drop pipe to an automatic backpressure valve (BPV) for large commercial applications with very deep static levels.

Compensating for modest suction levels normally can be accomplished by a simple ball valve inserted into the line returning to the well. Also, as shown earlier, using the 90-degree bend in the return line at the bleed takeoff point adds additional and desirable backpressure to the well return line. Applications with very deep statics and multiple wells with varying statics make use of a constant BPV. The automatic constant BPV provides a positive pressure

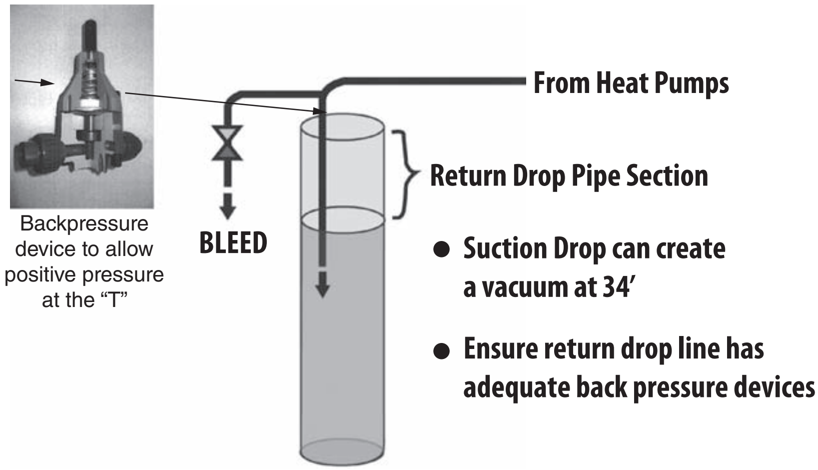


FIGURE 7-20 Too much emphasis cannot be placed on the importance of keeping air out of the drop line. Adequate backpressure devices and specialties must be implemented to ensure trouble-free operation. The necessary gauges, backpressure devices, and controls must be implemented in a method similar to the one depicted here. (*Artwork: Sarah Cheney; photo: Water Energy Distributors*.)

at the bleed-line takeoff over a range of flow and suction pressures, ensuring that a bleed call will have adequate pressure to direct water out of the bleed line at varying flow rates. Please note that BPV are not pressure reducing valves.

The return line must be fitted with a compound pressure gauge. This gauge measures both positive and negative pressures and is most useful in balancing out a system with any significant suction on the return line.

Final Assembly

Disinfection of an open well is important and minimal-cost insurance. As the well is being drilled, the drilling contractor should maintain the well in a disinfected state. If the well is to be temporarily sealed during the construction process, the well casing must be completely sealed with a temporary tack-welded cap, a well seal, or the final sanitary seal. The well in its standby configuration must be maintained in a disinfected state. Typical disinfecting chemicals include the following:

Recommended:

- Sodium hypochlorate
- Bleach (form of sodium hypochlorate)
- Calcium hypochlorate (a swimming pool disinfectant)
- Well-disinfection chemicals approved by the National Water Well Association

Effective but not recommended:

- Sulfamic acid
- Potassium hexametafluoride

The hypochlorates are recommended because they are inexpensive, easily purchased, and when used properly, offer no residual health risk. An additional advantage is their odor—a high concentration can be smelled. After a well has been disinfected and then cleared, the lack of odor indicates a successful process. Other chemicals may be better bactericides but require professional chemical analysis to determine that the water is safe to drink after disinfection. Well disinfection is not a unique geothermal requirement, but true of any water well.

What to Expect

A well-designed SCW will provide a reliable earth coupling with a minimum of land surface area required and often lower first-cost earth-coupling installation. Heat-pump efficiencies will be higher than with a closed-loop system and only slightly lower than with an open-well system. The use of a bleed circuit provides the designer with assurance that unexpected design demands, unforeseen weather, or construction changes will not affect the geoexchange performance. The use of a bleed circuit can allow the designer to reduce the length of the bore with consequent reduction in the cost of the system. A typical small SCW result is as shown in Fig. 7-21.

Figure 7-21 shows the results of a 2-year-long, weekly averaging monitoring of a 7-ton installation in Raymond, Maine. The well depth was 600 ft, and the water column was 530 ft (75 l ft/ton). Of note, the well had a low water yield, and the designer could only achieve a reliable 5 percent bleed.

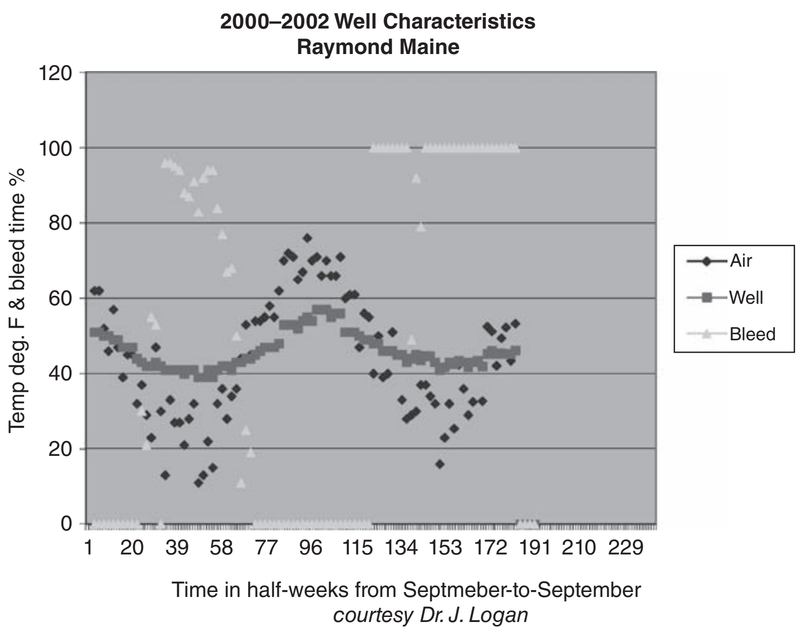


Figure 7-21 Unlike closed-loop systems, SCW systems with a bleed circuit have the capability of correcting themselves, as shown in this 2-year well characteristics chart. (*Dr. J Logan*.)

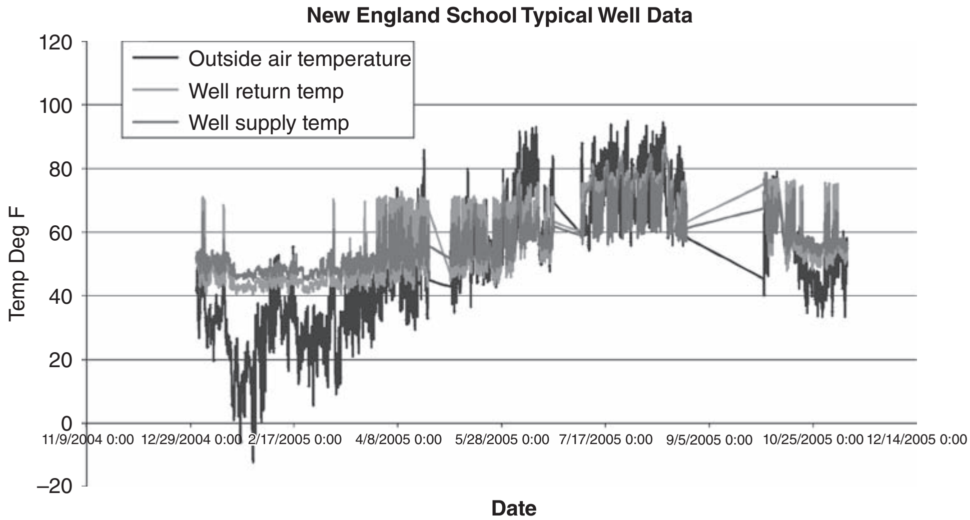


Figure 7-22 At 10 years, many closed-loop systems with umbalanced cooling and heating loads are showing significant trends toward thermal retention or thermal extraction, whereas this SCW system record shows no effect on mean earth temperature. (*ASHRAE Transactions 06-006*.)

In the first year, the bleed circuit was activated by the entering water falling below a set point of 42°F (6°C). In the second year, the bleed circuit was activated each time the heat pump was called.

Concern has been voiced about closed-loop systems that have not maintained thermal stability or have experienced *temperature creep*, also termed *field failure* over multiyear operation. Underdesigned closed loops can manifest a long-term trend toward an increase or decrease in mean/average earth temperature. The unwanted trend can be attributed to misinterpretation of the earth/rock characteristics, a building with a greater than design cooling or heating load, a warmer summer than predicted by designed standards, and other effects. A closed-loop system cannot make any mean earth temperature correction without adding more buried loops or cooling or heating augmentation. Advective flows for both SCW and open systems have the advantage of restabilizing mean earth temperatures when unexpected earth or load conditions occur. Figure 7-22 is a 12-month graph of a Massachusetts school with a 200-ton SCW system. While the annual temperature swing from the bore varies by approximately 30°F, note that the 52°F mean earth temperature has remained unchanged after operation for over 10 years. Of note, the system was not initially designed for air conditioning and consequently does not bleed for temperature stabilization in summer months.

Regulatory Factors

Federal environmental water-related regulations are consistent for open and SCW systems but do not necessarily apply in all states. Certain states have their own interpretations and requirements. Many of the states are presently (2012) drafting or have in place closed-loop earth-coupling regulations.

A state regulation is the product of the interpretation of that state's regulators and state legislature; most are based on the federal baselines and local, sometimes subjective, requirements.

The authors have found that various state regulators are committed to their environmental responsibilities but are also anxious to protect the economic health and energy efficiency of local home and business owners. State regulations and interpretations are often in flux and subject to change—a prudent geothermal installer should maintain close contact with his or her state's regulators.

Regulations apply to

- *Removal of water from the earth—diversion*. These regulations often list maximum periodic (i.e., daily, weekly, or monthly) removal of waters from a well. Differing levels of permitting or waivers (no permit) are required.
- *Returning water to the earth—reinjection*. These regulations ensure that waters being returned to earth at least meet primary federal drinking quality standards and underground injection control (UIC) requirements. Water not meeting these primary health standards from the earth cannot be returned to the earth without verification that it is returned to the same aquifer, undergoes treatment, or a waiver is issued.
- *Closed-loop antifreeze*. The authors only support propylene glycol–based antifreeze. Water Energy Distributors, Inc., does not support methanol, ethylene glycol, or other toxic or flammable antifreezes. All antifreeze compounds must list any additives in the anti-freeze solution. Some states permit ethanol with strict limitations on the denaturants allowed.

Glossary

Air-Conditioning and Refrigeration Institute (ARI) An organization that authors third-party evaluation methods for heat pumps and other related equipment.

American Society of Heating, Refrigeration and Air-Conditioning Engineers Research Report (ASHRAE RP) RP-1119 is a definitive report on SCWs.

Backpressure valve (BPV) An automatic backpressure valve that maintains a constant backpressure over a large input pressure range.

Civil engineer (CE) Geothermal team member who provides assistance in water regulatory and permitting matters.

Class V A category of beneficial use of groundwater without further degradation. It is a category of federal and state underground injection criteria (UIC) regulations.

CP gauge A pressure gauge that measures positive pressure and a vacuum (negative pressure).

Diffusion well A borehole that accepts water for reinjection into the earth. Diffusion wells are generally two to three times larger (more depth and/or diameter) than regular wells.

Electrofusion An automatic method to join high-density plastic pipes that requires less skill and space.

Electrolysis An unwanted electric current that erodes the metal from a positive (anode) charge conductor.

Entering water temperature (EWT) Usually into a heat exchanger; opposite of leaving water temperature (LWT).

Environmental Protection Agency (EPA) Federal agency that regulates water quality.

eQUEST Software package available from the U.S. Department of Energy for geothermal applications. ClimateMaster Corp. provides a geothermal enhancement for this software.

GLPRO A geothermal heat-transfer software package available from Oklahoma State University; used particularly for large closed-loop and SCW evaluations and design.

High-density polyethylene (HDPE) A semirigid, long-lived, and very tough plastic pipe used only for underground geothermal well and closed loops. Geothermal pipe must meet specific resin and cell categorization requirements.

International Ground Source Heat Pump Association (IGSPHA) A trade organization based at Oklahoma State University (OSU); a long-time proponent of geothermal education, closed loops, and the geothermal industry.

International Standards Organization (ISO) 13256 ISO Standard 13256 provides an international standard with a similar function to the ARI standards, authoring evaluation standards, and results for various geothermal heat pumps. Standard 13256 comparatively rates groundwater (well water) and ground-loop (closed-loop) geothermal heat pumps.

National Pipe Thread (NPT) The national standard for pipe sizing and thread configuration.

pH Hydrogen ion concentration, a measure of the activity of an acid or alkaline chemical, ranging from 0 to 14. Seven is neutral (no activity); higher numbers indicate alkalinity and lower numbers indicate acidic activity.

Pitless adapter A popular device used by the water-well industry to allow removal of a submersible well pump and not require digging a temporary pit to disconnect the well pump from the offset pipe to a building.

Porter shroud A plastic tube attached to the end of a submersible well pump that allows the well pump to be located near the top of the SCW for ease of service and reduction of wiring cost.

Radiofrequency (RF) A radiofrequency signal emitted by a VFD or other electronic device that can interfere with radio, TV, and other devices that receive electromagnetic energy.

Reynolds number A fluid flow factor that predicts the character of a fluid flow. For ideal heat transfer, the Reynolds number should be higher than 2500. Flow rate and fluid density are factors used in computing it.

Spoils Rock cuttings or soil debris being lifted out of a borehole by air and/or water pressure.

Standing-column well (SCW) One of three geothermal earth-coupling methods.

Test bore The first borehole in a well field. It is critically evaluated and can serve as a reliable estimate of the character of succeeding boreholes.

Torque arrester A holding device that centers a submersible well pump so that it does not impact the side of the borehole or casing when it starts up. The soft start of a VFD can lessen but not remove the need for a torque arrestor.

Total dynamic head (TDH) The total amount of pressure needed to push water through a pipe train from the bottom of a well through the piping, heat pump, valving, and other devices back into the bore.

Underground injection control (UIC) A federal set of water-quality standards relating to returning water to the earth. Adopted by many states and integrated into their water regulatory structure.

Review Questions

1. Convective heat transfer as it applies to SCWs refers to
   a. a nonevaporative fluid cooler component.
   b. natural flow of the water within the column.
   c. latent and/or sensible heat removed from the space conditioned.
   d. transfer through the casing where voids are present in the borehole.
2. Water being returned to a standing column should not be allowed to free fall because
   a. a perfect vacuum may be formed if the distance is greater than 34 ft.
   b. free-falling water entraps air and reduces heat exchanger performance.
   c. erosion of the borehole casing will occur.
   d. Both a and b
3. The pitless adapter is used in a well casing to
   a. reduce the size of the pit needed to service the pump.
   b. provide an enclosure for the variable-frequency drive.
   c. provide connection through the casing for the piping that supports and serves the submersible-pump assembly.
   d. provide a means by which the sanitary well seal can be removed and serviced.
4. A Porter shroud is used in a well to facilitate
   a. prevention of debris from entering the well.
   b. placing of the submersible pump at a point higher in the well than the point at which water is drawn.
   c. creation of the facade to prevent vandalism and damage from maintenance equipment.
   d. a higher lift suction than could be attained with a submersible pump alone.
5. Proper grounding of all the components in the system will reduce
   a. heat-exchanger damage.
   b. the possibility of electrical shock.
   c. the likelihood of a hot neutral.
   d. All the above.
6. The best way to increase the tonnage of an SCW is to
   a. increase the depth of the SCW.
   b. increase the bleed rate of the SCW.
   c. increase the width of the SCW.
   d. increase the number of SCWs.

7. When using multiple heat pumps with an SCW, one of the better primary means of controlling water volume is
   a. a variable-frequency drive on the well pump motor controlled by the heat-pump discharge temperature.
   b. a proportional motorized valve on the discharge of each heat pump controlled by the head pressure of the heat pump.
   c. a solenoid valve at the discharge of the heat pumps operating in tandem with the call for cooling or heating.
   d. a pump pressure switch in tandem with a bladder tank set at between 40 and 60 lb/in^2.
8. When using a pump to reinjection well system, regulatory authorities normally legislate that
   a. discharge water must be treated to meet NSF standards.
   b. the temperature rise must not be more than 20°F for the discharge well.
   c. the discharge water may be used only for flushing toilets.
   d. the discharge water must be returned to the same permeable zone from which it was pumped.
9. A bleed circuit in an SCW system may be used to
   a. provide irrigation water.
   b. provide water for flushing toilets.
   c. control supply-water temperature.
   d. All the above
10. Disinfection of an open well is important and should be completed
    a. at least once every 5 years.
    b. using sodium hypochlorate.
    c. using well-disinfection chemicals approved by the NGWA.
    d. Both b and c
11. The use of an SCW or an open-to-reinjection well for geothermal HVAC equipment will
    a. provide thermal stability for the HVAC equipment.
    b. experience thermal creep if the load is imbalanced.
    c. cause the aquifer to overheat or overcool.
    d. present hazards to aquifer safety.
12. Closed-loop geothermal HVAC systems prove favorable when
    a. the loads are smaller, as in a small residential system.
    b. the summer and winter seasons present similar runtime loads.
    c. there is a good thermal bond between the HDPE and the earth.
    d. All the above
13. Advective flow in a geothermal well refers to
    a. the movement of water in the borehole.
    b. the transfer of heat between the water in the borehole and the adjacent rock strata.
    c. the movement of both conductive and convective heat through fractures in the rock.
    d. the coalescing of entrapped oxygen promoting heat transfer within the water column.

14. The average depth of a commercial SCW is
    a. 150 ft.
    b. between 1000 and 1500 ft.
    c. 400 ft.
    d. 1000 to 2000 ft.
15. The average tonnage of heat rejection per borehole for closed-loop geothermal systems is
    a. 20 to 30 tons.
    b. 1 ton per 300 ft.
    c. between 1 and 3 tons.
    d. 10 tons.
16. The average tonnage of heat rejection per borehole for SCW commercial geothermal systems is
    a. 3 to 5 tons.
    b. 1 ton per 500 ft.
    c. from 33 to 43 tons.
    d. limited only by gallon per minute pump size.

CHAPTER 8

Fundamentals of Comfort, Psychrometrics, and Thermodynamics

Occupant comfort is a prime goal of any commercial heating, ventilation, and air-conditioning (HVAC) system. Comfort in a building is a function of its construction and the particulars of the HVAC system installed.

The design and operation of all HVAC systems, no matter what the source of energy used, are determined by the fundamental laws of physics. An individual's perception of comfort is influenced by many factors, some related to the building and its HVAC system and others related to personal factors outside the purview of the HVAC professional. Yet those perceptions also rest on the same basic physical laws. Therefore, before we can determine how to create an indoor environment that will be perceived as comfortable by the majority of a building's occupants, we have to understand the nature and components of comfort.

What Is Comfort?

Comfort has a tremendous impact on our ability to fully engage in work or play. All other things being equal, a comfortable person is content and can focus on the task at hand. An uncomfortable person is short-tempered, distracted, inefficient, and more likely to make errors.

Although comfort is subjective, varying from person to person and influenced by a wide variety of factors, including temperature, humidity, activity level, the individual's physical makeup, condition, and emotional state, it also can be defined objectively for the purposes of HVAC system design and operation. One element of comfort is the dry-bulb temperature of the air. This is defined as the temperature measured by a standard thermometer freely exposed to the air but shielded from radiation and moisture, with the measurement being in either Fahrenheit or Celsius degrees.

A second element of comfort is the *sensible* heat content of air. This is defined as the heat absorbed or evolved by a substance during a change in temperature that is not accompanied by a change in state, as determine by the dry-bulb temperature. Most people are "comfortable" with the dry-bulb temperature between 72 and 75°F, whereas most are uncomfortable when the dry-bulb temperature is below 70°F or above 80°F.

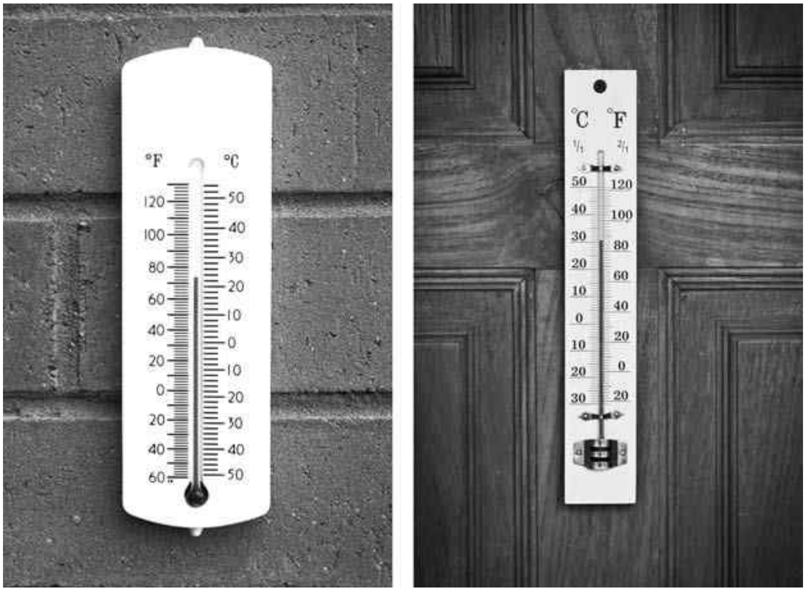


Figure 8-1 Thermometer showing the dry-bulb temperature.

Within these ranges, the comfort of any one individual also will depend on factors such as age, sex, type and weight of clothing, and air motion (Fig. 8-1).

Another element of comfort is the amount of humidity in the air, which is determined by measuring the wet-bulb temperature (Fig. 8-2). The wet-bulb temperature is measured with a thermometer having the liquid bulb covered with a wick dampened in water. This thermometer will register a lower reading than a dry-bulb thermometer because of the evaporative cooling caused by the water on the wick. The difference between the wet- and dry-bulb temperatures indicates the moisture content of the air. If the air sample contains no moisture, a rare event, then the wet- and dry-bulb temperatures will be the same.

The difference between the dry-bulb temperature and the lower wet-bulb temperature, caused by evaporative cooling, is an illustration of still another factor in the perception of comfort—*latent heat*. This is defined as the heat released or absorbed by a body during a change of state—in this case, from liquid to vapor—at a constant temperature. In other words, it is the heat energy released in the change of state as opposed to a change in the sensible heat of the air.

Comfort is also affected by the amount of radiant heat—heat transferred directly by electromagnetic radiation—and the mean radiant temperature (MRT) (Fig. 8-3). The human body gains or loses heat according to the temperature difference between the body surface including clothing and adjacent objects. The condition of these surfaces is determined by their MRT. If the body is warmer than the MRT, it will be losing heat. If it is cooler, it will be gaining heat.

The conditions that make up the typical comfort zone for people can be illustrated on a psychrometric chart showing the properties of air in a given location (Fig. 8-4). The chart was developed by Willis Carrier, the father of air conditioning, in 1904 to simplify the task of air-conditioning design. The parameters plotted on a psychrometric chart

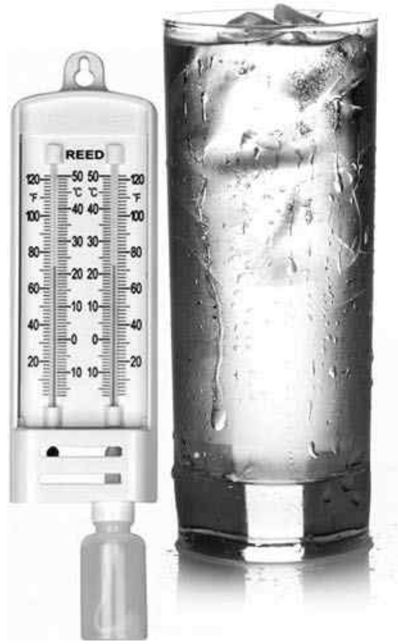


Figure 8-2 Wet-bulb thermometer and a glass of water with condensation on the outside.

Figure 8-3 Radiant heat is an important element of comfort.

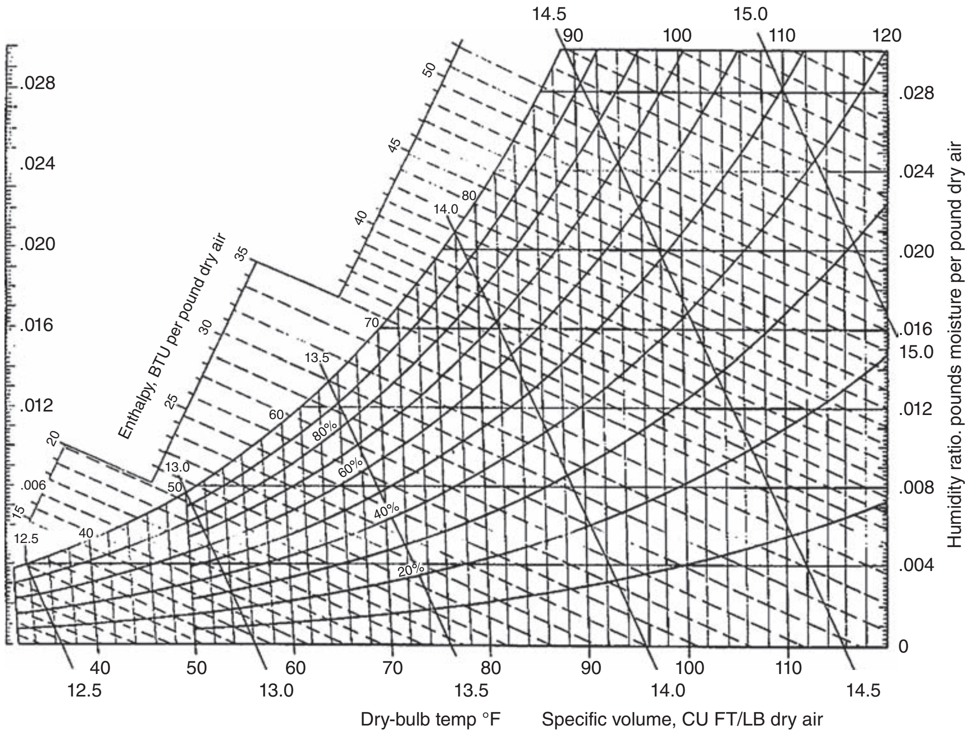


FIGURE 8-4 Psychrometric chart showing the properties of air.

include the dry- and wet-bulb temperatures, the dew-point temperature, relative and specific humidity, enthalpy and the density of air.

Dry-bulb temperature is shown by the vertical lines. Wet-bulb temperature is indicated by the sloping lines from upper left to the lower right. Relative humidity is charted by the curved lines from the lower left to the upper right. The specific humidity ratio is equal to the pounds of moisture in 1 lb of dry air or grains of moisture in 1 lb of dry air (7,000 grains per lb) and shows up on the right side of the chart as horizontal lines.

Enthalpy lines also slope downward to the right, indicating the heat content for any combination of wet- and dry-bulb temperatures. Enthalpy is the heat energy content of (moist) air. It is the sum of sensible heat + latent heat. Sensible heat is a result of a change in temperature. Latent heat is a result of a change in phase, i.e., water to vapor. This can be expressed as:

$$
\begin{aligned}
H_{\text{total}} &= H_{\text{dry air}} + H_{\text{water vapor}} \text{ (Btu/lb)} \\
&= c_{p\text{ dry air}}T + (V_{\text{water}} + c_{p\text{ water}}T) \\
&= .024\text{T} + \text{W}(1061 + .444\text{T})\text{ (Btu/lb)}
\end{aligned}
$$

where H = enthalpy (Btu/lb)

c_p = specific heat of fluid (Btu/$\text{lb}_{\text{dry air}}$)

V = latent heat of vaporization for water (Btu/lb_{water})

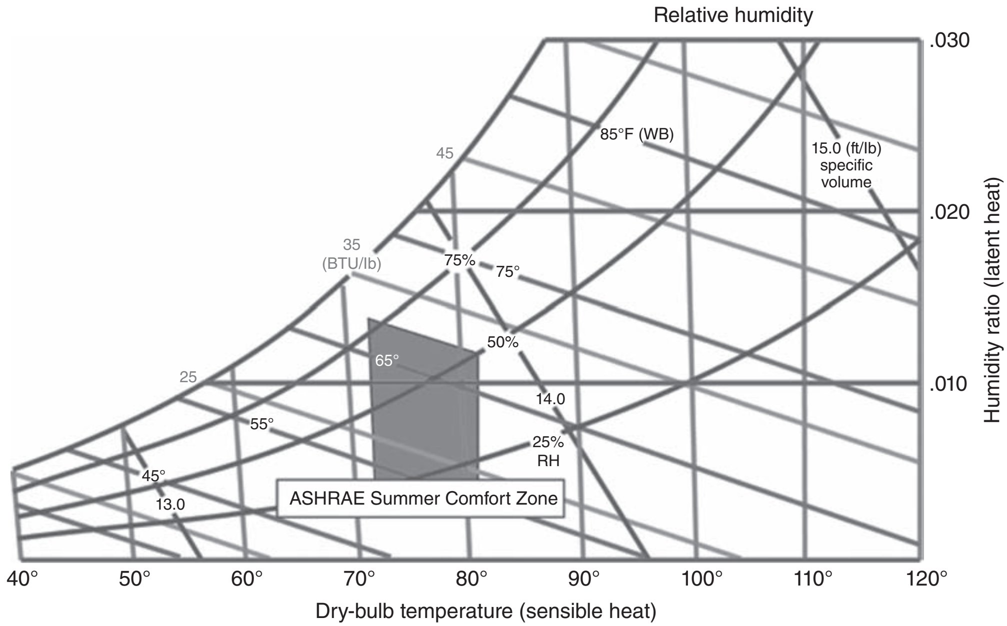


Figure 8-5 ASHRAE comfort zone.

Finally, one last set of lines is used to represent the specific volume of the air at each condition. These are the steeper lines, sloping from upper left to lower right.

As stated earlier, the temperature and humidity conditions that any one person finds comfortable will depend on that person's age, health, sex, food, activity level, type and weight of clothing, air motion, and other factors. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has defined acceptable ranges of operative temperature and humidity as shown by the box located in the psychrometric chart in Fig. 8-5. This is referred to as the *ASHRAE comfort zone*. Within this box, most people are comfortable.

The psychrometric chart can be used to indicate all operating parameters of an HVAC system, the outdoor conditions, and the spaces served. In the example shown in Fig. 8-6 outdoor air design conditions for Jacksonville, Florida, are plotted here as 90°F dry bulb and 80°F wet bulb. The desired room condition is 75°F dry bulb and 62°F wet bulb. The air-handling system is mixing 15 percent outdoor air with 85 percent room air so that the combined dry-bulb temperature is 77°F and the corresponding wet-bulb temperature is 64°F. The combination of dry- and wet-bulb temperatures is the condition of the air entering the cooling coil. The condition of the air leaving the cooling coil is 55°F dry bulb and 53°F wet bulb. The supply air warms up as it enters the room along the sensible-heat-ratio (SHR) line, which is defined as the sensible heat divided by the total heat (sensible heat plus latent heat).

As you can see, comfort is a difficult quality to quantify because it combines both objective factors, such as temperature, humidity, and air flow, and an occupant's wholly subjective internal experience of "comfort." Nevertheless, it is the HVAC system designer's challenge to deliver comfort to a building's occupants as well as efficient and cost-effective operation to the building owner.

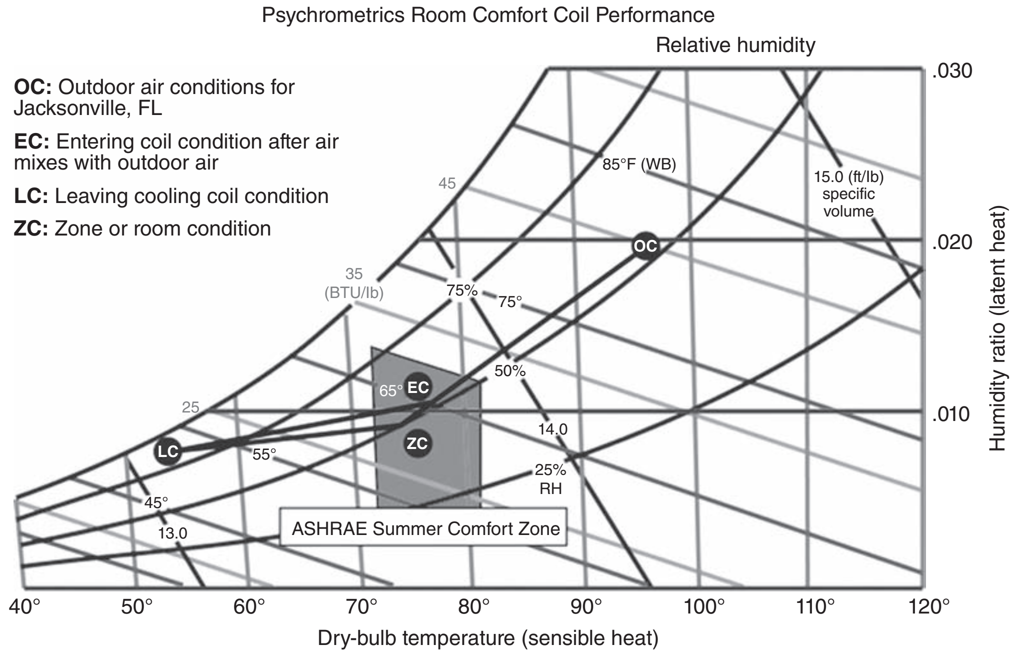


Figure 8-6 Psychrometirc chart example for Jackonsville, FL.

In addition a comfortable environment is also healthy. Air conditioning has been responsible for a dramatic decline in heat-related deaths in the USA over the last 50 years, according to a new report from the Massachusetts Institute of Technology (MIT).

Engineering Laws of Thermodynamics

The fundamental laws of thermodynamics govern both the conditions in which an HVAC system operates and operation of the system itself. The HVAC system designer must be thoroughly familiar with basic thermodynamics, take them into account when designing a system, and use them to best advantage to create an effective and efficient system.

The first law of thermodynamics is a version of the law of conservation of energy, which states that the net amount of energy added to a system minus the net energy extracted equals the net increase of stored energy in the system. Another way to describe the first law of thermodynamics is to say that energy in – energy out = Increase in stored energy. This can be paraphrased as stuff in – stuff out = stuff left. This means that the maximum efficiency of any process is 100 percent, and energy (mass) cannot be created but only changed from one form to another.

Mathematically this can be expressed as

$$\Delta Q_{\text{in}} + \Delta W_{\text{in}} - \Delta Q_{\text{out}} - \Delta W_{\text{out}} = \Delta E$$

where ΔE = change in Energy
ΔQ = change in heat
ΔW = change in Work

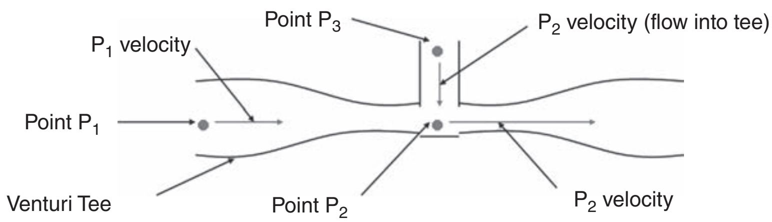


Figure 8-7 Venturi tee flowmeter flow.

One application of the first law is Bernoulli's equation. This can be stated as:

$$P_{\text{total}} = P_{\text{static}} + P_{\text{velocity}}$$

where P_{total} = total pressure
P_{static} = static pressure (ρh)
P_{velocity} = velocity pressure ($v^2/2g$)

Applications of Bernoulis' equation in the HVAC industry include venturi tees for single pipe hydronic systems, venturi flowmeters for hydronic systems, and the Coanda effect for air diffusers. Other real life applications produce lift for airplane wings and thrust for sailboat sails.

For a Venturi Tee (Fig. 8-7) this can be shown as:

$$P_{1\text{ total}} = P_{2\text{ total}} = \text{constant; and } P_{1\text{ static}} + P_{1\text{ velocity}} = P_{2\text{ static}} + P_{2\text{ velocity}}$$

For Increase in Velocity at Point 2

$P_{2\text{ static}} + P_{2\text{ velocity}}$ = constant
$P_{2\text{ static}}$ must decrease and therefore $P_{2\text{ static}} < P_{1\text{ static}}$
If $P_{3\text{ static}} < P_{1\text{ static}}$ then Velocity 3 (Flow) is into tee.

Diffusers in an HVAC system "dumping" cold air onto an occupant's shoulders and neck cause discomfort. To prevent this, the diffuser should be constructed using the "Coanda" effect. The Coanda effect is the ability to discharge air parallel with the ceiling and maintain the airstream literally attached to the ceiling until it mixes with the room air and warms up before falling to the floor. This is an application of Bernoulis' equation and can be shown in Fig. 8-8 as:

$$P_{1\text{ total}} = P_{2\text{ total}} = \text{constant; and } P_{1\text{ static}} + P_{1\text{ velocity}} = P_{2\text{ static}} + P_{2\text{ velocity}}$$

For Increase in Velocity at Point 2:

$P_{2\text{ static}} + P_{2\text{ velocity}}$ = constant
$P_{2\text{ static}}$ must decrease and therefore $P_{2\text{ static}} < P_{1\text{ static}}$ creating force to hold airstream to ceiling.

Slot diffusers can produce the higher velocity necessary to create the Coanda effect. Louvered step down diffusers and "hole covers" using perforated faces cannot produce the higher velocities and will "dump" creating drafts and uncomfortable conditions.

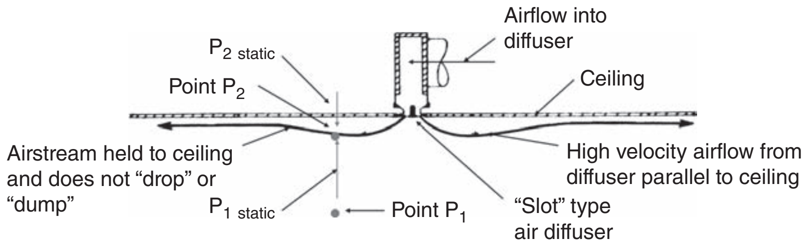


Figure 8-8 Coanda effect in slot diffuser.

The second law of thermodynamics is the law of energy transfer, which differentiates and quantifies processes that proceed only in a certain direction (irreversible) from those that are reversible. The efficiency of any process is less than 100 percent, and in most real-world cases it is significantly less than 100 percent. Energy is transferred from a state of higher energy to a state of lower energy; in other words, heat flows downhill, not uphill.

The third law of thermodynamics, the law of energy degradation, says that energy continues to degrade to the lowest form of energy, which is heat. The lowest state of heat, absolute zero, is unattainable in finite steps.

So how do these laws of thermodynamics apply to HVAC systems?

In layman's terms the laws of thermodynamics can be related to a football game. The first law says you can't win (maximum 100 percent efficiency). The second law says you can't even come close (efficiency is significantly less than 100 percent). The third law says you can't get out of the game (energy continues to degrade to the lowest form, heat).

HVAC Applications of the Laws of Thermodynamics

In terms of practical application, the first and second laws of thermodynamics are of most concern to HVAC system designers. The first law may be stated as energy cannot be created or destroyed, and all forms of energy are mutually convertible. For example, electrical energy can be converted to thermal energy or mechanical energy. Likewise, thermal energy can be converted to electrical energy or mechanical energy.

The second law of thermodynamics can be stated as heat energy will flow from one area to another area of lower temperature. Heat flows to cold; cold does not flow to heat. This law also defines the three ways by which energy can be transferred. These are conduction, convection, and radiation. Conduction heat transfer occurs when energy moves through a solid material. When a heat source, such as an electric stovetop heating element, touches a solid material, such as the bottom of a pan, the water in the pan starts to boil because heat is being transferred by conduction. The element warms the bottom of the pan, heat transfers through the metal, and the inside of the pan becomes hot, causing food to cook (Fig. 8-9).

Convection heat transfer takes place through a gas or fluid such as air or water. If you place your hand above a hot-water or steam radiator, you will feel warm air rising up from the heated surface. This is convection heat transfer. The same process happens in a pan of water on a stove. The fluid in contact with the bottom of the pan will be heated and rise. Cooler water replaces the heated water by convection flow until all the water is at the same temperature (Fig. 8-10).

Figure 8-9 A familiar example of conduction heat transfer.

Figure 8-10 Common examples of convection heat transfer.

The third kind of heat transfer, radiation heat transfer, takes place through open space via electromagnetic waves. The most obvious example of radiation heat transfer comes from the sun (Fig. 8-11). The warmth you feel when standing near a blazing fireplace is another example of radiant heat transfer.

Heating and Cooling Load Calculations

Before we can use conduction, convection, and/or radiation to provide comfortable indoor conditions, we must determine the amount of heating and cooling that will be needed for each space. Historically, there have been many approaches to determining the correct amount of heating or cooling required for a given space. Residential contractors with

Figure 8-11 Common examples of radiant heat transfer.

many years of experience can become adept at estimating the heating and cooling loads of a building. However, this approach isn't practical for calculating loads for large commercial HVAC systems.

Various methods based on complex calculations have been developed over the years for making accurate determinations of heating and cooling loads. American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) is the most widely recognized authority for technical information in the HVAC and refrigeration industries. ASHRAE is a membership organization of engineers, contractors, manufacturers, vendors, educators, and others historically dedicated to the accumulation and dissemination of technical materials.

Recently, ASHRAE has been moving from focusing solely on HVAC and refrigeration to providing guidance for total building design, reconstruction, construction, and operation. ASHRAE is working to improve the quality in the built environment while leaving a lasting legacy for future generations. The organization is focused on improving engineering standards and market position, operating as a community of engineers and related professionals that is united by knowledge, mission, and a code of ethics to design, construct, and operate better places for people to live, work, and play.

Manual Heat Load Calculations

The first calculations to determine the amount of heating or cooling needed for a space were done manually. The equation for calculating heat transfer through a building element can be expressed as the steady state single dimensional heat transfer equation of

$$\Delta Q = U \times A \times (T_1 - T_2)$$

where ΔQ is the amount of heat needed, U is a measurement of the resistance to heat flow of each different type of building material, A represents the area of the wall, window, roof, door, or other building component, and $T_1 - T_2$, commonly referred to as the "delta T" (ΔT), is the temperature difference between the desired inside temperature and the historical outdoor design temperature.

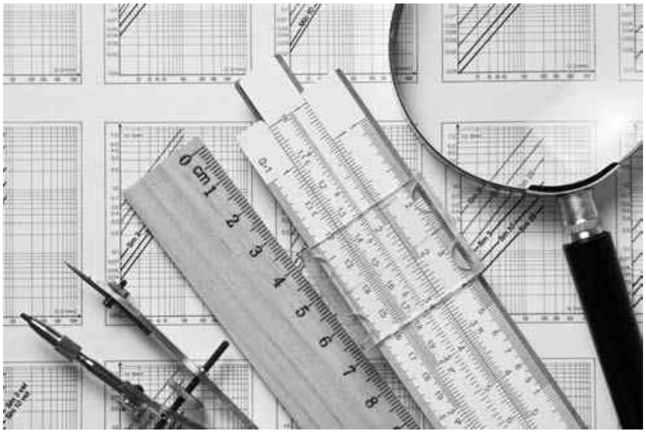


Figure 8-12 Tools used for manual heat load calculations.

This formula is sufficient for many manual heating-only calculations (Fig. 8-12). The outdoor design temperature must be obtained from reference publications such as the *ASHRAE Handbook of Fundamentals*. The outdoor design temperature is an average of recorded temperatures for a given location, not a randomly selected temperature based on the user's experience with the coldest winter day.

The U value in the formula is the reciprocal of the sum of the resistances (R value) for each type of material in a building component, such as a wall or window and can be determined from the following relationship:

$$U = 1/R_i + R_1 + R_2 + \cdots + R_o$$

where R_i = the resistivity of a "boundary layer" of air on the inside surface.

R_1, R_2 = the resistivity of each component of the walls for the actual thickness of the component used. If the resistance per inch thickness is used, the value should be multiplied by the thickness of that component.

R_o = the resistivity of the "air boundary layer" on the outside surface of the wall.

The R value for most common building materials must be obtained from the manufacturers of the components or from reference books. For a typical wall the interior surface of the wall, R_i, assuming still air, will have a resistance of 0.68. The outside-surface R_o value will be 0.17 if we include the effect of a 15-mi/h wind.

Assume the R values for each component including insulation of 13.0 add up to 19.11. U is the reciprocal of the resistance and 19.11 is divided into 1 to obtain 0.0523. It would be common practice to round this value to 0.05. This calculation ignores the thermal bridging effect of the wood stud, which is significant. If we remove the resistance value for the insulation, 13.0, and substitute the R value for the wood stud, 4.38, the total R value becomes 10.49, and the U value is 0.095. The *ASHRAE Handbook* lists two methods of combining these U values into one number for the entire wall. The parallel-path method results in a U value of 0.063, and the isothermal-planes method yields a *U* value of 0.067. The difference between these numbers will not be significant in a total building heat loss calculation.

Automated Heating and Cooling Load Calculations

After World War II, people began to expect their homes, offices, schools, and other building to be provided with air-conditioning systems as well as heating systems. This led to the development of manual methods to calculate the heat gain of a building in addition to the heat loss. These hand calculations were very time-consuming to perform, so they were adapted to computers, thereby speeding the process. There are several computerized heating and cooling load programs available today, including Trace 700 by the Trane Company, E20-II by Carrier Corp, Load Tool by Taco, Inc., and Rhvac by Elite Software, to name some of the most common ones. Most of the programs have an initial cost as well as an annual fee for software maintenance. The Load Tool program by Taco is provided as a free download from the company website. See Fig. 8-13 for a sample of an output screen of the Taco Load Tool.

Many methods of calculating heating and cooling loads have been created over the years. At differing times, ASHRAE has developed total equivalent temperature difference (TETD), cooling load temperature difference (CLTD), transfer function

FIGURE 8-13 Taco Load Tool results screen.

method (TFM), heat balance (HB), and radiant time series (RTS) methods. The Air Conditioning Contractors of America (ACCA) has created the manual N method for commercial buildings and the manual J method for residences. Different programs are used for 8760 hour-by-hour annual energy analyses such as EnergyPro, eQUEST, REM/Rate, and others that are based on the Department of Energy (DOE) 2.1e Program.

The ASHRAE RTS method is probably the best overall commercial peak-load calculation method available today because it provides high accuracy, and the load contributions of the roof, wall, glass, and so on are listed individually. For residential calculations, the ACCA MJ8 procedures are the most widely used.

The Refrigeration Cycle

Heating, ventilation, and air-conditioning systems, whether powered by geothermal or other forms of energy, depend on the refrigeration cycle for space cooling. The *refrigeration cycle* is a sequence of processes that relies on the fundamental nature of matter and the laws of thermodynamics to operate. In other words, it is a practical application of fundamental physical laws.

Cooling takes place as a result of a refrigerant changing state from liquid to gas and back again to liquid as it circulates through a cooling system. With each change of state, heat energy is either absorbed or expelled from the system.

To understand the dynamics of the refrigeration cycle, it is necessary to understand a few key concepts. First, as discussed earlier, heat always flows to cold. Cold does not flow to heat. Heat one end of an iron bar, and the heat travels down the bar to the cold end and will continue to do so as long as there is a difference in temperature within the bar. Once the temperature in the bar is uniform throughout, the flow of heat stops. Likewise, in two adjoining rooms, heat will flow from the warmer room into the cooler room until both are the same temperature.

This can be shown in a Mollier diagram for the Carnot refrigeration cycle plotting entropy against temperature in Fig. 8-14. Here the work (in) supplied by the compressor is shown in the enclosed white box at the upper portion of the diagram

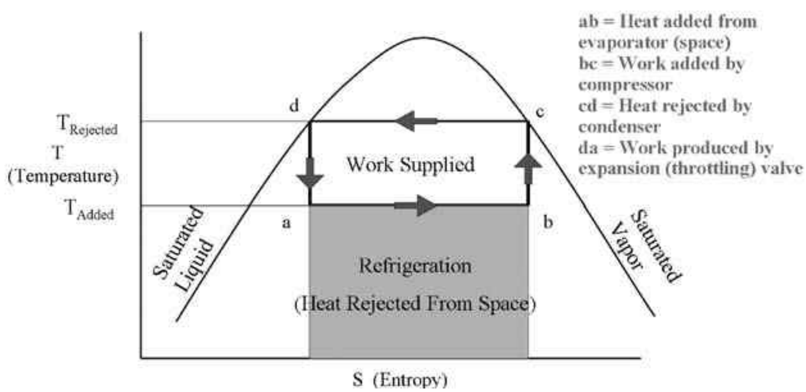


FIGURE 8-14 Carnot refrigeration cycle.

and the refrigeration effect or heat rejected (out) is shown in the shaded box at the lower portion of the diagram.

The efficiency of a refrigeration cycle can be expressed as

$$\begin{aligned}\text{Efficiency} &= \text{COP (Coefficient of Performance)}\\ &= \text{Heat rejected (from space)/work in}\\ &= \Delta Q_{\text{rejected from space}}/\Delta W_{\text{in from compressor}} \text{ (dimensionless)}\end{aligned}$$

In the HVAC industry this is typically expressed in English units as

$$\begin{aligned}\text{EER (Energy Efficiency Ratio)} &= \text{COP (watts/watts)} \times 3.413 \text{ (Btu/kW)}\\ &= \text{(Btu/kWh)}\end{aligned}$$

The maximum efficiency of the refrigeration cycle can be expressed as

$$\text{Maximum Efficiency} = T_{\text{added}}/(T_{\text{rejected}} - T_{\text{added}})$$

For a typical HVAC comfort cooling system

$$T_{\text{added}} \text{ (refrigerant suction temperature)} = 40°\text{F (500 degrees Rankine)}$$

$$T_{\text{rejected}} \text{ (refrigerant condensing temperature)} = 110°\text{F (570 degrees Rankine)}$$

Second, as defined earlier, there are two types of heat energy—sensible heat and latent heat. Sensible heat is the heat energy that causes a change in temperature, as can be read on a thermometer. Latent heat is the heat energy that causes a change in state, such as liquid water to solid ice. One characteristic of latent heat is that the temperature of a substance remains the same while a change of state is taking place. Water remains at 32°F while changing its state to ice as long as the change in state is in process. While any water remains in a liquid state, it will be 32°F. Only when the change of state is complete can the temperature of the ice decrease. Likewise, boiling water remains at boiling temperature (212°F at sea level) while changing state to steam.

You can also characterize latent heat by the state change that occurs. The latent heat of fusion, for example, is the heat involved when a substance changes state from a gas to a liquid and a liquid to a solid. The latent heat of evaporation, on the other hand, is the heat involved when a solid becomes a liquid or a liquid changes state to a gas.

Finally, the terms *hot* and *cold* are relative. They are valid only when comparing one substance or space to another. A 60°F room feels cool when you come in from a summer day. The same room feels warm when you come in from a snowstorm.

When describing the refrigeration cycle, we say that the refrigerant is warm or cool, hot or cold, but here, too, these are relative terms. Even “warm” refrigerant may feel cold to the touch because its boiling point may be well below 0°F.

Knowing this, we can understand the basic principles and operation of the refrigeration cycle. Because the processes of refrigeration are cyclic, we can start at any point in the process to describe how it works.

A schematic of the refrigeration cycle is shown in Fig. 8-15. We’ll start with the evaporator. The refrigerant enters the evaporator (point a) as a cold liquid (40°F). Warm air (75°F) from the interior space we want to cool passes over and around the

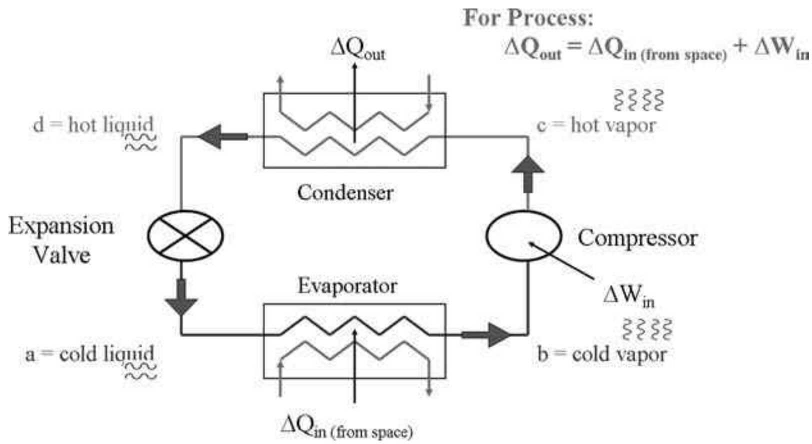


Figure 8-15 Refrigeration schematic diagram.

coils of the evaporator. Because heat always flows to cold, heat in the warm air flows to the cold refrigerant. As the refrigerant absorbs heat, the heat causes a change of state from liquid to gas. The refrigerant leaves the evaporator (point b) as a cold gas (40°F).

The refrigerant next flows into the compressor. The compressor raises the pressure of the gaseous refrigerant, the molecules of gas are compressed in a smaller space, and as a result, the temperature of the gas refrigerant also increases. This is due to Boyle's law which says that the product of pressure times volume is equal to a constant times temperature. Mathematically this is

$$PV = RT$$

In this case the refrigerant leaves the compressor (point c) as a hot gas (110°F). From there the hot, gaseous refrigerant flows into the condenser. As the refrigerant flows through the coils of the condenser, heat in the refrigerant flows to the lower-temperature outside air (95°F) and is removed from the system. As the refrigerant loses heat, it again changes state from a gas to a liquid.

The refrigerant leaves the condenser (point d) as a hot liquid (110°F) then flows through an expansion valve where the pressure, and consequently, the temperature, is greatly reduced, but no state change occurs. The refrigerant needs to be returned to its' original state of a cold liquid. This is accomplished by passing the refrigerant through an expansion valve. This process is the reverse of the compressor. The refrigerant expands and through Boyle's law cools. The now cold liquid (40°F) refrigerant flows into the evaporator and the refrigeration cycle begins again.

Rating Refrigeration Energy Efficiency

The *coefficient of performance* (COP) is the heating energy efficiency of a heat pump. It is the (dimensionless) ratio of the heat output divided by the supplied work input. A geothermal heat pump (GHP) operating at a COP for heating of 4.0 provides 4.0 units of heat for each unit of energy consumed. A heat pump with a higher COP will consume less purchased electricity than one with a lower COP.

Figure 8-16 Water cooled chiller, air cooled chiller, and air cooled condensing unit.

The *energy-efficiency ratio* (EER) is the cooling energy efficiency of a heat pump expressed in units of Btuh/watt and is the ratio of the cooling capacity of an air conditioner (Btuh) divided by the electrical input (watts). Air conditioners with EER ratings higher than 10 are considered most cost-effective. The higher the ratio, the less the unit will cost to operate.

The efficiency of a residential air conditioner over an entire season is rated by the *seasonal energy-efficiency ratio* (SEER). This is defined by ASHRAE Standard ARI 210/240: Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment. The SEER rating of a unit is the cooling output in British thermal units during a typical cooling season divided by the total electrical energy input. The higher the unit's SEER rating, the more energy efficient it is.

Commercial cooling equipment is now being rated by part load conditions. The part load EER is expressed as an integrated energy efficiency ratio or IEER for air cooled equipment and integrated part load value or IPLV for water cooled equipment. (See chapter 14 for a more complete discussion of IEER's and IPLV's.)

The basic refrigeration cycle is used in many types of heating, refrigerating, and air-conditioning products. Both air- and water-cooled chillers use the expansion or boiling of the refrigerant in the evaporator to cool the water. The water-cooled chiller most often uses a cooling tower on the condenser side to change the hot refrigerant gas into a liquid by removing heat. The air-cooled chiller employs the same process but uses ambient air to condense the refrigerant from a hot gas to a liquid. A packaged rooftop heating-cooling unit has air passing through both the evaporator and the condenser to complete the refrigerant cycle. See Fig. 8-16 for a water cooled chiller, air cooled chiller, and an air cooled condensing unit.

A split system operates the same way as a packaged heating-cooling unit except that the evaporator section is usually inside the building, whereas the condenser section is located outdoors (Fig. 8-17). Solid or flexible piping, usually copper, connects the two sections and allows the refrigerant to flow between the components.

Heat Pumps

Heat pumps are an air conditioner with the one important difference being that the refrigerant cycle is reversible. An air-to-air heat pump looks exactly like a split system with an indoor evaporator section and an outdoor condenser section.

Figure 8-17 Air-cooled condensing unit.

When rooms need cooling, the evaporator removes heat from the indoor air and transfers it outdoors to the condenser section via refrigerant piping, where the heat is rejected to ambient air. If the rooms need heating, a reversing valve changes the direction of refrigerant flow so that the outdoor air is cooled and the heat is rejected to the indoor air.

This system works well in milder southern climates but loses efficiency for heating when the outdoor air temperatures drop too low. A supplemental heat source, such as an electric coil or a gas-fired heat exchanger, must be included to provide adequate heat in very cold weather.

Water-to-air heat pumps use the same process, except that the condenser is a refrigerant-to-water heat exchanger. The evaporator section heats or cools the indoor air and either rejects or obtains heat from the water in the condenser section. The water is then heated by a boiler, cooled by a cooling tower, or coupled with the ground in an open or closed loop (Fig. 8-18).

Figure 8-18 Air-to-water heat pump.

Practical Applications: Effects of Building Construction and HVAC Systems

A commercial HVAC system must operate efficiently in the real world. The system designer must take into account not only the psychrometric factors discussed earlier but also the particulars of the building and the HVAC system itself. The construction of a building can have a significant impact on the comfort of the building's occupants. For example, if the building is loosely constructed and drafty, occupants will be uncomfortable in winter (Fig. 8-19). In summer, it may be more humid in the building because of the inability to control the infiltration of humid outdoor air into the building.

The size and placement of windows also will affect occupant comfort. In buildings with large expanses of glass, radiant heat transfer will make an occupant cold if he or she is sitting close to the glass in winter. In summer, the person will be hot if he or she is close to the glass on a sunny day and affected by solar radiation through the glass (Fig. 8-20). Architects like lots of glass but very seldom think about its impact on the comfort of a building's occupants.

A properly designed and operating HVAC system can mitigate the effects of a building's poor construction or design (Fig. 8-21).

In these examples, a properly designed dedicated outside air system (DOAS) can introduce enough fresh air into a building to pressurize it and prevent the infiltration of cold outside air in the winter and warm, humid air in the summer. Installation of floor-mounted baseboard heating and ceiling-mounted passive chilled beams or valence cooling/passive chilled beam can wash windows with warm air (flowing up) in the winter and cool air (flowing down) in the summer (Fig. 8-22).

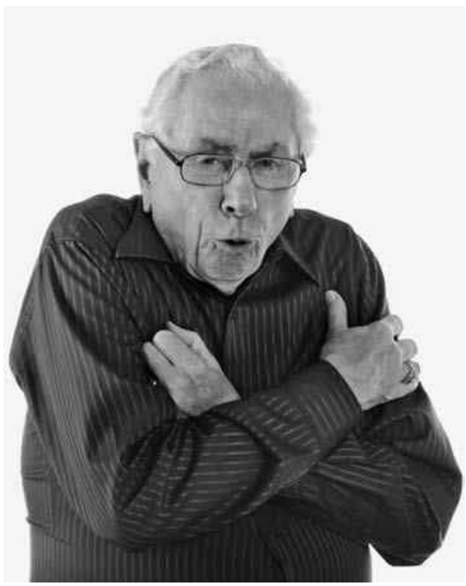


Figure 8-19 Effect of cold drafts on occupants in winter.

Figure 8-20 Effect of cold windows on occupants in winter.

Figure 8-21 Occupant comfort is a result of a good HVAC system.

Other factors in an HVAC system's design also will influence comfort independent of the construction of the building. These include adequate zoning, proper air distribution, and the fluctuation in room temperature.

Adequate zoning is probably the least understood aspect of comfort but one of its biggest influences. In a desire to save money, HVAC designers and contractors will choose HVAC systems that provide fewer zones of control. These systems are generally all-air systems, such as warm-air furnaces or direct-expansion (DX) cooling. For residential applications, this can be functional but not ideal. For commercial buildings with different

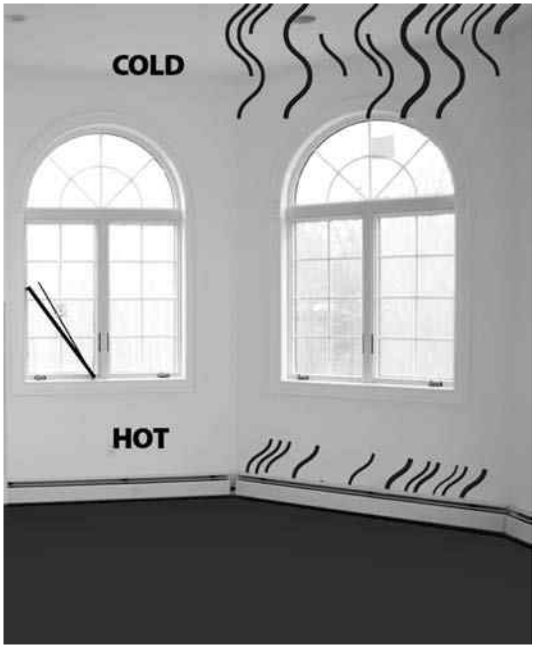


Figure 8-22 Baseboard heat in winter and valence cooling/passive chilled beam in summer.

zones having different thermal loads, this is seldom satisfactory. In fact, lack of adequate zone control is the principal reason for comfort complaints in commercial buildings.

A common error in zoning is to place exterior and interior zones on the same thermostat. Exterior zones in buildings in almost all regions of North America experience seasonal variations from heating to cooling. Interior zones, found in almost every commercial and some large residential buildings, are almost always cooling. This is due to internal heat gains from lights, equipment, and people and lack of exterior walls experiencing heat loss in winter.

If the thermostat for these zones is placed in an exterior room, the occupants in the exterior rooms will be comfortable. The occupants in the interior rooms will be more or less comfortable in the summer. In the winter they will be hot because they very seldom receive cooling given that the exterior rooms are always heating. This may seem obvious, but it is the single biggest error made in the design of HVAC system zoning (Fig. 8-23).

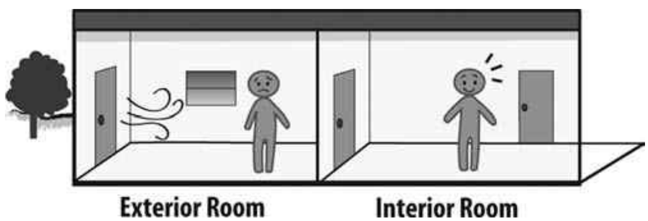


Figure 8-23 Placing interior and exterior rooms in the same zone is a common error.

Another error in zoning is to place exterior rooms on the same zones but mix rooms on different exposures in the same zones. The same reasoning applies to this problem as well, mixing zones of different thermal characteristics on the same zone. For exterior rooms with any number of windows, the position of the sun will affect the thermal characteristics of the space. For instance, if a zone has two different exposures, the exposure with sun will need more cooling than the exposure without sun. Again, if the thermostat is in the room with the sunlight, this room will be comfortable. The room with exposure without the sun will be cold.

An example of the problems created by these kinds of zoning errors was an office building for an accounting (CPA) firm. The building had over 40 CPA offices. CPAs work long hours, especially during tax season. Being comfortable while they are working in their offices is beneficial not only to them but also their clients. Having your mind distracted by the environment is not conducive to focusing on your client's needs.

The original design involved over 20 zones using a water-to-air heat-pump system. The project was bid and was "over the money." As you can guess, the architect wanted all the money taken out of the HVAC system and nothing out of the architectural design.

The architect instructed the HVAC designer to design a rooftop system with three zones, one interior and two exterior. The designer managed to provide five units, one for each exposure and one for the interior rooms. The resulting building was a disaster. No one was comfortable or happy, and the project eventually ended up in litigation.

Some years ago a system was introduced to the HVAC industry that claimed to solve a major problem in the industry—providing almost unlimited zoning but at a low cost. The system, variable volume and temperature (VVT), professed to offer the performance of variable air volume (VAV) systems with numerous zones of control but at the cost of a single-zone rooftop unit. In addition, the zone damper was a low-cost air damper (Fig. 8-24). The system has been referred to as a "poor man's VAV system."

Figure 8-24 VVT air damper.

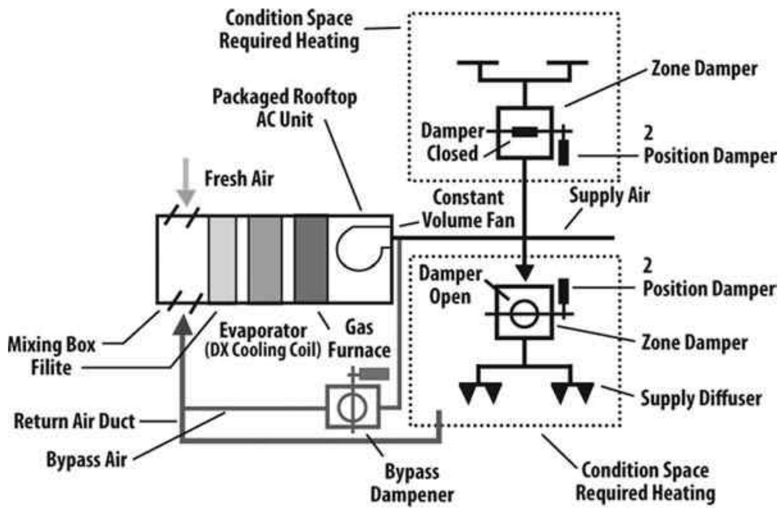


FIGURE 8-25 All-air VVT system operating in cooling mode.

Variable volume and temperature (VVT) systems were supposed to solve the higher first cost of dual- or single-duct VAV systems with hydronic reheat. The concept was to use a single-zone rooftop unit with a gas-fired furnace and DX condensing unit. A single duct would supply alternating airflows of hot or cold air (Fig. 8-25). If most of the zones in a building needed heating, the unit was to run in heating until all heating zones were satisfied and then run in cooling until all cooling zones were satisfied.

The actual application of the system did not live up to its supporters' claims. The system typically mixed interior and exterior zones and zones with different exposures on one unit. One project involved using a single rooftop unit for an office building in a northern climate. The problem in actual operation was that the unit could not get out of heating to restart in cooling on colder days. One zone was always calling for heating. In particular, one zone, the entry, was almost always calling for heating. The interior rooms very seldom got cooling and were uncomfortable in the winter.

The solution is to grossly oversize the unit so that it can quickly satisfy the heating or cooling loads and restart in the opposite mode. This is inefficient and increases first cost as well.

Another solution is to use five units, one for each exposure and one for the interior. This at least put rooms of similar thermal characteristics on the same unit. A similar office building in the same northern climate using this approach worked better but negated the first-cost savings of using one rooftop unit.

This is a practical example of the application of the first law of thermodynamics: You can't get something for nothing. Low costs typically come with low performance. As a result, the system did not become a commercial success, as was originally claimed.

Another example of poor zoning, but in a southern climate, was a building in the Caribbean. The building had multiple floors, with each floor approximately 20,000 ft^2. The original zoning plan on several floors proposed only seven zones. Not only did a number of the zones include interior and exterior rooms, but one zone mixed multiple exterior exposures as well. This zone had three different exposures plus several interior rooms.

No one in this zone would be comfortable. The reality was quite the opposite. The only common denominator would be that everyone would be uncomfortable. A redesign of the layout eliminated interior and exterior rooms on the same zone and put only exterior rooms of the same exposure on the same zone. This resulted in 15 to 20 zones on a typical floor.

The other factor exerting a large influence on comfort is air distribution or air movement. Air movement causes evaporative cooling on your skin, making you uncomfortable (Fig. 8-26). Air cooling systems (VAV, VVT, and VRF) distribute large quantities of air to cool, typically 8 to 10 air changes per hour. Proper selection of diffusers is critical to comfort in these systems.

Lower-cost diffusers such as perforated-face diffusers often "dump" low-velocity cold air into the space and on the occupant's head and body, causing evaporative cooling and uncomfortable systems. VAV systems attempt to mitigate this condition by using slot diffusers. Slot diffusers can create higher velocities and a Coanda effect to reduce evaporative cooling effects. However, slot diffusers are more expensive and are seldom used in today's more competitive environment.

An example of this was a project in California that used rooftop units with perforated-face diffusers. Some areas were so uncomfortable because of the poor air distribution (and evaporative cooling) that the owner had abandoned several rooms. The perforated-face diffusers were replaced with slot diffusers, and the space suddenly became habitable!

Hydronic radiant heating and cooling and chilled-beam systems use substantially less air, often only one to two air changes per hour. These systems will provide higher comfort levels because of reduced airflow. These systems also use substantially less electric fan energy.

Figure 8-26 Drafts cause comfort problems.

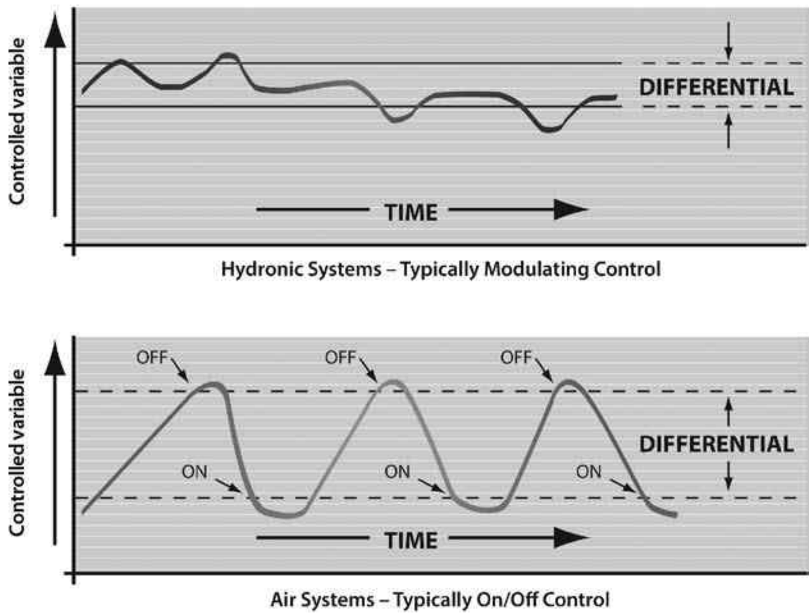


Figure 8-27 Hydronic systems have a higher thermal inertia than hydronic systems and will provide more even temperatures and better comfort.

The other major factor in comfort is the thermal inertia of the fluid used for heating and cooling. Air systems have a lower thermal inertia than hydronic systems. As a result, the air temperature in an air system will vary rapidly (Fig. 8-27 lower diagram) whereas the air temperature in a hydronic system will be more even (Fig. 8-27 upper diagram) and provide better comfort.

It is clear that many factors have a significant effect on occupant comfort. These include but may not be limited to: The particulars of a building's design, the orientation of the building on its lot, the method and materials of construction, the window area, the amount of natural ventilation, interior design, the building's purpose and use, and the type, size and design of the HVAC system.

The challenges inherent in designing an HVAC system to deal with such a complex mix of interdependent factors are significant. The opportunities to meet those challenges are enhanced when the HVAC system design is considered early in the overall building design process, that it is treated as an integral part of that process, and when the HVAC designer works as part of an integrated design team.

Conclusion

In this chapter the authors have presented some of the fundamental principles that govern the design and operation of commercial HVAC systems. In addition, the chapter examined the complex concept of comfort and the many factors that contribute to an individual's perception of comfort. Finally, the chapter examined some of the practical applications of HVAC systems and the problems that can result from faulty design.

Review Questions

1. The first law of thermodynamics, the law of conservation of energy, states that
   a. the net amount of energy added to a system will equal the discharged heat at the supply grills.
   b. the net amount of energy added to a system minus the heat removed will equal the increase in stored energy.
   c. the usable energy provided for the process is equivalent to 1.3 times the input energy.
   d. Both a and b
2. The heart of any building HVAC system is
   a. the reciprocating refrigeration compressor.
   b. the pumps and blower equipment.
   c. the central plant equipment.
   d. the boilers and chillers.
3. A split system operates the same as packaged heating and cooling units except that
   a. high-density polyethylene piping connects the evaporator to the condenser.
   b. solid or flexible piping connects the two sections and allows refrigerant flow between the components.
   c. the evaporator section is usually inside the building.
   d. Both b and c
4. What are the factors that led to the development of manual methods to calculate the heat gain of a building in addition to the heat loss?
   a. People began to expect their homes, offices, and schools to be provided with air conditioning and heating.
   b. The need to reduce allergens in buildings occupied by humans
   c. The advent of electrical service to homes and businesses
   d. The need to control humidity along with temperature
5. Perhaps the best overall commercial peak-load calculation method available today is
   a. manual N heat gain and loss analysis.
   b. ASHRAE radiant time series (RTS).
   c. the ASHRAE bin method.
   d. manual J heat gain and loss analysis.
6. Coefficient of performance (COP) can be calculated for certain types of mechanical refrigeration system and will provide
   a. the ratio of the heat output to supplied work input.
   b. an indication of the energy efficiency of a heat pump.
   c. information that can be correlated to EER.
   d. all the above.
7. The phase-change process for refrigerant can be likened to
   a. the difference between single- and three-phase power.
   b. a pot of water on the stove boiling changing water into steam.
   c. thermal exchange between hot and cold liquids.
   d. heat transfer between refrigerant and water.

8. The term air-to-air heat pump refers to
   a. a heat pump that does not use water in the refrigeration cycle.
   b. a heat pump that does not need refrigerant.
   c. a heat pump that uses air across refrigerant coils as a heat-transfer medium.
   d. a pump that heats air.
9. A fan-coil unit comprises
   a. a blower fan and a refrigerant coil.
   b. a blower fan and an electric heater coil.
   c. a blower fan and a hydronic cooling coil.
   d. All of the above.
10. Residential baseboard heaters
    a. can be used to both heat and cool.
    b. are comprised of baseboard molding and integrated electrical resistance heaters.
    c. are typically hydronic or electric.
    d. are a fire hazard.
11. Hydronic systems provide for higher comfort to a building's occupants primarily due to reduced
    a. refrigerant flow.
    b. airflow.
    c. energy consumption.
    d. humidity.
12. One of the biggest influences on comfort that seems to be least understood is
    a. oversizing the HVAC equipment.
    b. undersizing the heating equipment.
    c. adequate zoning.
    d. thermostats.
13. The psychrometric chart is used to indicate all operating parameters of an HVAC system with the exception of
    a. the wet-bulb temperature.
    b. the dry-bulb temperature when below 32°F.
    c. the grains of moisture.
    d. There are no exceptions.

CHAPTER 9

Heating, Ventilation, and Air-Conditioning System Basics

As is the case in many areas of design, form follows function in commercial heating, ventilation, and air-conditioning (HVAC) systems. There is wide variation in the specifics of commercial HVAC systems based on climate, building design and construction, the intended purpose of the building, and cost considerations. However, because the function of the HVAC system is the same in all cases—to provide occupant comfort, and efficient and cost-effective operation—all commercial HVAC systems must share certain components and similar system configurations. This chapter will cover those components and examine several of the basic systems into which they are most often configured.

Basic Hydronic Systems

Central Plant Components

The heart of any hydronic HVAC system is the central plant equipment. On most projects, the primary heating and cooling devices are situated in one location and consists of boilers, chillers, cooling towers, heat pumps, pumps, piping, and accessories.

Boilers

The boiler is the system component that produces heat in the form of hot water or steam for distribution throughout the system. Boilers may use a variety of fuel sources, including oil, natural gas, electricity, and geothermal energy.

Three categories of boilers are commonly used in commercial heating/cooling applications: fire-tube boilers, water-tube boilers, and cast-iron boilers. In a fire-tube boiler, gases heated by combustion pass through tubes immersed in a water-filled chamber where heat is transferred to produce steam. Fire-tube boilers are most appropriate for large buildings that require steam for process or heating loads (Fig. 9-1).

In a water-tube boiler, water passes through tubes that absorb heat directly from combustion gasses outside the tubes. This flexible type boiler is used mostly for hydronic heating systems in medium-sized buildings (Fig. 9-2).

Figure 9-1 A fire-tube boiler.

Figure 9-2 A water-tube boiler.

Figure 9-3 A cast-iron boiler and a modulating-condensing boiler.

Cast-iron boilers, long the standard in many hydronic heating systems, offer installation flexibility. These can be shipped "packaged" as a fully assembled unit or "knocked down" for applications where an existing building opening is too small to accommodate a factory-assembled unit. The many pieces of the boiler are then assembled on site into a complete, functioning boiler.

The combustion efficiency of most boiler types traditionally has been limited to some 80 percent. However, newer, high-efficiency (modulating-condensing) boilers can achieve up to 95 percent efficiency by condensing the flue gases to recover additional energy (Fig. 9-3).

Chillers

For cooling, the central plant equipment that provides air conditioning to a large building is usually a water- or air-cooled chiller. Both types use a compressor—reciprocating, centrifugal, or rotary—to create the refrigeration effect. The difference between the two types of chillers lies in the way in which they reject heat. A water-cooled chiller has its condensing system connected to a cooling tower for heat rejection. An air-cooled chiller uses fans to pull ambient air through the condensing coil to eliminate heat (Fig. 9-4).

Cooling towers (Fig. 9-5) are used to remove or reject heat from water-cooled chillers. The two most common types for HVAC applications are the induced-draft cooling tower, which uses the cross-flow process, and the forced-draft cooling tower, which uses counterflow. In a cross-flow, induced-draft cooling tower, an upward-facing fan pulls air in from the sides of the tower and rejects it out the top. Water flows from the top of the tower down and across the air in cross-flow fashion, thereby cooling it. Counterflow towers have a forced-draft fan that blows air in at the bottom and discharges it up and out the top. Water is sprayed down on the medium, causing the water to be cooled.

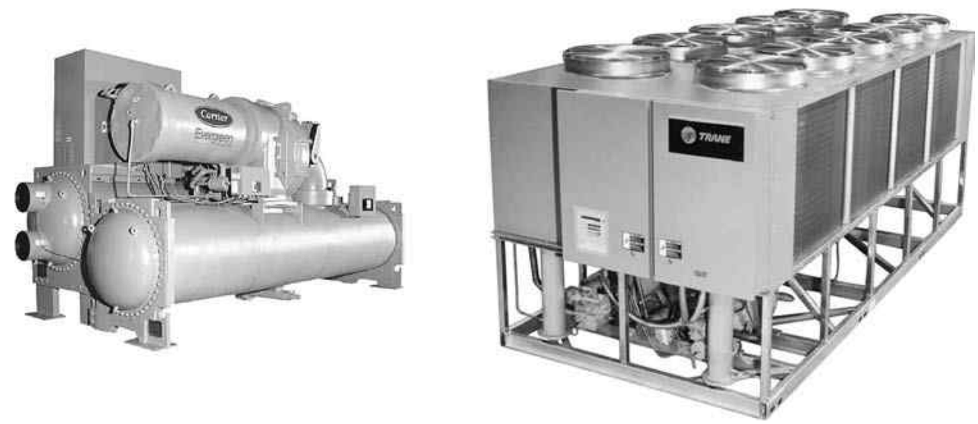


Figure 9-4 A water-cooled chiller (left) and an air-cooled chiller (right).

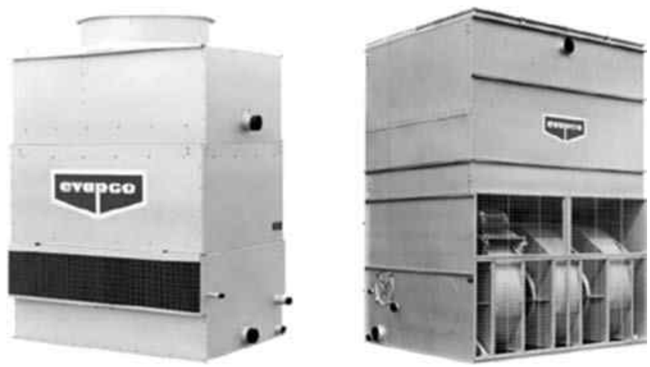


Figure 9-5 An induced draft cooling tower (left) and a forced draft cooling tower (right).

Piping

Boilers and chillers are connected to heating and cooling devices throughout the building with piping systems. As we will see later in this chapter, there are several commonly used distribution piping arrangements. Heating, chilled, or condenser water is circulated from the central plant to the building using any of a broad variety of types of pumps ranging from wet-rotor circulators and in-line pumps to vertical and horizontal split-case pumps, multistage pumps, and base-mounted/close-coupled pumps.

Pumps

There are numerous types of pumps commonly used in hydronic HVAC systems, each with its own characteristics and each type best suited for particular applications (Fig. 9-6). Base-mounted pumps, for example, have been used for larger buildings; whereas inline have been used for smaller buildings. However, larger vertical inline pumps are now being used for larger buildings. They have the advantage of a smaller footprint and simpler maintenance when changing seals. Wet-rotor circulators serve

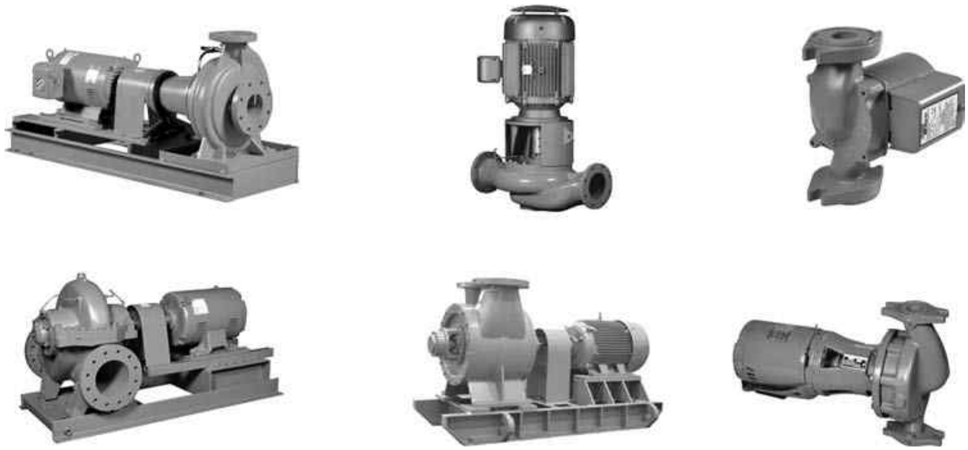


Figure 9-6 The Taco family of pumps, base mounted (upper left), horizontal split case (lower left), inline vertical (middle center), vertical split case (lower center), wet rotor (upper right) and horizontal inline (lower right).

individual loads such as heating and cooling terminal devices. Horizontal and vertical split-case pumps are usually installed in large buildings and campus or district (city) wide central plants to provide hot- or chilled-water service.

Delivery/Terminal Devices

Delivery or terminal devices are the means by which heating and cooling are delivered to the individual building spaces and provide comfort to the occupants. These devices are available in many forms. Heating units include radiators, radiant panels, convectors, and valance units. Cooling terminal devices include fan coil units, heat pumps, chilled beams and radiant panels (Fig. 9-7).

Figure 9-7 Terminal devices; radiators and convectors (above), fan coil (lower left) and chilled beam (lower right).

Accessories

In addition to these major components, commercial HVAC systems use numerous accessories for system control and distribution. These include various types of flow and control valves, buffer tanks, expansion tanks, air separators, flow and pressure sensors, and zoning devices.

Alternative Approaches

Although the systems and components just described are the most commonly used examples used in commercial applications, there are practical alternatives. For example, another method of providing central plant heating and cooling services is to use the constant temperature of the earth, which eliminates the need for boilers and chillers. Other chapters of this book include detailed information about the design of geothermal heating and cooling systems (Fig. 9-8).

Central plant heating also can be supplemented with active solar panels. They are usually installed on the roof of a building and connected to the central heating plant piping system. Solar panels produce heating water temperatures that are much lower than those of typical boilers, so these applications must be designed both to take advantage of solar capabilities and to recognize its limitations. Domestic water heating is the most common use of hydronic solar heating panels (Fig. 9-9).

Another specialty type of central plant equipment is the thermal storage system using an ice bank. These systems take advantage of the lower electrical rates many utility companies offer during off-peak hours, typically from late at night through early morning. Central plant chillers can be designed to make ice in large storage tanks during the off-peak period. The central plant cooling system then uses this ice to provide some of the building air-conditioning requirements during the hottest part of the day (Fig. 9-10).

One of the original configurations of modern hydronic heating systems and still in use today is the district heating/cooling system. These were first used in the downtown areas of cities with a concentration of commercial buildings. These systems are also common on college and university campuses, where a large central plant with many boilers and chillers provides steam or hot and chilled water to many buildings. Often these central plants use coal-fired boilers to minimize fuel costs. The distribution piping is usually installed in underground tunnels that connect the buildings to the central plant (Fig. 9-11).

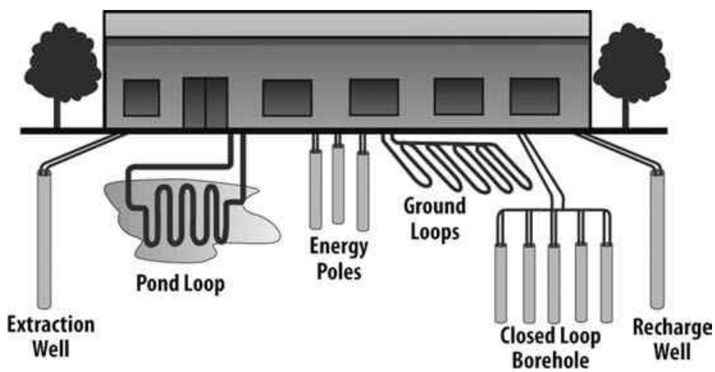


Figure 9-8 Geothermal system schematic.

Figure 9-9 Hydronic solar heating installation.

Figure 9-10 An ice-bank thermal storage tank.

Hydronic Piping Systems

In a hydronic system, the piping system is used to distribute heating and cooling from the central plant to all areas of a building (or district). Although several piping layouts are used, the most common distribution system is the two-pipe system, using one pipe for supply and the other for return.

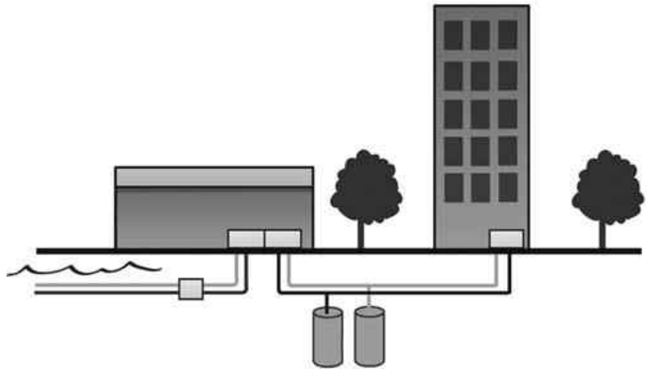


Figure 9-11 Diagram of a district heating/cooling system.

Prior to 1970, many buildings were constructed with the same piping system being used to convey both the heating and cooling water (Fig 9-12). This two-pipe changeover system provided hot water during the heating season and chilled water during the cooling season. A series of valves located in the central plant was changed, depending on the season, so that either the boilers or the chillers were connected to the piping system. These valves could be operated manually by a maintenance person or automatically by a sophisticated temperature-control system.

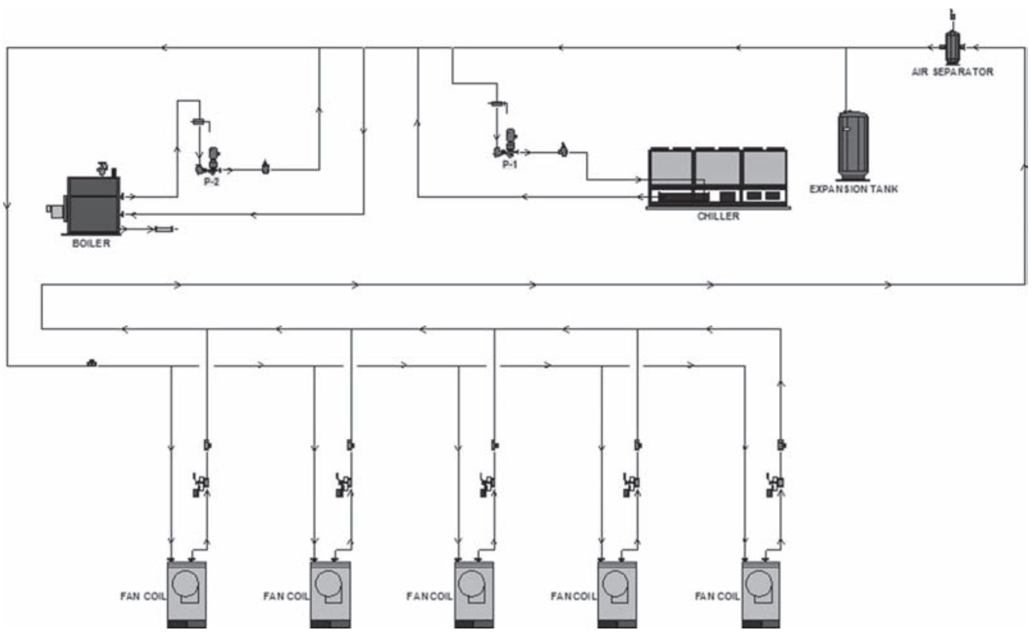


Figure 9-12 Diagram of a two-pipe changeover system.

The shortcoming of such systems is a lack of simultaneous heating and cooling. Frequently, some portions of a building may need cooling, whereas other areas need heating. A common example is a building with a large floor area divided into a number of rooms. The perimeter rooms may need heating during the winter, but interior rooms, with no exterior walls or roof, simultaneously need cooling. The two-pipe heating/cooling system cannot meet these simultaneous requirements.

Such disparate requirements can be more efficiently satisfied by a distribution system that has separate supply and return pipes for heating and cooling—a four-pipe system. Hot-water supply and return pipes can deliver heat to perimeter areas of a building while the chilled water mains simultaneously provide cooling to interior spaces. The four-pipe hydronic system has been used very successfully in millions of larger buildings over the past 60+ years. The most significant disadvantage of this design, however, is the high cost of installing two complete piping systems in every area of a building. Installation costs are further raised because the central plant also must include separate pumps, expansion tanks, air separators, valves, and temperature controls for each piping system (Fig. 9-13).

All piping systems must include a method of ensuring that the proper amount of heating, chilled, or condenser water flows to each terminal device. This can be achieved in several ways. If the supply and return pipes start in the central plant and extend to each heating or cooling coil, the system is called a *direct-return type*. This employs the idea of "first coil supplied is the first coil returned." The terminals closest to the main circulating pumps will experience a high-pressure drop across their coils, which will result in excessive flow unless balancing valves are included in the design. These valves restrict the flow to the coils near the boiler room and force water to the more distant areas of the building.

A much more effective design uses a reverse-return piping system. This employs the idea of "first coil supplied is the last coil returned." Each coil on the reverse-return piping system will "see" the same pressure differential and thereby be mostly self-balancing (Fig. 9-14).

An old idea of using only one pipe to both supply and return the hot or chilled water has been reinvigorated and introduced by the Taco company. The system, called *LoadMatch®*, uses computer software to design the piping system so that each heating

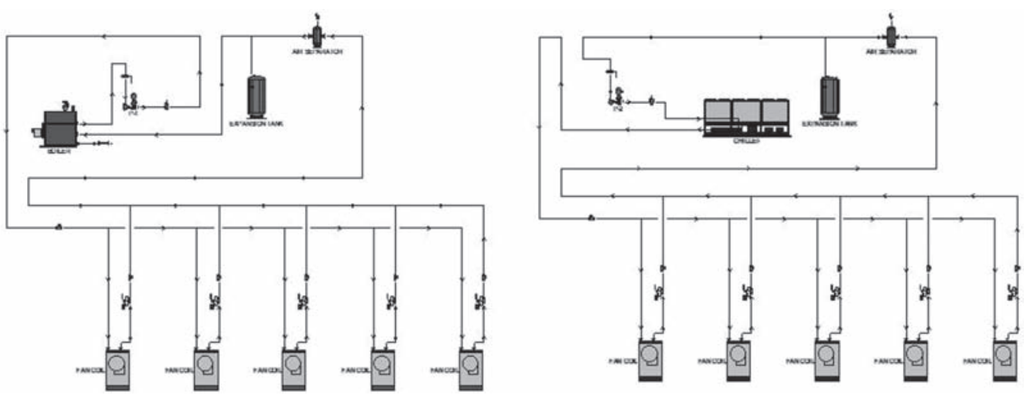


Figure 9-13 Diagram of a four-pipe system.

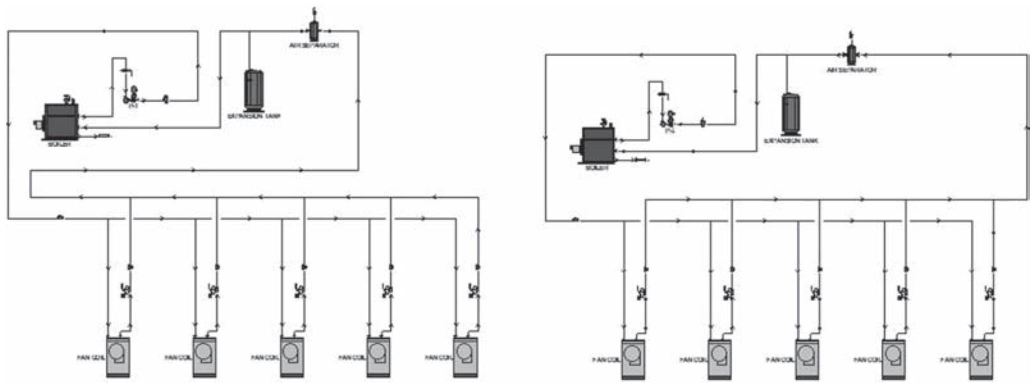


Figure 9-14 Direct-return piping system (left) and reverse-return piping system (right).

or cooling unit receives the appropriate amount of water to satisfy the needs of the given space. This results in a very significant cost savings because system piping is reduced by up to 40 percent. In addition the system is self balancing reducing commissioning and simplifying operation. In addition the pumping energy is reduced by up to 30 percent since both control and balance valves are eliminated (Fig. 9-15).

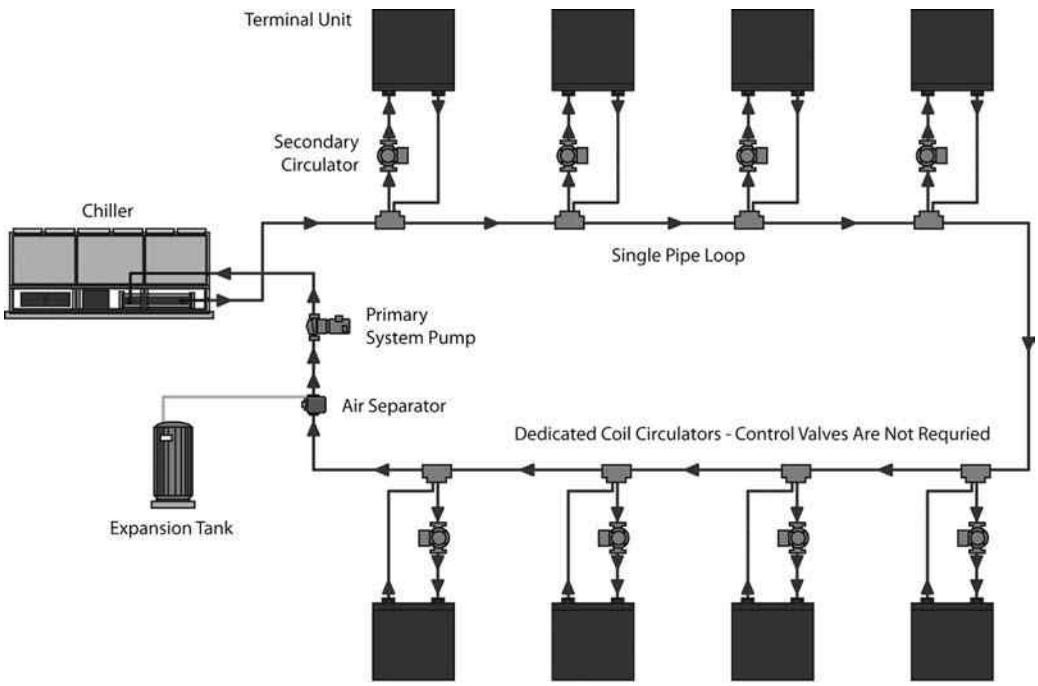


Figure 9-15 LoadMatch single-pipe system.

Hydronic Terminal Units

The terminal units are the interface between the HVAC system and the building spaces and their occupants. It is the terminal units that actually deliver the heating/cooling effects of the system.

Systems that provide only space heating may use baseboard or fintube units. The term *baseboard* refers to lighter-duty metal cabinets enclosing heating elements often consisting of aluminum fins on a copper pipe. These units are most appropriate in residential or very light and inexpensive commercial applications. Fintube heating units have a similar internal element of copper pipe with aluminum fins, but the cabinets are made of heavier steel and come in many shapes, sizes, and colors. These are used in all types of commercial, educational, and institutional buildings (Fig. 9-16).

Fan-coil units and cabinet-unit heaters are used when larger amounts of heat are needed than can be delivered by fintube or baseboard heaters. Both of these units use internal fans to force air across water-to-air-type coils and deliver it to the conditioned spaces. Cabinet heaters typically provide only heating, whereas fan-coil units can be used to both heat and cool a room. Both types of units have durable metal cabinets that can be used for mounting on a wall or in the ceiling, and have a wide range of heating, cooling, and air-delivery capabilities (Fig. 9-17).

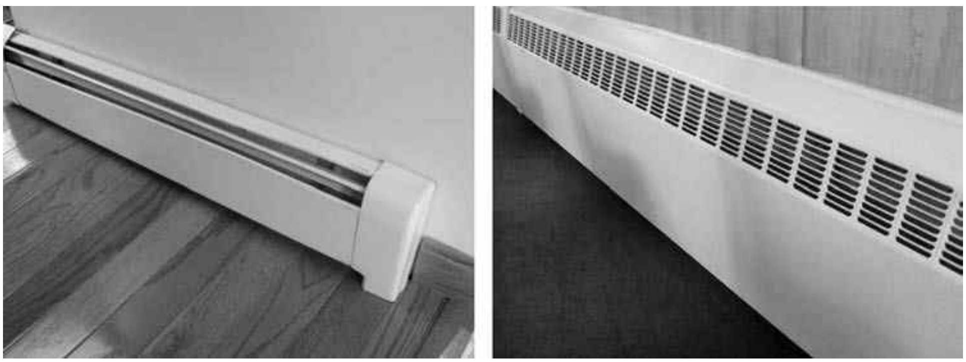


Figure 9-16 Residential baseboard and commercial fintube radiation.

Figure 9-17 A wall-mounted console unit and a ceiling-mounted unit.

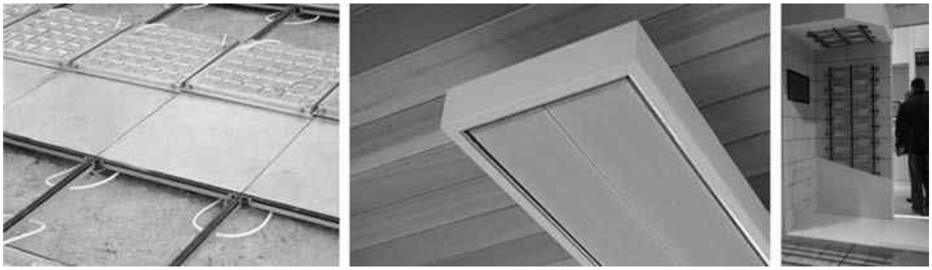


Figure 9-18 Floor-mounted, ceiling-mounted, and wall-mounted radiant panels.

Another type of terminal unit finding more applications today is the radiant panel. These have been on the market for many years but mostly as ceiling-mounted heating panels. They are made of a copper tube bonded to the back of a metal panel designed to sit on the tee bars of a lay-in ceiling. Fiberglass insulation is installed over the top of the panel to slow the heat flow upward and increase the radiant heating effect in the rooms below. Radiant panels are finding increased use today as engineers search for more efficient ways to provide air conditioning (Fig. 9-18). The panels are designed like the heating units, but chilled water is circulated through the copper piping. This provides a radiant-cooling effect in the room below the panel. Special attention is needed in the design of these systems to ensure that condensation does not form on the panel surface. These panels are covered in more detail in Chap. 11.

Chilled beams are used in the most modern, low-energy-use buildings to deliver fresh air and air conditioning to the rooms. A passive chilled beam operates much like a radiant panel. Cold water circulates through a coil in a ceiling-mounted unit to provide radiant and natural convection cooling to the room below. An *active* chilled beam provides the same radiant cooling coil but is also used to deliver dehumidified fresh air through slots along the side of the coil (Fig.9-19). The airflow across the coil substantially

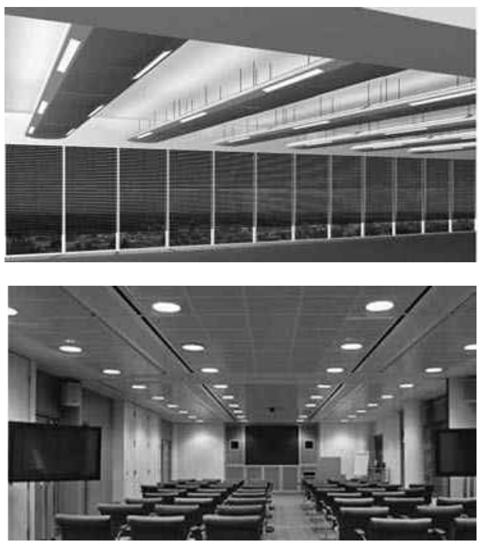


Figure 9-19 Diagrams of passive and active chilled beams.

Figure 9-20 A school classroom console-type unit ventilator.

increases the (forced) convection cooling delivered to the room while removing moisture and thereby preventing condensation. Radiant cooling and chilled beam systems are covered in detail Chap. 11.

A unit ventilator is similar to a fan-coil unit but is usually of larger capacity and has the ability to introduce fresh air to the room. Historically, school classrooms were designed with unit ventilators in areas where building codes required outside air to be introduced for each student, even though unit ventilators often had only heating capability (Fig. 9-20). The unit ventilator is able to perform both functions in a heavy-duty metal cabinet that is typically mounted on the outside wall under a window. Unit ventilators are also available with chilled-water or direct-expansion cooling capabilities. These units have drawbacks, however. Teachers frequently complain of the noise generated by the fan, and kids love stuffing objects into the discharge air grilles. In cold climates, the fresh air coming into the back of the unit also can cause the coils to freeze and break.

Another type of hydronic terminal unit is called a *water-source heat pump*. These units contain a direct-expansion refrigeration system capable of operating in two directions. A fan forces air over a coil, which heats or cools the air depending on the direction of refrigerant flow. The other side of the refrigerant circuit contains a coaxial coil, where a flow of water is heated or cooled. When the heat pump is in air-conditioning mode, the air is cooled, and the water is warmed. When the unit is in heating mode, the reverse takes place. Air is heated, and water is cooled. The water side of all heat pumps is connected to a piping system. This can be a closed loop, ground-coupled, or open-loop system (Fig. 9-21).

One heating and cooling system noteworthy for having one of the lowest initial costs is the packaged terminal air-conditioning (PTAC) unit. These units are commonly found in motels, hotels, and apartment houses as self-contained heating and cooling units mounted through a wall. They contain a refrigerant system for air conditioning

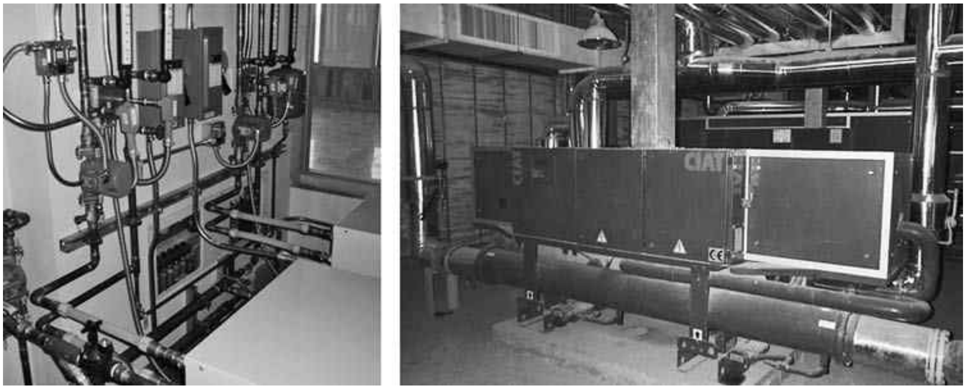


FIGURE 9-21 A closed-loop system and a geothermal ground-coupled open-loop system.

FIGURE 9-22 A motel-type PTAC unit.

and an electric or hydronic coil for heating. In moderate climates, PTAC units are designed as heat pumps, with the ability to heat and cool a room without a separate heating coil (Fig. 9-22). The drawback to these units is that they are noisy and create uncomfortable drafts in the room.

A computer-room air conditioner (CRAC) is a very high-end heating and cooling system designed specifically for the needs of main-frame computer rooms. Their primary function is to provide large amounts of cooling, but they also may contain a hydronic coil for limited space heating. CRACs also have a humidifier to maintain a minimum level of moisture in the space to facilitate flow of paper through the printers. Sophisticated electronic controls cycle the cooling to remove excess humidity, maintain space temperatures, monitor all functions of the CRAC, and provide alarms for system malfunctions (Fig. 9-23).

Figure 9-23 A computer-room air-conditioning (CRAC) unit.

Basic Air Systems

Most large buildings in the United States have been designed over the past 50+ years with basic or advanced air-handling systems. The basic air system consists of a fan unit, ductwork system, and terminal distribution units (Fig. 9-24). The fan is usually called an *air-handling unit* and consists of a centrifugal fan, heating coil, cooling coil, and filter system. The heating coil can be hydronic hot water, steam, or electric resistance. If the system is to provide air conditioning, a cooling coil is included using either hydronic chilled water or direct-expansion refrigerant. The air-handling unit discharges tempered air into a system of ductwork that conveys it to the terminal distribution devices. Ductwork is made of galvanized sheet metal or rigid fiberglass boards. Air terminals are mounted on the ceiling, sidewall, or floor depending on the construction of the building.

The most basic air system is a single-duct, constant-volume system (Fig. 9-25). Such a system uses an air-handling unit to discharge one temperature of air to all rooms. The fan runs at a constant volume, delivering air to each room in a fixed amount. One thermostat controls the air-handling unit and adjusts the amount of heating and cooling that will be delivered to all rooms. If all rooms have similar heating and cooling needs, this system can provide very satisfactory results. However, much too often rooms have varying needs caused by the number of people, exposure to sunny or shady sides of the building, lights being on or off, and many other factors. This causes the actual temperatures in individual rooms to be considerably different from the desired temperature set point.

Another type of basic air system is a dual-duct constant-volume system (Fig. 9-26). This type of system was designed to provide for the different heating and cooling needs of each room. This system uses two ducts with cold air flowing in one duct and warm

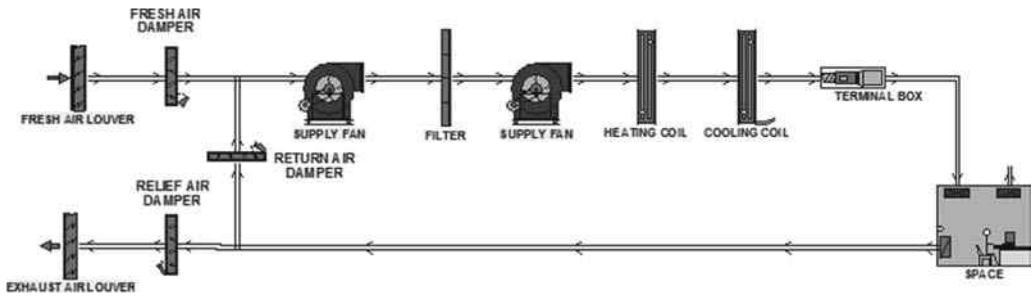


Figure 9-24 An air system diagram.

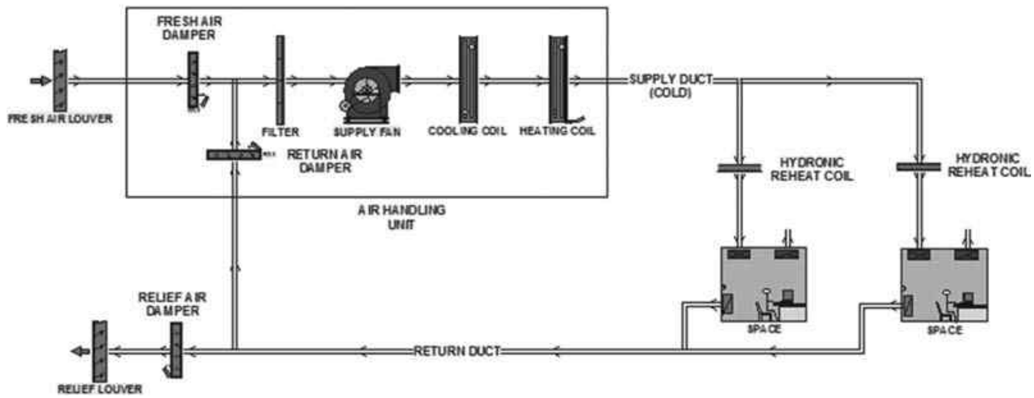


Figure 9-25 A single-duct, constant-volume system.

air in the other. At each room, a thermostatically controlled damper opens the warm duct when heating is needed and the cold duct when cooling is required. The damper also can be positioned, modulated, at many locations to blend the warm and cold air to exactly match the needs of each room. This concept has worked extremely well for many years and was used widely until the mid-1970s to the 1980s. However, as energy costs escalated, many building owners and designers recognized that mixing heated air with cool air was wasteful of both. Most dual-duct, constant-volume systems have been modified over the past few decades to operate as variable-volume systems.

A variable-air-volume (VAV) system (Fig. 9-27) changes the amount of air being delivered to each room in response to a wall-mounted thermostat. Cold air is discharged by the air-handling unit into the ductwork system. A thermostat is connected to a motorized damper in the branch duct for each room. This damper opens and closes to vary the amount of cold air supplied. The maximum damper position supplies the amount of cold air needed at the highest cooling requirement. The minimum damper position supplies the least amount of air needed to satisfy the ventilation requirements

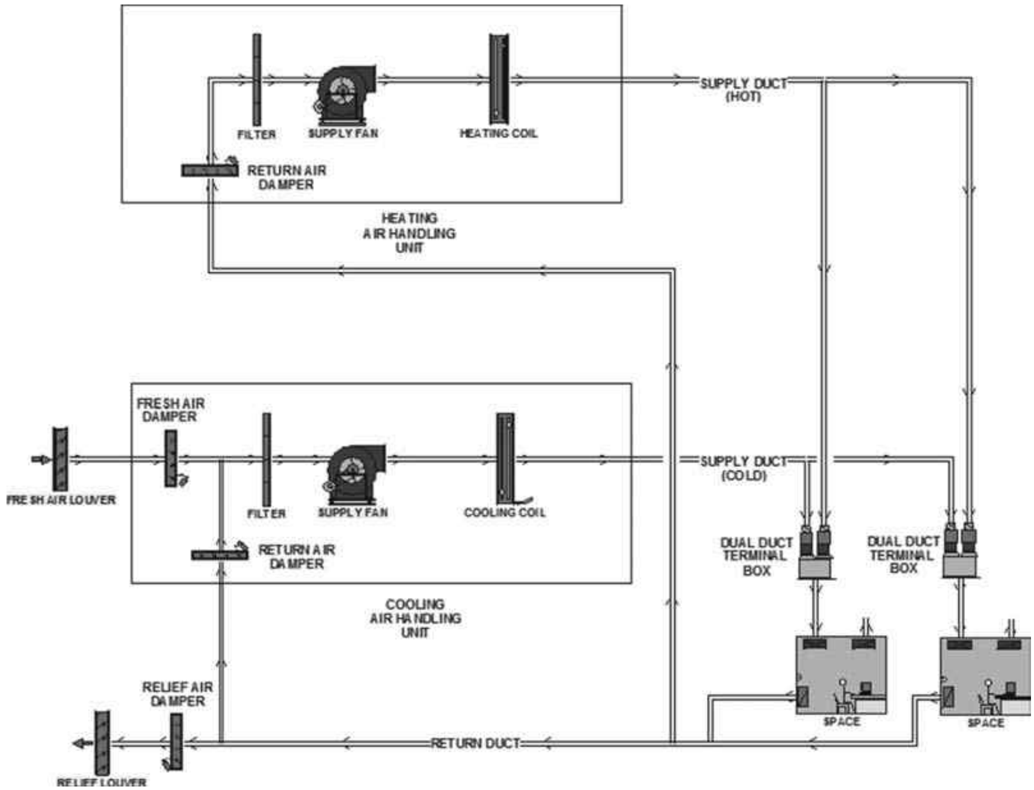


Figure 9-26 A dual-duct constant-volume system.

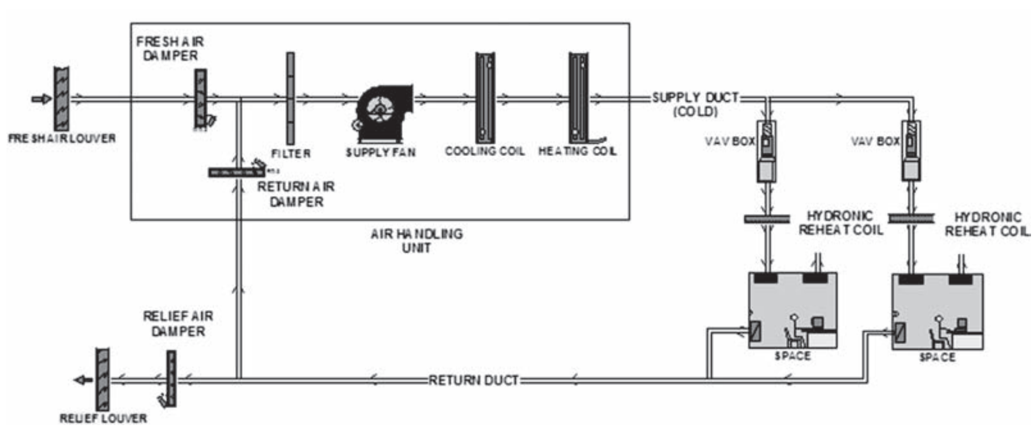


Figure 9-27 An single duct VAV system.

of applicable codes. If the airflow at the minimum damper position is more than the room requires, a heating coil located near the VAV terminal will warm the air to prevent overcooling the room. This is called the *reheat coil*, and it can be hydronic hot water or electric resistance.

Some VAV systems use induction terminals, which are located under the windows. The cold air from the air-handling unit is discharged through the terminal, inducing a large quantity of room air to travel through the unit. This raises the supply air temperature is the fan terminal unit, which provides more comfortable room conditions. Another type of VAV terminal includes a fan, which delivers air either parallel to or in series with the primary cold air. This fan maintains constant room air motion, providing for greater comfort while the cold air varies to save energy.

One of the most commonly used basic air systems is the single-zone packaged rooftop system (Fig. 9-28). These units come to the factory preassembled with fan, heating section, cooling section, and filters. The cooling is most often supplied by a direct-expansion refrigerant coil. The heating section can be hydronic hot water, natural gas–fired, or fuel oil–fired. The gas-fired heating section is by far the most common in parts of the United States where it is readily available. The rooftop units are usually mounted on a curb. The supply and return ducts are connected to the distribution ductwork, and one wall-mounted thermostat controls all functions. These systems operate in exactly the same way as a single-duct, constant-volume system discussed previously. The disadvantage to this system is that it is only a single zone with one thermostat.

The split system is another basic air system. Two components, a furnace and a condensing unit, are split or separated, with the furnace installed inside the building and the condensing unit outside and connected with two copper refrigerant pipes (Fig. 9-29). One pipe carries liquid refrigerant into the furnace, where a direct-expansion coil causes

Figure 9-28 A single-zone air system with packaged rooftop unit.

Figure 9-29 A furnace with a remote condensing unit connected with refrigerant piping.

the furnace airflow to be cooled. The other pipe brings the cold refrigerant vapor back to the condensing unit, where a compressor turns it into a hot refrigerant gas. The coil of the condensing unit then converts the hot gas into a liquid and sends it back to the furnace. The furnace is connected to a ductwork system that conveys the heated or cooled air to all rooms served by the system. The split system is used most commonly in residential and light-commercial buildings.

Yet another type of system, the air-to-air heat-pump system, looks very similar to a split system (Fig. 9-30). The difference is that the refrigerant cycle is reversible in the air-to-air heat pump. The indoor furnace is connected to an outdoor condensing unit with copper piping. During the air-conditioning season, the system operates exactly like a split system, with the furnace coil cooling the air and the condensing unit rejecting the heat outdoors. During the heating season, the condensing unit cools the surrounding outdoor air and transfers the heat to the furnace coil, thereby warming the building. This works very efficiently when outdoor temperatures are above freezing. As the weather cools below 32°F, however, the system becomes less efficient and eventually must be deactivated. The furnace must be equipped with electrical resistance coils or a gas-fired heating section to warm the building in the coldest winter weather. For this reason, the air-to-air heat-pump system is used extensively in the warmer climates of the southern United States but seldom in the northern states.

A variation of the split system that is being used more often in recent years is called a *variable-refrigerant-*flow (VRF) *system* (Fig. 9-31). One of the limitations of the split system is that all rooms served by the furnace receive the same temperature of air because there is only one thermostat. A VRF system uses one condensing unit but multiple fan units. The liquid refrigerant flowing from the outdoor condenser is divided into several pipes,

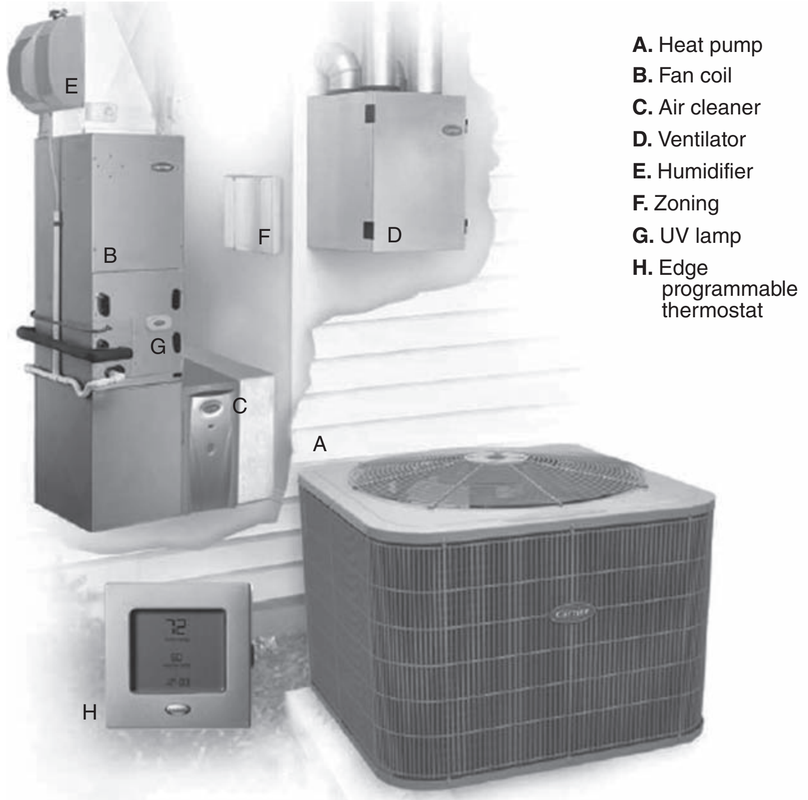


FIGURE 9-30 An air-to-air heat-pump system.

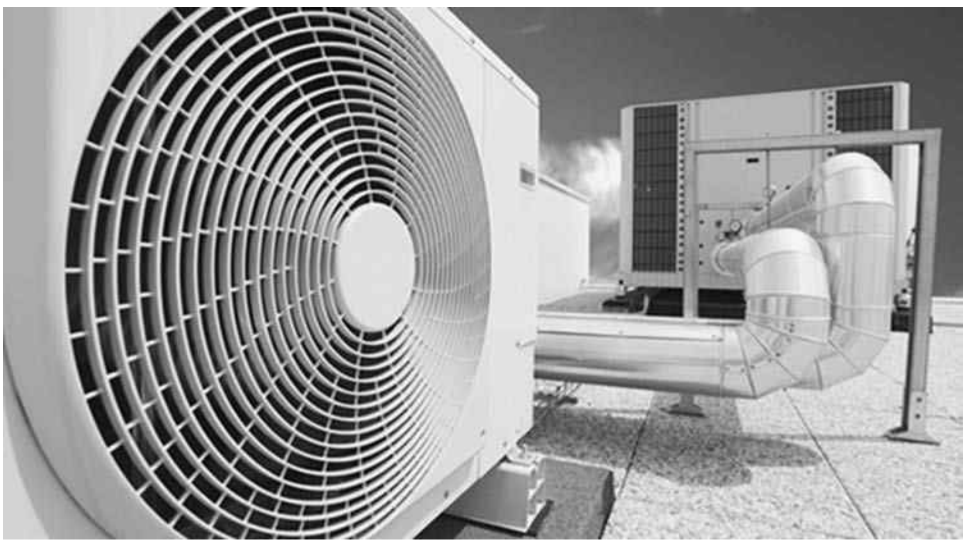


FIGURE 9-31 A VRF system.

FIGURE 9-32 An evaporative cooling unit.

with each going to a fan system controlled by a separate thermostat. This provides numerous rooms or zones of temperature control, which more accurately satisfies the comfort requirements of the occupants. The difficulty with VRF systems is the fluid refrigerant which is toxic and in high enough quantities, lethal. Refrigerant gas is heavier than air and if enough refrigerant is discharged into a space from a leak the refrigerant will displace the oxygen in the room and you will suffocate. As a result refrigeration codes limit the amount of refrigerant that can be discharged into a space to prevent suffocation. The compressor is more efficient at part loads because it is operated variable speed. See Chapter 14 for more discussion on part load efficiencies.

Another system, the direct evaporative cooling system, is frequently referred to as a *swamp cooler* (Fig. 9-32). These systems use the cooling effect caused by the evaporation of water to reduce the temperature of a fan-forced airflow. They are used most commonly in very warm climates that have low outdoor humidity, such as in the American Southwest.

An evaporative cooling system does not perform well in hot, humid climates because the air is already too close to saturation, so little evaporation takes place. These systems are not appropriate for recirculating the air for the same reason. The air becomes too saturated to allow for additional evaporation. The system relies on large amounts of outdoor air drawn by a centrifugal fan through pads of medium moistened with water. The evaporating water cools the air but leaves impurities in the medium. These pads must be changed periodically to keep the airflow from being blocked by the scale-plugged medium.

A variation of the direct evaporative system is called an *indirect/direct* (I/D) *evaporative cooling system* (Fig. 9-33). This system uses the evaporative-cooling concept, but it separates the airflow from the water. The fan-forced supply air travels through plastic tubes, which are covered with a cloth wick medium. Water is sprayed over the

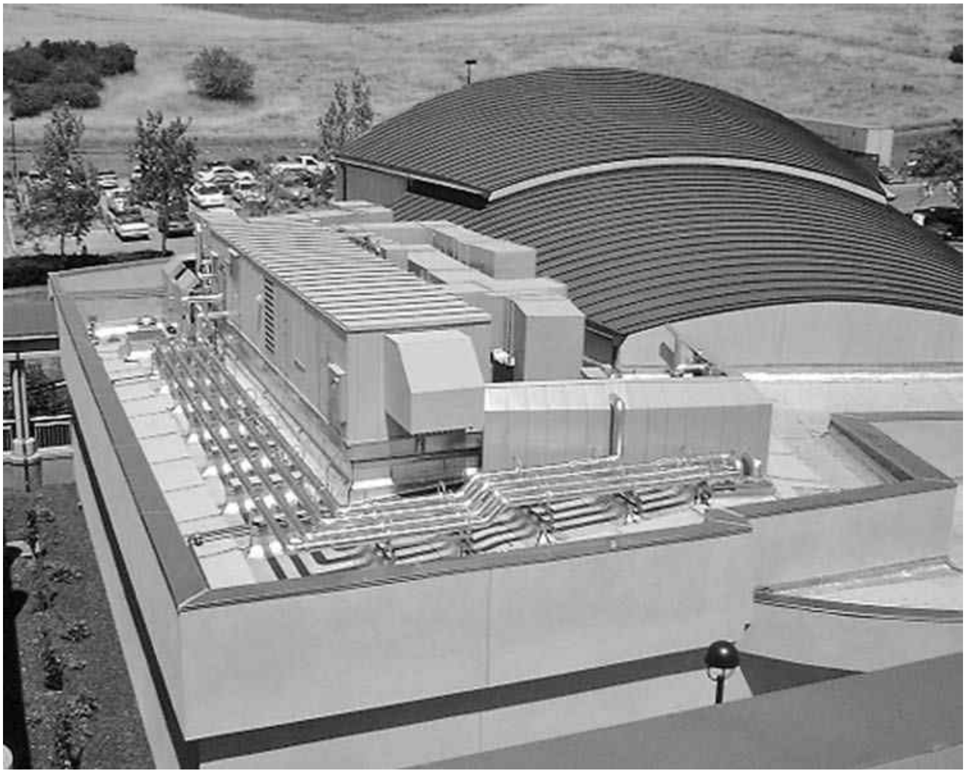


Figure 9-33 An indirect/direct evaporative cooling unit.

medium, causing the air inside the tube to be cooled. This system is less efficient than the direct cooling method, but it has the advantage of not adding the evaporative moisture to the conditioned space. For this reason, it can be used to condition air that is recirculated. The I/D evaporative cooling system also can be used as the first stage of an air-conditioning system that has a refrigerant coil as a second stage. An evaporative precooling stage will reduce the operating cost of a large air-conditioning system significantly.

Figure 9-34 is a psychometric diagram of an I/D system. Outside air at point OA is brought into the I/D unit. From here it is cooled sensibly to LI. The efficiency of the indirect section is typically 60 percent which means the air is cooled 60 percent of the way from the outside air condition OA to the dew point. The air now enters the direct section and is cooled adiabatically following the wet bulb line to saturation. The efficiency of this process is approximately 90 percent which means the air is discharged close to saturation of 90 percent of the way between LI and LD, the point at which it leaves the direct section. The air has been cooled in this example to approximately 57°F discharge air temperature. For this location, Salt Lake, a dry climate will yield a system that can cool the building approximately 80 to 90 percent of the time with the I/D system.

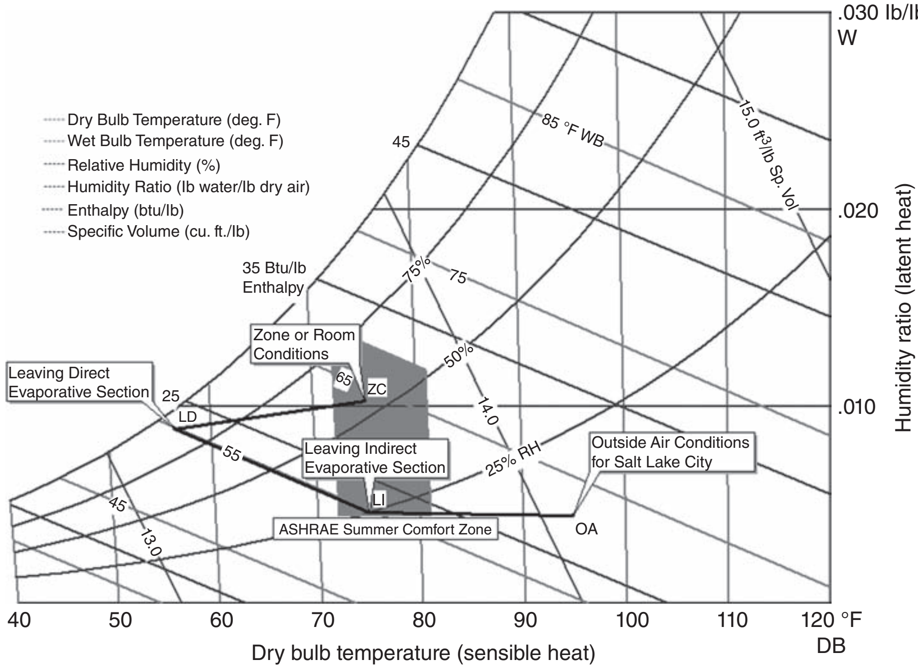


FIGURE 9-34 Psychrometric diagram of an indirect/direct evaporative cooling unit.

Refrigerant or Direct-Expansion Systems

Refrigerant or direct-expansion (DX) systems have been in use for a shorter time than air or hydronic systems. These typically have been smaller split systems for residential and small-commercial use. However, larger commercial DX systems—variable-refrigerant-flow (VRF) systems—are now coming into more general use in the market. VRF has been called "another refinement of DX refrigerant split systems." Unlike earlier versions of DX refrigerant split systems that employed multiple air-cooled condensers matched to a single evaporator and refrigerant lines, VRF systems typically use one large condenser, one set of refrigerant pipes for the entire building, and a separate evaporator for each zone of temperature control, similar to a hydronic chilled-water system, but with refrigerant pipe.

VRF systems have lower cooling-energy costs than previous constant-speed refrigeration equipment because of the variable-speed operation of the compressors. Variable-speed systems of any kind (air, water, or refrigerant) pump less mass flow, resulting in less horsepower to move the fluid. In addition, at part load, the heat exchanger is oversized for the lower mass flow rate because it was sized for full load, and the system is more efficient. There is some lower limit for reduced mass flow and turndown, at which point flow becomes laminar, and heat transfer decreases. For refrigeration equipment, this is somewhere around approximately 25 percent part load.

The HVAC industry is now offering variable-speed refrigeration equipment for chillers, heat pumps, and packaged equipment in addition to VRF equipment. All this equipment exhibits increases in efficiency at part loads similar to VRF equipment.

Although the first cost of a typical DX split system is lower than that of a hydronic distribution system, the first cost of VRF systems is greater because of the more complicated refrigerant management system and controls.

Most significantly, VRF systems use refrigerant, a toxic fluid that in high enough concentrations is a lethal fluid. Mechanical codes have recognized this and set limits on the amount of refrigerant that can be discharged into a room to protect the occupants.

Since acceptance of the Montreal Protocol, refrigerant manufacturers have moved away from use of chlorofluorohydrocarbons (CFCs) such as R-11/R-12 to hydrochlorofluorohydrocarbons (HCFCs) and refrigerants such as R-22. The newer refrigerants, such as R-410 and R-134A, have less impact on the environment, which is good, but they typically require higher pressures and more expensive materials. With rising energy and first costs, there's a need for variable-speed technology to provide more attractive returns.

A different refrigerant, based on the principle of water refrigeration, is now being used in Europe. R-718, or *water vapor* as it's called, is benign on both the environment and building occupants but requires an expensive titanium compressor to be able to spin fast enough to achieve the higher pressures. Work on substituting a cheaper carbon-fiber plastic for titanium is under way in order to achieve higher efficiency at lower first costs.

Choosing a System

In determining the best HVAC system for a given installation, the HVAC system designer is well advised to consider as many relevant factors of performance and cost as possible. For hydronic and air-based HVAC systems, safety isn't a paramount consideration because these systems don't generally pose a potential hazard to building occupants. This is not true of VRF systems because they use refrigerant throughout the occupied and unoccupied spaces in a structure.

The major concern about VRF systems is the safety factor stemming from a potential refrigerant leak. As stated earlier, refrigerant is a toxic fluid that can be lethal in sufficient concentrations and, as such, is classified as a hazard to human health in the relevant codes, namely, ANSI/ASHRAE Standards 15 and 34 and the *International Mechanical Code* (*IMC*).

These codes define how refrigerant systems are applied, including classifying refrigerants in terms of their hazard to human health and the refrigerant concentration limits required to avoid immediate and long-term negative effects on human health. These codes place restrictions on how much refrigerant can be discharged into a living area or workspace. Refrigerant gas is heavier than air, and because of this, it displaces oxygen in a room—if it takes enough oxygen out of a space, a person exposed to it can suffocate. Because refrigerant can't be readily detected by human senses—it cannot be seen or smelled—codes also require refrigerant alarms and ventilation systems in spaces where the concentration of the fluid is high enough to cause a lethal accident.

ASHRAE Standard 34 defines both a *refrigerant concentration limit* (RCL) and an *oxygen-deprivation limit* (ODL). The RCL is "intended to reduce the risks of acute toxicity . . . in normally occupied, enclosed spaces" and is typically expressed in units of pound per 1000 ft^3 or concentration in parts per million (ppm). The RCL deals primarily with physiologic effects on humans to the heart, lungs, and central nervous system. The ODL defines "the concentration of a refrigerant or other gas that results in insufficient oxygen for normal breathing." The ODL deals with asphyxiation.

These two parameters can be used to determine the maximum amount of refrigerant that can be released into a space in the event of a catastrophic leak of refrigerant to prevent injury and death. Because of the nature of hydronic and air-based systems, these restrictions don't apply because the systems pose no similar threat.

Safety concerns aside, in general, it is advisable to choose a heating/cooling system on the basis of its total life-cycle cost rather than solely on the initial installation cost. Making a choice based on first costs can prove to be very expensive over the life of a building despite apparent savings in the beginning.

Energy and maintenance costs vary widely for each type of HVAC system. Recently, variable-speed equipment, which increases efficiency at part loads, further complicated making system cost comparisons. There can be so many variables involved that making a wise determination unaided becomes nearly impossible. However, today there are computer programs that designers can use to greatly simplify the very complex calculations involved.

One such system is the Taco System Analysis Tool (Fig. 9-35). This software enables a designer to compare different system configurations on the fly during the design process. It allows quick and easy comparison of HVAC system operating costs and life-cycle costs

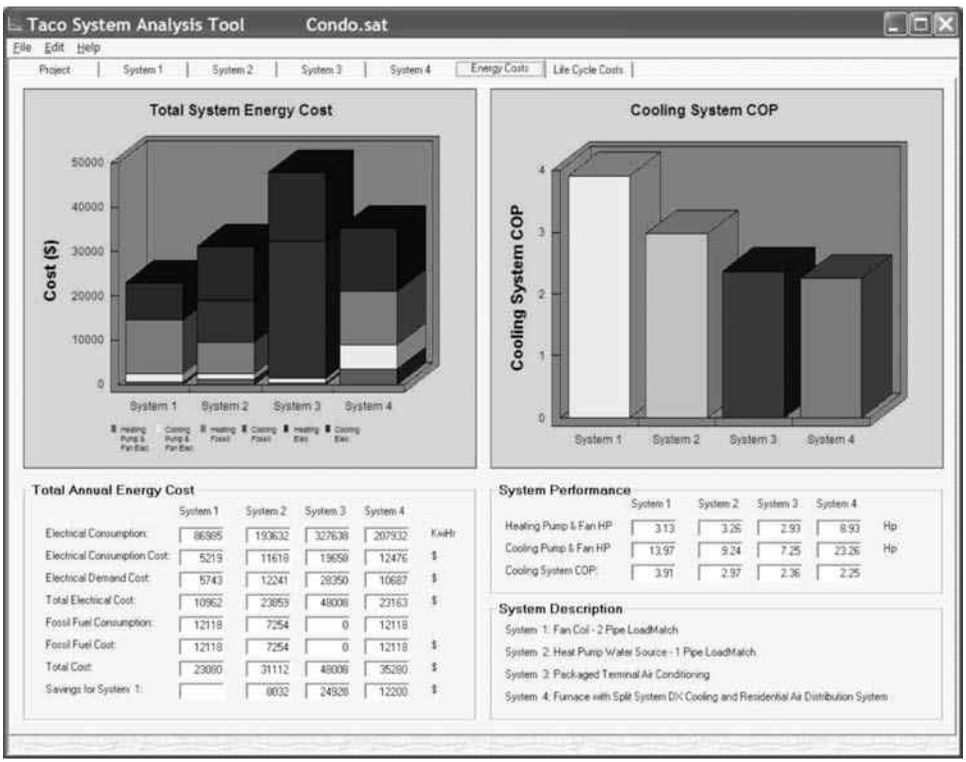


Figure 9-35 Typical output from Taco System Analysis Tool.

at the beginning of a project, when crucial design decisions must be made, and the tool's interactive functions eliminate the need for recalculation as the designer tests various system options. With tools such as these, it may become apparent to system designers that investing a few more dollars in the initial system will save many more dollars during the decades the building will be in service.

Review Questions

1. Wet-rotor circulators normally serve individual loads such as
   a. domestic hot-water tanks.
   b. hydronic heating coils.
   c. terminal cooling devices.
   d. All the above
2. One of the advantages of an ice-bank thermal storage plant is
   a. the ability to use energy off-peak.
   b. the ability to increase the capacity of the plant.
   c. the elimination of heating needs.
   d. Both a and b
3. The use of a two-pipe hydronic system provides challenges for a building in that
   a. the system can only cool or heat, not both at the same time.
   b. the piping became worn too quickly.
   c. electrolysis and biologic fouling of exchangers is frequently present.
   d. controllers are not responsive enough.
4. A passive chilled beam is used in modern buildings to
   a. deliver fresh air to the rooms.
   b. provide cooling to the rooms.
   c. replace baseboard chillers.
   d. deliver dehumidified fresh air through slots.
5. Commercial HVAC systems use several major components and accessories for system control and distribution. Which of the following is *not* part of the system?
   a. Refractometer valve
   b. Buffer tank
   c. Thermostatic expansion valve
   d. Expansion tank
6. The fan assembly used to distribute air throughout a duct system is commonly referred to as
   a. the thrust assembly.
   b. the fan coil.
   c. the air handling unit.
   d. the condenser-fan assembly.
7. The location of an air-cooled remote condenser unit is typically
   a. at least 20 ft higher than the evaporator assembly.
   b. outside the building that it is servicing.
   c. in the supply-air ductwork.
   d. in the mechanical room adjacent to be condenser water pumps.

8. A definition of a direct-expansion (DX) system is a
   a. system in which the size is easily expandable.
   b. system in which the cooling coil contains refrigerant.
   c. system in which the ductwork expands to accommodate greater airflow.
   d. system in which the cooling coil is water-sourced.
9. A variable-refrigerant-flow system is a system in which
   a. chemical refrigerants are used.
   b. multiple direct-expansion evaporators are used.
   c. refrigerant is piped to evaporators throughout the building through copper tubing.
   d. All the above
10. Hydronic HVAC systems can be considered a better choice than DX systems in that
    a. water is used throughout the building as the means of heat transfer.
    b. water is safer and less expensive than chemical refrigerant.
    c. the chance of asphyxiation of the occupants due to a leak is 0 percent.
    d. All the above
11. When considering the specification of equipment for a commercial building, the specifying engineer should
    a. ensure parts availability for future needs.
    b. ensure compatibility with commonly acceptable control protocols.
    c. follow guidelines of ASHRAE Standards 15 and 34 (Classification of Refrigerant Hazards to Humans).
    d. All the above
12. ASHRAE Standard 34 defines the refrigeration concentration limit (RCL) and the oxygen-deprivation limit (ODL) as guidelines that are intended to
    a. "reduce the risks of acute toxicity . . . in normally occupied, enclosed spaces."
    b. be relatively unimportant and only a guideline.
    c. be applicable to evaporative cooling towers.
    d. be a guideline that can be legislated by manufacturers.
13. For hydronic and air-based HVAC systems, safety is
    a. more easily attained by dual-speed compressors.
    b. more easily accomplished than in the design of variable-refrigerant systems.
    c. not as important in commercial buildings.
    d. All the above

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CHAPTER 10

Hydronic Heating, Ventilation, and Air-Conditioning System Equipment

This chapter will examine the various types of hydronic equipment that comprise the basic heating, ventilation, and air-conditioning (HVAC) systems detailed in Chap. 9. This equipment includes pumps and pumping, air elimination, expansion control, heat exchangers, and piping systems.

The various hydronic components are assembled together to operate interdependently—in other words, as a system—to pump water through a piping system and thus deliver heating or cooling to the various interior spaces of a structure. All the components must work together for the system to operate properly and achieve its purpose. However, of all the system components, it is the pump that is most important. The analogy to the human heart is apt. The pump is quite literally the "heart" of the hydronic system and is essential for the "life" of every hydronic system.

Closed- and Open-Loop Piping Systems

In a closed-loop system, one in which the same fluid is continually recirculated, the fluid flows from the area of higher pressure at the pump discharge to an area of lower pressure at the pump inlet. To create that flow, the pump must create, at a minimum, sufficient pressure differential to overcome the pressure loss, or head, in the piping loop that is caused by the friction of the water moving through the system piping valves and fittings. If the pipe is of small diameter or if the run of pipe is very long, the pump will be required to create more pressure to overcome the increased system head. If the pipe diameter is very large in relation to the amount of water flowing through it, the pressure differential required to create flow will be less. In a closed loop system the pump does not have to overcome the height of the water column. This is the case because the static pressure or height of the water column is the same on both sides of the pump and is concealed out.

In an open-loop piping system, one in which the fluid may enter or leave the system, the pressure developed by a pump also can be used to move water from a lower elevation to a higher elevation, such as moving water from one open tank to another open tank above the first. In this case, however, the pump must overcome the resistance (friction) of the pipe interior plus the difference in elevation between the two points in the piping loop. In a closed-loop system, the elevation of the pipe at any point in the loop has no effect on the differential pressure needed to move water around the loop. The piping loop can be in the ceiling of a one-story building or in a multistory high-rise building.

Pumps and Pumping

Although there are several types of pumps commonly used in industrial applications, such as positive-displacement pumps and air-driven pumps, the most widely used type is the centrifugal pump.

Centrifugal Pumps Overview

There are many types and configurations of centrifugal pumps, but they all have the same primary purpose—to create differential pressure in the system. Water or any other fluid (and gases) always flows from an area of high pressure to an area of lower pressure. Centrifugal pumps create this differential pressure, which is often referred to as ΔP. In other words, centrifugal pumps create differential pressure according to Bernoulli's principle, which states that as the speed of a liquid increases, the pressure simultaneously decreases.

According to the Hydraulic Institute, "A centrifugal pump is a kinetic machine converting mechanical energy into hydraulic energy through centrifugal force." Fluid enters the pump casing, or volute, where a motor-driven impeller spins at high speed. Fluid then enters the eye of the impeller, which accelerates the fluid and flings it radially to the perimeter or outside wall of the casing. The cutwater diverts liquid from the edge of the impeller to the pump discharge. The suction or eye of the impeller is the point of lowest pressure. The discharge of the pump is the point of highest pressure.

As the speed of the fluid increases, pressure decreases, thus creating the pressure differential that draws more water into the pump casing in a continuous flow. Centrifugal pumps are also designed so that the inlet is larger than the outlet. As water enters the smaller outlet, pressure is increased further (Fig. 10-1).

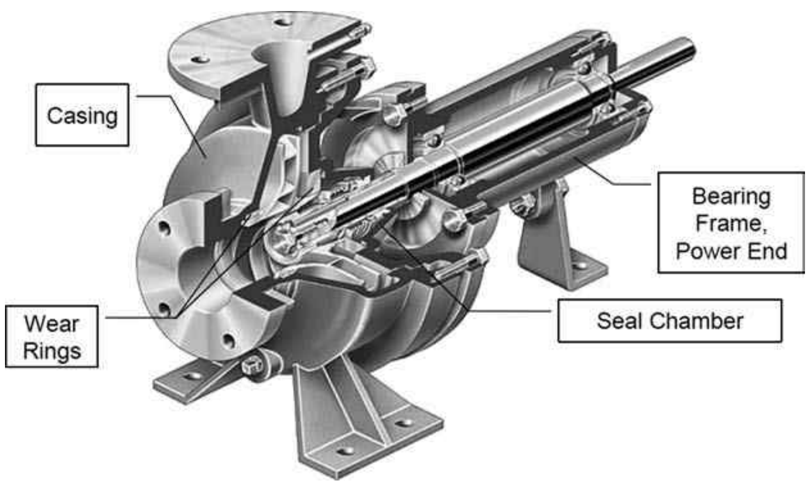

FIGURE 10-1

Centrifugal Pump Types

Base-Mounted Centrifugal Pumps

Base-mounted centrifugal pumps are designed to be mounted on the floor of an equipment room. They are available in several models and are used in a wide variety of commercial HVAC applications, such as heating and air conditioning, pressure boosting, and cooling-water transfer.

These pumps can be close-coupled, with the pump impeller installed directly on the motor shaft, or flexibly coupled, with the motor connected to the pump shaft by a flexible connector. Flexibly coupled pumps are used when vibration and noise concerns are most important. Close-coupled pumps are generally considered to transfer more noise and vibration into the piping system.

Base-Mounted Centrifugal Pump Discharge Arrangements

A base-mounted centrifugal pump may be designed with the discharge chute or outlet to one or the other side—a tangential discharge—or with the discharge on the centerline of the pump. Centerline discharge pumps offer the advantage of having their weight evenly distributed over the feet and base, which improves the stability of the pump while in operation. These pumps are also self-venting because there is no place for air to collect at the high point of the pump. All entrained air is automatically carried up the discharge chute with the system fluid.

The weight of a pump with tangential discharge, on the other hand, is unevenly distributed on the base (Fig. 10-2), and the pump has a pocket at the top of the volute where air can become trapped. These pumps have a plug at the top of the volute that must be removed to release the trapped air. Some major pump manufacturers, such as Taco, Inc., build all their end suction base-mounted pumps with a centerline discharge because of the advantages inherent in such a design.

Vertical In-line Centrifugal Pumps

Vertical in-line centrifugal pumps (Fig. 10-3) are designed to be installed directly in a piping system instead of on the floor of the equipment room. These pumps also can be flexibly coupled or close-coupled, as are base-mounted pumps. These pumps take less floor space to install and are easier to change seals.

Vertical turbine pumps (Fig. 10-4), on the other hand, are designed with the pump motor mounted at the top of a shaft and the pump at the bottom. The length of the shaft

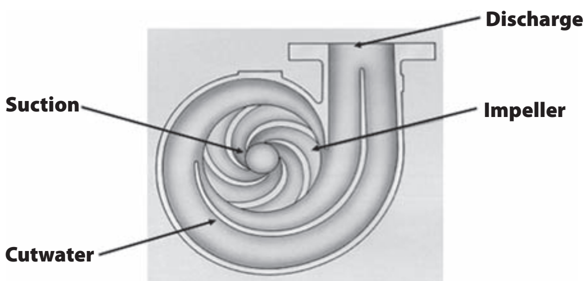

FIGURE 10-2 Tangential discharge pump.

Figure 10-3 Vertical in-line pump.

Figure 10-4 Vertical turbine pump.

can vary considerably, as required by the application. This type of centrifugal pump is used to lift liquid from a sump, tank, or other water supply and may be installed inside or outdoors. Vertical in-line turbine pumps also may be multistage to provide the required lift or head to deliver water as needed.

Horizontal Base-Mounted Centrifugal Pumps

Base-mounted pumps of the horizontal type are manufactured with the shaft in a horizontal position. Like the vertical type, these are also available with the motor flexibly coupled or close-coupled (Fig. 10-5).

Split-Case Centrifugal Pumps

Split-case base-mounted centrifugal pumps (Fig. 10-6) are designed in both horizontal and vertical configurations. The horizontal type requires more floor space in the equipment room but is easy to maintain because the top of the casing is removable. The vertical-inlet/discharge-style split-case pump is more compact owing to its top-mounted piping connections. Split-case pumps are generally available in larger sizes and are always flexibly connected. Both vertical and horizontal models allow access to the impeller and seal without removing the motor or disturbing the piping, which is a significant advantage for performing maintenance or repairs. These pumps are equipped with motors as large as 1500 hp.

Wet-Rotor Centrifugal Pumps

Wet-rotor centrifugal pumps are so called because the system fluid is also used to lubricate the pump. Generally available with lower flow capacities than the other types of centrifugal pumps discussed here, wet-rotor pumps are always close-coupled. Small wet-rotor pumps in commercial HVAC systems are used extensively in zoning and zone-control applications (Fig. 10-7).

Centrifugal Pump Components

Because they are designed to perform similar tasks, most centrifugal pumps have many components in common. These include the casing, impeller, bearing-frame assembly, pump shaft, seal and motor. When the pump and motor are separate components, their

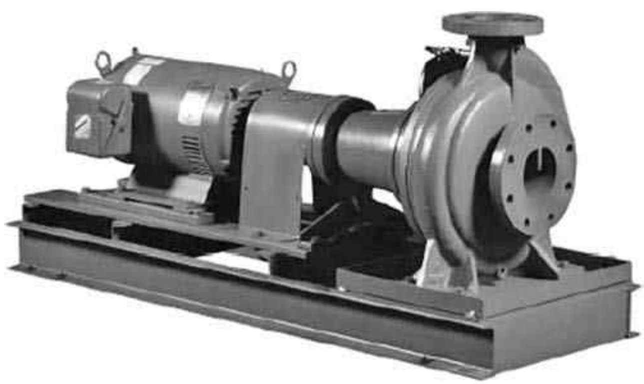

Figure 10-5 Horizontal base-mounted flexible coupled pump.

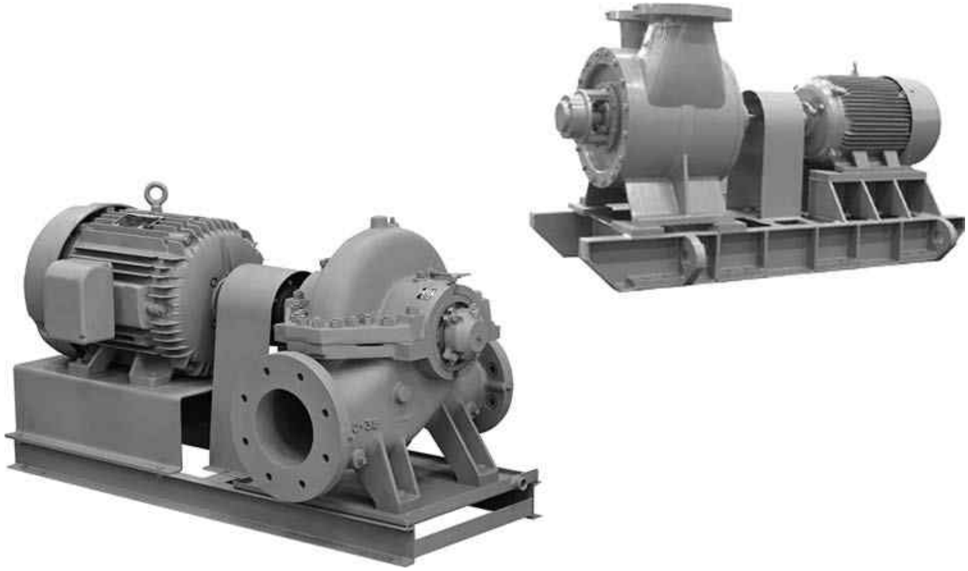

Figure 10-6 Split case horizontal pump (left) and vertical (right).

Figure 10-7 Wet rotor circulator.

shafts are connected by a flexible connector. Casings are usually cast iron, except when the application (e.g., potable water) requires another material such as bronze. Most impellers are bronze, and shafts are either steel or stainless steel, but many alternatives are available for both the impeller and the shaft depending on the application.

Various types of seals are used to separate the fluid cavities from the bearings, including ethylene propylene terpolymer (EPT), carbon, ceramic, and packing box. Motors can be open, drip-proof, or totally enclosed and fan-cooled with standard or premium efficiency. Many specialty motors are also available for unique applications.

Hydraulic Efficiencies and the Best Efficiency Point

No pump is able to convert all the kinetic energy it produces into the pressure differential (i.e., pressure energy) required to create flow in an HVAC system because of such factors as the pump's mechanical operation, friction, turbulence in the flow, and so on. The flow rate where the pump has its highest efficiency—where it converts the maximum kinetic energy to pressure—is called the *best efficiency point* (BEP). The BEP (Fig. 10-8) is important in HVAC system design and pump selection because of its effect on the overall flow range of the pump, its target operating flow range, and other operating parameters.

Affinity Laws

The affinity laws, expressed in a series of formulas, describe the relationship among three important variables—flow, head (pressure), and power—involved in pump (and fan) performance. These formulas indicate that the flow of a pump Q is directly proportional to the revolutions per minute speed R and the impeller diameter D. The head or pressure developed H is related to the squared value of speed and impeller diameter. The brake horsepower B is related to the cube of the speed and impeller diameter.

The pump affinity laws are a series of relationships for flow (Q), head (H), horsepower (BHP), RPM speed (R), and impeller diameter (D). The affinity laws are as follows:

$$Q2 = Q1 \times (R2/R1) \qquad \text{Flow}$$
$$Q2 = Q1 \times (D2/D1)$$

$$H2 = H1 \times (R2/R1)^2 \qquad \text{Head}$$
$$H2 = H1 \times (D2/D1)^2$$

$$BHP2 = BHP1 \times (R2/R1)^2 \qquad \text{Horsepower}$$
$$BHP2 = BHP1 \times (D2/D1)^3$$

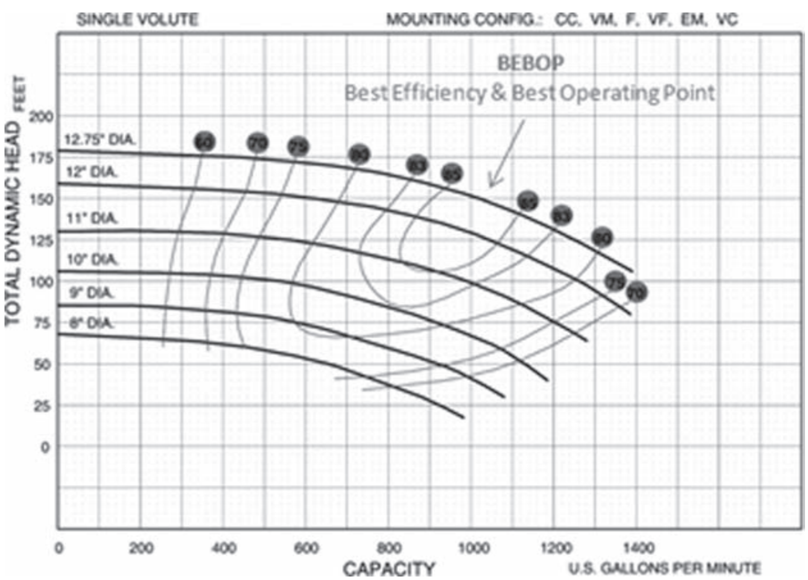

Figure 10-8 Pump curve BEP (best efficiency point).

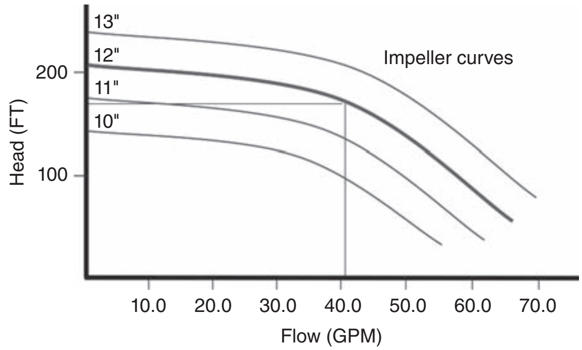

Figure 10-9 Pump curve.

Pump Curves

A pump performance curve, usually called simply a *pump curve*, is a graphic representation of the performance of a pump based on testing by the pump manufacturer. Every pump has its own curve, formed by a series of points, where different head and flow values intersect. These curves vary widely from pump to pump depending on many factors, such as the horsepower of the motor and size and shape of the impeller. Pump curves are useful for providing information on many aspects of pump performance.

A fixed-speed pump can only operate on the curve based on the specific size of the impeller installed by the manufacturer. The pump illustrated in Fig. 10-9 is equipped with a 12-in-diameter impeller, so any combination of flow, in gallons per minute, and head, in feet, must fall on the 12-inch impeller curve. It is impossible for this pump to deliver 20 gal/min at 200 ft of head or 50 gal/min at 100 ft of head because the intersections of those points do not fall on the 12-inch impeller curve.

System Curves

A closed-loop piping system is defined by its system curve, which, like a pump curve, is a graphic representation of system flow and head. Every system has its own characteristic curve because head losses will vary for each system based on the size of pipe, length of pipe runs, fittings, and so on. Every combination of flow, in gallons per minute, and head, in feet, for a specific piping system will fall on this curve. If the piping system is altered in any way, the system curve will change because the head changes for any given amount of flow.

The piping-system curve must be plotted on the same page as the pump curve for a specific pump to determine the correct model and impeller size for each project. The intersection of the system curve and the impeller curve is called the *operating point*. Pump curves also illustrate horsepower requirements and pump-efficiency curves that aid in selecting the best combination of pump, impeller, and motor size (Fig. 10-10).

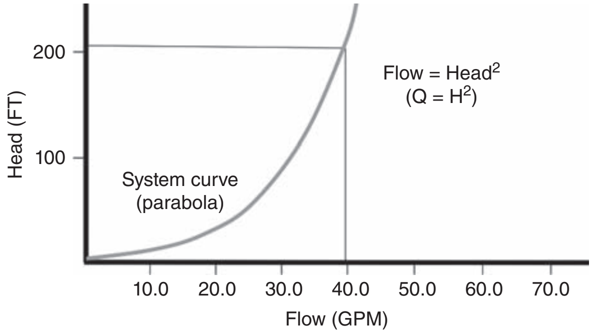

Figure 10-10 System and pump curve.

Parallel Pumping

Parallel pumping—continuously operating two or more pumps—can offer advantages in an HVAC system. First, pumps in parallel greatly enhance system reliability because either pump can deliver approximately 75 percent of the required maximum system flow. This will be adequate in all but the most severe design conditions. Second, the technique can provide opportunities for significant energy savings.

There is a common misconception that operating two pumps in parallel doubles the flow rate. In fact, it does increase the flow rate, but it doesn't double it because of several factors. The increased flow rate brings with it increased head loss owing to fluid friction. The increased rate also alters the efficiency of each pump, and in addition, more energy is required to transfer a given fluid volume.

In parallel pumping, the system curve remains the same, but the pump curves have a significant increase in flow for each condition of head. For systems that require 100 percent reliability, the designer must select two pumps, either of which can provide the full system flow, and the system must be equipped with automatic control systems to start the backup pump if the lead pump fails.

In the example illustrated in Fig. 10-11, parallel pumps would be selected to provide 27 gal/min at 100 ft of head. If 100 percent redundancy is required, each pump would have to be selected for 42 gal/min and 200 ft of head.

Variable-Speed Pumping

With the advent of variable-speed circulators and drives, variable-speed pumping has in recent years become an eminently practical way to achieve higher system efficiencies and save energy in a variety of HVAC applications. The heat load of a building changes frequently as the outdoor temperature varies or when the number of zones calling for heat changes, for example. In variable-speed pumping, the speed of the pump varies on the basis of outside information, such as system pressure or pressure differential, to more exactly satisfy the frequent changes in the heat load.

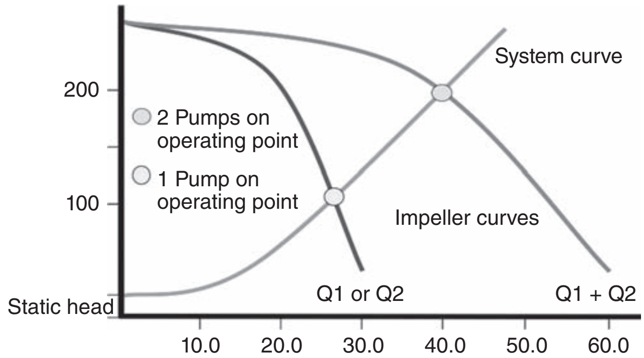

FIGURE 10-11 Pumps in parallel.

HVAC systems are designed to meet the requirements of a benchmark coldest or hottest day of the year. In actuality, this benchmark condition may exist only occasionally. Any HVAC system operates far below its capacity for the great majority of the time. Changing the revolutions per minute (rpm) of the pump to create only the flow necessary to meet the current demand results in substantial energy savings and significantly lowers operating costs. Much of these savings are the result of the affinity laws that, in part, state that if system flow is reduced by 50 percent, the theoretical horsepower required is only 12 percent. In actual operation, inefficiencies in the electronics of the variable-frequency drives (VFDs) that control pumping reduce the theoretical savings somewhat, but the real savings remain significant.

Air Elimination

The presence of air in a hydronic HVAC system is undesirable but inevitable. This means that HVAC system designers and engineers must find ways to reduce or (virtually) eliminate air from their heating and cooling systems.

Air is found in hydronic systems in one of three states:

- *Air dissolved in fluid.* For our purposes, air is always present in water. The amount of air is a function of the fluid temperature and pressure, based on Henry's law. Hot water contains less dissolved air (oxygen) than cold water. High pressure forces more air into solution than low pressure.
- *Bubbles at the fluid surface.* These are bubbles that gather at high points in the piping system when the dissolved air "settles out" of the fluid. This results in air pockets that can negatively affect system performance and efficiency.
- *Bubbles carried by or entrained in the fluid.* The difference between air that creates air pockets and entrained air is the velocity of the system flow and related turbulence created by that velocity. Faster flow tends to be more turbulent, which keeps air bubbles mixed into the fluid. Slower flow allows those bubbles to settle out and rise to high points.

Air is introduced into a hydronic system from many sources. First, every pipe and piece of equipment is filled almost entirely with air before installation of the system begins.

The water used to fill the system contains entrained air bubbles and dissolved oxygen. Occasionally, air also gets pulled into a piping system through leaky seals and fittings if a low-pressure condition is present in the pipe. This is an unusual circumstance, but it does happen. Similarly, plain-steel expansion tanks don't contain a membrane to separate the compressible air from the system fluid. Over time, the air cushion in the tank will slowly get absorbed by the system fluid and then be released again somewhere in the piping system.

Finally, the most common source of ongoing air problems is makeup water. When fluid leaks from a hydronic system, the pressure drops slightly, causing the makeup water valve to make up for it by allowing some fresh water back in. The more leaks in a system, the more makeup water will be introduced. Older piping networks tend to have more leaks due to corrosion over time. The biggest culprit is underground pipes, where leaks can go undetected for years.

Henry's law describes the solubility of a gas in a liquid. It states: At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid. In practical terms, the amount of air dissolved in a hydronic system depends on the temperature and pressure in the system. High pressure forces more air into solution than low pressure, and hot water contains less dissolved air than cold water. See Fig. 10-12 for the solubility of air in water at different pressures and temperatures.

An everyday example of the effect of pressure is the behavior of soda when the cap is removed from the bottle. The fluid inside decreases in pressure, and the dissolved gas, in this case CO_2, immediately bubbles out of the liquid. The effect of temperature is obvious in a pot of water heating on a stove. As the water reaches the boiling point, the escaping oxygen forms bubbles that rise to the surface and enter the atmosphere of the room (Fig. 10-13).

Because there is always some air in any hydronic system, there also must be some way to remove it if the system is to perform well.

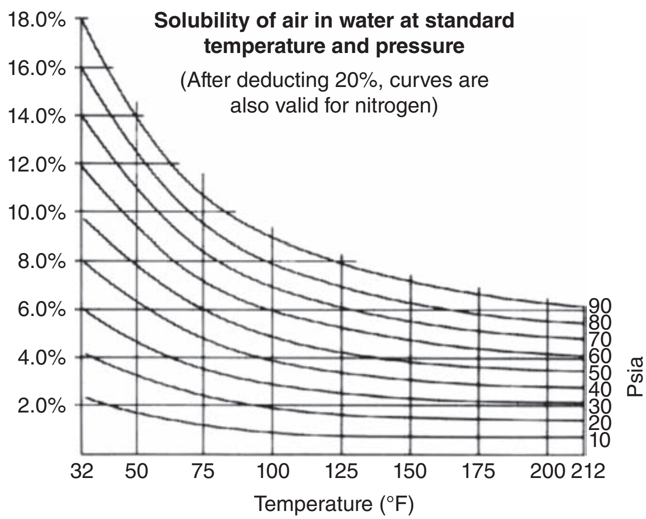

Figure 10-12 Solubility of air in water.

Figure 10-13 Air in boiling water (left) and air escaping from soda bottle (right).

Ways to Remove Air

There are several techniques for removing air from hydronic systems. Perhaps the most obvious is to install air vents at the highest point(s) in the system, where air bubbles are most likely to accumulate. Vents can be either automatic (float-type) or manual.

Reducing fluid velocity with an air separator is another approach. Slowing the flow gives bubbles more time to rise to the surface of a pipe or tank, where they can be vented. Flow velocity is reduced when pipe diameter is increased. An air-separator tank is basically a very large-diameter pipe that is oriented vertically. Changing the direction of flow also helps to eliminate system air. Forcing the water to leave a tank through an opening lower than where it entered also reduces the chances of air bubbles getting swept along with the flow. Most traditional air separators employ this principles of reducing velocity and changing fluid direction (Fig. 10-14).

Reducing system pressure also helps to remove air. This is the primary principle used in tangential air separators, where the path of the entering flow is tangential to the

Figure 10-14 Tank type air separator.

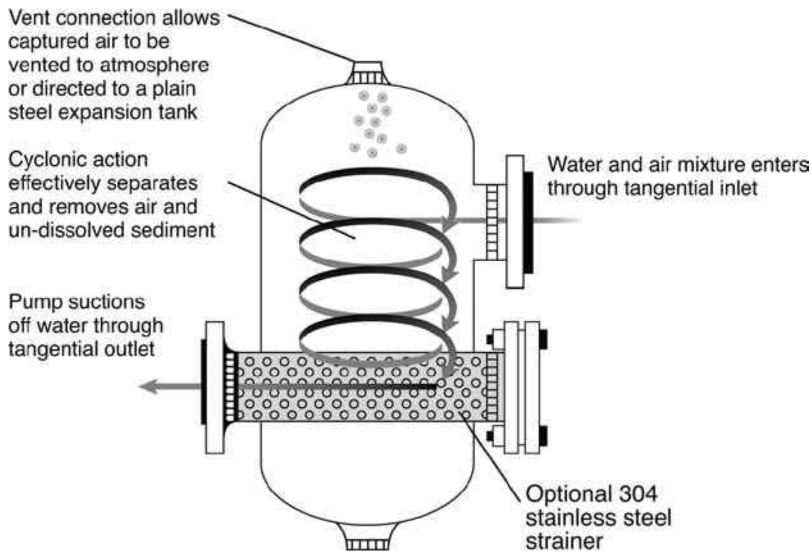

Figure 10-15 Tangential air separator.

walls of the tank. This causes a centrifugal, or cyclonic, action within the fluid in the tank. In the spinning fluid, the heaviest molecules (i.e., fluid and particulates) are forced to the perimeter of the tank, and the lightest molecules (i.e., air) are forced to the center of the tank, where they can rise to be vented (Fig. 10-15).

Finally, the related techniques of coalescence and subsaturation can be used. Coalescence (in air separation) is the process of small bubbles (microbubbles) joining together to form larger ones. Coalescing continues until the bubbles are large enough to have sufficient buoyancy to carry them to the top of the tank to be vented. When system fluid is subsaturated, it contain less than 100 percent of the air it is capable of retaining at a given temperature and pressure. In this state, the fluid is "starved" for air and consequently will absorb air pockets in the system in an attempt to get back to its "normal" saturation level of 100 percent (Fig. 10-16).

Types of Air-Removal Devices

There is traditional, simple technology for removing air from a hydronic system, as well as more recent and complex technology. Which technology the HVAC system designer chooses will depend on the specifics of the system.

The air vent is a traditional device for air removal. Air vents are placed at the highest point in the system and simply allow air to collect and vent from that point (Fig. 10-17).

The air scoop works in a similar fashion. The air scoop is placed in the piping. Air bubbles being carried along with the flow rise to the top of an air-separating chamber as the flow enters the air scoop. Air accumulates at the top of the chamber and then moves upward into an automatic float-type air vent that ejects it from the system. These are passive devices, in that they simply allow air to collect and vent (Fig. 10-18).

Air separators, on the other hand, are active devices. Many air separators create a rapid internal swirling action (vortex) of the system fluid. As in a tornado, a low pressure

Figure 10-16 Microbubble air separator.

Figure 10-17 Air vents.

develops near the center of the vortex. This reduced pressure causes dissolved air to be released from the fluid. Because the density of the system water is much higher than that of air, it is driven to the outer edge of the circulating pattern, whereas the separated air remains near the center of the vortex. The air and water separate as the water flows downward toward the outlet, and the air rises to the top of the chamber, where it collects and is ejected (Fig. 10-19).

Only a few of the most advanced air separators contain the technology required to create coalescence and the consequent subsaturation of system fluid. One example is the 4900 Series Air Separators manufactured by Taco, Inc. These air separators use PALL rings for this purpose. PALL rings are used in the processing industry to mix gases with or separate gases from liquids, but the use of this technology in HVAC applications is so unique that it is patented. PALL rings are able to remove microbubbles as small as

Figure 10-18 Air scoop.

Figure 10-19 Vortex air separator.

18×10^{-6}, far smaller than those removed by other types of air separators. As a result, the fluid is subsaturated, which aids in further air removal from the system (Fig. 10-20).

Expansion Control

Air Control through Pressure Control

All hydronic systems operate under a variable amount of pressure. For closed systems, the pressure varies primarily due to the expansion of water as it is heated or cooled. As the water is heated, the pressure increases, and as the water is cooled, the pressure decreases.

The pressure in a closed system varies between a minimum and a maximum. The minimum is controlled by the fill valve and the initial fill pressure of the expansion tank. The maximum pressure is determined by the relief valve and the size of the expansion tank. If the pressure is not maintained between these limits, then the system will not perform properly.

Not maintaining minimum pressures will create air problems. Water contains a certain amount of entrained air. If this air comes out of solution at lower pressures, it can increase corrosion rates of metals within the system. In addition, air can form pockets at the tops of pipes and coils of terminal units. These air pockets actually can restrict or block flow in a hydronic piping system. This is referred to as *air locking*.

Figure 10-21 is repeated and shows a solubility curve for air in water. Note that at a fixed temperature, reducing the pressure reduces the amount of air that can be dissolved or entrained. For example, at 100°F and 80 lb/in^2, water can contain 8 percent air by volume. At 100°F and 20 lb/in^2, the number decreases to 2 percent.

FIGURE 10-20 Taco 4900 microbubble air separator.

The conclusion is that air is least soluble in water at lowest pressure. Air separators therefore should be located at these points. The lowest pressure in a system is typically at the expansion tank because this is the point of no pressure change and the location of the fill valve. Therefore, the general rule of thumb in hydronic systems is that *air separators should be located at the expansion tank connection to the system.* Figures 10-22 and 10-23 show the correct locations of boiler/chiller, pump, air separator, and expansion tank.

For multistory buildings, this is important. If the system pressure is not maintained above atmospheric pressure at the top of the building, then not only will air come out of solution, but air also actually can be drawn into the system. This will result in loss of system performance with areas of low or no flow in this portion of the system. For high-rise buildings, this is especially important. Frequently, the expansion tank, air separator, and fill valve are located at lower levels of the building. At the upper levels, air will come out of solution as the pressure decreases. This is similar to what divers experience

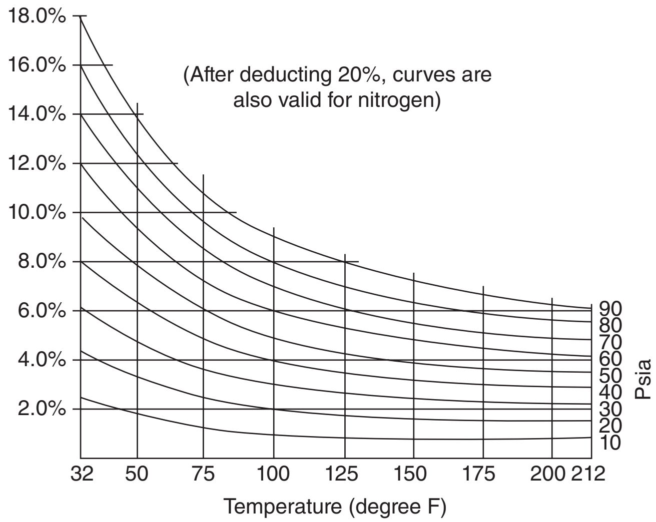

Figure 10-21 Solubility of air in water at standard temperature and pressure.

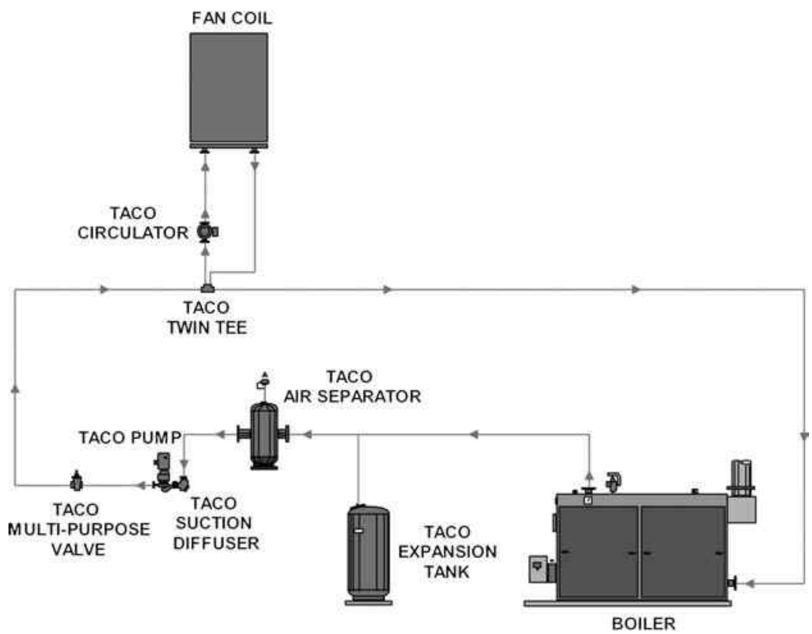

Figure 10-22 Boiler and expansion-tank/air-separator locations.

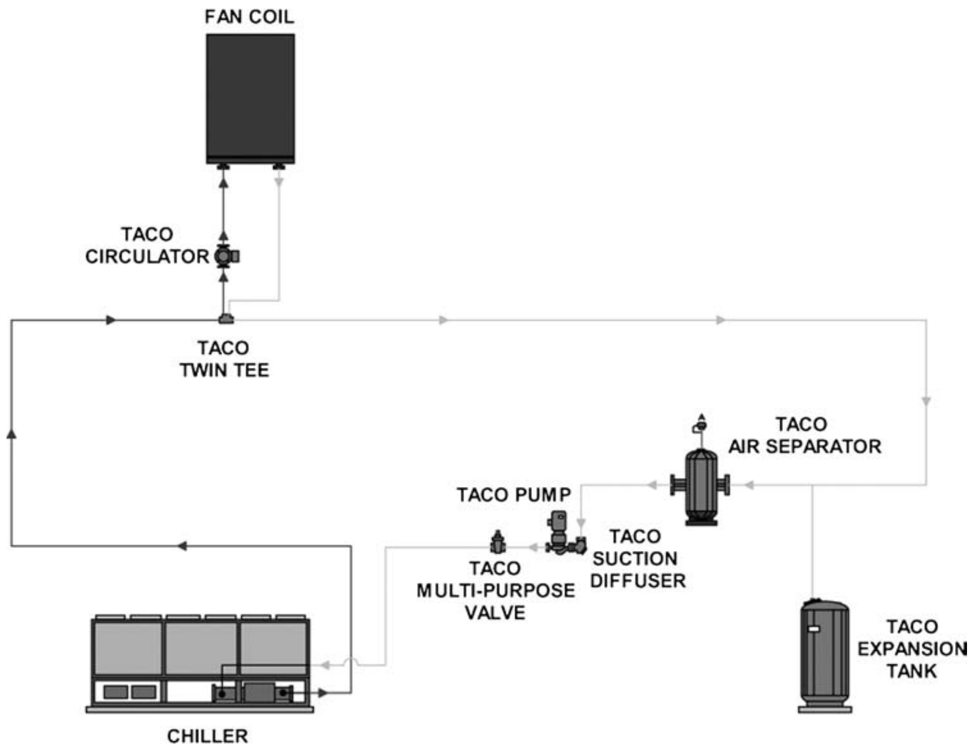

FIGURE 10-23 Chiller and expansion-tank/air-separator locations.

as the *bends*. One solution, which designers and maintenance personnel learned over time, was to overpump the system through high pump heads. This increased the pressure at upper levels of the building and forced air back into the system.

For example, in a 50-story building, the static pressure at the bottom of the system could be 250 lb/in^2. The solubility of air in water at this pressure and 40°F is 45 percent. At the top of the building, assuming 10-lb/in^2 positive pressure, the solubility is only 4 percent. Obviously, air will come out of solution at the top of the building with the expansion tank and air separator located at the bottom. By overpumping to, say, maintain 40 lb/in^2 at the top of the building, the solubility of air goes back up to 10 percent.

For pumps located at the upper levels of the building, this is even more problematic. Pumps in these locations actually can be attempting to pump air. For centrifugal pumps, the point at which their head falls off is in the range of 3 to 5 percent air volume in water.

Maintenance personnel and field engineers report many instance of poor pump performance due to unknown causes. A large number of these mysterious problems has turned out to be secondary pumps located above expansion tanks.

A better solution to overpumping is to install additional air separators at upper levels of the building. A hydronic system can have multiple air separators but should have only one expansion tank. These air separators should be high-efficiency separators similar to Taco's 4900. See Taco Catalog No. 400-1.4 for additional information.

Another solution is to locate the expansion tank and air separator at the top of the building where the pressure is the lowest and the air is least soluble in water. This also will reduce the size of the expansion tank because the difference between the initial fill or minimum pressure and relief valve or maximum pressure can be larger. Not maintaining maximum pressure can result in several problems, including burst diaphragms or bladders in partial expansion captive air tanks, weeping relief valves, and failure of components. Causes of maximum pressure can be undersized expansion tanks, water-logged air-cushion plain-steel expansion tanks, and burst diaphragms or bladders in captive air tanks.

Pressure Control through Air Control

Many systems designed in the past and some designed today attempt to control air by means of an old-style air-cushion plain-steel tank and air vents in the piping. The air-cushion plain-steel tank uses a tank filled with water and an air cushion at the top of the tank for water to expand into as it is heated. The initial atmospheric air in the tank must be compressed to the fill pressure. This requires an initial charge or fill of water to accomplish this, as shown in Fig. 10-24.

The tank must now be sized for the initial fill volume plus the volume of any expanded water. This makes the tank much larger. As air is released through air vents, the air cushion in the tank can be depleted, leaving the tank water-logged and the system pressure control gone. In addition, the air cushion can be depleted due to absorption of air into the water. With a water-logged expansion tank, the expanded water now must seek a new outlet, which can be the relief valve on one of the major components.

A better solution is to use a captive-air tank. In a captive-air tank, the air is held captive by the use of a bladder or diaphragm, with the expanded water being held on one side of the diaphragm or bladder and the air on the other side. This permanent separation allows the tank to be precharged on the air side to the minimum operating or fill pressure. This eliminates the initial water fill to compress atmospheric-pressure air in an air-cushion plain-steel tank to the fill pressure, as shown in Fig. 10-25. This allows

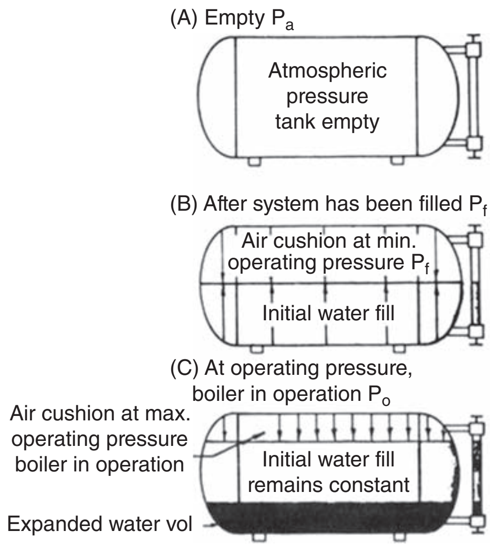

FIGURE 10-24 Plain-steel pressurization process.

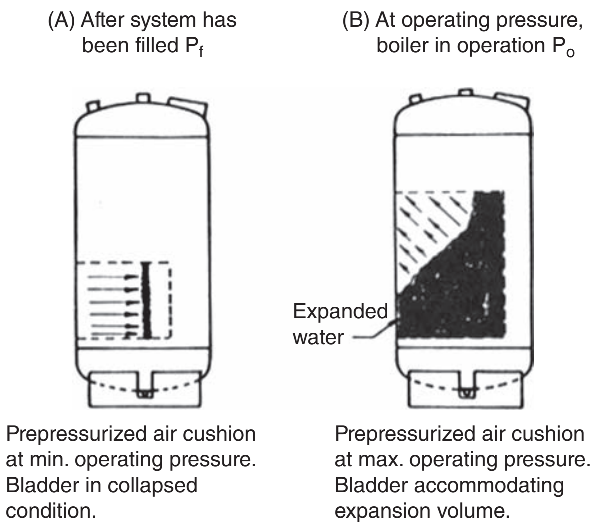

FIGURE 10-25 Captive-air pressurization process.

a reduction in the size of the captive-air expansion tank of up to 80 percent compared with air-cushion plain-steel tanks.

During system operation, any expanded water, in the diaphragm or in bladder, compresses the precharged air to maximum pressure. This compressed air then pushes the fluid back into the system when it contracts. This can be seen in the following example problem:

System: Chilled water at 40°F

System volume: 3000 gallons

The ASHRAE formula for expansion-tank sizing is

$$V_t = \frac{V_s[V_2/V_1 - 1] - 3\alpha\Delta T}{P_a/P_f \; P_o/P_a}$$

where V_t = volume of tank
V_s = volume of system
V_1 = specific volume of water at lower temperature
V_2 = specific volume of water at higher temperature
α = coefficient of expansion of pipe material
ΔT = design operating temperature difference
P_a = tank fill pressure (lb/in^2)
= atmospheric pressure for plain steel
= fill pressure for captive air
P_f = minimum system operating pressure (lb/in^2)
P_o = maximum system operating pressure (lb/in^2)

Sizing a Plain-Steel Expansion Tank

$$V_t = \frac{V_s\ 0.00041T - 0.0466}{P_a/P_f\ P_o/P_a}$$

for $V_s = 3000$ gal, $T = 200°F$, $P_a = 14.7$ lb/in^2, $P_f = 65$ lb/in^2 + 14.7, and $P_o = 90$ lb/in^2 + 14.7. Thus $V_s = 2412$ gal.

Sizing a Captive-Air Expansion Tank

$$V_t = \frac{V_s\ 0.00041T - 0.0466}{1 - P_o/P_a}$$

for $V_s = 3000$ gal, $T = 200°F$, $P_a = 14.7$ lb/in^2, $P_f = 65$ lb.in^2 + 14.7, and $P_o = 90$ lb/in^2 + 14.7. Thus $V_s = 444$ gal. This is an 84 percent reduction in tank size.

Another advantage of the permanent separation of air and water in a captive-air tank is to eliminate the absorption of air back into the water that is found in air-cushion or plain-steel tanks.

Location of Expansion Tank

The location of the expansion tank in the system also will affect system performance. The expansion tank is the point of no pressure change in the system. This can be seen from Boyle's law:

$$P_1V_1/T_1 = P_2V_2/T_2$$

If the temperature (T_1 and T_2) and volume (V_1 and V_2) are constant with the pump on or off, then the pressure (P_1 and P_2) also must remain constant. Therefore, the point of connection of the expansion tank to the system is a point of no pressure change. To prevent air from being drawn into the system, the pressure in the system must be everywhere above atmospheric pressure.

The location of the expansion tank relative to the pump suction will then determine if the system is everywhere above atmospheric pressure. This can be seen in the following figures. In Fig. 10-26, the expansion tank is located on the discharge side of the pump. The fill pressure is 25 lb/in^2. The pump differential pressure is 35 lb/in^2. Because the expansion tank is the point of no pressure change; the pump differential pressure is subtracted from the fill pressure. The pump suction pressure is now –10 lb/in^2 (25 – 35), or below atmospheric pressure. This will cause air problems, with air potentially being drawn into the system.

Figure 10-27 is the expansion tank located on the suction side of the pump. The fill pressure, and pump suction pressure, is 25 lb/in^2. The pump differential pressure is 35 lb/in^2. Because the expansion tank is the point of no pressure change, the pump differential pressure is added to the fill pressure. The pump discharge pressure is now 60 lb/in^2 (25 + 35), or above atmospheric pressure. Everywhere in the system the pressure is above atmospheric pressure.

Therefore, the general rule of thumb in hydronic systems is that *expansion tanks should be located on the suction side of pumps.*

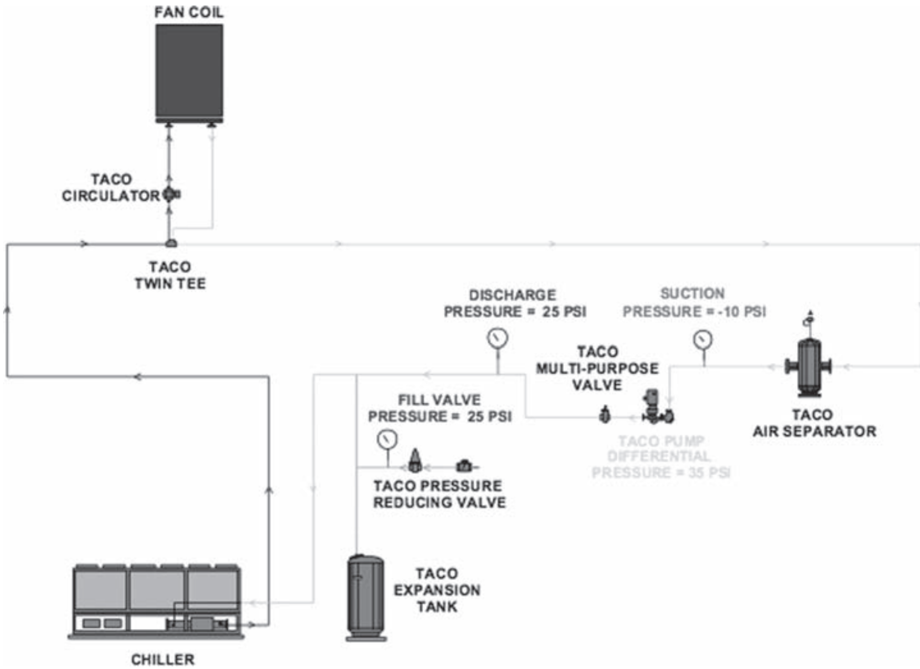

FIGURE 10-26 Expansion tank located on discharge of pump.

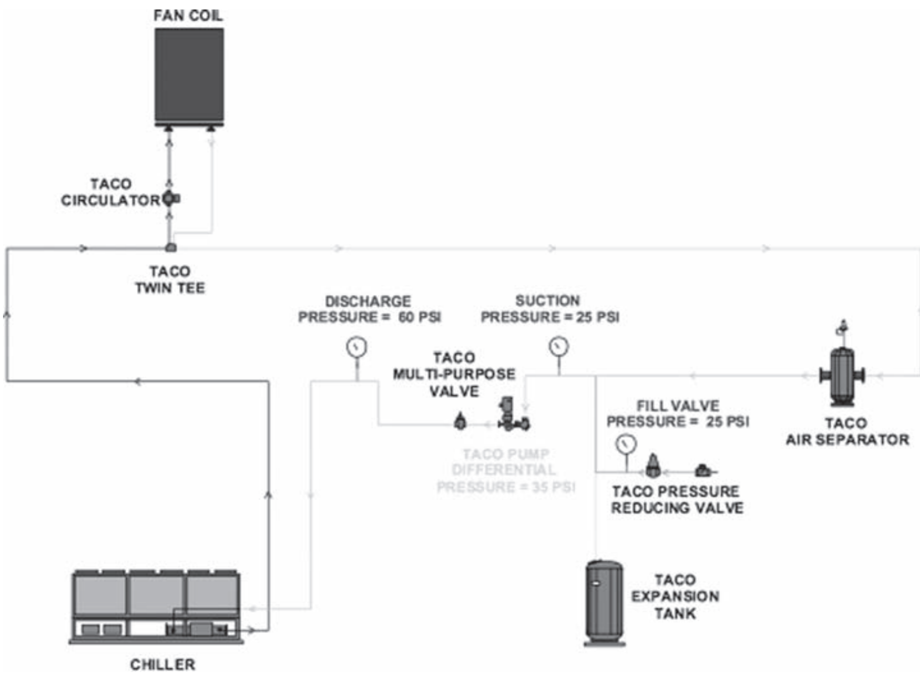

FIGURE 10-27 Expansion tank located on suction side of pump.

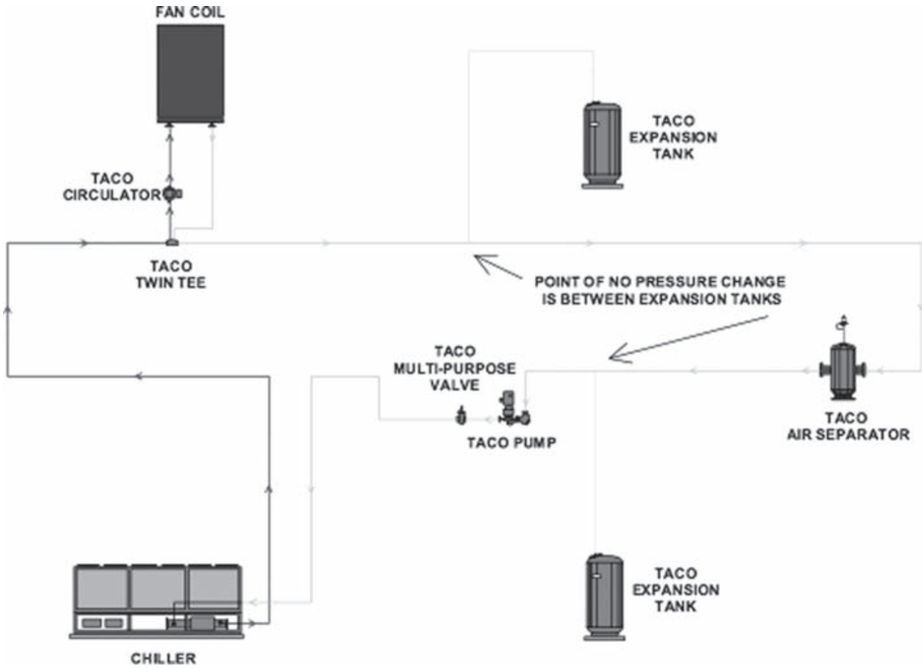

Figure 10-28 Multiple expansion tanks in a system.

Multiple expansion tanks will cause pressure problems in systems. The location of the expansion tank in the system is the point of no pressure change. The pump head does not affect the pressure in the tank. If there are multiple tanks in the system, then the pump head *will* affect the pressure in the tank. The pump will be able to transfer water from one tank to another depending on the pressure difference generated by the pump between the tanks.

Figure 10-28 shows a system with two expansion tanks. The point of no pressure change will be somewhere between the two tanks.

Therefore, the general rule of thumb in hydronic systems is that *multiple expansion tanks in a system are not recommended* because unstable pressure conditions will result.

Air-Cushion Plain-Steel Expansion Tanks

Air-cushion plain-steel tanks are applied in commercial, institutional, and industrial applications for the control of pressure in hydronic systems. The air-cushion plain-steel tank uses a tank filled with water and an air cushion at the top of the tank for water to expand into as it is heated.

In this type of tank, it is desirable to direct the separated air from the air separator to the space above the water level in the expansion tank (Fig. 10-29). The air from the air separator is piped to the expansion tank through a special tank fitting.

This fitting directs the air to the top portion of the tank and discourages air from migrating back into the system (Fig. 10-30) when the system cools. Note that because the air is "recycled" to provide a cushion in the expansion tank, this system is called an *air-control system*.

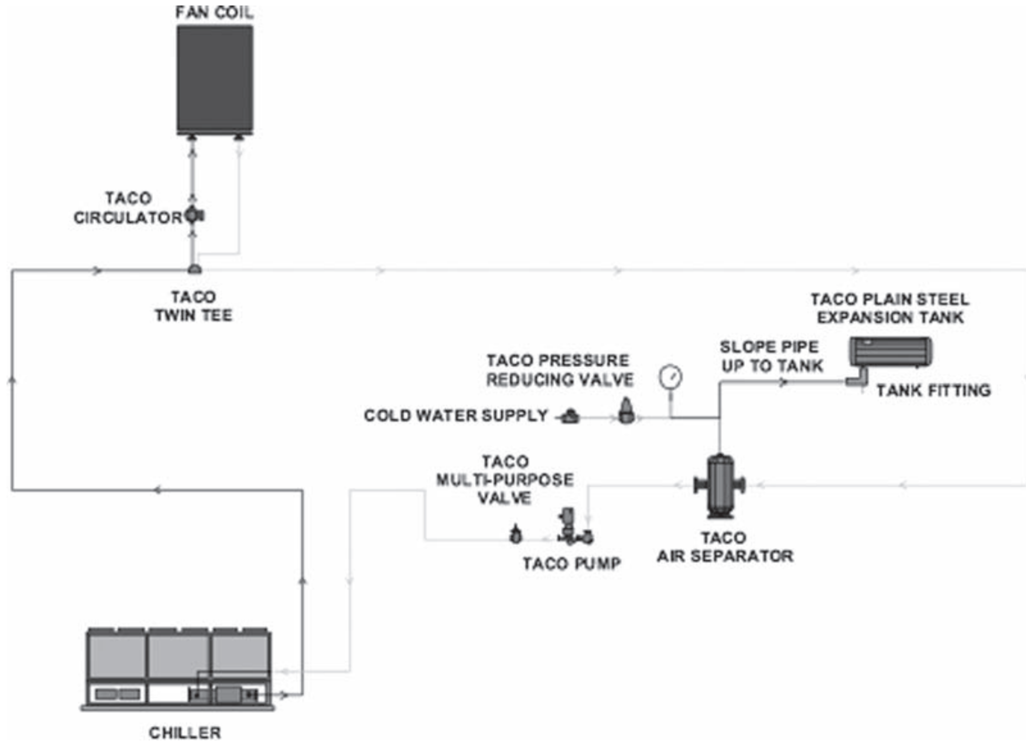

Figure 10-29 Air-cushion or plain-steel expansion tank.

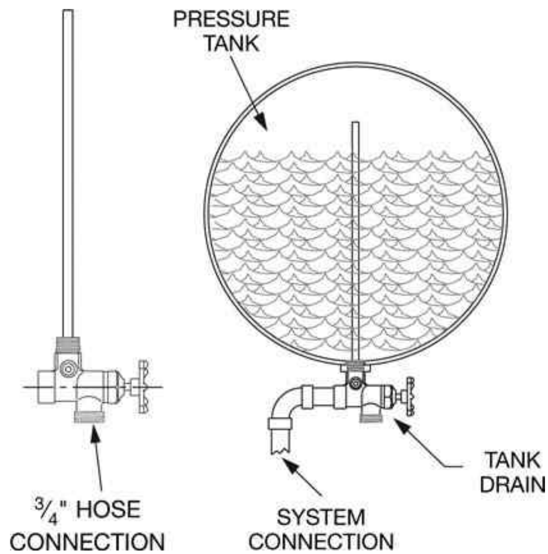

Figure 10-30 Expansion-tank air fitting.

As noted previously, the air cushion in the tank can be depleted due to absorption of air into the water. It also can be depleted by loosing air through air vents in the piping. Care must be taken to ensure that piping between the air separator and the plain-steel expansion tank is pitched at least 3 degrees (see Fig. 10-29) to facilitate migration of captured air back into the expansion vessel. Systems with plain-steel expansion tanks must not have automatic air vents installed because this would lead to loss of the expansion-tank air cushion.

If air is lost in the system, then the tank will become water-logged. With a water-logged expansion tank, the expanded water now must seek a new outlet, which can be the relief valve on one of the major components.

As noted previously, the tank must be sized for the expansion of the water in the system plus the initial charge of water to compress atmospheric air in the tank to the fill pressure. This makes the tank much larger. The tank is also subject to corrosion with the presence of air and oxygen in the tank.

Applications

- Smaller systems
- Lower cost
- Ceiling-mounted to save floor space

Heat Exchangers

Heat exchanger is a fundamental component of most HVAC systems. They are the means by which thermal energy is transferred from one medium to another, and they are used to hydraulically separate piping systems. They are found in a variety of HVAC applications, including geothermal, space heating, air conditioning, refrigeration, and waste-heat recovery.

Although there are several different types, configurations, and sizes of heat exchangers, they all work on the same thermodynamic principle. Two materials are separated by a wall or barrier, and heat energy is transferred through the wall from the warmer material to the cooler material.

There are heat exchangers designed specifically for heat transfer from fluid to fluid, fluid to air, and steam to water. All are designed to affect the most efficient transfer of heat, with minimal heat loss between the materials.

Heat exchangers are usually well insulated so that the energy coming in on one side, such as from a boiler, will be equal to the energy going out the other side, for example, to a heating-water system. The energy transfer is by conduction through a solid material, such as the copper tubes of a shell and tube heat exchanger in accordance with the formula

$$\Delta Q = U \times A \times \Delta T$$

where DQ is the rate of heat transfer within the heat exchanger (in Btu/h), U is the heat-transfer coefficient (in Btu/h · ft^2 · °F) and is a function of velocity or flow through the heat exchanger (the higher the velocity, the higher is the U value and therefore heat transfer), A is the heat-transfer surface area (in ft^2) (this is a function of tube diameter, length, and quantity in a shell and tube heat exchanger; any unit with more area will have more heat transfer), and ΔT, or ΔT, is the temperature difference (in °F) between the heating fluid and the heated fluid (a larger ΔT will result in more heat transfer).

Types of Heat Exchangers

Fluid-to-Fluid Heat Exchangers

One of the most common types of fluid-to-fluid heat exchangers is the shell and tube unit. The shell and head are usually made of steel, but other materials are available depending on the corrosive properties of the fluid in the shell. The tubes are often made of copper and arranged in the shape of a U. This is a very efficient and cost-effective method of achieving a large tube surface area, which serves to increase the heat transfer. Tubes can be arranged without the U bend and with removable heads on both ends. This design is needed when the tubes must be cleaned periodically. A geothermal heating system using surface water from a lake would require cleanable tubes in a heat exchanger, for example (Fig. 10-31).

Another type of fluid-to-fluid heat exchanger is the brazed-plate unit. These rugged and reliable designs represent the latest technology in high-performance heat exchangers. Taco, Inc. makes the TFP Series specifically for domestic hot-water applications, in-floor radiant heating, snow-melt applications, and as a general alternative to shell and tube type heat exchangers. These compact units feature copper-brazed stainless steel plates that offer a highly efficient, low-fouling transfer service. These units usually have male pipe thread fittings and mounting stud bolts as standard equipment. The brazed-plate heat exchanger isn't suitable for the higher heat-transfer loads of boilers, chillers, and geothermal heating or cooling system requirements (Fig. 10-32).

On the other hand, plate and frame heat exchanger can be used for a wide variety of applications. Their compact size and ease of servicing make them ideal for applications such as economizer free cooling, geothermal heat pumps, groundwater cooling, water-source heat-pump freeze-protection isolation, campus- or district-wide heating and cooling systems, industrial processes, and pressure-zone isolation.

Plate and frame heat exchangers are composed of a number of stainless steel sheets with gaskets around the edges and clamped between heavy-steel end plates. The stainless steel sheets have alternating passages for the heating and heated fluids so that the

FIGURE 10-31 Taco shell and tube heat exchanger.

Figure 10-32 Taco brazed-plate heat exchanger.

heat-transfer area is much greater than in a shell and tube heat exchanger. This allows for very large capacity units to be installed with a small space requirement. The large number of sizes, plate designs, and plate quantities requires computerized product selection to choose the heat exchanger that is best for each application (Fig. 10-33).

Immersion-coil heat exchangers are another type of fluid-to-fluid device used when a tank of fluid needs to be heated from an external source. One common application is a tank for domestic hot water. Cold water usually enters the bottom of the tank and is heated with a U-tube bundle inserted in the side of the tank. These tube bundles are available in a wide range of sizes and materials to fulfill the requirements of virtually any job. Selection software for this task is readily available from equipment manufacturers and other sources.

Fluid-to-Air Heat Exchangers

This type of heat exchanger is designed for applications where a heating medium is used to warm a flow of air. The heat-exchanger coil uses heated water inside the copper tubes that make up the coils to warm the air flowing over the fins. These coils can be very small, as in a duct-mounted coil, or extremely large for industrial applications. Specialized tube materials are available for different types of heating fluids. The air side of the coil can be either aluminum with special coating or other materials such as copper (Fig. 10-34).

Steam-to-Water Heat Exchangers

A steam-to-water heat exchanger is often referred to as a *converter* because the steam appears to be converted into water. The steam-to-water U-tube design is very similar to the water-to-water heat exchanger. The main differences are in the internal baffles and the sizes of the shell connections. Steam enters the top of the shell through a fairly large pipe connection. The fluid in the tubes removes energy from the steam and converts it to water, which is referred to as *condensate*. The condensate then flows out the bottom of

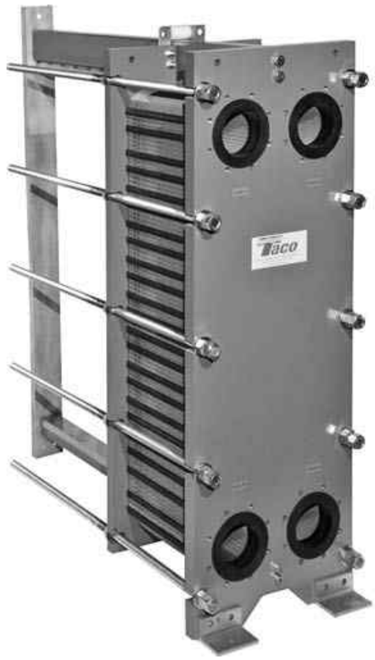

Figure 10-33 Plate and frame heat exchanger.

Figure 10-34 Water-to-air heat exchanger.

Figure 10-35 Steam-to-water heat exchanger.

the shell through a much smaller pipe connection. A steam trap on the condensate outlet separates the steam from the condensate return system (Fig. 10-35).

Proper sizing of each type of heat exchanger and/or converter is critically important because the capacity and efficiency of the heat exchanger will have a significant effect on the overall performance of the HVAC system. The HVAC designer or engineer always must strike a balance between the heat-exchanger capabilities and cost. There are a nearly infinite number of combinations of materials, sizes, flow rates, arrangements, and so on. Most manufacturers of this equipment have very capable computer programs for proper selection, and the local factory representatives are generally ready and able to assist the user in proper selection. After the selection is made, all important parameters should be listed on a schedule so that the installation crew and operational personnel fully understand how the unit is supposed to perform.

Conclusion

This chapter has covered only the major components of hydronic HVAC systems, yet any system will include many other components that must work in concert to achieve overall system performance. These components include various types of valves—zone- and flow-control valves, pressure and mixing valves, and so on—fittings, hydraulic separators, buffer and expansion tanks, thermostats, sensors, and other electronic controls. HVAC professionals are well served to become thoroughly familiar with these system components and to stay abreast of the rapid product innovation that continues to take place in the industry.

Review Questions

1. The most widely type of pump used in hydronic systems is
   a. the positive-displacement pump.
   b. the centrifugal pump.
   c. the hydraulic pump.
   d. the air-driven pump.

2. Centrifugal pumps come in a variety of mounting types and styles. Which of the following is *not* included?
   a. Split-line mounting
   b. Vertical in-line mounting
   c. Split-case centrifugal
   d. Horizontal in-line mounting
3. The location of an expansion tank relative to the pump suction will
   a. determine overall system differential pressure.
   b. function to remove entrained air.
   c. ceiling-mounted to save space.
   d. All of the above
4. Air-cushion plain-steel pressure tanks are applied in
   a. smaller systems.
   b. lower cost.
   c. ceiling-mounted to save space.
   d. All of the above
5. The fitting or device designed to direct air into the uppermost portion of an expansion tank is called
   a. an expansion-tank air fitting.
   b. an air-admittance device.
   c. an air separator.
   d. an air tube.
6. The use of a captive-air expansion tank allows
   a. the tank to be precharged on the air side to the minimum operating pressure.
   b. for a smaller tank that plain steel tank.
   c. greater latitude in expansion-tank placement within the hydronic circuit.
   d. All the above
7. Vertical in-line centrifugal pumps are designed to be installed
   a. on the floor in the mechanical piping circuit.
   b. where there is plenty of floor space.
   c. directly in a piping system rather than on the floor.
   d. with the shaft in the horizontal position.
8. Affinity laws, expressed in a series of formulas, describe the relationship among three variables. Which of the following is *not* included?
   a. Suction pressure
   b. Flow
   c. Head pressure
   d. Power
9. A pump performance curve is a graphic representation of
   a. intersecting flow values of other pumps.
   b. pump performance based on testing.
   c. the impeller size and rpm design factors.
   d. All the above

10. The piping-system curve must be plotted on
    a. the AHRI pump-designation software.
    b. a pump curve rated 30 percent higher than design for safety purposes.
    c. a kinetic energy chart.
    d. the same page as the pump curves for which it is designed.
11. With the advent of VFDs in recent years, variable pumping has become
    a. a way to save energy.
    b. a way to achieve higher system efficiency.
    c. eminently practical.
    d. All the above
12. Air is found in a hydronic system in one of three states. Which of the following is *not* included?
    a. Air dissolved in fluid
    b. Below-surface bubbles
    c. Bubbles at the surface of the fluid
    d. Bubbles carried by or entrained in the fluid
13. Coalescence in air separation is the process of
    a. fragmentation of surface bubbles.
    b. joining of small bubbles to produce larger bubbles.
    c. chemical bonding of bubbles to facilitate removal.
    d. infusion of carbon dioxide to chase out oxygen.
14. For centrifugal pumps facing entrained air, the point at which their head falls off is
    a. 10 to 12 percent air volume in water.
    b. 30 to 40 percent air volume in water.
    c. 3 to 5 percent air volume in water.
    d. 5 to 7 percent air volume in water.
15. The flow rate at which a pump has its highest efficiency is
    a. called the BEP (best efficiency point).
    b. where it converts the maximum kinetic energy to pressure.
    c. Both a and b
    d. its TER (target efficiency rate).

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CHAPTER 11

Variations and Improvements to Hydronic Systems

The idea of hydronic (water- or steam-based) heating and cooling isn't new. The fundamentals of hydronic heating/cooling systems go back some 250 years, and the underlying concepts reach back many centuries more. Even so, hydronic systems in recent decades have continued to evolve with some rapidity to provide greater efficiency and comfort in a broader range of applications than ever before.

The wider use of hydronic heating, ventilation, and air-conditioning (HVAC) systems in commercial buildings is being driven by many factors. First costs, life-cycle costs, environmental concerns, the demand for the wise use of natural resources, and the practical use of renewable-energy resources such as solar, wind, and geothermal power all fuel the drive for enhanced system efficiency and the more efficient use of energy and reduced operating costs that result.

The search for greater energy efficiency has led HVAC system engineers to hydronic systems because of the fundamental advantage hydronic systems have versus an all air-based system or a refrigerant systems using air as the distribution system in a room or zone. Water is 300 times denser than air and therefore has a much greater capacity to carry heat throughout an HVAC system. This translates into numerous system advantages.

Hydronic systems require far less energy to move British thermal units (Btu's) than do air systems. The transport or distribution system (piping) for hydronic systems is much smaller than the ducts of comparable air systems, saving money and valuable interior real estate. And certainly not least, hydronic HVAC systems improve occupant comfort, as we will detail later in this chapter.

This elemental advantage of water versus air ensures that hydronic systems are destined to become even more energy efficient and more widely used as engineers and designers continue to refine the technology through innovation.

History of Hydronic Systems

The origins of central heating systems reach back some 2000 years to when various systems of underfloor heating were used in China, Korea, and the Ottoman and Roman Empires. However, true steam-based hydronic heating only became possible after 1776, when James Watt succeeded in putting the first practical steam engine into commercial operation. The use of steam power spread rapidly, until by the mid-nineteenth century it was the dominant source of commercial/industrial power. As a natural adjunct, hydronic heating systems spread with it.

The first large-scale hydronic systems were *district* heating systems. In these systems, a single large steam plant typically supplied heat to a concentrated downtown urban area using the waste steam left over from the generation of electricity. By the beginning of the twentieth century, such systems were in widespread use in many U.S. cities, including New York, Philadelphia, Detroit, and Seattle.

Throughout the twentieth century, water-based hydronic systems gradually began to replace steam-based systems in residential use and, to a lesser degree, in commercial/industrial applications. Beginning at midcentury, hydronic systems took on new life because of a series of advances in design and components that continues today. These developments have enhanced hydronic system efficiency, improved system control, improved the ability to provide comfort to occupants throughout multiple zones in a building, and for the first time made large-scale hydronic heating and cooling systems practical and efficient for commercial applications.

Modern Hydronic System Innovations

Much of the progress in the effectiveness and versatility of hydronic HVAC systems in recent decades is the result of the effective use of two ideas and some new technology. Neither concept is new. But used together with improvements in various system components, they make possible today's highly energy-efficient and comfortable hydronic HVAC systems.

The first concept is primary-secondary distribution piping, the use of a primary circuit with some number of decoupled secondary circuits or loops, each with its own terminal unit, such as a radiator, fan coil, heat register, and so on. The second concept is single-pipe distribution, a piping arrangement in which a single loop of pipe is used for both the supply and return water. In a conventional two-pipe system, there are separate loops for the supply water and return water. In a conventional heating and cooling system, there are four pipes, one pair for each side of the system.

Primary-Secondary Piping

In primary-secondary piping, the primary loop is piped from the supply side of the heat source to its return. Secondary circuits or takeoffs branch from the primary circuit, each through a pair of tee fittings—supply and return. The secondary loop carries the system water to the terminal units in each loop (Fig. 11-1). The tees to the secondary circuit should be as close together as possible. This hydraulically decouples the secondary loop from the primary loop (Fig. 11-2). As a result the flow in the secondary loop is not influenced by the flow in the primary and vice versa.

Closely Spaced or Twin Tees

Closely spaced tees are the key to properly functioning primary-secondary piping systems. In reality this is not always achieved in the field. Recognizing this hydrodynamic reality led to the development of a type of specialized tee. One of the first was the Duo-Flo Control by Bell and Gossett in the 1950s. Other examples include the Taco Twin Tee.

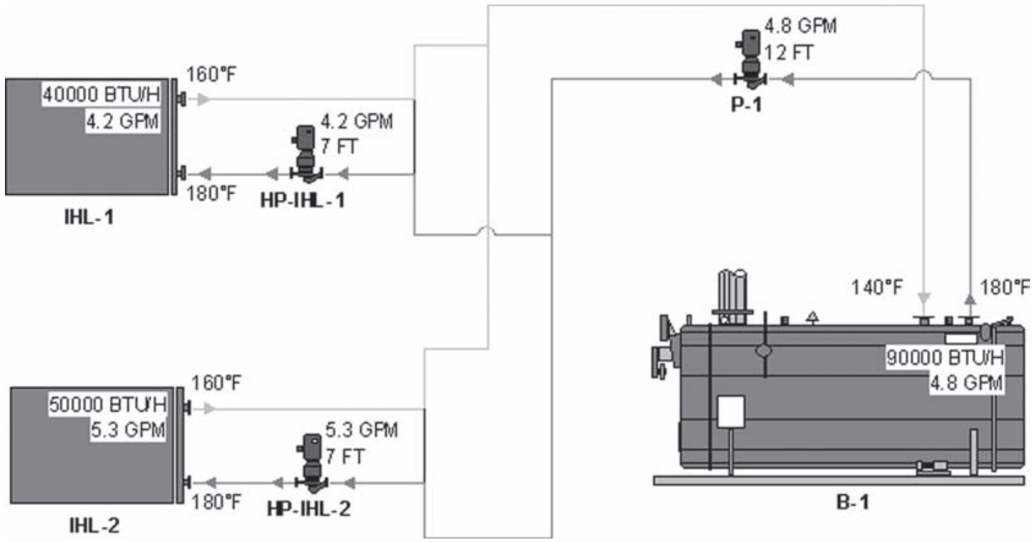


Figure 11-1 Primary-secondary piping diagram.

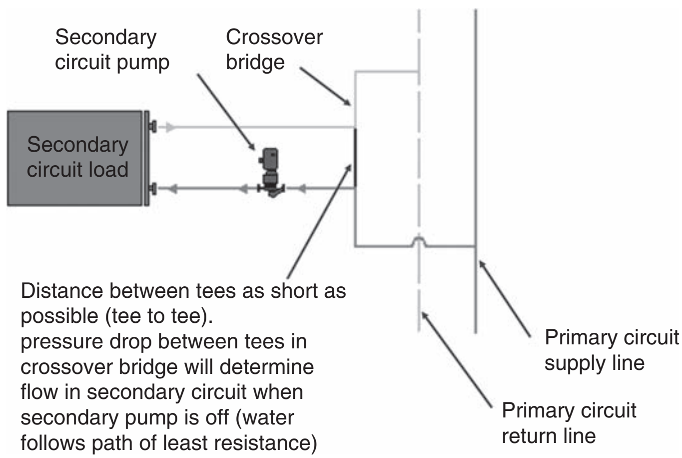


Figure 11-2 Pressure drop between tees and relative to the secondary circuit.

These devices replace the supply and return tees to a secondary circuit with a single, integrated unit. In effect, these *twin tees* place the supply and return tees right next to one another, reducing the length of common piping to an absolute minimum and with it any drop in pressure.

With these devices, the HVAC engineer finally could, with confidence, decouple or hydraulically separate the primary circuit from its secondary circuits and secondary circuits from each other so that every circuit could operate independently of the others. However, one more component was needed to make primary-secondary piping fully effective and comfortable as an HVAC distribution scheme. This was the method to create a pressure differential in the secondary circuit to move water. Early attempts used a venturi tee to create a venturi effect to create the pressure difference. Bell and Gossett referred to this as their Monoflo system. Taco referred to this as their Venturi Tee system. Newer technology uses small, inline wet rotor circulators to give HVAC engineers a precise means of system and zone control. With the advent of these units, HVAC engineers and designers finally had practical primary-secondary pumping to complement and take full advantage of primary-secondary piping for distribution.

Primary-secondary pumping for zone temperature control uses individual small circulators on the primary circuit and each of the secondary circuits. All circulators are controlled independently. With the primary circulator on, flow is created through the primary loop. Water, following the path of least resistance, flows around the loop without entering any of the secondary circuits. By using small, inline circulators, HVAC engineers could finally reap all the benefits of primary-secondary piping—system flexibility, precise response to heating loads, precise temperature control in all zones, enhanced occupant comfort, improved energy efficiency, and lower operating costs.

Single-Pipe Hydronic Systems

Broader recognition of the value of single-pipe systems helped to usher in the present state of the art of commercial hydronic systems. In many ways, single-pipe systems are optimal for HVAC systems for commercial buildings. Simplicity is the hallmark of a single-pipe system. A conventional two-pipe system requires a supply and return pipe in the primary circuit, which takes up more space. In many applications this can be problematic—there may not be enough space, and additional holes with fire-stopping may have to be cut in walls, floors, and so on. In a single-pipe system, one pipe has to be installed. This translates into space, material, and labor savings.

Single-pipe systems provide comfort to all building zones. They can handle either heating or cooling requirements with a seasonal changeover. To handle heating and cooling on a simultaneous basis, a two-pipe version of the system is needed. This is the preferred configuration. They are easy to install, operate, and maintain. They are competitive on the basis of both first costs and operating costs. And being highly energy efficient, they conserve the use of raw materials, which makes them highly desirable for any green building.

A single-pipe system is a green system used in reducing not only materials needed but also energy consumption. It's also green because it's hydronic and not air. Hydronic systems require less horsepower to move Btu's around a building than air systems because the fluid is denser and has a higher specific heat. This difference is about one-half. Additionally, a single-pipe system has a lower head loss than a conventional two-pipe system owing to the elimination of the control- and balancing-valve pressure drops and less need for additional pipe if the conventional two-pipe system is reverse-return. As a result, energy consumption to operate the pumps in a single-pipe system is less than that for the fans in an air system or the pumps in a two-pipe system.

As discussed in Chap. 9 the distribution piping for a commercial HVAC system can be configured in one of several ways. The conventional two-pipe system uses one loop for the supply water and a separate loop for the return. In a system designed to handle both heating and cooling, the distribution piping is configured as a four-pipe system consisting of separate supply and return pairs for heating and cooling.

A single-pipe system, as the name suggests, consists of one piping loop to handle both the supply and return sides of the system. Both heating and cooling can be handled by a single-pipe system. Until the 1950s, these systems used venturi tees to provide differential pressure to force water through terminal units and control valves to regulate temperature in the various zones. This limited their use to residential applications because of their inability to provide individual zone control. That changed when system designers began to use primary-secondary piping and small, inline circulators.

These inline circulators—maintenance-free, wet-rotor models—provide the differential pressure to direct water through the secondary circuits and for temperature control in each zone. A wet-rotor circulator is one that uses system water to lubricate the bearings rather than oil. The advantage of wet-rotor technology is a circulator that has no seals, couplings, or bearing assemblies. In fact, a wet-rotor circulator is entirely maintenance-free.

In a single-pipe system, one constant-size pipe circulates all the flow for the entire system throughout the building, floor, or wing. Each terminal unit has its own decoupled secondary piping circuit with a dedicated wet-rotor circulator for that zone. The circulator is controlled based on temperature in the zone either with an on/off arrangement or by a variable-speed drive. This allows for very accurate temperature control in the zone.

These single-pipe systems provide all the other benefits of the older systems as well. They're simple to design and install, competitive on first costs, simple to maintain, and economical to operate. In terms of comfort, these systems actually perform better than any other system available, hydronic or air, because they are self-balancing, thanks to the wet-rotor circulators in each decoupled secondary piping circuit. Because the flow in all secondary circuits is independent of the flow in the primary circuit, the need for balancing valves at the terminal units is eliminated (Fig. 11-3).

With a self-balancing system, correct flow to each zone is achieved, so there's no need to tweak balancing valves to satisfy the building's occupants for comfort. In the single-pipe system, the volume of fluid and total Btus that the system needs are available to any terminal unit in the system at any time and are not short-circuited to any other terminal unit.

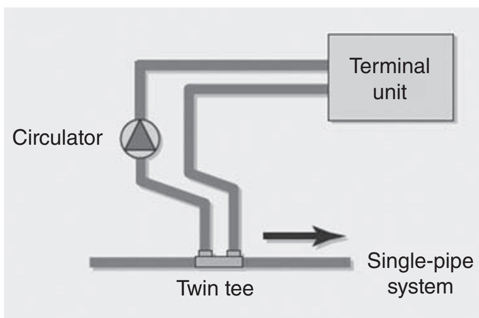


FIGURE 11-3 Single-pipe system.

Single-Pipe System Design

In a single-pipe distribution system, the primary circuit is a single-pipe loop, and the secondary distribution system consists of multiple decoupled secondary-piping loops, one loop for each terminal unit in the system. Flow in each secondary circuit is *independent* of the flow in the primary circuit. Circulators in each secondary circuit are sized for the correct flow and head of that circuit. As a given circulator operates, it provides correct flow and head to satisfy the requirements for its individual zone at all times. The flow for each terminal unit cannot be diverted to any other terminal unit.

The simplicity of this arrangement enables the HVAC system designer to specify one size of pipe for large portions of the system. In single-loop installations, there is no limit to the number of coils that can be installed. Final pipe size is determined by the total load of the loop and ΔT.

If the loop is heavily loaded, it is practical to split the system into two loops with smaller pipe sizes. This change saves installation costs, energy, and money and can reduce pump head and lower horsepower requirements. When loops are carrying equal loads and arranged symmetrically, they will nearly self-balance. The resulting configuration will keep balancing losses down and will lower ongoing energy costs.

The run-out piping between the single-pipe loop and the terminal unit follows conventional design practice. When a coil is farther away from the loop, the run-out length simply may be extended and the circulator adjusted for any increase in head. Boilers, chillers, and terminal units are always sized based on heat-gain and heat-loss calculations and are selected to suit the loads. Unlike reverse-return systems, single-pipe hydronic systems provide highly efficient Btu transport between the generators and the heating or cooling terminal units.

Temperature Management

Two-pipe systems control comfort indirectly by attempting to manage flow or gallons per minute to a terminal unit. Single-pipe systems, however, control comfort directly by managing the temperature or Btus to a terminal unit. This temperature or cascade can be calculated at the design stage and used to properly select a terminal unit that provides the required capacity throughout the system or piping loop. Whether in heating or cooling mode, this mixed water temperature can be used to calculate ΔT values, flow rates, and pipe sizing (Fig. 11-4). What's more, large safety factors are not required when designing these systems.

To further increase the system's efficiency, small, fractional-horsepower circulators are specified to match the design's flow rate for each fan coil, air-handling unit, heat pump, or other terminal unit. These dedicated small circulators provide finely tuned control to yield substantially higher system efficiencies. The use of integral variable-speed drives on the circulators can provide precise modulating flow control for the ultimate in comfort.

How to accurately control temperatures when there are varying inlet water conditions is often a concern of HVAC engineers when evaluating single-pipe hydronic systems. However, as long as a terminal unit is sized for the correct entering water temperature in a single-pipe system (see previous discussion and Fig. 11-3), a standard on/off or modulating analog control sequence will function the same as a two-pipe system and therefore maintain comfortable conditions in a space.

$$\text{Mixed water temperature} = \frac{(\text{Coil GPM} \times \text{LWT}) + (\text{Loop GPM - Coil GPM}) \times \text{EWT}}{\text{Loop GPM}}$$

$$\text{MWT T2} = \frac{(6 \times 48) + (25 - 6) \times 40}{25} = 42°\text{F}$$

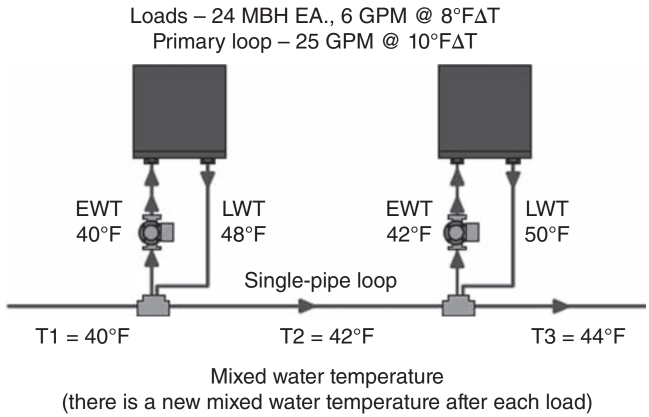


Figure 11-4 Temperature cascade in single-pipe system.

Using a variable-speed drive circulator in a cascaded entering-water-temperature system will achieve better comfort control than a constant entering-water-temperature system using control valves. This is the result of the control sequence employed by the variable-speed circulator. A typical pneumatic or electric control valve on a terminal unit has a turndown in the range of 20:1 or 30:1. This means that below flows of 1/20 to 1/30 of the valves' maximum flow, the valve operates basically on/off or two position. Therefore, at low loads, comfort is compromised.

A variable-speed drive on a circulator, however, can employ a control sequence that uses pulse-width modulation at low speeds. What this means is that the pump can be pulsed at 100 percent voltage or torque, and the length and distance between the pulses are varied to achieve turndowns far greater than a control valve can accomplish. This results in much higher turndowns approaching 300:1 and better comfort conditions at low loads.

Perhaps the most cited concern about single-pipe hydronic systems is the temperature cascade of the system. Because the water temperature in the loop changes, it would appear that the terminal units at the ends of the loops will not be able to provide the necessary Btus for the heating or cooling loads.

In cooling systems in particular, engineers are often concerned about, for example, how a system will be able to provide the same capacity, including dehumidification, at the end of a loop experiencing 50°F entering water when other units at the start of the loop are experiencing 40°F entering water.

Such concerns are legitimate, but an examination of basic heat-transfer fundamentals will provide the answer. Consider the single-dimensional steady-state heat transfer form of the Navier-Stokes equation:

$$\Delta Q = U \times A \times \Delta T$$

where ΔQ is the heat-transfer rate, U is the heat-transfer coefficient, A is the surface area, and ΔT is the temperature difference.

Let's take a room that we want to maintain at 70°F. If the room is at the beginning of the loop, we have a 40°F water supply, so the ΔT between the water supply and the room is 30°F different (70°F-40°F). However, at the end of the loop, the water is at 50°F, so now the ΔT is 20°F (70°F-50°F). In order to maintain the heat transfer of a terminal unit at constant capacity with a decreased ΔT, either the heat-transfer coefficient or U value or area A or a combination of both has to be increased.

The heat-transfer coefficient or U value in a typical terminal unit is a function of fluid velocity, and the area A is a function of rows. The answer lies in increasing the flow rate through the heat exchanger or in adding more rows or a combination of both to compensate for the decreased ΔT. Following is an example of applying this simple concept to a typical fan-coil unit.

Figure 11-5 is an example of applying this simple concept to a typical fan-coil unit. As the graph shows, the sensible and latent capacity of the terminal unit can be achieved in several ways by varying combinations of increased heat-transfer coefficient or U value (velocity) or area A (number of rows).

At the beginning of the loop—shown by the point at the left of the graph—at 42°F entering water, using a two-row coil at 1 gal/min yields a given sensible and latent capacity. At the end of the loop—as shown by the point at the middle of the graph—we can achieve the same sensible and latent capacity (52°F entering-water temperature) by increasing the U value or velocity (52°F entering water temperature, two rows, and 2.0 gal/min). As an alternative—shown by the point at the right of the graph—we can achieve the same capacity by increasing the area or number of rows (52°F entering-water temperature, three rows, and 1.5 gal/min).

This is possible because the dew point of the airstream on the coil at the ASHRAE room comfort zone conditions of 75°F and 60 percent relative humidity (RH) has a dew point of 60°F. Therefore, an entering chilled-water temperature of 50°F is certainly capable of dehumidifying this airstream.

Despite concerns about the temperature cascade in a single-pipe cooling system, the use of basic principles of thermodynamics and psychrometrics, as described earlier,

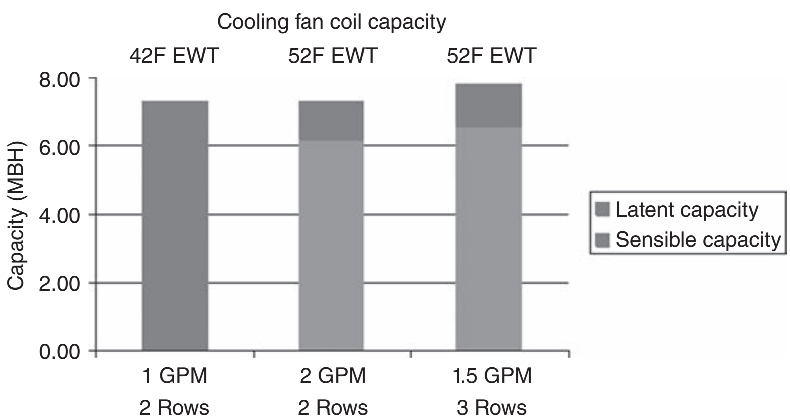


Figure 11-5 Fan coil unit capacity at different entering water temperatures and row.

will result in comfortable room conditions, including dehumidification, in very humid climates.

Software is now generally available (e.g., Taco's Hydronic System Solutions software) that will calculate the temperature cascade automatically and provide a flow-diagram printout of the entering-water temperature at every terminal unit in the system. Using the flow-diagram temperature-cascade information, the engineer selects the terminal unit for the correct cascaded entering-water temperature at each terminal unit.

Another approach to selecting all the terminal units at different entering-water temperatures is to select the terminal units at the same entering-water temperature. A recommendation is to use a worst-case entering-water temperature, taking into account the diversity of the system. *Diversity* is typically defined as the actual load divided by the design load. For our 10°F design ΔT example, and assuming a 70 percent diversity factor, one can select all the units at 49°F entering-water temperature ($49°F = 42 + 0.7 \times 10$). Therefore, using this method, the process to select terminal units for a single-pipe system is no different from selecting terminal units for a two-pipe system.

A second concern about the temperature cascade that should be addressed here is a common misconception that the use of multiple terminal units on a loop adversely affects the temperature cascade. Again, an examination of basic heat-transfer fundamentals will provide the answer.

Take the steady-state mass-transfer equation:

$$\Delta Q = M \times Cp \times \Delta T$$

where ΔQ is the heat-transfer rate, M is the mass-transfer rate, Cp is the specific heat, and ΔT is the temperature difference. In any loop, the mass flow rate M is a function of the total load of all the terminal units divided by the specific heat and the design ΔT for the system. Because the ΔT values are determined by the design and not by the number of terminal units, the flow will always increase to match the load. Therefore, the last terminal unit on a loop will never experience more than the design ΔT.

Interestingly, the more terminal units on a loop, the better the temperature cascade will be at the last terminal unit. This concept is admittedly counterintuitive but is the result of the diversity in the system. With more terminal units, there will be more diversity and a better entering-water temperature at the last terminal unit.

Secondary-Circuit Control

In a single-pipe system, the secondary circuit is not fully shut off when circulators are used for temperature control. Without a control valve in place, the circuit is open to flow at all times. Therefore, it is important to prevent induced flows—sometimes referred to as *ghost flows*—because overheating or overcooling can take place. In a heating system, for example, if there is a difference in the height of the terminal unit above the main, gravity flow can occur in the secondary circuit. Use of a spring-type check valve, or flow check, will eliminate gravity flows. Although the addition of a spring-loaded check valve will add pressure drop to the system, the elimination of control and balance valves will reduce total pressure drop. A typical spring-loaded check valve has a pressure drop of approximately 0.5 ft, a typical control valve has a pressure drop of 10 to 15 ft, and a typical balance valve has a pressure drop of 2 to 5 ft. The net result is a *decrease* in system pressure drop of 10 to 20 ft.

Figure 11-6 Stetham or Twin Tee.

Another factor that comes with induced flows is the pressure differential between two conventional tees and the primary pipe that connects to the secondary circuit. If the pressure differential between the two tees is not zero, then the path of least resistance for some of the water is through the terminal unit. This will result in overheating or overcooling. This pressure differential–induced flow can be prevented by using a twin tee or Stetham tee, invented by Walter Stetham (Fig. 11-6). In the Stetham tee, the two takeoffs to the secondary circuit are perpendicular to the flow. In this arrangement, the pressure difference between the tees is in fact zero. There is, however, a baffle installed in the tee to prevent short circuiting between the return and supply takeoffs.

Balancing and Variable-Volume Flow

Balancing of fluid systems, both air and water, is always a challenge in terms of providing good comfort throughout a building. This is why an entire portion of the hydronics industry has developed around automatic flow control. In two-pipe systems, a reverse-return system is often included so that the differential pressure at every terminal unit is roughly the same, and the system is therefore self-balancing. Typically, reverse-return systems require extra piping, more pressure drop, and more cost. A single-pipe system, however, is always a direct-return self-balancing system with lower head losses and less pipe. As a result, total installed horsepower to move Btus around the system is reduced.

Because the single-pipe system is self-balancing, we can eliminate balance valves on all the terminal units. In the secondary circuits of a single-pipe system the circulators operate to match the load, and the average flow is therefore the variable volume because the circulators cycle on/off. This achieves a variable-volume flow in the secondary circuits even with constant-volume circulators. A variable-speed drive also can be used to provide modulating control and better comfort, if desired. This also achieves a variable-volume flow in the secondary circuit.

A Modern Single-Pipe System: LoadMatch

The LoadMatch system manufactured by Taco, Inc. (Cranston, RI), is an ideal example of a modern single-pipe hydronic system (Fig. 11-7). The system offers all the advantages of single-pipe systems detailed earlier. In addition, it has proven itself highly flexible, having

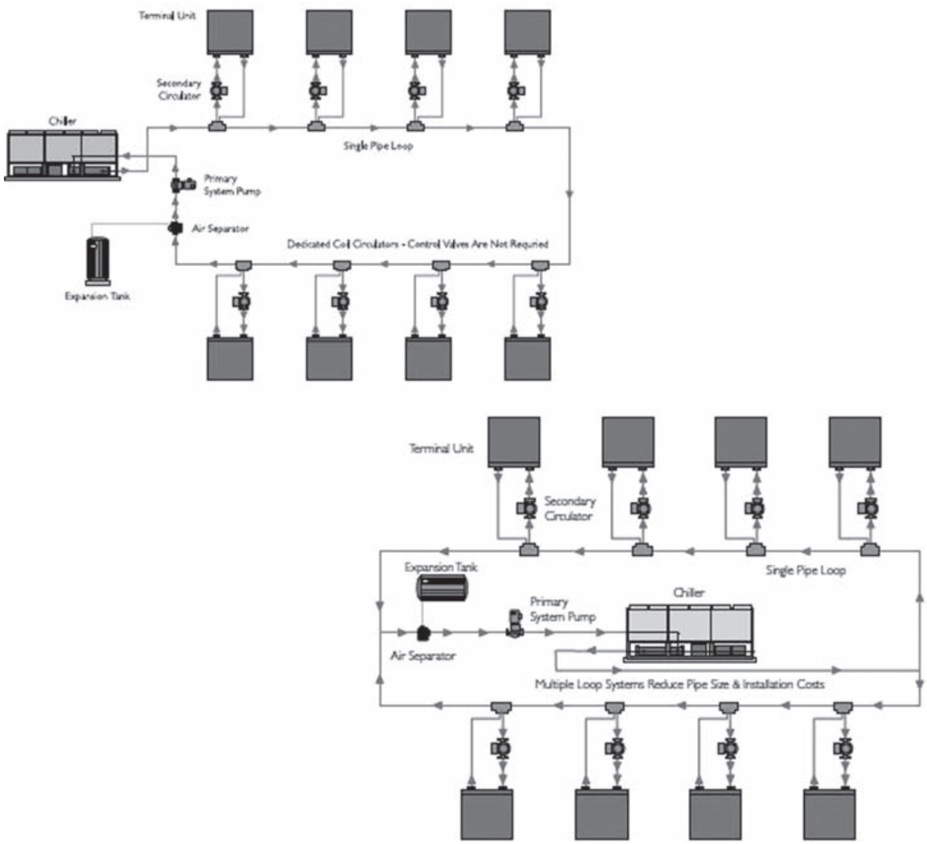


FIGURE 11-7 Typical single-pipe system.

been used successfully in applications ranging from colleges and hotels to manufacturing facilities and medical centers, including projects in numerous challenging climates such as the Florida panhandle and Curacao, in the Netherlands Antilles.

In addition to the energy savings inherent in hydronic systems, the LoadMatch system eliminates head loss by eliminating control valves, balance valves, and some pipe when compared with a conventional reverse-return system. This results in lower pump head and less energy consumption to move the water.

Simplicity is a key feature of the LoadMatch system. This allows the designer to specify one size of pipe for large portions of the system. In single-loop installations, there is no limit to the number of coils that can be installed. Final pipe size is determined by the total load of the loop and ΔT. If a loop is heavily loaded, it is a practical matter to split the system into two loops with smaller pipe sizes. This change results in lower installation costs, less overall expense, and less energy used and can reduce pump head and lower motor horsepower requirements.

When loops are carrying equal loads and arranged symmetrically, they will nearly self-balance. The resulting configuration will keep balancing losses down and will lower ongoing energy costs.

The run-out piping between the single-pipe loop and the terminal unit follows conventional design practice. When a coil is farther away from the loop, the run-out length simply can be extended and the affected circulator adjusted for any increase in head.

Boilers, chillers, and terminal units are always sized based on heat-gain and heat-loss calculations and are selected to suit the loads. Unlike reverse-return systems, the LoadMatch system provides highly efficient Btu transportation between the generators and the heating (or cooling) terminal units.

As stated earlier, single-pipe systems such as LoadMatch can provide both heating and cooling capabilities in single-pipe circuits using common terminal units. The desired heating/cooling mode is chosen at the thermostat, and the corresponding circulator is automatically selected.

The LoadMatch system and other single-pipe systems control comfort directly by managing the temperature or Btus to a terminal unit. This temperature or cascade can be calculated at the design stage and used to properly select a terminal unit that provides the required capacity throughout the system or piping loop. Whether in heating or cooling mode, this mixed water temperature can be used to calculate ΔT values, flow rates, and pipe sizing.

What's more, large safety factors are not required when designing a LoadMatch system. The system's small, in-line circulators are specified to match the design's flow rate for each fan coil, air-handling unit, heat pump, or other terminal unit to maximize overall system efficiency. The use of integral variable-speed drives on the circulators also provides precise modulating flow control for the ultimate in comfort.

The extreme flexibility of systems such as the LoadMatch system enables them to accommodate either horizontal or low-rise distribution requirements. LoadMatch horizontal fan coil, AHU, or heat-pump loops provide the ultimate in flexibility for any building, any size, anywhere. Generally, one loop per floor and exposure will suffice. However, grouping two loops per floor (the south with the west and the north with the east) using common risers is also practical. Distribution mains supply the parallel loops by direct return or by reverse-return and require balance valves, service valves, and air vents as indicated.

Likewise, there are no height limitations in designing a LoadMatch heating and cooling system. Vertical single-pipe loops with return mains in the upper and lower floors are the most popular form of design. If height exceeds working-pressure limitations, a second and third set of piping is stacked to overcome the issue. Equipment rooms are midway between the piping sets. Major equipment for each set of floors is isolated by plate and frame heat exchangers. With independent systems, all working pressure is kept within allowable constraints.

The overall design simplicity of single-pipe systems such as LoadMatch results in significant net savings of project design time. With the use of powerful software design tools such as the Taco Hydronic System Solutions intelligent computer-aided design (CAD) software, engineers can realize a typical saving of 30 percent in total design and construction administration time.

Radiant-Cooling Systems

Although the advantages and benefits of single-pipe hydronic heating systems have long been widely recognized, it is only more recently that these systems have proven themselves just as effective in commercial cooling applications. There has been rapid

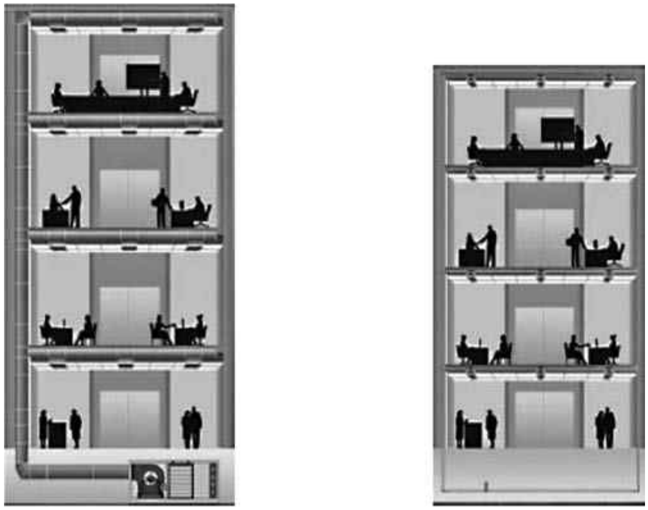


Figure 11-8 Comparison of interior building space with pipes versus ducts.

development of the capabilities of these radiant-cooling and chilled-beam systems in recent decades so that today they are a fully viable alternative to conventional cooling systems. They are now being used successfully in a broad range of building types—in offices and schools, data centers, health care facilities and laboratories, and in Leadership in Energy and Environmental Design (LEED) and other green buildings—in virtually all climates.

These systems offer a host of benefits, including extreme energy and thermal efficiency, far more efficient use of building space than conventional cooling systems, lower initial cost, and more efficient, cost-effective operation. As in heating applications, it is the inherent difference between air and water as a heat-transfer medium that makes hydronic systems dramatically more efficient in cooling applications, too.

A 1-in-diameter water pipe can transport as much cooling energy as an 18-in^2 air duct. The use of chilled beams therefore can reduce the size of air handlers, ductwork, and fan horsepower dramatically, enabling more efficient use of both horizontal and vertical building space. For a typical building, this results in a substantially lower building height and cost (Fig. 11-8).

In terms of energy use, compared with air systems, radiant-cooling and chilled-beam hydronic systems use approximately half the horsepower to move heating and cooling energy within a building. This can reduce the overall electrical energy demand of a radiant-cooling or chilled-beam system by up to 25 percent over a typical all-air variable-air-volume (VAV) system (Fig. 11-9).

Chilled-Beam Systems

An alternative to conventional VAV systems, chilled beams circulate chilled water through tubing embedded in a metal ceiling fixture to wick away heat, thus removing it from an interior space. The business end of a chilled beam is made of copper tubing

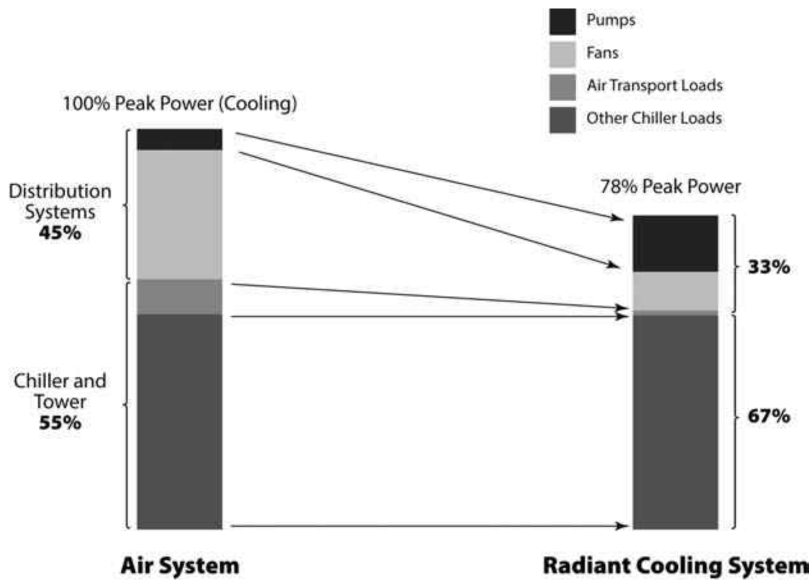


Figure 11-9 Comparison of cooling electrical demand for all air VAV vs. radiant cooling.

bonded to aluminum fins. The beam is housed in a sheet-metal enclosure typically placed at ceiling level.

There are three types of chilled beams: passive, active, and integrated/multiservice. The difference between passive and active chilled beams concerns airflow and the way fresh air is delivered to a space. Passive chilled beams employ natural convection, whereas active chilled beams employ forced convection. Passive chilled-beam systems supply the dedicated outside air supply (DOAS) airflow through a separate diffuser or grille in the room. An active chilled-beam supplies the DOAS airflow through the chilled beam.

Integrated/multiservice chilled beams—these can be active or passive—have lighting, sound, sprinkler, and cable pathways incorporated into the beam, along with the circulation piping. They are used in Europe but have yet to be explored in any depth in the United States.

In all chilled-beam systems, however, cooling and ventilation are *decoupled*. The chilled beams handle only *sensible cooling*, the removal of heat from the air, whereas the central air-handling system handles *latent cooling*, the removal of moisture from the air (i.e., dehumidification).

Chilled Ceilings (Panels)

The original radiant cooling system design of the 1980s was chilled ceilings. These systems use ceiling panels with embedded small-diameter pipe or tubing through which chilled water circulates (Fig. 11-10). Approximately 50 to 60 percent of the heat transfer from a radiant chilled panel is radiant, whereas 40 to 50 percent is convective. Chilled-water temperature must be above the dew point—between 55 and 60°F—to prevent condensation from forming on the bottom of the panels. Therefore, the driving

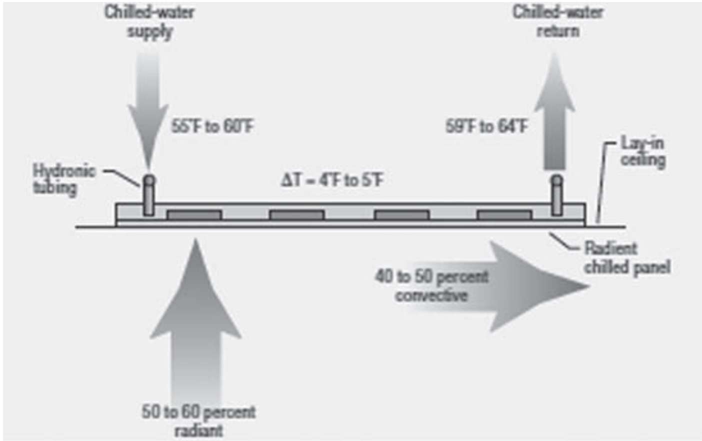


Figure 11-10 Radiant-cooling panel.

force—or approach—between chilled water and a room is reduced to 15 to 20°F. This is approximately half of a conventional chilled-water system using 40 to 45°F chilled water, which achieves an approach of 30 to 35°F. As a result, higher chilled-water flow rates are required to achieve reasonable capacities of the chilled ceiling panels.

Radiant cooling and chilled beams use chilled-water temperature differences or ΔT values of 4 to 5°F. Conventional chilled-water systems use chilled-water ΔT values of 8 to 12°F. Therefore, chilled-water flow rates for radiant-cooling and chilled-beam systems must be approximately double those of conventional chilled-water systems for the system to be effective. This means that the pumps, piping, and horsepower for the pumps also must be double.

Even with higher flow rates, chilled ceiling panels have relatively low capacities, ranging from 20 to 40 Btu/h per square foot of panel area. While this is adequate for cooling loads of interior spaces, it may not be adequate for exterior spaces.

Exterior spaces with larger glass areas can approach 60 to 70 Btu/h per square foot of floor area. For full sensible cooling in exterior spaces, the cooling load must be reduced or the chilled ceiling panels supplemented with other cooling sources.

Solar load can be reduced by using window-shading devices such as interior blinds or exterior sun shades that close when windows are exposed to direct sunlight. Additional cooling sources include chilled walls or floor panels, as shown in Fig. 11-11.

Chilled-beam and radiant-cooling systems (chilled ceiling, wall, or floor panels) also provide sensible cooling only using higher-temperature chilled water above the dew point. Latent cooling or dehumidification is provided by a separate decoupled 100 percent DOAS. This is accomplished by slightly pressurizing the building with dry-treated outdoor air from the DOAS unit to prevent the infiltration of warm, moist outside air.

The biggest advantage to decoupling sensible and latent loads is substantial airflow reduction. A typical air-based cooling system will require 8 to 12 air changes per hour of recirculated and outside air. A radiant-cooling or chilled-beam system, employing a DOAS, will require one to two changes of outside air per hour only. This reduces the horsepower and materials required to move air by up to 10 times.

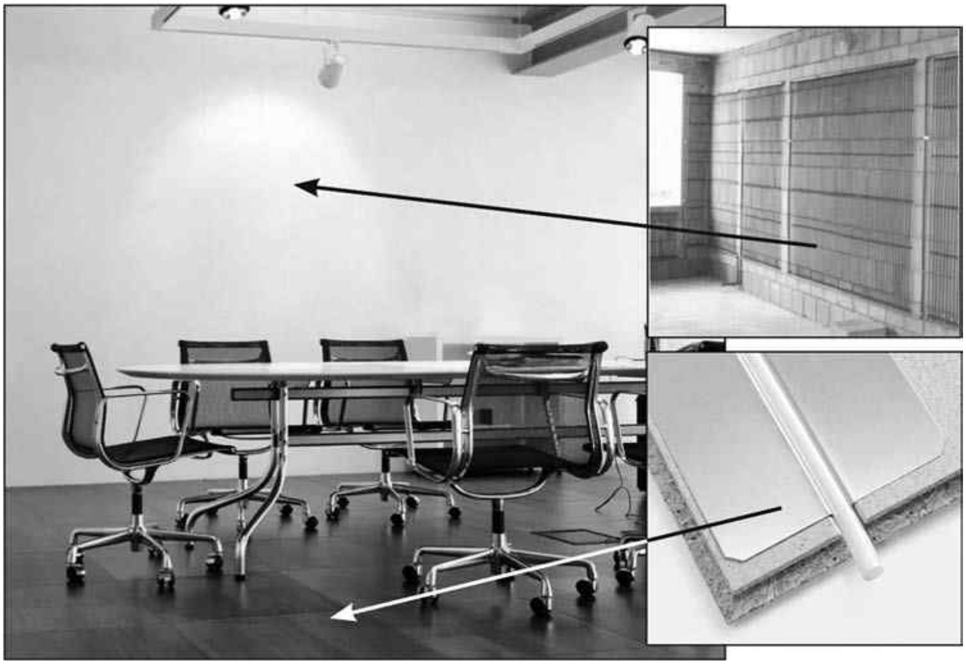


Figure 11-11 Radiant wall panels.

Passive Chilled Beams

The Europeans discovered that by lowering the chilled ceiling panel below the ceiling the convective cooling component of the panel could be increased. This satisfied the increased cooling loads from the increased use of computers seen in the 1990s. There also was a desire to provide higher cooling capacities for exterior zones to provide better overall comfort.

By lowering the panel below the ceiling and making it an open coil, as shown in Fig. 11-12, the capacity of the chilled panel can be increased. The industry has designated this configuration as a *passive chilled beam*. It resembles a (structural) beam when

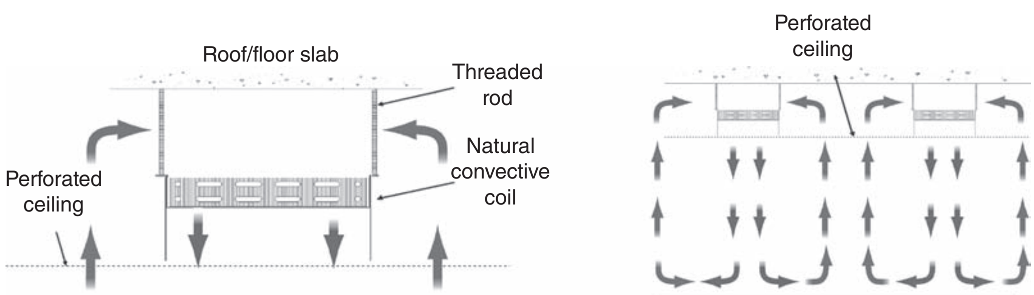


Figure 11-12 Passive chilled beam.

mounted below the ceiling. It is passive because the convective cooling component is natural convection.

As shown in the figure, warm air plumes from the room rise naturally (convectively) and create a warm air pool in the upper portion of the space (or ceiling cavity). As this air contacts the coil surface, the heat is removed, which causes it to drop back into the space. In this application, the convective component of the cooling increases to about 85 percent of the total heat removal, and it also increases the total capacity to 120 to 150 Btu/h per square foot of panel area.

Active Chilled Beams

To further increase a chilled beam's cooling capacity, conditioned ventilation air from the DOAS can be used to flow air through a chilled coil, further increasing the beam's convective component by using forced convection. This configuration is referred to as an *active chilled beam*, as shown in Fig. 11-13. Ventilation air from the DOAS is introduced to a chilled beam in a plenum above the coil and through a venturi, generating a higher velocity and, subsequently, a lower-pressure region inside the lower plenum in the chilled beam. This low-pressure region induces room air to flow up through the chilled coil and mix with primary air from the DOAS. The airflow over the chilled coil is reversed for an active chilled beam, and the induced room air flows up through the coil.

Active chilled beams are sometimes referred to as *induction diffusers*. They are really 1970's induction-unit technology, only mounted in a ceiling and supplied with high-temperature chilled water.

Air from an active chilled beam is introduced into a space through a slot diffuser, creating a Coanda effect. This eliminates drafts by preventing the chilled beam from "dumping" cold air. The Coanda effect is the ability of a cold airstream to hug the ceiling and not dump. This is the case because the air is discharged at higher velocity by the slot diffuser, creating an upward force from the static pressure difference between the airstream and the room (Bernoulli's principle). This forces the cold air to hug the ceiling and not dump.

Inducing warm room air to blow through a chilled coil substantially increases chilled-beam capacity. Active chilled-beam capacities range from 400 to 600 Btu/h per square foot of beam or beam-coil area. Depending on the temperature and quantity of primary supply air from a DOAS, this can add an additional 300 to 400 Btu/h per

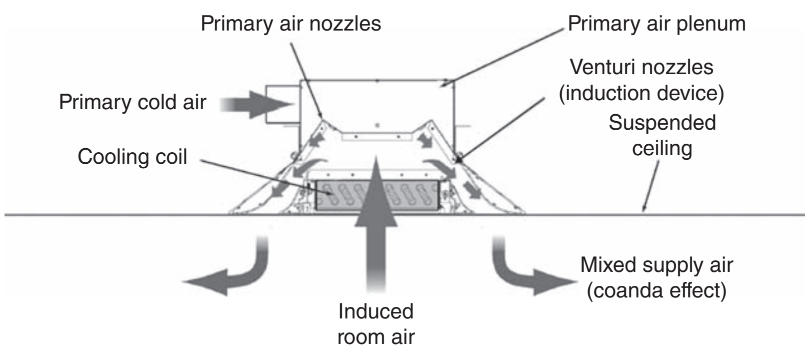


FIGURE 11-13 Active chilled beam.

square foot of beam or beam-coil area. An active chilled beam therefore can deliver from 700 to 1000 Btu/h per square foot of beam or beam-coil area between the chilled coil and primary air.

Chilled-Beam System Advantages

All varieties of chilled-beam systems share several advantages. They all require very little ceiling space and height, which makes them good for retrofit applications as well as new construction. Also important, as we have seen with single-pipe hydronic heating systems, is water's high capacity to carry heat energy (Btus) relative to forced-air systems. A forced-air system is significantly less efficient because of the low density of air, which, in turn, necessitates the use of more space and materials to accommodate the large ducts required.

One very important aspect of chilled beams is their requirement for well-controlled and effective dehumidification. Chilled beams are ceiling-mounted and do not use drain pans; therefore, the chilled-water supply temperature must be maintained above the ambient dew point. This means that dehumidification, or latent cooling, must be handled by a DOAS.

As stated earlier, with passive chilled-beam systems, outdoor air is supplied through a separate diffuser or grille in the room. With active chilled-beam systems, it is supplied through the beams. This means that the amount of outside air required to operate a typical chilled-beam system is much less than that needed for a forced-air system, typically one air change per hour versus 8 to 10 air changes of recirculated and fresh air to cool a space with a central air system, even though the total volume of air circulated by the central system is reduced dramatically, often by 80 to 90 percent (Fig. 11-9). This reduces the energy needed to operate fans as well because of the low pressure of the relatively small amount of primary air being circulated by the central system. Electrical energy demand is typically reduced by some 25 percent, which results in lower operating costs overall.

Chilled-Water Flow

In any HVAC cooling system, humidity and the danger of condensation forming is a concern if the surface temperature of any cooling unit falls below the dew point in the immediate area. This is equally true for radiant chilled-beam systems. In any radiant chilled-beam system, the chilled-water temperature must remain above dew point—typically 55 to 60°F—to prevent condensation from forming on the underside of panels. The difference in temperature between the chilled water and a 75°F room, for example, is 15 to 20°F, as opposed to the 30 to 35°F difference with a conventional chilled-water system, which uses 40 to 45°F chilled water. As a result, higher chilled-water flow rates are required to achieve reasonable capacities—4.5 to 6 gal/min per ton using chilled-water ΔT values of 4 to 5°F, as opposed to the 2 to 3 gal/min per ton using ΔT values of 8 to 12°F with a conventional chilled-water system.

Primary/ventilation air is introduced into an active chilled beam through a series of nozzles. This induces room air into the chilled beam and, in turn, through a water coil. Induced room air is cooled and/or heated by the water coil and then mixed with ventilation air and released.

The technology works in tandem with a central air system, which is calibrated to circulate only the amount of air needed for ventilation and latent-load purposes. The chilled beams provide the additional air movement and sensible cooling and/or heating required through the induced room air and secondary water coil.

As ventilation air moves through venturi nozzles, creating a low-pressure zone within an active beam, room air is induced upward (Fig. 11-13), where it makes contact with the cooling coil. This air and primary ventilation air then mix and are delivered through linear slot diffusers. In this way, chilled beams transfer a huge portion of the cooling or heating loads from the less efficient air-distribution system to the greatly more efficient water-distribution system.

Radiant-cooling/chilled-beam systems have proven to deliver many significant benefits when compared with conventional cooling systems. First, occupants are more comfortable because these systems circulate less air and do not create drafts or evaporative cooling on the skin. Noise levels are also reduced because radiant-cooling/chilled-beam systems circulate far less air than all-air systems, such as VAV systems. Building owners also benefit in both new and retrofit applications. Installation costs are less because small-diameter pipe replaces large ductwork and only a single pipe is required. The necessary floor-to-floor height is reduced, which can result in a lower overall building height as well. In either new or retrofit applications, space is maximized. Last, but certainly not the least, energy consumption is reduced as are overall operating costs.

Low-Flow Injection Pumping

Just as small, inline circulators are essential to effective primary-secondary distribution, so similar circulators provide chilled-beam systems with the high-efficiency radiant cooling that modern commercial applications demand. As we have seen, improvements in the basic design of chilled beams have resulted in far greater efficiency than was possible with the original chilled panels and ceilings. Still greater efficiency can be achieved when low-flow injection pumping is used to deliver heating and cooling energy to terminal units, including chilled ceiling panels, chilled beams, fan coils, and heat pumps, in the same piping-distribution system, even if each unit requires a different temperature.

Injection pumping lowers the peak power demand of a radiant-cooling system by reducing the chilled-water flow in the system. It is a well-proven technique that has been widely used in radiant-heating systems for a number of years to lower 180°F boiler water to the 100 to 120°F needed for a radiant floor panel. The same principle can be applied to a radiant-cooling system in reverse by raising 40 to 45°F chilled water to the 55 to 60°F required by a chilled ceiling panel or beam.

The primary chiller flow in an injection-piping system is lower than that in a conventional system. Primary chilled-water temperature in an injection piping system is 16°F, or 1.5 gal/min per ton, whereas a conventional system ranges from 8 to 12°F, or 2 to 3 gal/min per ton and a conventional chilled-beam system ranges from 4 to 6F or 4 to 6 gpm per ton. An injection-piping system's flow rate is therefore 50 percent less than that of a conventional system and 75 percent less than that of a typical radiant-cooling or chilled-beam system, resulting in a corresponding decrease in pump horsepower and materials for smaller pipe. An injection-piping system keeps the transport horsepower used to move a building's heating and cooling energy to a minimum.

The use of low-temperature chilled water also allows spot dehumidification. A 100 percent DOAS pressurizes a building, negating infiltration of outside air. Natural infiltration temporarily can overwhelm the amount of outside conditioned air delivered by a DOAS when a building's outside door is opened, especially in humid climates.

Local dehumidification is needed to overcome temporary infiltration overloads and typically is provided by fan coils installed at building entrances. A fan coil requires chilled water (50°F maximum) to achieve adequate dehumidification, which cannot be supplied by a distribution system using 55 to 60°F chilled water for radiant panels and chilled beams. With a proper low-flow piping layout, an injection-pumping system can deliver chilled water to building entrances for adequate dehumidification. Additionally, lower chiller operating temperatures (e.g., 40 to 45°F) allow a DOAS, rather than a direct-expansion unit, to use chilled water.

The peak power demand of a low-flow injection-pumping radiant-cooling system is up to 35 percent less than that of an all-air system. The transport energy for this type of radiant-cooling system is 20 percent of the total energy of an HVAC system and one-third the energy of an air system. It combines hydronic heating- and cooling-energy transport with injection radiant heating and cooling energy delivery in a conditioned space.

Modern Low-Flow Injection Pumping: The LOFlo System

The LOFlo injection-pumping system manufactured by Taco, Inc., is an excellent example of how low-flow injection pumping can be implemented to maximize efficiency and provide a green alternative to traditional and conventional airside designs. A keystone of the system is the LOFlo mixing block (LMB). The LMB can be easily incorporated into heating and cooling systems for cost-effective results in a variety of areas.

The LMB is a complete injection-mixing station contained in a simple factory-assembled package that controls each individual zone at the lowest possible flow rate by maintaining the highest possible supply-water temperatures in cooling and lowest possible supply-water temperatures in heating. The LMB consists of a single cast header that functions as a hydraulic separator, to which small circulators are attached—one for the primary-system flow and the other an injection circulator that adjusts to precisely match the required load on a given zone.

When installed within modern radiant systems (i.e., wall, floor, or ceiling panels) or chilled-beam systems (active or passive), only two pipes are needed. Flow rates are reduced because there are no control valves, balancing valves, or piping losses to overcome. The small, reliable circulators take the place of all these components. The LMB automatically provides only the flow and temperature of water needed to satisfy the zone load at any given time.

Figure 11-14 illustrates how the water supply from the primary circuit enters the LMB at port Ps. The return water from the secondary-terminal loop enters the LMB at

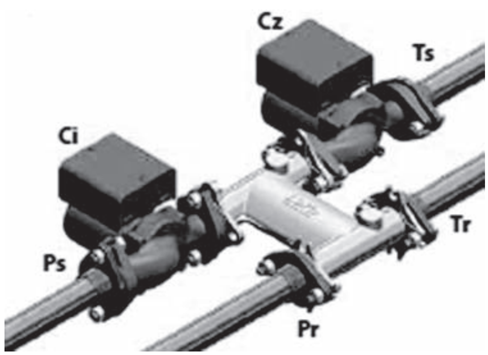


Figure 11-14 LOFlo Mixing Block flow.

terminal *Tr*. As the terminal unit calls for either heating or cooling, the injection circulator (*Ci*) varies in speed/flow to blend the two water temperatures to satisfy the needs of the zone. This blended supply water is sent to the terminal though port Ts, and primary return water exits the LMB at port Pr. A variety of sizes of LOFlo mixing blocks can handle flows up to 30 gal/min, making them suitable for almost all installations.

As mentioned earlier, if the chilled-water flow rate of a radiant-cooling/chilled-beam system can be reduced to that of a conventional system, peak power demand can be reduced even further. Injection pumping can achieve this goal.

The LMB is not constrained by the primary-supply-water temperature, but rather it can supply the precise temperatures required through its unique injection feature. The LMB also eliminates the need for flow checks because they are built into the circulator body.

The LMB is a packaged unit that includes an injection circulator and zone circulator. The injection circulator is controlled by variable speed to maintain the supply-water set point (58°F) to the chilled beam. The zone circulator is controlled by the room thermostat. It can be either constant or variable speed.

The simplicity of the LOFlo concept allows a single pipe size for the primary distribution system. The total Btu load and ΔT determine the required flow and pipe size. Once this has been done, the number of secondary loops is simply a matter of space-conditioning locations. There is no need to account for added pressure drops in the secondary circuits due to piping lengths, balancing valves, check valves, and so on. Thus primary pump size is smaller, piping sizes and arrangements are simplified, and the small circulators are selected to account for secondary pump runs and accessories. A typical LOFlo system application is shown in Fig. 11-15. This is a chilled-beam system using active chilled-beam terminal units and a fan coil in a single-pipe cooling system. The diagram clearly illustrates the simplicity of this system.

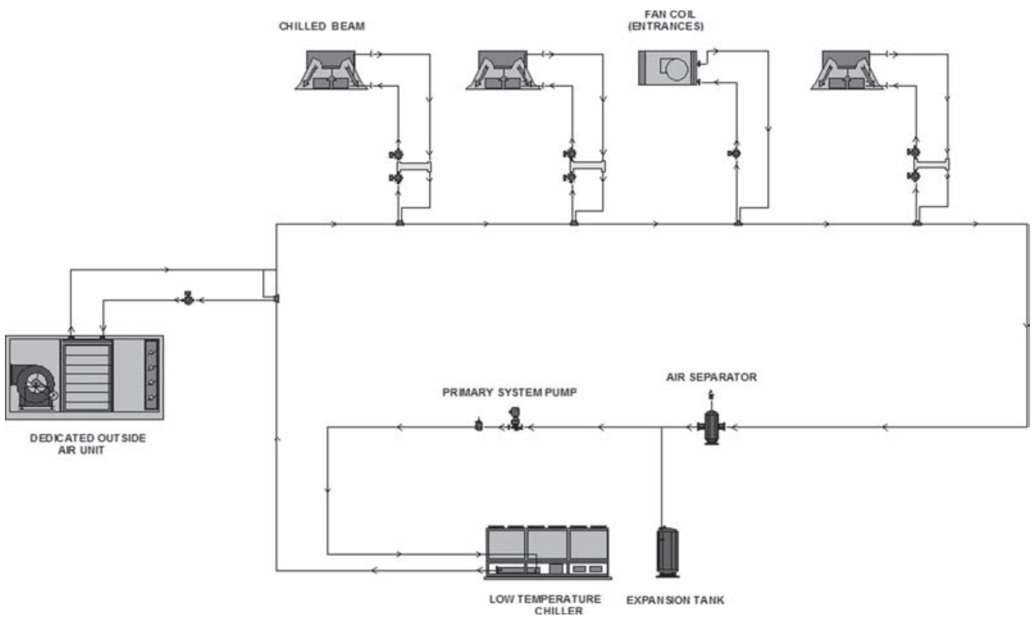


Figure 11-15 LOFlo piping system.

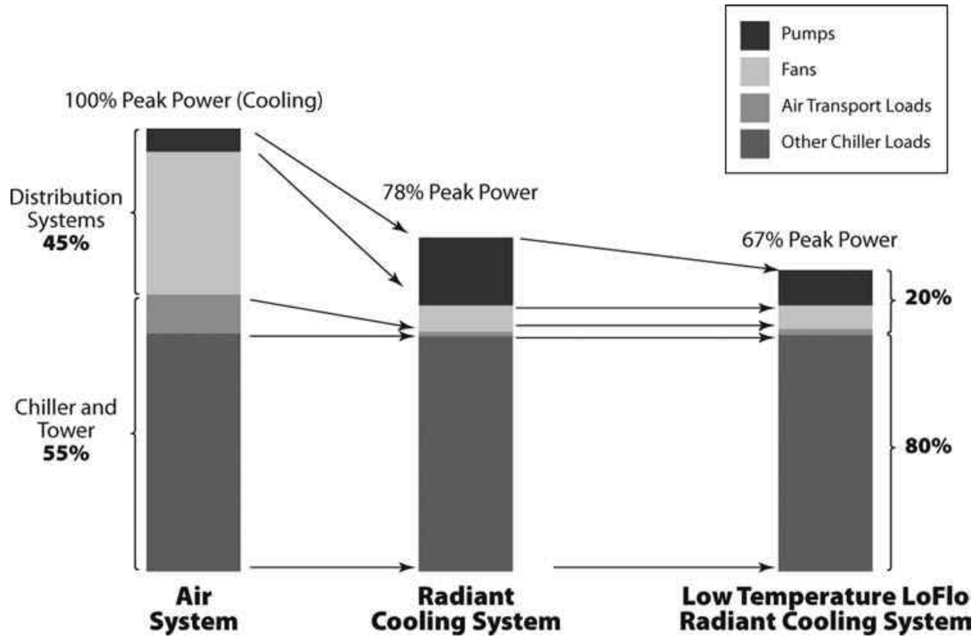


FIGURE 11-16 LOFlo system electrical demand.

The LMB allows the designer to use a 42°F supply-water temperature and a ΔT of 18°F versus that required by the chilled beams of 60°F with a ΔT of 4°F. The LMB will vary the flow of supply water such that each terminal is satisfied at the higher temperature and the lower ΔT.

This change in the primary-loop temperature allows a much lower flow rate and thus requires a smaller pipe diameter. In fact, the primary-circuit flow is typically reduced by 75 percent. This is the case because a LOFlo system uses a primary-circuit ΔT of 16 to 20°F versus a conventional radiant-cooling/chilled-beam system of 4 to 5°F.

Figure 11-16 shows a comparison of peak power demand for a LOFlo injection-pumping system versus an all-air VAV system and a conventional radiant-cooling/chilled-beam system. The peak power demand of a low-flow injection-pumping radiant-cooling system is up to 35 percent less than that of an all-air system. The transport energy for this type of radiant-cooling/chilled-beam system is only 20 percent of the total energy of an HVAC system.

In addition to energy savings, a LOFlo system can provide better comfort. This is a result of less air delivered and therefore less evaporative cooling effects on the building occupant's skin. The system is also quieter because of the reduced air volumes.

The system also can deliver different supply-water temperatures to various types of terminal units for increased versatility and comfort, as shown in Fig. 11-17. In this example, the chilled beams and chilled ceilings require 60°F supply water, the heat pumps 80°F supply water, the DOAS unit 42°F supply water, and the fan coils less than 50°F supply water. All these different supply-water temperatures can be supplied from a single chilled-water pipe at 42°F!

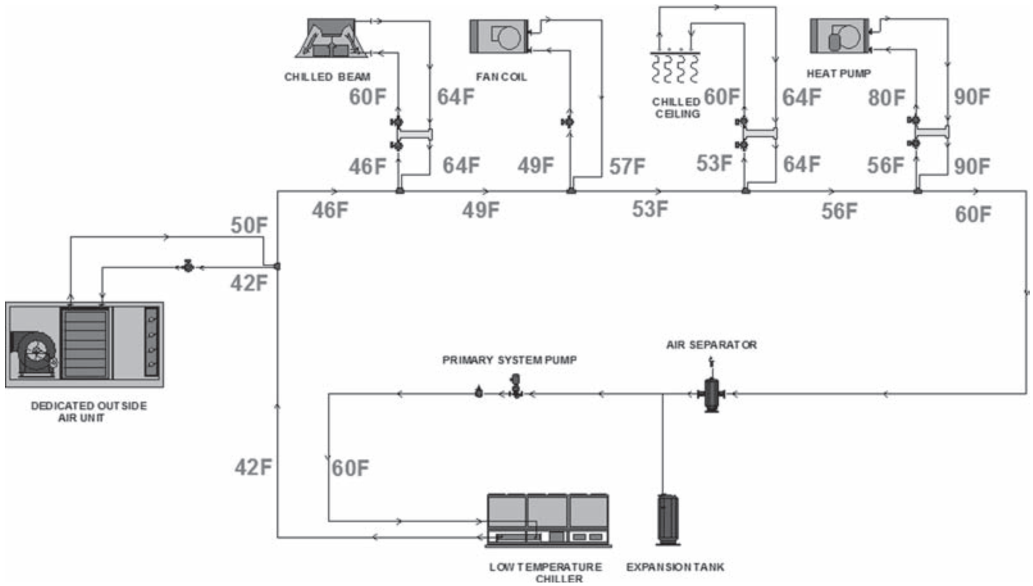


Figure 11-17 LOFlo system supplying different water temperatures.

In this green system, each terminal unit is essentially decoupled from the primary loop. Each will operate automatically to control the load in the zone. Each terminal unit and LMB is easily connected to the primary loop through a single pipe fitting designed to replace two primary-circuit tees (such as the Taco Twin-Tee) used when connecting a secondary load in a hydronic system.

Chilled-Beam System Design Considerations

As stated earlier, radiant-cooling/chilled-beam systems are an energy-efficient and comfortable choice for a wide range of commercial cooling (and heating) applications. Designing a chilled-beam system is very similar to designing a conventional system. However, there are additional design considerations the HVAC professional must keep in mind when determining if a chilled-beam system is right for a given job and how such a system is best designed. The *Trox Chilled Beam Applications Guidebook* is a comprehensive resource in this area.

As with all HVAC systems, the principal design objectives are occupant comfort, proper ventilation, system efficiency, energy efficiency, and cost-effective operation. To achieve these objectives, we have to carefully determine such factors as airflow, chilled-water flow rates, cooling capacity, sound levels, and the physical properties/restrictions of the building. It is essential to keep in mind the integrated air-water character of the system. In particular, the designer must provide for an adequate flow of outside air and sufficient dehumidification to eliminate possible condensation issues.

Occupant comfort is always a primary objective of a chilled-beam system. ANSI/ASHRAE Standard 55-2004 provides the necessary guidance about the environmental conditions that constitute occupant (thermal) comfort, such as dry-bulb temperature and dew-point temperature, air velocities, and so on. Design considerations on the air side of the system must take into account the likely occupancy of the space and the detailed requirements for space ventilation and dehumidification. Guidance for making the necessary calculations is provided by ASHRAE Standard 62-2004.

Water-side design considerations are largely driven by the ventilation and dehumidification requirements determined for the space. Primary among these is the source of supply for chilled water. Geothermal heat pump systems are excellent sources for the supply water for chilled-beam systems. The chilled-water temperature specification is also critical in these systems, as stated earlier, to prevent condensation on the chilled beams. Equally important are chilled-water flow rates.

When designing a chilled-beam system, the HVAC pro also must consider noise levels in the occupied space. The integration of the air and water sides in one system generally results in lower noise levels because ventilation requirements and the resulting fan noise are reduced. Acceptable noise levels are also determined by the intended use of the space. The *ASHRAE Handbook* details guidance for sound levels in various types of facilities.

For the chilled beams themselves, their performance in terms of sound, airflow, and cooling may differ considerably depending on manufacturer. But just as for the components of a conventional heating/cooling system, the manufacturers of chilled beams thoroughly document system performance in all parameters, and the information is readily available to the HVAC system designer.

Dedicated Outdoor Air System Design Guidelines

The design of DOAS component of an integrated chilled-beam system obviously is essential to achieve overall system effectiveness. However, the concept of decoupling the ventilation and air-conditioning functions (i.e., decoupling the handling of sensible- and latent-load requirements) runs contrary to the approach that has been considered the norm in commercial HVAC systems for many years.

Review Questions

1. Local dehumidification is needed to overcome temporary infiltration overloads and typically is provided by fan coils installed at building entrances. A fan coil requires
   a. a distribution system using 55 to 60°F chilled water.
   b. radiant panels and chilled beams.
   c. lowered chiller operating temperatures (e.g., 40 to 45°F).
   d. chilled water (50°F maximum) to achieve adequate dehumidification.
2. Primary ventilation air is introduced into active chilled beams
   a. via supply air grilles.
   b. via a fan-coil assembly.
   c. through a series of nozzles.
   d. at 350,000 Btu/ft^2.
3. The fundamentals of hydronic heating and cooling systems date back
   a. to the ancient Egyptians.
   b. some 250 years and underlying concepts many centuries before.
   c. to the early 1920s.
   d. to before Abraham Lincoln.

4. Hydronic systems require less __________ to move Btus than do air-based systems.
   a. energy
   b. space
   c. money
   d. All the above
5. Which of the following are *not* modern hydronic system innovations?
   a. Primary-secondary distribution piping
   b. Single-pipe distribution
   c. Variable-speed pumping
   d. Thermal-advantage pumping
6. A variable-speed drive on a circulator can employ
   a. a control sequence that uses pulse-width modulation.
   b. a pump that can be pulsed at 100 percent voltage or torque.
   c. variable-flow volume in the primary circuit.
   d. All the above
7. In a single-pipe system, the secondary circuit
   a. does not need control valves.
   b. is not fully shut off when circulators are used for temperature control.
   c. needs consideration to prevent induced flows.
   d. All the above
8. Because a single-type system is self-balancing,
   a. we can eliminate fan coils.
   b. chilled beams are no longer needed.
   c. we can eliminate balance valves.
   d. there is more pressure drop.
9. Multiple pressure sensors are typically used on two-pipe systems to determine
   a. the pressure at the end of the piping system.
   b. the speed for the variable-frequency drive.
   c. to determine the most hydraulically remote circuit because of the difference in pipe length.
   d. to determine the length of fluid flow under varying conditions.
10. For design engineers, the most cited concern about single-pipe hydronic systems is
    a. the lack of redundancy in piping.
    b. the increased pressure drop through the single pipe versus two pipes.
    c. the temperatures cascade of the system.
    d. the application of tertiary circuits.
11. In a single-pipe distribution system, the primary circuit is a single-pipe loop
    a. and the secondary consists of multiple decoupled loops.
    b. and the secondary system has one loop for each terminal unit.
    c. and the circulators in the secondary circuit are sized for the correct flow of that circuit.
    d. All the above

12. If a single-pipe distribution system is heavily loaded,
    a. it is better to switch to a reverse-return system.
    b. it is practical to split the system to loops with smaller pipe sizes.
    c. it is better to put redundant condenser pump motors rated at 60 percent of design.
    d. All the above
13. A radiant chilled panel must have water temperatures
    a. above the dew point.
    b. between 55 and 60°F.
    c. with a ΔT of 8 to 12°F.
    d. Both a and b
14. When designing a load-matched single-pipe system,
    a. large safety factors are required.
    b. larger circulators are needed.
    c. small fractional horsepower circulators are specified.
    d. copper pipe is recommended.
15. There are three types of chilled beams. Which of the following is *not* one of them?
    a. Passive
    b. Variable air volume
    c. Integrated/multiservice
    d. Active
16. The airflow of a DOAS unit is based on
    a. Building sensible load.
    b. Building latent load.
    c. The largest of infiltration + exhaust, ventilation, internal latent load or chilled beam airflow.
    d. Infiltration airflow.

CHAPTER 12

Control Systems

History of Control Systems

An automatic temperature control (ATC) and building automation system (BAS) are the heart of any heating, ventilation, and air-conditioning (HVAC) system. Without controls, the best-designed HVAC system will not work. Conversely, a well-designed and maintained control and BAS cannot compensate for poorly designed systems, misapplied systems, excessive under- or oversizing, or highly nonlinear processes.

The use of automatic controls for comfort dates back to the pre-1900s. Prior to this, control systems were manual; you put more wood in the wood stove or turned up the oil heater. The earliest controls were electric, using bimetal elements for sensing, relays for logic, and electric motors for driving controlled devices (Fig. 12-1). They were low cost, simple to maintain, and required relatively low-skilled technicians. They were typically on/off control and could not provide precise comfort, like modern modulating controls. The logic was hardwired and therefore not easily modified.

Pneumatic Controls

In the early 1900s, modulating controls appeared using air-powered pneumatic devices. They also used bimetal elements for sensing but used pressure regulators, diaphragms, and pistons to drive controlled devices such as valves, damper operators, and so on (see Fig. 12-1). Pneumatic controls were the workhorse of the HVAC industry for many decades. They were low cost and could provide more precise control and comfort through the use of modulating control. They were, however, much more difficult to maintain, requiring regular (annual) calibration to maintain accuracy of the components and comfort for occupants using skilled technicians. The logic was hard piped. This resulted in more complicated configurations for optimizing sequences.

Electronic Controls

Despite pneumatic controls becoming ubiquitous, building owners were looking for a better solution to the ongoing maintenance and cost required for pneumatic controls. Building owners were faced with service contracts that within a few years sometimes would total more than the installation cost of the system. The immediate solution was the appearance of electronic controls in the 1960s. Electronic controls employ electronic circuits consisting of thermistors for sensing; transistors, Wheatstone bridges, and electronic amplifiers for logic; and three-point floating electric motors or modulating magnetic operators to drive valves and damper operators. The technology was developed in both the United States and Europe, with the Europeans having the most

FIGURE 12-1 Pneumatic valve.

FIGURE 12-2 Staefa electronic control.

sophisticated hardware and packaging (Fig. 12-2). The European technology appeared in the United States in the late 1970s.

An example of the cost difference that electronic controls afforded was a school project that bid in the early 1980s. The installed price for electronic controls over pneumatics was approximately 25 percent more. The project documents required both system bidders (pneumatic and electronic) to submit bids for annual maintenance contracts. The electronic control system bidder submitted a price of zero for the annual maintenance contract—instead, he submitted a price to train the school district's own service personnel in operation of the system. The controls required no annual recalibration because they never got out of calibration, unlike pneumatics. In addition, any service could be performed by the district's own staff once they were trained. The payback on the electronic system was less than 4 years. The owner elected to purchase electronic controls.

The electronic system also was more accurate and provided better comfort because it didn't get out of calibration within a few months. The other advantage electronics offered was the promise of integration with controls and the budding personal computer industry. Building automation systems had started to appear. However, up to this point, the ATC and the BAS were two separate systems because controls used pneumatic signals, and the BAS used digital signals. Building automation systems also used large, more complicated, and more expensive main-frame and minicomputers.

Within a short period of time, electronics started overtaking pneumatics. In addition, the ATC and BAS started to merge, with the BAS able to monitor temperatures and so on using analog-to-digital (A/D) convertors and, conversely, control operators using D/A convertors.

Direct Digital Controls

Within a few years of electronic controls making inroads in the ATC and BAS world, direct digital control (DDC) systems made their appearance. DDC systems use small computers or microprocessors to process sensor input, compare with set points, and make decisions on bringing the equipment or room to set point. The advantages of DDC systems include:

- Lower maintenance cost
  - Do not require regular calibration to maintain accuracy.
  - Components do not wear out as frequently.
- Better comfort: Modulating control is easily achieved with higher accuracy using control sequences incorporating time parameters.
- Fully programmable logic
  - Virtually any sequence is possible by writing a programming subroutine.
  - More complicated optimizing and control sequences are easily achieved.
- Fully communicating: Monitoring and trouble-shooting of control systems, as well as HVAC systems, is readily obtainable.
  - Local communication over a local-area network (LAN).
  - Remote communication over a wide-area network (WAN) and the Internet.

The disadvantages include:

- Higher first cost
- Skilled technicians are required for programming, commissioning, and service. Programming of sequences requires intimate knowledge of computers and

little-used operating systems, communication protocols, and sequences outside the HVAC industry.

- Use of proprietary communication protocol makes owners dependent on one manufacturer.

However, the advantages far outweigh the disadvantages, and almost all new ATC and BAS installations in larger commercial buildings are DDC. The challenge for the industry is to provide the same DDC advantages at

- Lower cost, especially for smaller buildings (<50,000 ft^2)
- Reduce dependence on a small pool of skilled programmers and technicians
  - Offer preprogrammed controllers to eliminate as much field programming as possible and allow typical HVAC nonprogrammer technicians to set up and commission a BAS.
  - Offer self-discovering controllers for network addressing and commissioning to eliminate more field programming.
- Provide an open communication protocol: Lowers costs by increasing competition.

Types of Control Loops

There are two types of control loops that are common in the industry—on/off and modulating. On/off control is simple and less expensive, but it will result in larger, more rapid temperature swings and lower comfort (Fig. 12-3).

Modulating controls will provide smaller, less rapid temperature swings and higher comfort levels (Fig. 12-4).

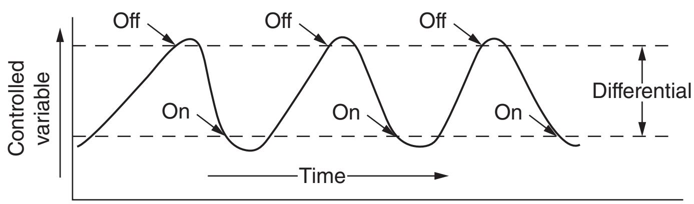


FIGURE 12-3 On/off control.

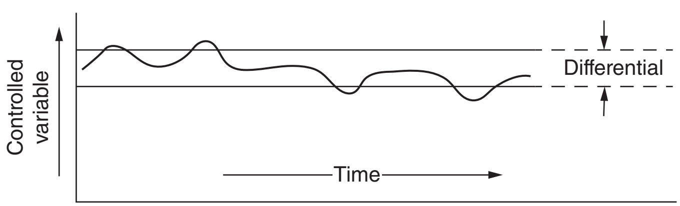


FIGURE 12-4 Modulating control.

There are several methods to achieve modulating operation of a controlled device. In the earliest electric motor–driven devices, using alternating-current (ac) motors, variable-speed bidirectional motors were not available. As a result, the industry developed a technology referred to as *three-point floating*. This technology used an operator with two motors, one to drive the device (valve or damper) open and one to drive it closed. Wiring to the operator required two wires for each motor. However, the neutral wire to both motors was at the same potential and did not carry the control signal. As a result, these two wires could be common or the same wire. Therefore, the operator only needed three wires, hence the nomenclature *three point* (three wires).

The *floating* designation comes from the fact that the position of the operator is not related to the control signal; hence the operator "floats" with the control signal. For instance, if the controller wants more heat because the room is cold, the controller "bumps" the drive-open motor to get to set point. If this does not accomplish the desired result, the controller will "bump" the drive-open motor again.

With the advent of pneumatic operators, true modulating control was possible. This was accomplished using a bellows that could be inflated and deflated using air pressure. The bellows could, in turn, move a piston that could open or close a valve or damper.

With the development of electronic controls, there was a need to return to electric operators. The European manufacturers developed a technology that used a modulating magnetic operator. It is essentially an electromagnet that can vary the strength of its magnetic field and the position of the operator. Electromagnets are two-position devices; they create a force when power is applied to their metal cores. The modulating magnetic valve operator uses a cone-shaped magnet to vary the force of the magnetic valve and create a modulating operator.

On/off control is the least accurate. It is typically used in residential construction and commercial projects where low cost is a deciding factor, such as the hospitality (hotel) industry. As shown in Fig. 12-5, it requires both a proportional band between the on/off signals and a deadband between heating and cooling set points. This results in wide temperature swings and lower comfort.

Modulating control is the most accurate. It is used in high-end residential construction and more demanding commercial environments such as hospitals, schools, and office

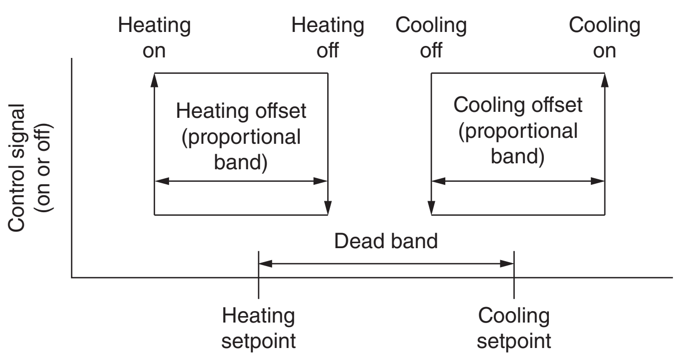


FIGURE 12-5 On/off control.

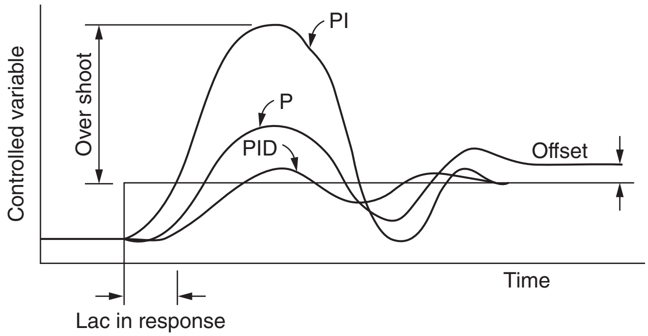


Figure 12-6 Modulating control.

environments. There are three basic modulating control loops—proportional (P), proportional + integral (PI), and proportional + integral + derivative (PID), as shown in Fig. 12-6.

P control is the easiest to implement, requiring the lease amount of commissioning effort or tuning of the control loop. It is, however, the least accurate because it will produce a lasting offset from set point (Fig. 12-7). The offset is necessary because that is what the loop is controlling to, the offset. It cannot be zero.

As with on/off control, P control uses a proportional band for the heating and cooling loops. If the proportional band is set too narrow, the control loop can "hunt," resulting in wide temperature swings and lower comfort (Fig. 12-8).

The proportional bands use two different kinds of signals—direct- and reverse-acting. In a direct-acting signal, the control signal increases with an increase from set point. This sequence is used most often in cooling. In a reverse-acting signal, the signal increases with a decrease from set point. This sequence is used most often in heating.

PI control is more accurate. It incorporates a time function by making small adjustments in the controlled device and then waiting to see what happens. If the control is still not at set point, it will make another small adjustment in the controlled device. In this way, it does not overshoot the set point and then undershoot, resulting in hunting (Fig. 12-9). However, it may take a while for the loop to wind up and get to set point. This loop requires more effort to tune because there are two parameters to adjust—the proportional constant and the integral constant.

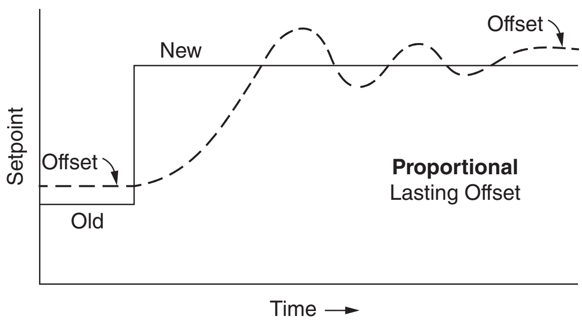


Figure 12-7 Proportional control.

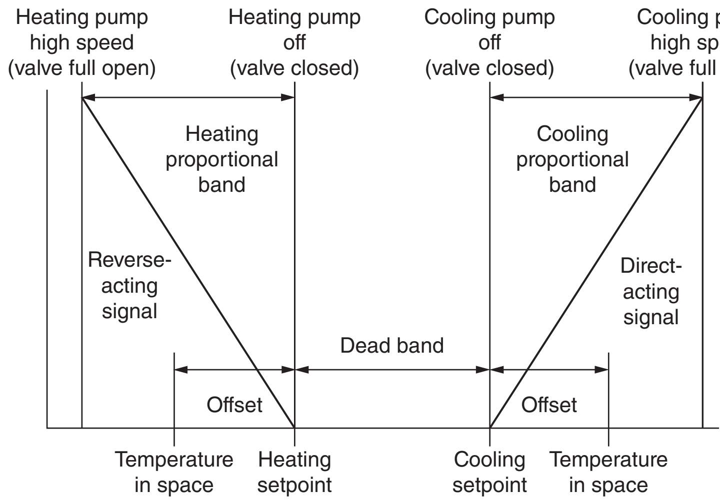


FIGURE 12-8 Proportional control.

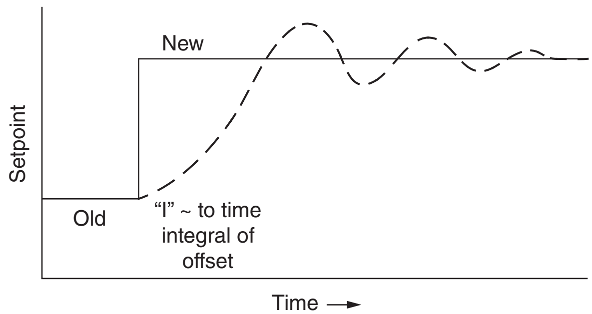


FIGURE 12-9 Proportional + integral control.

PID control is the most accurate. It incorporates another time parameter, which is essentially how long it is taking for the control loop to wind up or reach set point. Mathematically, this is the slope of the PI control curve or the rate at which the control loop is reaching set point (Fig. 12-10). It makes an adjustment to decrease the time to get to set point. It is the most stable control loop and will very seldom hunt if the loop is tuned correctly. However, it is the most difficult to tune.

Using computerized DDC control, the more sophisticated PI and PID controls are easier to implement because the control loop is a polynomial equation using proportional and derivative constants to arrive at a solution instead of adjusting potentiometers in an electronic circuit. The downside is that tuning of the loop in the field will take more time than a simple P control loop.

There are two types of control-loop logic—closed or feedback and open or feedforward (Fig. 12-11).

There are three basic components to a control system—the sensor, the controller, and the controlled device (Fig. 12-12). A closed-control loop uses a direct measurement

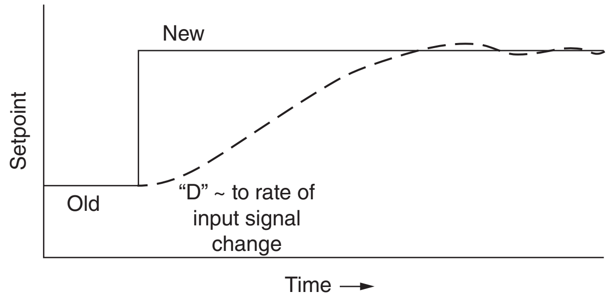


Figure 12-10 Proportional + integral + derivative control.

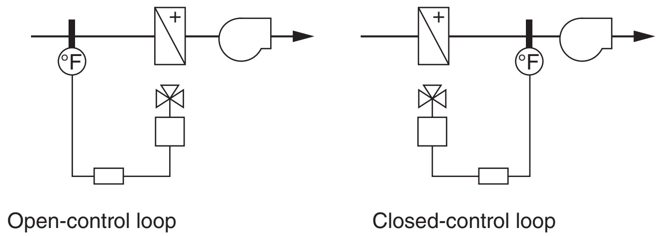


Figure 12-11 Control loops.

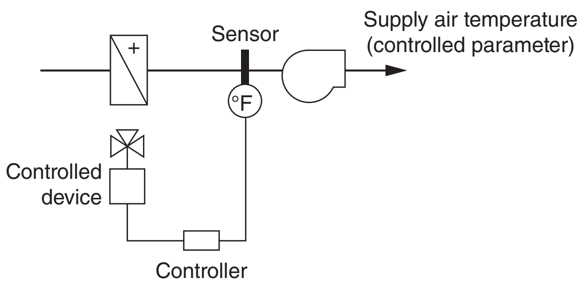


Figure 12-12 Closed-control loop.

of the parameter to be controlled. The controller then issues a control signal from the controller to the controlled device to maintain set point. It is the most accurate control logic. It is used typically for room or zone control, where accurate control of space temperature or humidity is the goal. In this example, the supply-air temperature is the controlled parameter. A control valve on a hydronic coil is the controlled device. A supply-air sensor measures the parameter, and the controller makes adjustments in the control loop to open or close the valve to arrive at set point.

An open-control loop uses an indirect measurement of the parameter to be controlled. The controller then issues a control signal to the controlled device to maintain the parameter set point (Fig. 12-13). It is used most commonly to reset the supply-water

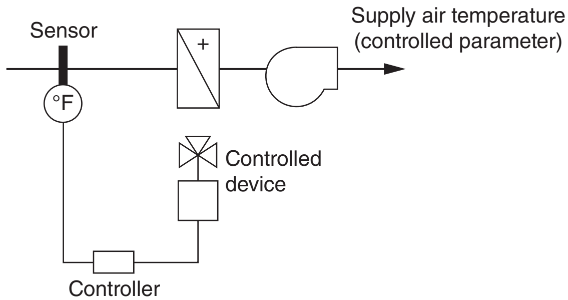


FIGURE 12-13 Open-control loop.

temperature from boilers and chillers as a function of heating or cooling demand in a building or outside air temperature. In this example, it is used to reset the discharge temperature of an air-handling unit based on outside air temperature.

Two types of control strategies are employed by controlled devices—control valves or circulators to control fluid flow to hydronic piping circuits and coils. These are linear and equal percentage (Fig. 12-14).

Linear control strategies are used where there is a direct relationship between the position of the controlled device and the desired result. An example would be in mixing of water in a primary-secondary piping loop to achieve a different temperature in the secondary loop from the primary loop. For instance, a primary boiler loop might be maintained at 180°F, but a secondary loop might be mixed down to 120°F for a radiant floor. Another example might be in mixing low-temperature chilled water at 42°F up to 60°F for a radiant-cooling or chilled-beam system.

Equal-percentage control strategies have been used for control of water to a coil. The output of a coil is nonlinear, so a small change in flow will result in a large change in output of the coil (see top curve of Fig. 12-14). Conversely, at close to maximum output of the coil, a large change in flow is required to produce a small change in output.

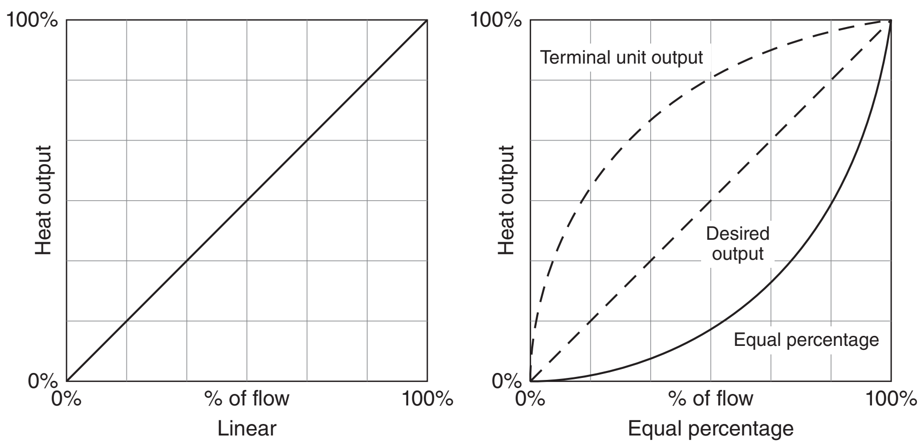


FIGURE 12-14 Linear and equal-percentage control strategy.

Figure 12-15 Taco variable-speed LoadMatch circulator.

What is desired is a linear change in output to flow. Some years ago, the control industry responded by manufacturing control valves with an opposite flow to output than the coil (see bottom curve of Fig. 12-14). This produces a linear change in coil output to flow (see middle curve of Fig. 12-14). This results in less hunting and better comfort.

There are now variable-speed wet rotor circulators that can provide both control strategies by selecting a dip switch on a control board. These same variable-speed circulators also have better turndown than control valves; as high as 300:1 as compared to a control valve at 30:1. (Fig. 12-15).

The ATC industry has adopted some common terminology for the types of points that a controller has available. These are:

- AI—analog in
- AO—analog out
- DI or BI—digital or binary in
- DO or BO—digital or binary out

Most DDC controllers label their points with these abbreviations so that field technicians can see at a glance what type of point is available to connect to.

The history of BASs is instructive in knowing how and why the industry has transformed itself and where it is today. A brief summary follows:

- Centralized intelligence—1960s
- Distributed intelligence—1970s
- Networked intelligence (proprietary protocol)—1980s
- Networked intelligence (open protocol)—1990s
- Web-based networked intelligence (open protocol)—2000s

Types of Building Automation Systems

As discussed previously, the first BAS appeared in the 1960s. These systems were generally separate from the (pneumatic) ATCs initially but morphed into semi-integrated systems. They employed mostly minicomputers as the front-end or host computer and field multiplexers that served as the interface from the digital (computer) to the analog (HVAC system) world (Fig. 12-16).

The multiplexers generally had no intelligence. The intelligence resided in the front-end computer. If the front-end computer failed, the entire system failed. The systems used a communication protocol to communicate (digitally) with the field multiplexers. The communication protocol was proprietary to each manufacturer of BASs.

Wiring to any points in the system (e.g., temperature sensors, controlled devices, and so on) had to be brought back to strategically located multiplexers throughout the building. The systems were expensive and difficult to program. However, for the first time, a building owner/maintenance staff could monitor and control a building from one central location. Global optimizing strategies that could be implemented at the front end included time-of-day scheduling, reset of system parameters, and limited-local temperature control.

By the 1970s, the BAS industry was evolving to distributed intelligence. The first computerized microprocessor DDC controllers appeared in the late 1970s and early 1980s. This technology enabled some intelligence to be moved out of the front-end computer to the zones (Fig. 12-17).

This was mostly local temperature control, with the global optimizing sequences still residing at the front-end computer. The use of local DDC zone controllers also reduced the cost of the systems. The wiring for the field points did not have to run all the way back to a multiplexer for an area of the building but only had to run to the DDC controller for the zone.

The front-end computer also started taking on a different configuration. Microcomputers (PCs) were making their appearance. The ATC front-end computer became two pieces. The ATC computer became a *system controller*, continuing to use a proprietary

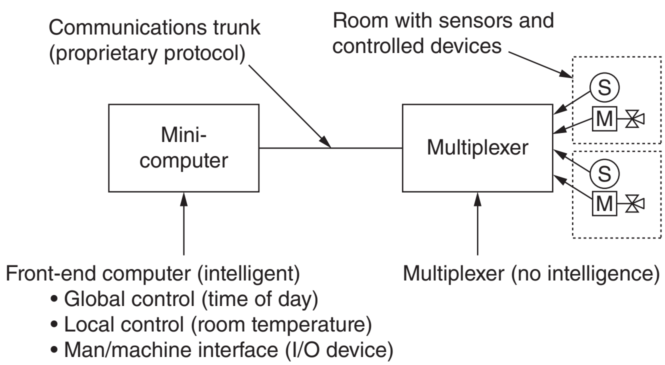


Figure 12-16 Centralized intelligence BAS, 1960s.

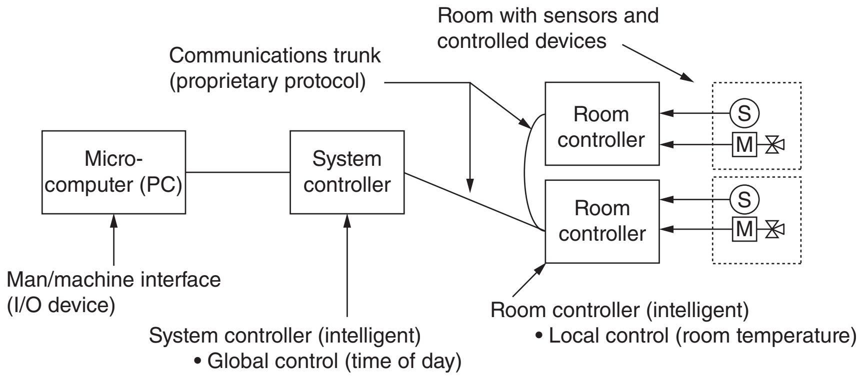


Figure 12-17 Distributed intelligence BAS, 1970s.

protocol to the local DDC controllers. This system controller was now manufactured by the BAS manufacturer. The man-machine interface (MMI) generally became a PC using a separate operating system (Windows) from the *network controller*.

The communication strategy between the system controller and the local DDC controllers had to change. Because there were now a number of DDC controllers rather than a few multiplexers, the DDC controllers could not continuously communicate with the system controller. The communication strategy employed a *polling* technique. The system controller polled each DDC controller on a rotating basis to update its information. The communication rate was initially relative slow by today's standards but was still adequate for the duty needed.

In the 1980s, BASs became true LANs using network controllers communicating through an upper-level proprietary communication protocol between each other and the continuing proprietary protocol and polling strategy to the local DDC controllers (Fig. 12-18).

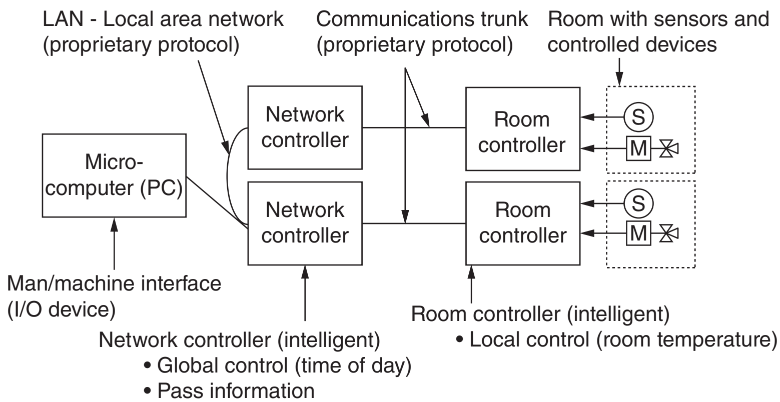


Figure 12-18 Networked intelligence BAS (proprietary protocol), 1980s.

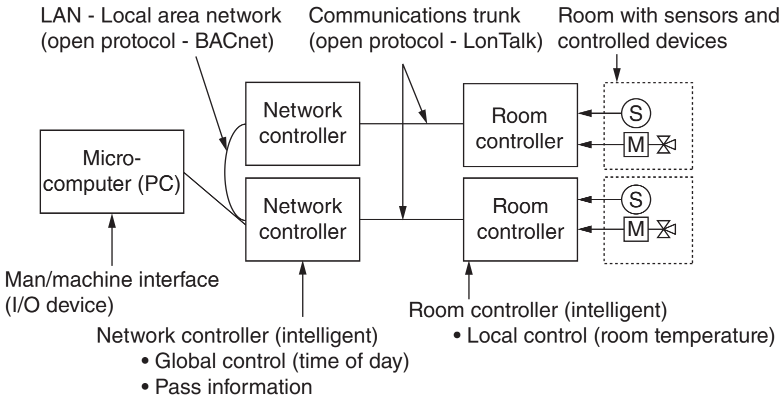


FIGURE 12-19 Networked intelligence BAS (open protocol), 1990s.

The system controller became a network controller sharing information between them. The MMI was still a PC using Windows. For the first time these systems also could communicate remotely through the use of dial-up telephone modems and dedicated phone lines.

In the 1990s, building owners were starting to look for ways to get out from under being locked into one BAS manufacturer after a system was installed. Because the communication protocol used by each BAS was proprietary to itself, another manufacturer/contractor could not work on the system. Just as the high maintenance costs in the pneumatic-controls era produced a new competitor, electronic controls, the high maintenance costs of locked in BASs produced a new competitor. This new competitor was the *open protocol* (Fig. 12-19).

Open protocol now permits any BAS manufacturer/contractor to be able to work on any other's system. It also enables many more manufacturers to enter the industry. Up to this point, all the (computer) components (network controller/DDC controller) of an ATC and BAS had to be made by one manufacturer. This resulted in a limited pool of manufacturers and higher prices.

With open protocol, any manufacturer's controller can communicate with any other manufacturer's controller. Manufacturers of HVAC equipment soon entered the ATC and BAS industry, manufacturing controllers that could control just their equipment. This includes boiler and chiller manufacturers but also terminal units such as heat pumps, fan coils, VAV boxes, air-handling units, rooftop units, and so on.

This also created a need for an installer who could make all these controllers from different manufacturers communicate over one network. Many of the independent control contractors morphed into *system integrators*, a contractor who was able to integrate all these different components into one living, breathing BAS. The BAS manufacturer company offices/branches also developed this expertise to enable their controllers to communicate with their BAS competitors and the HVAC equipment manufacturers.

The common open protocols are LON and *B*uilding *A*utomation and Control *Net*working (BACnet) and an older protocol, Modbus. LON was developed by Echelon and is supported by Echelon and a LonWorks industry consortium. Controllers that make use of LonWorks communicate with each other through what LonWorks calls "standard network variable types" (SNVTs, pronounced "snivets"). The SNVT method is a different approach to defining data objects that requires a detailed knowledge on the part of the sender and receiver of what the structure of each SNVT is. SNVTs are identified by a code number that the receiving controller can use to determine how to interpret the information presented in each SNVT.

BACnet was developed by ASHRAE and is now supported by ASHRAE and the American National Standards Institute (ANSI). BACnet's object-oriented approach to accessing and organizing information provides a consistent method for controlling, examining, modifying, and interoperating with different types of information in different types of devices, which is both vendor-independent and forward-compatible with future BACnet systems. BACnet defines standard *object types* that represent commonly used objects found in many existing automation systems. BACnet objects are collections of *properties*, each representing some piece of information or parameter. Some properties may only be examined (read), whereas others may also be modified (written). BACnet defines not only what the properties of standard objects are but also what types of behavior are to be expected from each property.

Modbus was developed originally by Modicon in 1979 for communication with industrial programmable logic controllers (PLCs). Modbus is supported by the Modbus Organization, an association formed of independent users and suppliers of Modbus-compliant devices that seeks to drive the adoption of the Modbus communication protocol suite. Modicon was purchased by Schneider Electric, and Schneider has transferred all Modbus rights to that organization.

Building automation systems continued to develop and in the 2000s adopted WAN technology and interface with the Internet (Fig. 12-20).

One of the other developments was the need to allow upper-level communication not just between local DDC controllers using an open communication protocol but also between front-end computers of different manufacturers and older legacy systems.

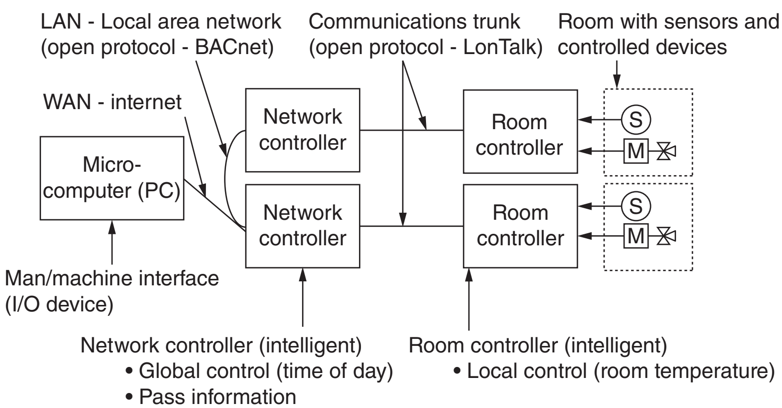


FIGURE 12-20 Web-based networked intelligence BAS (open protocol), 2000s.

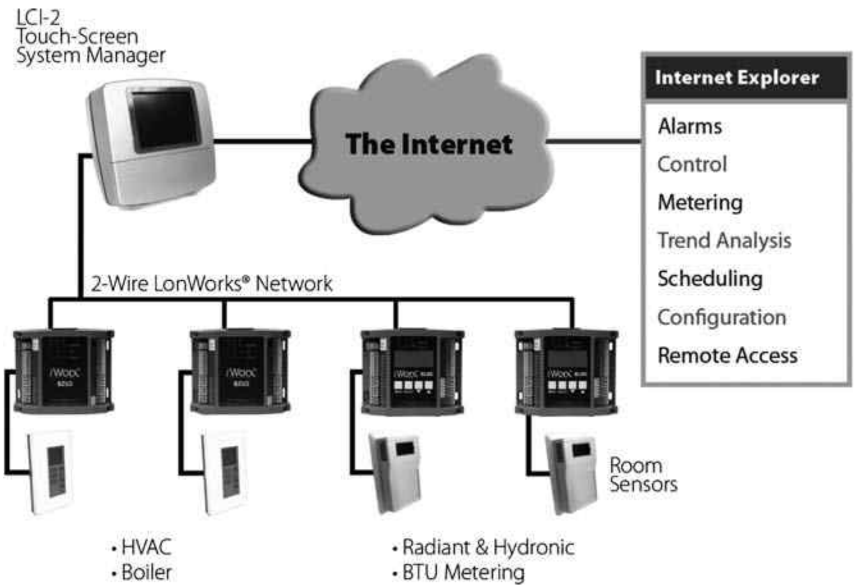


FIGURE 12-21 Taco iWorx web-based preprogrammed plug-and-play BAS.

A manufacturer, Tridium, created an operating system, Niagara, using a JAVA variant that allows multiple systems from multiple manufacturers to communicate through one gateway or front end. For the first time, older proprietary BASs and newer open-protocol systems can communicate. The Niagara Framework is a software platform that integrates diverse systems and devices regardless of manufacturer or communication protocol into a unified platform that can be easily managed and controlled in real time over the Internet using a standard web browser.

A difficulty that still remains for the BAS industry is the requirement for skilled technicians to program the computers used by the ATC and BAS industry. These include the local DDC controllers and the network controllers and front-end computers. This has limited the spread of this technology to mostly larger buildings. In the United States, over 40 percent of the floor space and 90 percent of the buildings are buildings of less than 50,000 ft^2. Applying the latest BAS technology is not competitive for a large portion of these buildings. Several manufacturers are addressing this need.

One manufacturer, Taco, has developed a system, iWorx, that requires no field programming and no field addressing of network addresses (Fig. 12-21).

Plug-and-play preprogrammed controllers are available for a variety of applications—boilers, chillers, pumps, chilled beams, fan coils, heat pumps, and so on. The system can be configured and commissioned by HVAC technicians with no special knowledge of computers or programming. The MMI also does not require a PC; it is a touch screen or local control interface (LCI). The LCI is also web-enabled. An upper-level Niagara-based network controller, Java-Enabled Network Engine (JENE), allows the system to communicate with other manufacturers' BASs or other equipment manufacturers' equipment (Fig. 12-22).

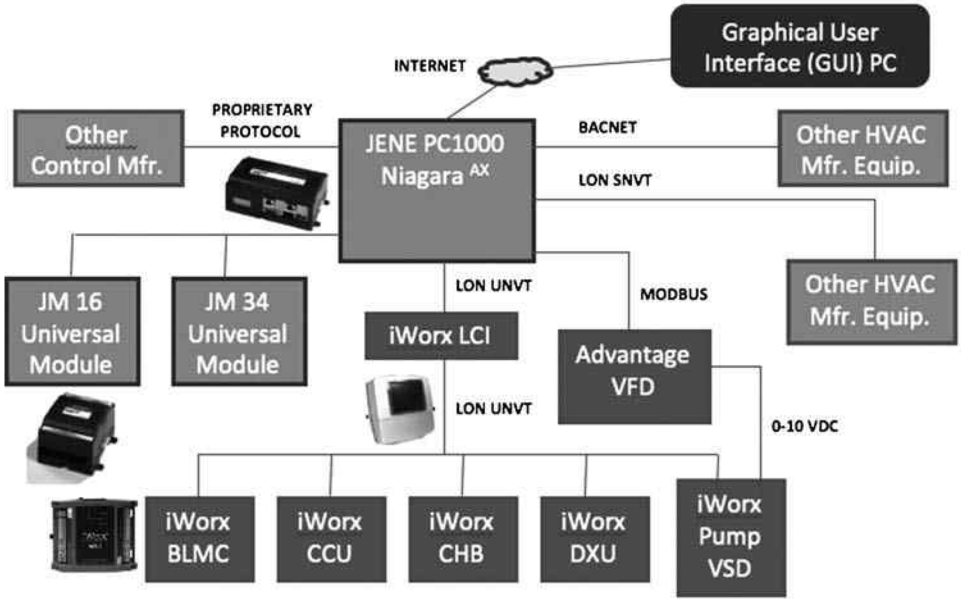


Figure 12-22 Taco iWorx and upper-level Niagara communication gateway.

Review Questions

1. By the 1970s, the building automation systems (BAS) industry was evolving to distributed intelligence. This enabled some intelligence to be moved
   a. to the software programs designed by the engineers.
   b. off-site.
   c. into Palm Pilots and similar devices.
   d. into the zones.

2. The first BAS appeared in the 1960s and were generally separate from
   a. semi-integrated systems.
   b. front-end or host computers.
   c. pneumatic or automatic temperature controls.
   d. field multiplexers that serve as interface.

3. Building automation systems will work in harmony with
   a. well-designed mechanical systems.
   b. lawn maintenance irrigation controls.
   c. misapplied systems.
   d. highly nonlinear processes.

4. The earliest temperature controls
   a. were electrical-resistant strips.
   b. were on/off and could not provide precise comfort.
   c. were mercury-filled.
   d. required highly skilled technicians.

5. Which of the following is *not* a common open protocol?
   a. BACnet
   b. LonWorks
   c. ANSI
   d. Modbus
6. The protocol known as LonWorks allows communication through what is called
   a. pulse data.
   b. an Ethernet bus.
   c. "snivets".
   d. USB ports.
7. With the advent of open protocols, many independent control contractors morphed into
   a. software engineers.
   b. information technology (IT) specialists.
   c. programmers.
   d. systems integrators.
8. The ATC industry has adopted some common terminology for the points a controller has available. Which of the following is *not* among these points?
   a. I/O—input output
   b. AI—analog in
   c. DI or BI—digital or binary in
   d. DO or BO—digital or binary out
9. Linear control strategies are used where there is
   a. an indirect relationship between the result and a controlled device.
   b. a mixing of water in a water-to-refrigerant exchanger.
   c. a direct relationship between the position of the controller device and the desired result.
   d. mixing of low-temperature chilled water at 33°F for controlling cooling in a radiant-floor heating system.
10. A closed control loop uses a
    a. direct measurement of the parameter to be controlled.
    b. an average measurement of the device to be controlled.
    c. a digital measurement of the device to be controlled.
    d. All the above
11. There are three basic components to a control system. Which of the following is *not* one of them?
    a. Supply-air temperature
    b. Sensor
    c. Control device
    d. Controller
12. There are three basic types of modulating control loops. Which is the most accurate?
    a. Proportional + derivative
    b. Proportional + integral + derivative
    c. Proportional + integral
    d. Proportional

13. Plug-and-play preprogrammed controllers are available for a variety of applications. It is important to note that HVAC technicians need
    a. specialized training for programming these devices.
    b. not concern themselves with RFI.
    c. no special knowledge of computers or programming.
    d. a PC in order to program the controllers.
14. A difficulty still remains for the controls industry in that there is significant requirement for skilled technicians to program the computers used for ATC and BAS. This is *not* true in the case of
    a. iWorX.
    b. Tridium.
    c. Niagara.
    d. Gateway.
15. Plug-and-play preprogrammed controllers are available from iWorX for all but which of the following applications?
    a. Boilers and chillers
    b. Chilled beams and fan coils
    c. Pumps and heat pumps
    d. All the above plus many more

CHAPTER 13

Load Sharing and Energy Recovery

In order to delve into this chapter, a basic understanding of the terminology used herein is important. In the very simplest form as it pertains to mechanical cooling and heating of structures and processes, *load sharing* means to share the *workload*. The work is to cool or heat something. That something can be a room in a structure occupied by people or a tank intended to hold water for domestic use. To share a load or the inverse, to recover the energy is the process we are describing.

Chapter 12 covered control systems. In the process of load sharing, the importance of proper controls is paramount. Use of proper controls allows you to treat your commercial building or residential structure like a piece of computer hardware. If you were, for example, to get a new mouse, a new keyboard, or a new printer, you could just plug it in to your computer USB port, and it works like magic. That is the magic we are working for with the iWorX platform, as well as other good manufacturers' of controls.

The lead author's previous book, *Geothermal HVAC: Green Heating and Cooling*, addressed the need to control the geothermal source pump (i.e., well pump), the condenser water circulator pumps, the domestic hot-water pumps, the compressor, the fan, the control valves, the pool heat pumps, and any other modulating specialties in harmony one with another. It's important to understand the matrix with which you are working.

The question might be raised in a geothermal/hydronic application, which of the following takes less energy overall?

- Running the geothermal source pump at a slower speed
- Running the source or load water pumps at a higher speed
- Running the compressor on first stage
- Lowering the evaporator fan speed
- Increasing the domestic hot-water pump speed
- Running the second stage on pool heating

By the time you consider the matrix of all these components and more and then consider how the smallest adjustment on condenser water pumps affects compressor power consumption, an adjustment of the evaporator fan speed affects overall humidity control, and increasing domestic hot-water volume may decrease available heat and resulting efficiency, you have an unimaginable matrix of algorithms to consider.

Thankfully, much like the control systems for the most efficient economy cars, such as the Prius, all these things are calculated in an instant, and a resulting "mpg" or, in our case, an energy-efficiency ratio (EER) is computed. With proper use of this type of control system, we can confidently enter the world of thermal-advantage load sharing/shedding in hydronic systems.

Throughout this chapter, examples will be used of methods to integrate variables and goals. Since we are working with heat pumps which are reversible refrigeration devices, remember; the condenser output is heated, and the evaporator output is cooled. One side of a heat pump produces heat, and the other, cold (air or liquids).

How We Got Here

In the 1980s, a device installed on air conditioners became very popular; it was called the *energy-conservation unit* (ECU). This device, shown in Fig. 13-1, was used to extract the waste heat from a direct-expansion air-conditioning system and channel that heat into the domestic hot-water tank.

In 1990, a geothermal heating, ventilation, and air-conditioning (HVAC) system was installed in a 10,000-ft^2 home, and the owner asked that the 25,000-gal pool be the (alternate) heat sink. With only manual valves to switch from a geothermal ground loop to the pool, it became a daunting task. Finally, some decent electromechanical controls were devised for that particular situation, but it was not a perfect science.

Time and time again, motors with variable-frequency drives or other modulating capabilities are reported to be operating far out of parameters because they were never integrated with other feed-back system components, commissioned or started properly or otherwise have been overridden. It is up to the engineers and professionals reading

Figure 13-1 An ECU is used to recover heat from a direct-expansion air-conditioning system and channel that heat into a domestic hot-water tank, providing essentially free water heating and increasing the efficiency of the air conditioner. This is an example of load sharing. (*ECU Energy Conservation Unit, Inc.*) *more appropriately called a desuperheater for domestic hot water generation.*

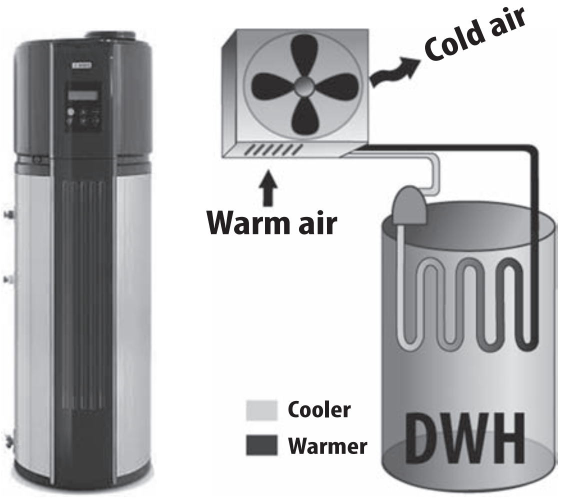


FIGURE 13-2 A heat-pump water heater, typically installed in a garage or mechanical room, has all the components needed to provide domestic hot-water needs and the waste by-product, space cooling. (*Bosch*.)

this book to use the technology at hand to ensure proper operation of our entire and integrated mechanical systems.

Recently, a device has come into the marketplace that is a more direct version of the ECU. It is called the *heat-pump water heater* (Fig. 13-2). This system usually comes with a tank for the domestic hot water, a compressor, and an evaporator coil. The system has everything needed to heat water and provide the by-product of heating water—space cooling.

It stands to reason that the question might be asked why would a heat-pump water heater be in the market when an ECU product seems to work in much the same way for all structures. The reason is another of those hard-learned lessons in combination with other increases in technology.

The hard-learned lesson is that tying refrigerant outside a factory-sealed condenser from an air-conditioning unit exposes the system to possible failure from refrigeration circuit dynamic pressure changes, refrigerant leaks and contamination of the refrigerant system and/or the domestic hot-water system. Often an ECU is installed outdoors, where conditions resulting from extreme weather, rodents, insects, and so on typically caused failure of such components as the pumps, contactors, and general packaging within 5 to 10 years (Fig. 13-3). When this failure occurred, it often resulted in failure of the entire HVAC system because of the interdependent nature of the refrigerant system.

As federal regulations required seasonal energy-efficiency ratio (SEER) ratings of air-conditioning units to be increased, the availability of waste heat for operations such as domestic hot-water recovery diminished. Manufacturers now recommend against installing ECU systems on their refrigeration circuits.

Another issue with these ECUs was the procurement of spare parts. The lead author can recall few times during his tenure as a contractor when he was to find a properly fitting spare pump, exchanger, thermocouple, or any of the other parts needed.

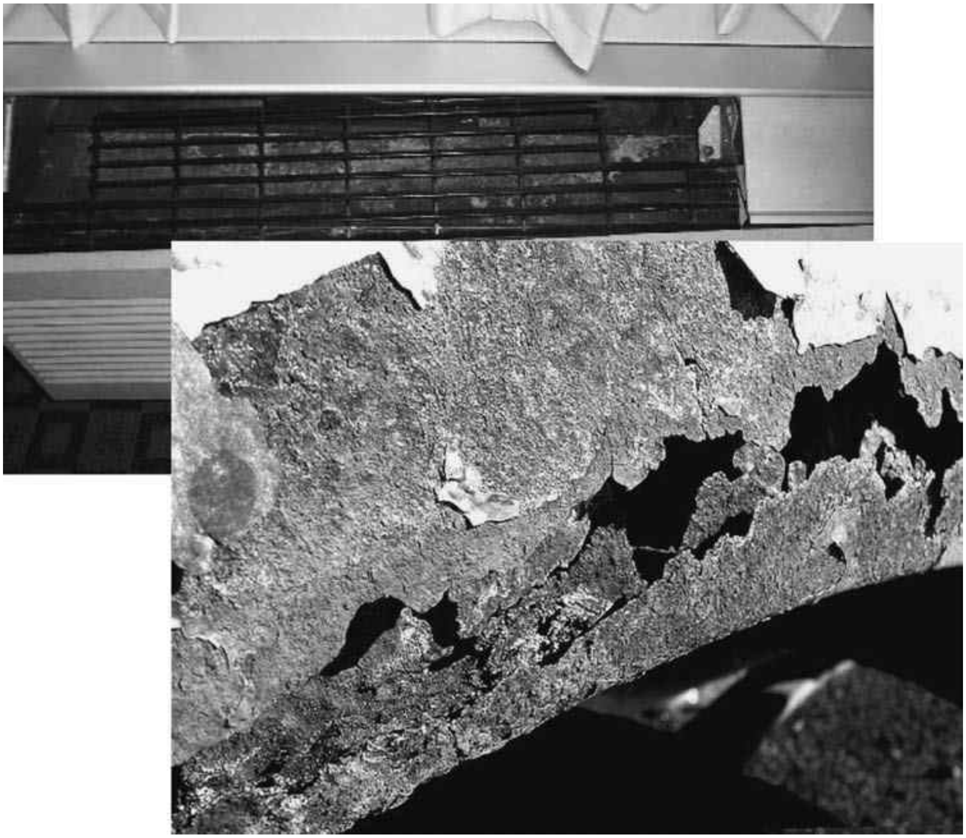


Figure 13-3 A 5- to 10-year-old ECU and Air Conditioner, exposed to the elements, is ready for the trash heap. (*Jason Hodges*.)

It seemed like the units were engineered for failure, and the likelihood of finding spare parts was less than favorable.

Interestingly enough, along the same lines, the same thing was happening with the smaller minisplit air conditioners (Fig. 13-4). Contracting companies would install many of these "splits" in bank teller lines, equipment rooms, stock rooms, and corner offices for customers. A couple of years later, when an evaporator motor, the condenser fan, or the like failed, it was nearly impossible to find replacement parts. The parts, the contractors were told, were already obsolete, and upgrading the entire system was recommended. Invariably, this problem made the lead author feel as if he had failed to provide a good product to his customers, and he would spend undue time trying to reengineer the system with a component that wasn't necessarily designed for it. These are not good memories.

The control sequences, overages, and protocols varied widely with these systems, and this was an issue that perplexed the lead author. Looking back now, it seems an easy way to make a model obsolete. There is a reason the lead author brought up these minisplits, and this will be discussed more later in this chapter.

Figure 13-4 Minisplit systems were used commonly for bank teller lines, equipment rooms, corner offices, or anywhere that needed a little more cooling. (*Northwest Georgia Recycling*.)

Now, to understand better the infinite possibilities with regard to load sharing, you must take a few moments to assess the opportunities available within a building. Here is a list of building systems that absorb or expel heat energy

- Space air conditioning
- Space heating
- Domestic hot water
- Pool heating
- Ice making
- Refrigeration (e.g., walk-in coolers/freezers)
- Laundry rooms
- Dedicated outdoor air systems (DOAS)

Depending on the season, space air conditioning and heating could be in either mode. During the middle of the winter or cold season, these systems may need heating, whereas in the summer or warm season, the spaces will need cooling. In commercial applications, internal heat gains from items such as computers, copiers, monitors, lighting, and so on put out enough heat that even in the middle of a cold northern winter, these buildings often need cooling capacity.

Jerry Baker and Greg Cunniff were involved in a project in Colorado in which a building was designed on a ground loop according to established procedures. Just a few years later, the ground was saturated with heat rejected from the building. This happens quite often in climates in which people think that heating is the dominant load. Commercial buildings typically have so much in the way of internal heat gains that the dominant load becomes cooling. When you understand this, you'll find that there is waste heat that can be used for other processes in the building. This is where load sharing really comes into play.

If you look at the systems in the preceding list that produce heat most of the time, the most obvious ones are refrigeration, ice making, and space air conditioning. The systems that need heat as part of their process include space heating, domestic water heating, pool heating, and laundry needs. Normally, the way that these heating needs are addressed is through either electrical resistance heat or the burning of fossil fuels. For example, consider the heat used for domestic hot-water needs; typically, there is a gas-fired or electric hot-water tank. You also may consider pool heating. Typically, pool heaters are gas-fired. Even under the best of conditions in these two examples, air-source heat pumps may be used. This is a great example of heat-pump usage for domestic pool hot-water needs. But with air-source heat pumps, the by-product of extracting heat from the air is relatively cold air. It would be wonderful to capture this colder air and pump it into the building that is in need of cooling.

What do you think is the best way to capture this air? If you haven't studied it previously, there are available energy-recovery ventilators and other devices that recover heat or cooling from an airstream (Fig. 13-5). These devices are installed within the airstream and provide an isolated cross-stream of air through channels that allow the transfer of heat between the airstreams.

This type of ECU is large and requires considerable service. The same amount of heat can be transferred in a water-to-water heat exchanger that is only a fraction of this size and requires virtually no service.

Figure 13-5 This exhaust-air ventilation recovery unit crosses the stream of conditioned air being exhausted from the building with outdoor air entering the dedicated outdoor air-conditioning unit. In this way, the air temperature and conditions entering the outdoor air unit are brought closer to the design air temperature for the building, saving considerable energy. (*ERV, Inc.*) *Energy Recovery Ventilator*

In many commercial buildings, as well as residential dwellings, you can find air-source heat pumps operating in close proximity to pool heat pumps (Fig. 13-6). The temperature of the air coming out of the air-source heat-pump condenser coil is between 80 and 120°F. The temperature of the air coming out of the pool heat pump might be 40°F or less. This is so because the heat pump cooling the building is rejecting heat and the heat pump heating the pool is absorbing heat. The waste from one can be used in the other.

Water absorbs heat through contact (conduction) 32 times faster than air. Hydronic piping uses a fraction of the space of forced-air ductwork (Fig. 13-7). All in all, hydronic systems provide the most economical and efficient transfer of heat. There is a move afoot to get people to believe that chemical refrigerants can replace water as an economical system for cooling large commercial buildings with multiple loads. It will be short-lived, and as you read this chapter, you'll see the reasons why water-based hydronic systems are far more economical and versatile.

It is safe to say that air-source cooling and heating equipment is not conducive to capturing the waste heat in a load-sharing capacity. Now let's look at a geothermal-sourced system and examine the opportunities for sharing the load. Figure 13-7 shows several pieces of equipment. In the first part of the figure, the air-source equipment is not able to effectively transfer its heat to other equipment that would benefit from the use of that heat. In the second depiction, however, you can see that the equipment is all tied together by one common condenser water line. The trick in this type of system is to use a hydraulic separator or an exchanger to tap into the geothermal source. The condenser water loop is then assigned a window or a range of temperature within which all the equipment can run. For example, the lower limit of the condenser water loop might be set for 40°F, and the upper limit might be 95°F.

FIGURE 13-6 These two heat pumps doing their job side by side for the same dwelling could be likened to the old adage, "One person's trash is another person's treasure." Much energy is expended in an effort to remove heat (for the building), while much energy is also expended in an effort to bring in the heat to the pool. (*EggGeothermal*.)

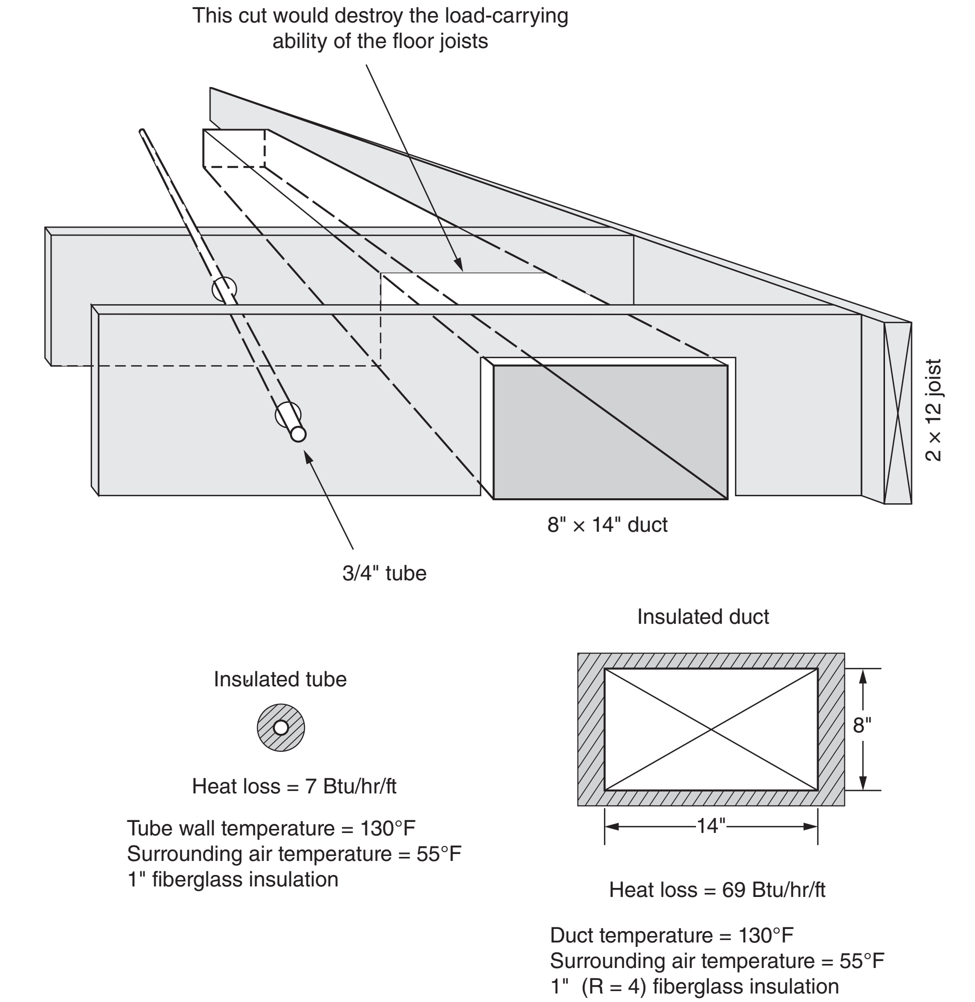


Figure 13-7 Geothermal and hydronic systems take up just a fraction of the space of forced-air systems, saving considerable construction dollars and energy. (*Appropriate Designs, Hydronicpros.com*.)

With a large storage/expansion tank, more opportunities for load shedding and sharing can be practiced. This type of load sharing cannot be accomplished effectively with variable refrigerant systems. The systems are specifically engineered for each application and do not have latitude for error or for load sharing of this nature. Additionally, when using a hydronic condenser water loop, the refrigerant type, temperature range, and equipment that can be served are almost endless. This is not possible with variable refrigerant systems. For example, just imagine trying to place a pool heat pump on a variable refrigerant circuit to use the waste heat for pool heating.

The key to this type of system, besides being water-based (hydronic), is that the geothermal pump (the pump that extracts and rejects heat to the earth) is hydraulically

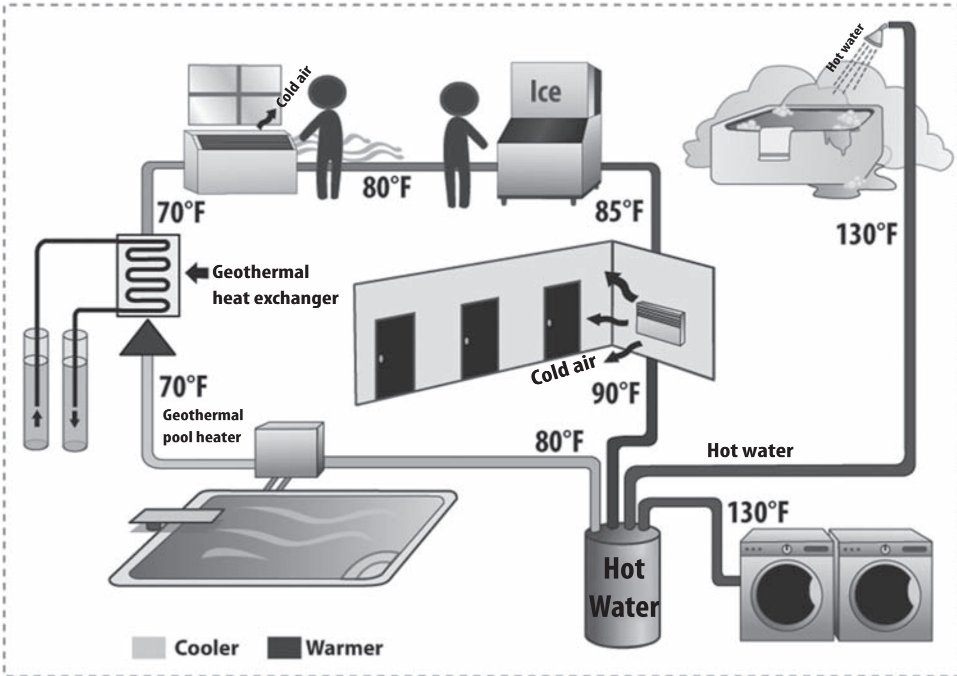


Figure 13-8 Notice the differing temperatures of the condenser water line as all the equipment on this line shares the condenser water loop. (*Sarah Cheney*.)

separated from the condenser or evaporator water loop. This can be done in one of the two general ways.

The first way is total separation of the circuits through an exchanger (Fig. 13-10). The heat exchanger is designed to eliminate the possibility of any fluid mixing between the geothermal loop and the condenser water loop. Only the exchange of temperature is achieved.

You can see that the condenser or evaporator water loop can operate without operation of the geothermal pump. The geothermal pump controller monitors the temperature of the condenser water loop and begins to operate as the temperature of the condenser water loop approaches the upper or lower limits. At this point, the geothermal pump operates only at the frequency needed to maintain the upper- or lower-limit set points.

In a closed-loop geothermal system, the water is treated and circulated through the ground-loop tubing. This eliminates the need for separation of the geothermal fluid from the condenser water in the system. In an effort to save energy and allow load sharing, though, we do not want the heat rejected in the building to be deposited underground until other equipment in the circuit has had an opportunity to use it.

In this case, a hydraulic separator is used. This is essentially a tank with four connections. Figure 13-11 shows that the fluid can circulate through the condenser or evaporator water loop and have no affect whatsoever on the circulation of water through the ground loop. In much the same way as shown in the plate and frame

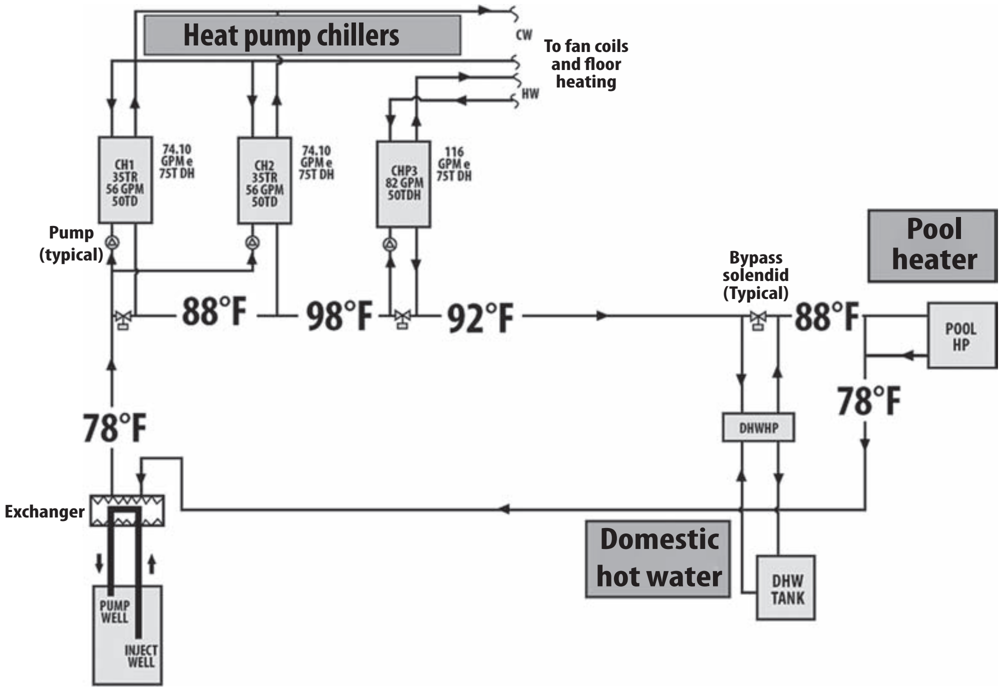


Figure 13-9 The temperatures in the condenser water loop vary by more than 20°F in this example. Because of this, all the systems are able to operate in load-sharing harmony. (*Sarah Cheney*.)

exchanger example, the pumps that operate the geothermal or ground-loop portion of the system must operate before any heat transfer with the earth can take place.

The use of variable refrigerant equipment is brought into question when essentially a less costly and more dependable type of refrigerant can be used. R-718 is just water. It's what we've been using for years because of the expense and hazard related to running refrigerant lines to each and every cooling/heating coil and building. In a system that contains 30 or more pounds of refrigerant, a leak in an evaporator coil within the space can displace all the oxygen and result in suffocation of the inhabitants.

In his previous book, *Geothermal HVAC: Green Heating and Cooling*, the lead author wrote about equipment that would be introduced into the market with questionable quality. An excerpt reads in part:

> We will likely see inferior equipment slip into the market. As this happens, we will see equipment failures in the first years and months, and we will have problems getting replacement parts. Much like a friend on my street who has a no-name four-wheeler ATV that needs a rear-end part. . . . He can't find it anywhere at any price.

Most have run into this problem; it becomes so troublesome to locate a part that we simply replace the mechanical component or abandon it. As he reflected on this, the lead author has considered over the past 23 years the numerous minisplit systems that

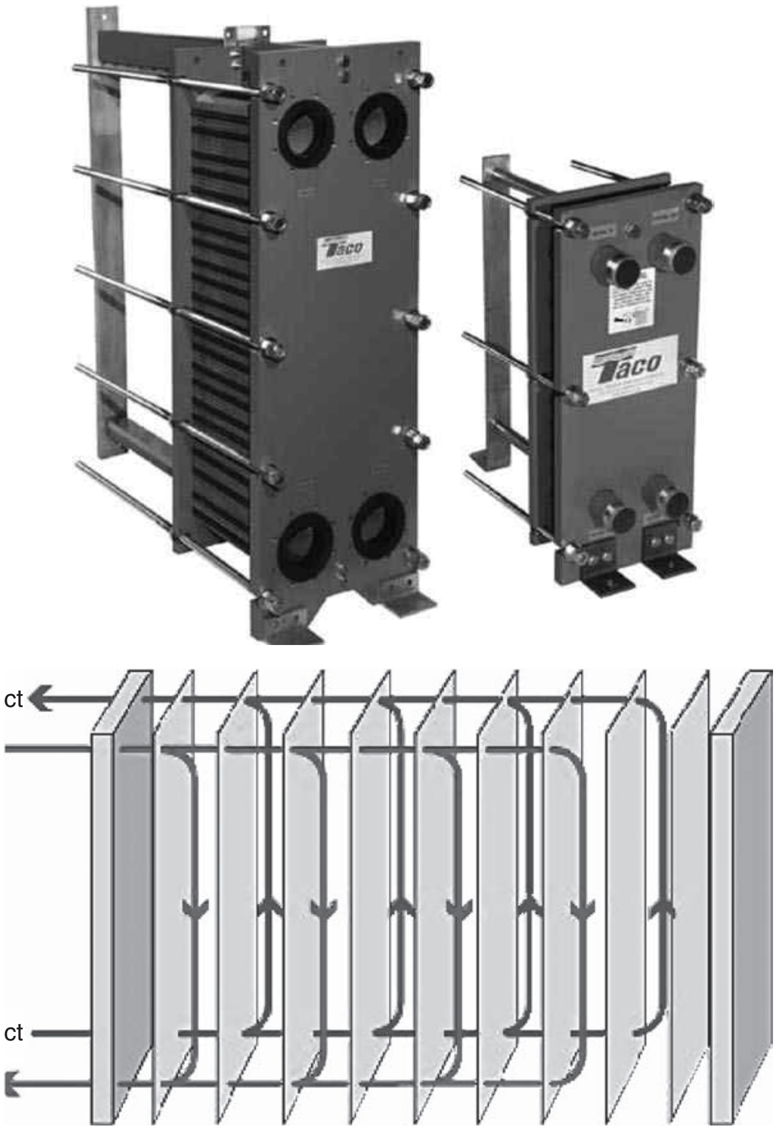


Figure 13-10 As you can see in the flow diagram for this plate and frame heat exchanger, water from two different sources is isolated one from the other by thin plates. (*Taco, Inc.*)

he has dealt with (Fig. 13-12). They went in fairly easily, but there were some inconsistencies that were troubling. Among these were

- Unusual control voltages
- Proprietary parts
- Unusual control sequences
- Parts and features not conducive to replacement

Figure 13-11 The hydraulic separator allows separate pumping of condenser water circuit to the heat-pump equipment and pumping of the fluid to the geothermal or ground-coupled portion of the system. This results in considerable pumping advantage and allows for load sharing. (*Taco, Inc*.)

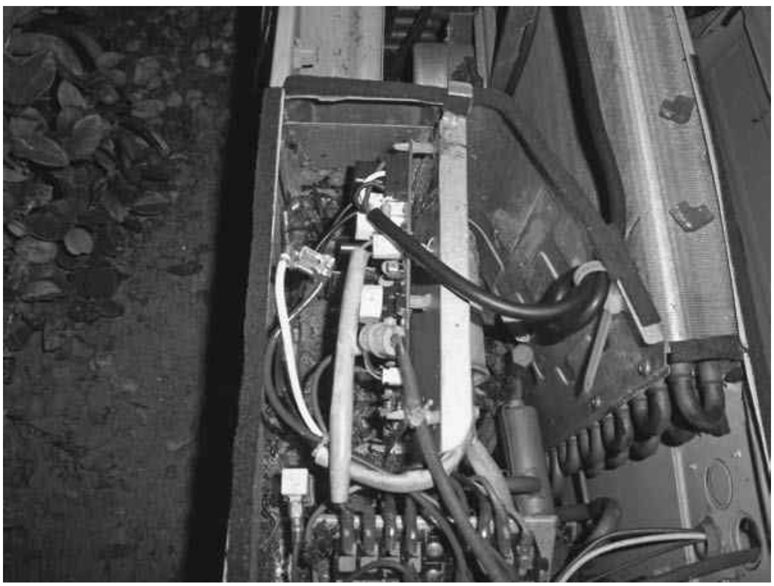


Figure 13-12 This minisplit condenser, just a few years old, was abandoned because of failed parts that were unavailable from wholesalers or manufacturers. (*EggGeothermal*.)

Indeed, it seems that every time a replacement was needed or a repair was affected, there were insurmountable problems getting replacement parts. To put it bluntly, the parts were already either obsolete or entirely unavailable. This left reputable contractors to try to recreate a control sequence within evaporator that didn't quite match or something of that nature.

Dedicated outdoor-air systems (DOAS) benefit remarkably from load sharing. These units are normally large-tonnage systems that are not available for use on a variable refrigerant system circuit.

Proper Operation and Calibration of Controls

In Dr. Steve Kavanaugh's report on long-term commercial geothermal-source heat-pump performance in the *ASHRAE Journal*, he noted in his conclusion that variable-speed pump drives were largely inoperable and likely saved little energy. It is evident that although engineers and designers do a good job indicating design parameters, there is a loss of communication down line. This is a good argument for commissioning of fully integrated geothermal systems, not just the isolated heat pump. For this reason, the authors highly recommend that systems be tested in balance by a certified agency. After it can be certified that the pump flows and airflows, temperatures, and so forth are correct according to engineer and manufacturer specifications, then the project can move on to the integrated commissioning.

Commissioning the system involves certifying that the system runs under all automatic modes in all conditions correctly. Commissioning can take quite some time depending on certain variables. Much communication among the owner, engineer, mechanical contractor, plumbing contractor, controls contractor, and other field personnel as necessary may be required to properly certify that a system is operating according to design.

For example, if you look again at Figs. 13-7 and 13-8, the application of intuitive and comprehensive controls for these systems can seem daunting. Take a look at the number of control points and the purpose and equipment they serve. There are several pumps operating in different variations of decoupled secondary circuits. These pumps are feeding chillers and chiller heat pumps that are operating independent of each other. In addition, the heat pump for the domestic hot-water system is operating on demand for the building's hot-water needs. The pool heat pump is operating on demand as well. The geothermal source, a pump and regeneration, is operated based on the differential of temperature for the condenser water circuit. This particular system has incredible opportunities for energy savings. If the system can operate, anticipating the operation of the other pieces of equipment within the system, incredible energy savings can result. In the figure, you can see that the temperature of the condenser water ranges from 78°F as it discharges from the plate and frame exchanger, the geothermal source raises it to 88°F, then to 98°F, back down to 92°F, then to 88°F, and back to 78°F. What this results in is a perfect harmony of thermal-advantage condenser water operation. This is also called *load shifting*, *load shedding*, or *load sharing*.

Of importance is the fact that these systems can operate in harmony if the pumps, valves, and heat pumps are calibrated and programmed properly. Control systems such as Taco's iWorX control system provide this type of complex control.

In many applications, a source such as a cooling tower, a boiler, or more appropriately in this case a geothermal heat sink/source is used. It is advantageous under these conditions to separate the condenser or evaporator water loop from the source loop by means of a plate and frame exchanger or a hydraulic separator. Figure 13-13 shows how

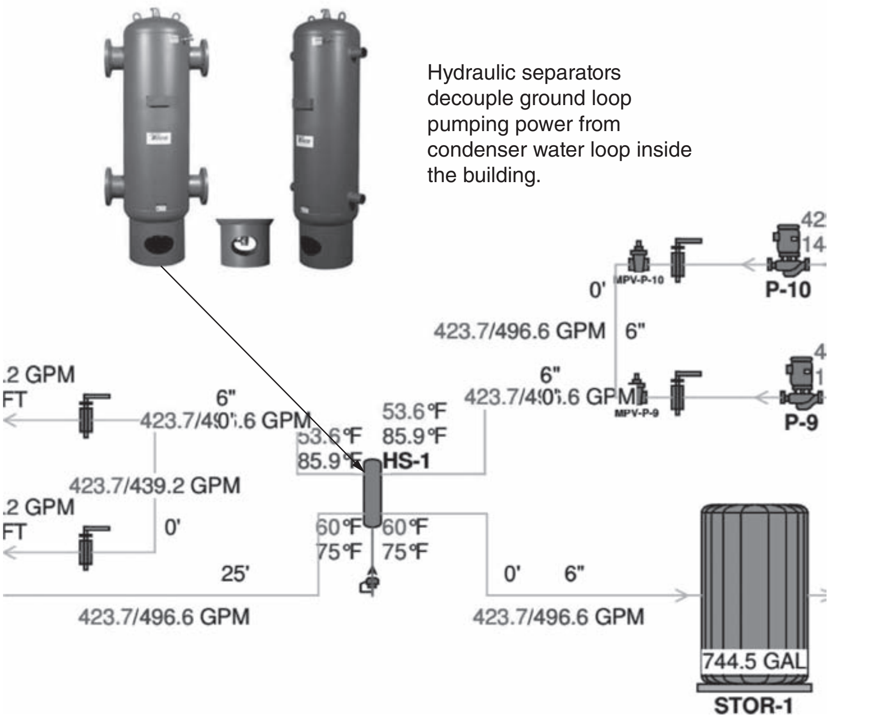


Figure 13-13 A hydraulic separator provides a separation between the heat source/sink and the condenser water circuit, allowing the work of thermal advantage to take place. (*EggGeothermal*.)

this is accomplished in the case of coupling with a closed-loop system, open-loop system, standing-column well, or whatever the case may be.

The advantage comes when a building has multiple loads. For example, during the winter, the spaces along the windows of a commercial building may need heating in northern climates. At the same time, the spaces in the interior of the building that are not adjacent to any windows or sources of heat loss that have significant internal heat gains (e.g., from copiers, computers, lighting, etc.) may need cooling. In this case, if the condenser water loop is allowed to run a temperature with a large enough window (between 40 and 85°F, for example), the source or sink for heat may not need to be tapped for extended periods of time. See Fig. 13-9 to review this example.

In a case study of a YWCA in Ohio by Yoder Geothermal, the contractor experienced this very situation. Tim Yoder, president of Yoder Geothermal, was pleased that the system's ability to perform load sharing or thermal advantage. He said that often during the winter the sun is in the southern sky all day, promoting the need to cool the spaces along the southern exposure of the building, whereas heating is needed along the northern exposure of the building. He has noted that there are many times when the source-well pump needn't run for extended periods of time while the condenser water loop is sharing the load from one heat pump to another. See Chap. 3 in *Variation of Earth Coupling* from this book, chapter 3 of "Modern Geothermal HVAC Engineering and Controls Applications" for this short case study on the YWCA.

Natatoriums (or Indoor Swimming Pools)

The design of indoor swimming pools offers tremendous opportunities for thermal advantage/load sharing. The big issue is that many critical design considerations must be fully understood and properly addressed to ensure comfortable, safe, and trouble-free operation.

It's important to note that natatoriums are notoriously difficult facilities to design because there are so many critical issues that, if overlooked, lead to problems with the building's structure or complaints from the occupants. The design issues at hand are

- Comfort and health
- Humidity control
- Indoor air quality
- Condensation control

Take a look at Fig. 13-14 to get an idea of the vast difference in air temperature versus water temperature recommended for natatoriums.

Some general notes to consider are

1. Facilities must maintain a relative humidity (RH) between 50 and 60 percent.
2. Facilities that perform physical therapy will tend to cater to the worker comfort before patient comfort because the patients are typically only in the space for about an hour at a time.
3. Elderly swimmers tend to prefer much warmer air and water temperatures.
4. Facilities with warmer water temperatures must have space temperatures that are warmer as well.

Typical Natatorium Design Conditions		
Pool Type	Air Temperature, °F	Water Temperature, °F
Competition	75 to 85	76 to 82
Diving	80 to 85	84 to 88
Elderly Swimmers	84 to 85	85 to 90
Hotel	82 to 85	82 to 86
Physical Therapy	80 to 85	90 to 95
Recreational	82 to 85	80 to 85
Whirlpool/spa	80 to 85	102 to 104

Figure 13-14 In this table it is clear that there is a vast difference in air and water temperatures in natatoriums. (*Seresco*.)

With humidity control at the center of concern with regard to destructive effects on building structure, the following are some of the most important issues with which contractors and engineers must work

1. Load calculations
2. Evaporation rates
3. Occupancy load
4. Outdoor air requirements

These issues all have one thing in common—they deal with latent heat or the moisture load of the natatorium. There are typically three ways to control humidity

1. Package refrigeration systems
2. A central chilled-water plant and an air handler
3. One-hundred percent outdoor air ventilation

Outdoor air requirements based on the American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 62-1999 are as follows

- 0.5 ft^3/min per square foot for pool and wet-deck areas
- 15 ft^3/min per square foot for spectator areas

Systems are coupled with geothermal pool heat pumps, which, as shown in Fig. 13-15, use a common condenser water line and encumbrance of control system, and full integration of the geothermal advantage loop is achieved. In the figure, notice that four geothermal heat pumps are tied in as a decoupled secondary loop of the main geothermal loop that is conditioning the structure.

In addition to this, passive/active heating for the pool is being provided by waste heat from air conditioning the structure through a separate heat exchanger (Fig. 13-16).

The Big Picture for Thermal Advantage

Even in a book of this size, the authors cannot begin to address all the potential opportunities for load shedding and load sharing. We have just skimmed the surface in this chapter, and other books on the subject will delve deeply into the subject of thermal advantage, geothermal HVAC applications, and the opportunities beyond what have been discussed here.

When implementing geothermal HVAC applications in a community that includes a significant amount of infrastructure, there are several energy-producing/energy-absorbing opportunities. Among these are

1. Rooftop solar collectors
2. Swimming pools
3. Retention ponds
4. Storm water
5. Wastewater
6. Gray water

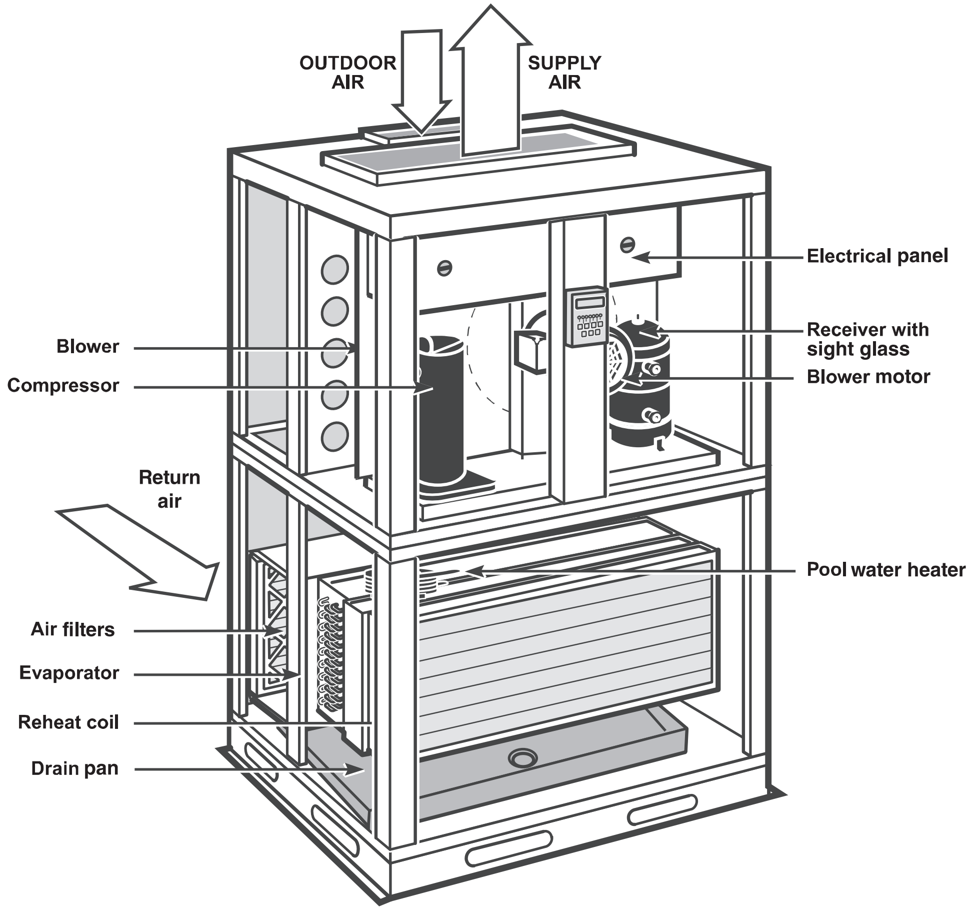


Figure 13-15 Much like this depiction of a Seresco vertical air dehumidifier, pool water-heater options provide waste heat for pool heating from the operation of dehumidification. (*Seresco*.)

This type of thermal-advantage load-sharing is as wide and varied as the imagination can comprehend. You may have heard much about wastewater treatment. Much of the water that goes down the drains in homes and offices is at 70°F or higher, sometimes much higher. Think about showers and laundry. All that heat may be thermally extracted to plate and frame exchangers and returned to the community.

Indoor pools can exchange heat with indoor air conditioners, providing a symbiotic relationship. There is always a little bit of an imbalance, sometimes a lot of an imbalance, and that deficit can be made up by irrigation wells, retention ponds, solar thermal, or even the occasional neighborhood ice rink (I know, big neighborhood).

When speaking of commercial thermal advantage, it's easy to see that there is an endless source of heat not only from the earth but, more important, the waste heat generated by internal heat gains from large commercial buildings in downtown districts. How many times have you found yourself driving through a downtown area on the

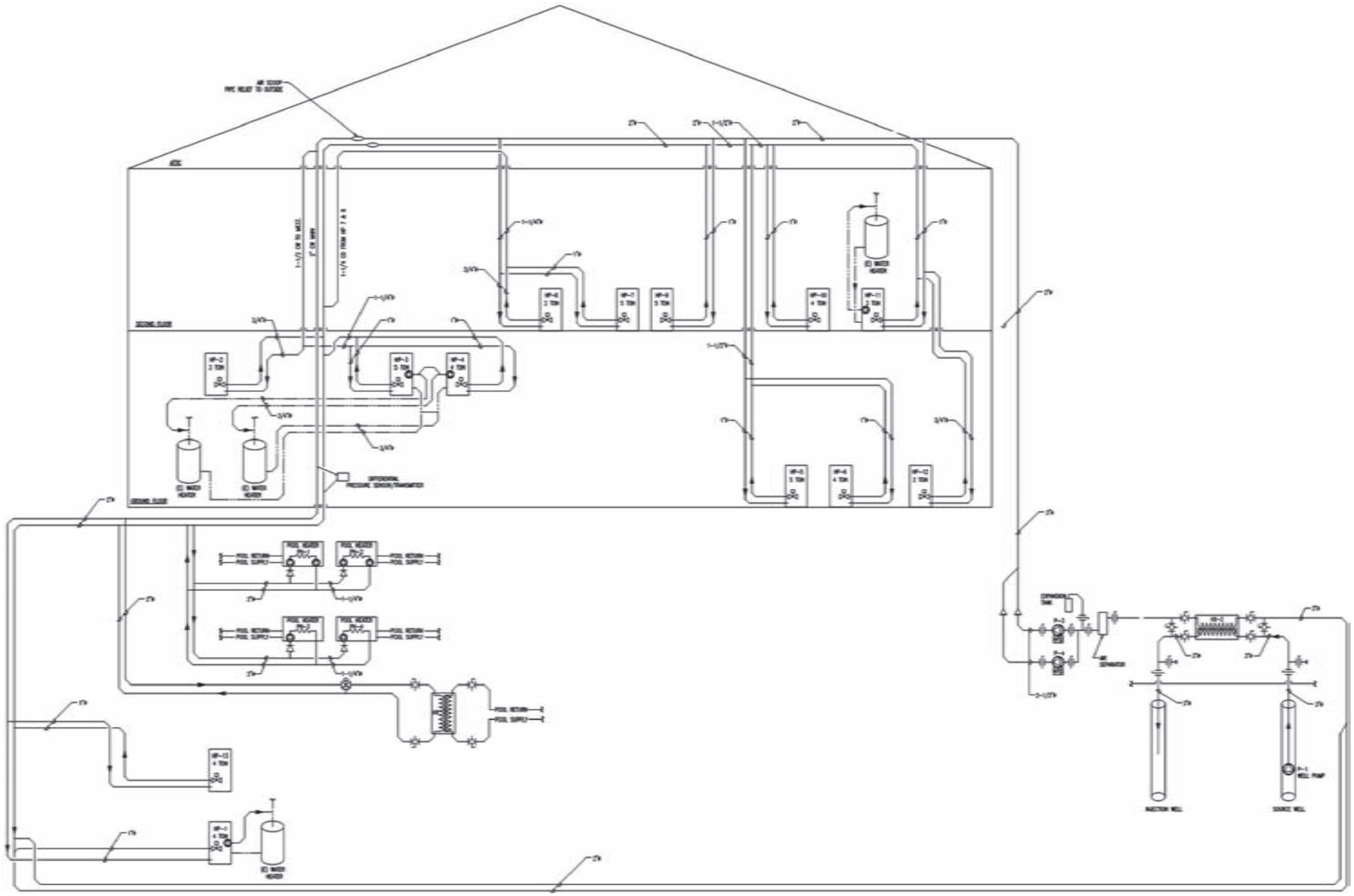


Figure 13-16 In this one-line condenser drawing you can see that the pool heating equipment is taking thermal advantage from the condenser water circuit for the heat pumps in the structure. Instead of just basically reclaiming the heat from the air dehumidification system, the pool heat pumps are able to carefully maintain pool temperature as well as building humidity and temperature. (*EggGeothermal.*)

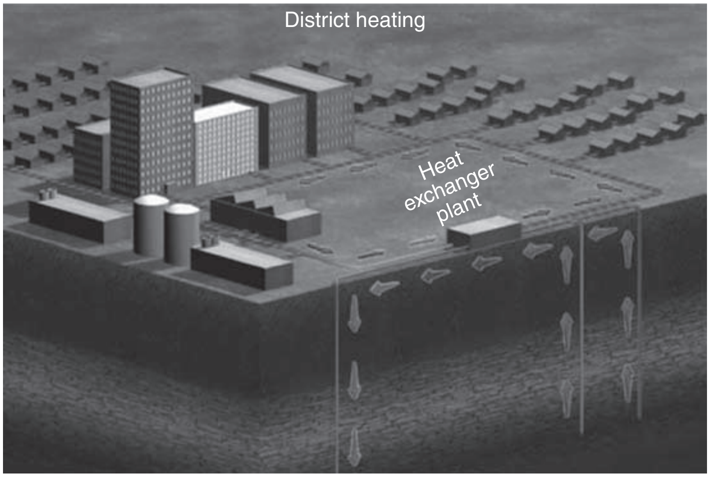


Figure 13-17 District geothermal systems provide enormous amounts of waste heat for the potential benefit and use of many. (*Inhabitat.com*.)

interstate with the temperature well below freezing outside and steam rising from cooling towers, pipes, and process stacks atop commercial buildings?

District geothermal systems provide seemingly infinite amounts of waste heat (Fig. 13-17). Communities centered around geothermal HVAC construction offer the most opportunities for load sharing and load shedding.

Review Questions

1. Use of a hydraulic separator will facilitate
   a. separate operation of ground loop and condenser water loop.
   b. operation at different pressures throughout the system.
   c. adequate heat transfer in most geothermal systems.
   d. All the above
2. The decoupled secondary piping circuit involves
   a. separation from the piping circuit by a plate and frame exchanger.
   b. the supply and return lines coming out of and into a single-pipe circuit.
   c. an independent circulator for the circuit.
   d. Both a and c
3. In a thermal-advantage loop, the best-case balance involves
   a. a situation in which the geothermal source/sink remains idle.
   b. the same number of heating and cooling units installed on the condenser water circuit.
   c. a pool heat pump in the heating mode and a building heat pump in the cooling mode.
   d. a situation in which the domestic hot-water tank always remains satisfied.

4. Aftermarket products such as energy-recovery units for domestic hot water
   a. tend to be very long-lasting and durable.
   b. should be avoided to protect the integrity of the factory equipment.
   c. can be installed inside the condenser.
   d. are easy to replace when parts fail.
5. A good example of a stand-alone thermal-advantage product is a
   a. photovoltaic solar cell.
   b. solar thermal water-heating device.
   c. domestic hot-water generator.
   d. heat-pump water heater.
6. A good temperature range for thermal-advantage load sharing in a condenser water loop is
   a. between 0 and 120°F.
   b. between 30 and 90°F.
   c. between 45 and 85°F.
   d. between 70 and 80°F.
7. Proprietary control systems and parts on HVAC equipment
   a. put the customer at a disadvantage.
   b. create longer downtimes.
   c. restrict creative control opportunities.
   d. All the above
8. In a single-pipe load-match circuit, the cascade effect refers to
   a. the incremental increase or decrease in temperature down the line.
   b. the overflow of water at the end of the condenser loop.
   c. the decoupled pumping device cavitation.
   d. entrained air in the water.
9. Load match uses a parallel/series circuit when
   a. more than one heat pump is used.
   b. more than five heat pumps are used.
   c. the cascade effect becomes too great.
   d. more than one floor is used.
10. A variable-frequency drive that is not been commissioned for optimal performance within a hydronic system
    a. will cause low system efficiency.
    b. will result in premature failure of associated equipment.
    c. will result in sporadic system operation and unusual downtimes.
    d. All the above
11. Manual or electromechanical control of valves in a thermal-advantage system will result in
    a. precise control of equipment.
    b. less than optimal system efficiency.
    c. a higher coefficient of performance (COP).
    d. the ability to tie in domestic hot-water generators.

CHAPTER 14

Calculating System Efficiencies

The world we live in would not be the same if air conditioning wasn't available (thank you again, Mr. Carrier; Fig. 14-1). Entire regions of the world would have remained undeveloped, sustaining minimal populations, if air conditioning hadn't become a part of our lives. Today, air conditioning is rightly considered a necessity rather than a luxury. Certainly a good amount of economic activity and hence progress would not have been achieved without it. It is one of the key inventions sustaining modern life. In fact, the *Encyclopedia Britannica* lists air conditioning as one of its greatest inventions of all time.

With air conditioning so essential, it helps to understand how it is provided via modern heating, ventilation, and air-conditioning (HVAC) systems and what the major differences are between the three principal delivery systems: hydronics, air, and refrigerant or direct-expansion (DX) systems. Which system can provide the owner or user with the most comfort for the least amount of dollars in both first cost and operating cost regardless of the building's size, configuration, or climate setting? And beyond cost, is one system better than another in terms of attainable comfort levels, indoor air quality, energy use, and in particular, matters relating to safety and liability?

Comparing Water, Air, and Refrigerant Systems

There are three basic methods to provide comfort and move British thermal units (Btus) around a building—water, air, or refrigerant. Air systems have been around for a long time. They were the first systems to provide cooling comfort from fans through evaporative cooling from a person's skin thousands of years ago. Direct evaporative cooling appeared not soon afterward. Fresco paintings from ancient Egypt depict slaves waving fans over containers of water. This appears to be the earliest recorded use of direct evaporative cooling. Wealthy citizens of Rome during the Roman Empire had water circulated through their walls. The common people hung wet mats over their doors for cooling.

Cooling towers were constructed in medieval times. The towers were designed to trap wind and funnel it past water before it entered a building. This method is believed to have been developed in Persia. Water evaporative cooling was used in New England textile mills during the 1800s.

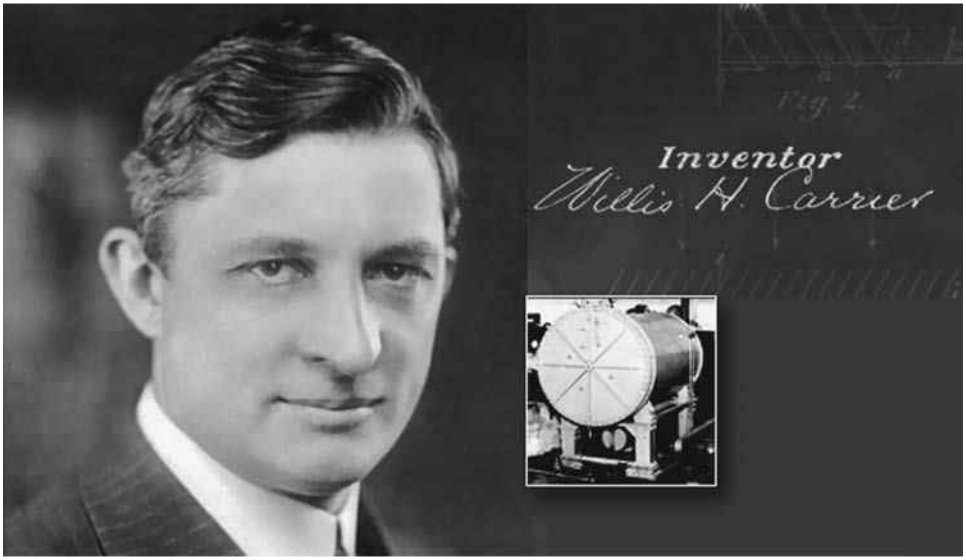


Figure 14-1 Willis Carrier (1876–1950), widely regarded as the father of modern refrigeration and air conditioning, and co-founder of Carrier Engineering Co. in 1915.

Later this evolved into direct evaporative cooling, or swamp coolers, used principally in the southwestern United States until the early 1960s. With the advent of mechanical cooling, the use of air conditioning in residences increased dramatically. In the 1960s, fewer than 30 percent of new homes were constructed with air conditioning. Today it is over 90 percent.

Air-distribution systems are generally less labor-intensive to build. However, they take up more space and require almost three times as much horsepower and three times as much material to move Btus around a building than a hydronic or refrigerant distribution system. This has a significant impact on the environment in higher energy consumption for the building and an impact on the global environment from the mining, processing, and transport of more building materials for the comfort distribution system. A building with an all-air duct system can require up to several feet more of ceiling space than a building with a hydronic or refrigerant distribution system, resulting in a taller building and, again, more materials for its construction.

Water hydronic systems have long provided very comfortable and reliable heating and air conditioning, and they come with several major advantages. They offer excellent indoor comfort (especially with multiple zones) because air is not circulated from one room to another. The systems also have lower energy costs. In addition, there are new developments occurring with hydronic-based chilled-water systems. One is the growing popularity and use of radiant-heat systems that now include a radiant-cooling and chilled-beam option and the emergence of new single-pipe systems that can substantially lower the usually higher first costs of a hydronic system in comparison with an air or refrigerant system. Another is the emergence of new piping materials, such as polypropylene, substantially reducing the labor penalty for piping distribution systems. There is also technology available today to substantially reduce the amount of pumping energy for a hydronic distribution system using a single-pipe distribution system and injection pumping. Using variable-speed drives will further reduce pump energy consumption.

Refrigerant or direct-expansion (DX) systems have been around a shorter time than air or hydronic systems. These typically have been smaller, split systems for residential and small-commercial use. Larger commercial DX systems—variable refrigerant volume (VRV) and variable refrigerant flow (VRF) supplied principally by Asian manufacturers—are now on the market and gaining market share here in the United States. VRF has been called "another refinement of DX refrigerant split systems." Unlike earlier versions of DX refrigerant split systems that employed multiple air-cooled condensers matched to a single evaporator and refrigerant lines, VRF systems typically use one large condenser, one set of refrigerant pipes for the entire building, and a separate evaporator for each zone of temperature control, similar to a hydronic chilled-water system but with refrigerant pipe.

VRF systems in some instances can have lower cooling-energy costs than previous constant-speed refrigeration equipment because of the variable-speed operation of the compressors. Variable-speed systems of any kind (e.g., air, water, or refrigerant) pump less mass flow, resulting in less horsepower needed to move the fluid. In addition, at part load, the heat exchanger is oversized for the lower mass flow rate because it was sized for full load, and the system is more efficient. There is some lower limit for reduced mass flow and turndown at which point flow becomes laminar and heat transfer decreases. For refrigeration equipment, this is somewhere at approximately 25 percent of load.

The HVAC industry is now offering variable-speed refrigeration equipment for chillers, heat pumps, and packaged equipment in addition to VRF equipment. All this equipment exhibits increases in efficiency at part loads similar to VRF equipment.

Although the first cost of a typical DX split system is lower than that of a hydronic distribution system, the first cost of VRF systems is greater because of the more complicated refrigerant management system and controls. Most significantly, VRF systems use refrigerant, a toxic fluid. Mechanical codes have recognized this and set limits on the amount of refrigerant that can be discharged into a room to protect the occupants.

Since acceptance of the Montreal Protocol, refrigerant manufacturers have moved away from the use of chlorofluorocarbons (CFCs) like R-11/R-12 to hydrochlorofluorohydrocarbons (HCFCs) and refrigerants such as R-22. The newer hydrofluorocarbon (HFC) refrigerants, such as 134A and R-410, are having less impact on the environment, which is good, but they typically require higher pressures and more expensive materials. With rising energy and first costs, there's a need for variable-speed technology to provide more attractive returns.

A different refrigerant, based on the principle of water refrigeration, is now being used in Europe. R-718, or water vapor, as it's called, is benign on both the environment and building occupants but requires an expensive titanium compressor to be able to spin fast enough to achieve the higher pressures. Work on substituting a cheaper carbon-fiber plastic for titanium is under way in order to achieve higher efficiency at lower first cost.

Moving British Thermal Units around a Building

Air systems use a fluid that is nontoxic and readily available—air. However, air systems use a fluid that has a low specific heat and low density. As a result, it takes more horsepower to move Btus around a building and distribute them in an occupied space with air than any other fluid. Air systems can take as much as 40 percent of the total electrical demand, generation, and distribution for a cooling system just to move the Btus.

Refrigerant is a denser fluid that has a higher specific heat than air. Whereas VRF refrigerant systems don't take as much horsepower to move refrigerant around a building, they still have to distribute the Btus within the occupied space with something besides refrigerant. This typically requires local air-handling units or fan coils using air to distribute Btus within a room. As a result, refrigerant systems can require up to 30 percent of the total electrical demand of a cooling system to move the Btus.

Hydronic systems also use a fluid that is nontoxic and readily available—water. Water is also a denser fluid and has a higher specific heat than air. This allows it to move Btus around a building using less horsepower than ducted air systems. In fact, it takes about a third the horsepower to move Btus with water versus air. This can be as low as 10 to 20 percent of the total electrical demand of a cooling system.

The science and technology behind hydronics has advanced to the point today where we can literally distribute Btus without ***any*** air movement. The problem with air movement from a comfort standpoint is the creation of evaporative cooling—it can be uncomfortable when air is blowing over your body. Hydronic heating systems have been in place for a number of years that use radiation as the principal means of heat transfer, providing excellent comfort. The principal method of heat transfer from the hot water running through piping in the floor to your cold body above is radiation, which requires very little air movement in the form of natural convection.

Our European hydronic mentors have been working on radiant technology in reverse for about 30 years now in the form of radiant cooling. With radiant cooling, piping installed in the ceiling has chilled water in it. Your warm body radiates to the cold or chilled ceiling above to cool you down, again with very little air movement in the form of natural convection.

Radiant Cooling and Chilled Beams

An emerging technology for hydronic chilled-water systems is radiant cooling. Radiant cooling is an exciting feature that avoids some of the challenges of space cooling distribution common to both air and VRF types of air-conditioning systems.

Radiant-cooling systems are now coming of notice here in the United States, and design engineers are turning to them to achieve high energy efficiencies and superior comfort levels. Radiant cooling, like most hydronic-based applications, is common in Europe and is becoming increasingly common here in the United States. There are a number of domestic radiant-cooling manufacturers today with successful installations. There have been further advances in radiant-cooling systems with the introduction of passive chilled beams, which are more efficient cooling devices employing natural convection and radiation, and especially with active chilled beams, which combine forced convection with radiation.

As with its counterpart, radiant heating, radiant cooling and chilled beams will only obtain a greater market share in the years ahead now that use of 100 percent direct outside air systems (DOAS) are better understood and ideally matched with the benefits of radiant cooling/chilled beams.

At Taco's Milton (Toronto), Canada operation and U.S. headquarters in Cranston, RI, active chilled-beam systems cool the office and training areas (Fig. 14-2). In this application, passive chilled beams are employed along with radiant chilled ceilings to

Figure 14-2 Taco Milton (Toronto) facility.

supplement. Together they allow the DOAS unit to reduce fan energy by up to 90 percent because the only air circulation that's required is from a DOAS. This system supplies just enough treated, dehumidified outdoor air to slightly pressurize the building, negating natural infiltration of humid outside air, and to provide ventilation for occupants.

The use of chilled beams with injection pumping, employing a single-pipe system, makes hydronics more competitive on a first-cost basis due to the reduced piping. This system is also self-balancing because it uses a decoupled primary-secondary piping system to distribute Btus from the primary to the secondary or terminal circuit unit. Use of ΔT values as high as 20°F from the single-pipe injection system reduces chilled-water flow rates and pumps 50 percent more than a standard two-pipe chilled-water system and 75 percent more than a typical chilled-beam system. All this represents a significant reduction in pumping horsepower and a big advantage in terms of first cost for installation and startup and commissioning simplicity.

With a chilled-water system, it's easier and less costly to provide multiple zones of temperature control, particularly in larger buildings, because multiple terminal units (chilled beams, heat pumps, fan coils, etc.) are linked to one set of central generation equipment with one piping distribution system. One of the traditional concerns with chilled-water systems has been balancing the system on startup and commissioning and achieving the correct distribution of water to all the terminal units. However, the development of automatic flow-control valves that can automatically adjust for differences in pressure and flow rates has improved balancing of hydronic systems. And with the advent of single-pipe systems that *self-balance*, system startup and commissioning have become that much simpler.

Dehumidification

Another major issue between water, air, and refrigerant systems is how the systems treat humidity, a critical consideration in providing air-conditioned comfort. Hydronic and refrigerant coils handle dehumidification differently. The biggest challenge with dehumidification is being able to remove moisture on a more or less continuous basis for optimal comfort.

Most buildings are dehumidified by a process of passive dehumidification. Dehumidification is achieved only when the coil is cycled on to satisfy the sensible load. However, the coil needs to remain on to satisfy the latent load in humid climates. Therefore, selection of the coil and the airflow over the coil is critical to achieve adequate dehumidification. Humid climates in particular provide a mismatch between the sensible-heat ratio of the load and coil, particularly in refrigerant systems, making dehumidification difficult at best.

The sensible-heat ratio is the ratio of the sensible to total heat. Typical loads in humid climates will have sensible-heat ratios in the low to middle 70 percent range. However, the sensible-heat ratios of most cooling coils is in the 80 percent range. As a result, the unit satisfies the sensible load and shuts off before the latent load is satisfied. Often moisture remains on the coil to be reevaporated into the airstream. All this contributes to rooms feeling clammy in humid climates.

This problem can be mitigated by changing the circuiting and row selection of the coil and the face velocity of the airflow. Changing the circuiting or rows and lowering the face velocities of a coil will yield lower sensible-heat ratios. This is difficult in DX and VRF systems, where coil configuration, sizes, and so on are limited. This is not the case for hydronic coils. Chilled-water systems will provide better dehumidification because of the wider range of coil-circuiting and face-velocity configurations. In addition, the chilled-water flow through a coil can be modulated more easily with control valves or variable-speed circulators, matching the chilled-water capacity to the load. In high-humid climates, hydronic reheat also can be easily provided for direct humidity control rather than passive dehumidification. Controlling humidity directly through a space humidistat and reheat will achieve precise humidity control and maximum comfort. Taken together, buildings cooled with chilled-water systems will have higher comfort levels than buildings with typical DX or VRF systems, whether they are constant or variable volume.

Variable-Speed Technology

Most HVAC systems are designed to keep a building cool on the hottest days and warm on the coldest days. This being the case, an HVAC system needs to work at full capacity on only the hottest and coldest days of the year. For the rest of the year, such system should operate at a reduced capacity to save energy. This is where a system equipped with variable-speed technology can be used to match system fluid flow to actual heating/cooling demands. As mentioned earlier, variable-speed systems of any kind (water, air, or refrigerant) pump less mass flow, resulting in less horsepower to move the fluid. In addition, at part load, the heat exchanger is oversized for the lower mass flow rate because it was sized for full load. The system is therefore more efficient.

Use of variable-speed or variable-frequency drives (VFDs) for larger motors can reduce motor speed when full flow is not required, thereby reducing the power required and the electrical energy used. For a fixed-size-distribution system, power is a function of flow cubed. For example, at 80 percent nominal flow, power consumption is reduced by some 50 percent when using a VFD.

Air systems have employed variable-speed fans with variable air volume (VAV) systems for more than 30 years. Hydronic systems have employed variable-speed pumps for almost the same time period. DX-type systems have essentially functioned as constant-volume systems using one evaporator coupled with an air-cooled condenser along with a set of refrigerant pipes in between. VRF systems now incorporate variable-speed technology using multiple evaporators on a single condensing unit, essentially making a chilled-water refrigerant system. The refrigeration industry is now providing variable-speed compressors for chillers and heat pumps as well as VRF because it provides higher efficiencies at part loads.

Comparing Energy Efficiency

The energy consumption of an HVAC system consists of two components, (Btu) generation equipment and (Btu) distribution equipment. The challenge is to compare the energy efficiency of HVAC systems taking into account both these components.

As mentioned earlier, distribution energy is not insignificant. It can take 40 percent of total electrical cooling-energy demand to move Btus in an air system, 30 percent for refrigeration systems, and 20 percent for hydronic systems. Water and refrigerant both have a much higher specific heat and density than air and require less horsepower to move Btus than air. Ductless water and refrigerant systems therefore save energy over air-based central-ducted systems. Fan coils, water-source heat pumps, and VRF systems are examples of ductless systems. The airflow to distribute Btus in a zone are the same for ductless systems as for all central air systems. However, this air is circulated within the zone and is not distributed from a central air-handling system. As a result, the static pressure and energy to move this air are less than for a central air system.

Any ductless air or refrigerant system and radiant or chilled-beam system must still provide fresh-air ventilation. However, the amount of air needed for ventilation and pressurization is in the range of 1 to 2 air changes per hour as opposed to all-air systems requiring 8 to 10 air changes for cooling and ventilation. Ductless systems still require 8 to 10 air changes for cooling, but recirculated in the space.

Hydronic systems can further reduce distribution energy employing radiant and chilled-beam technology. Radiant systems require no airflow. Chilled-beam systems require only ventilation airflow, just enough to pressurize the building.The generation energy constitute most of the energy consumption in an HVAC system. Comparing the efficiency of various pieces of generation equipment, cooling or heating, is the subject of numerous technical articles and discussions. The problem is comparing apples to apples using the same set of test criteria. Manufacturers in the past did not test their equipment to different ambient and part-load conditions, and no data were available to model their performance.

Earlier energy-simulation computer programs therefore attempted to use first principles to try to model these part-load conditions. However, this proved difficult. Now, a number of computerized energy-simulation programs are available for purchase. This includes Trane's Trace, Carrier's Hourly Analysis Program (HAP), McQuay's Energy Analyzer, and Energy Soft's EnergyPro. Free software includes Department of Energy's eQuest and EnergyPlus and Taco's System Analysis Tool.

Use of these programs can require extensive input and multiple screens of input, in some cases up to 40 screens.

The programs use hourly weather data and can model a variety of systems, but it can take several hours of input for an experienced user to model just one system. For an inexperienced user, this can be 4 to 8 hours to compare several systems. Two programs, however, McQuay's Energy Analyzer and Taco's System Analysis Tool (SAT), offer the opportunity to model multiple systems with only a few minutes of input. The Taco SAT in particular requires only one screen of input for each system, with the ability to choose between a number of different system configurations.

The measure of instantaneous energy efficiency for a refrigeration or heating/cooling system is defined thermodynamically as the Coefficient of Performance or COP. It is the heating or cooling produced divided by the work to produce it. For a refrigeration cycle this is the heating or cooling out divided by the (compressor) work in.

This ratio is dimensionless and in the HVAC industry is generally calculated from watts of heating or cooling out divided by watts of the compressor in.

This ratio can be expressed as:

$$\begin{aligned} \text{COP} &= \Delta Q_{out} / \Delta W_{in} \\ &= \text{Watts}_{out} / \text{Watts}_{in} \end{aligned}$$

In the US, HVAC equipment capacities are rated in Btu/hr or Btuh and compressor energy is rated in Watts. To simplify the math COP's are typically calculated as Btuh out divided by Watts_{in}. This ratio is commonly referred to as an energy efficiency ratio (EER):

$$\begin{aligned} \text{EER} &= \Delta Q_{out} / \Delta W_{in} \\ &= \text{Btuh}_{out} / \text{Watts}_{in} \end{aligned}$$

To avoid confusion, the HVAC industry in the US has taken to rating compressorized heating equipment performance as a COP and compressorized cooling equipment performance as an EER. Mathematically the difference is the conversion from Watts to Btuh or:

$$\begin{aligned} \text{EER} &= \text{COP (Watts/Watts)} \times 3.413 \text{ (Btuh/Watt)} \\ &= \text{COP} \times 3.413 \end{aligned}$$

For either heating or cooling equipment the larger the COP or EER the more efficient the equipment is.

Another means of expressing a compressorized cooling equipment's performance is the inverse of the COP commonly referred to as kW/ton. Since 1 ton of cooling is 12,000 Btuh this is:

$$\begin{aligned} \text{kW/ton} &= 1/\text{EER (Btuh/Watt)} \times 12{,}000 \text{ Btuh/ton}/1{,}000 \text{ Watts/kW} \\ &= 1/\text{EER} \times 12 \end{aligned}$$

For cooling equipment the smaller the kW/ton the more efficient the equipment is.

For smaller residential air conditioning systems (less than 6 tons) a seasonal EER or SEER can be defined. This is "the total heat removed from the conditioned space during the annual cooling season, expressed in Btu's, divided by the total electrical energy consumed by the air conditioner…during the same season, expressed in watt-hours". This is:

$$\text{SEER} = \Delta\text{E cooling}_{\text{out}}/\Delta\text{E}_{\text{in}}$$
$$= \text{Btu}_{\text{out}}/\text{Watt-Hr}_{\text{in}}$$

A similar rating for the same smaller residential systems can be defined for heating as a heating season performance factor or HSPF. This is "the total space heating required during the space heating season, expressed in Btu's, divided by the total electrical energy consumed by the heat pump system during the same season, expressed in watt-hours". This is:

$$\text{HSPF} = \Delta\text{E Heating}_{\text{out}}/\Delta\text{E}_{\text{in}}$$
$$= \text{Btu}_{\text{out}}/\text{Watt-Hr}_{\text{in}}$$

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) in conjunction with the American National Standards Institute (ANSI) and the American Society of Heating, Refrigeration and Air Conditioning (ASHRAE) have developed new standards to test various types of equipment.

The new AHRI standards have attempted to simplify the effort required by energy simulation programs to compare system efficiencies by developing a single number that can be used to compare various manufacturers' equipment. This number is necessarily a weighted seasonal average of efficiency for various climate (ambient) conditions and part loads.

A detailed energy analysis, using one of the previously mentioned energy simulation programs, is suggested to calculate actual energy consumption for a specific climate zone and local energy costs. However, the AHRI ratings can provide a very reasonable tool for comparing relative energy consumption of various systems.

The AHRI, in conjunction with the ANSI and the ASHRAE, has developed new standards to test various types of equipment. The new AHRI standards have attempted to simplify the effort required by energy-simulation programs to compare system efficiencies by developing a single number that can be used to compare various manufacturers' equipment. This number is necessarily a weighted seasonal average of efficiency for various climate (ambient) conditions and part loads.

The standards provide ambient and part-load conditions to test equipment. This information is now published in the AHRI *Directory of Certified Performance* for various equipment. This can be found on the AHRI website at www.ahridirectory.org/ahriDirectory/pages/home.aspx.

For unitary and packaged cooling equipment, this single efficiency number is the *integrated energy-efficiency ratio* (IEER). For chillers and condensing units, this is the *integrated part-load value* (IPLV). AHRI Standard 550/590 establishes rating conditions for chillers, Standard 13256 establishes rating conditions for water-source heat pumps, Standard 340/360 establishes rating conditions for commercial air-source heat pumps, and Standard 365 establishes rating conditions for commercial air-source condensing units.

Initially, VRF system manufacturers did not publish data on their efficiencies. AHRI has recently responded to the need for data by introducing Standard 1230: Performance Rating of VRF Equipment. VRF performance data are now obtainable from

Equipment	AHRI Standard	Rating Designation	Ambient Testing Conditions (F) 100% Part Load	75% Part Load	50% Part Load	25% Part Load
Chillers, Air Cooled	550/590	IPLV	95	80	65	55
Chillers, Water Cooled	550/590	IPLV	85	75	65	65
Air Source Condensing Units	365	IPLV	95	81.5	68	65
Air Source Heat Pump	340/360	IEER	95	81.5	68	65
Variable Refrigerant Flow, Air Cooled	1230	IEER	95	81.5	68	65
Variable Refrigerant Flow, Water Cooled	1230	IEER	85	73.5	62	55

Table 14-1 Ambient Conditions for Cooling-Part-Load IEER and IPLV Ratings

AHRI for equipment performance comparisons. Table 14-1 shows the AHRI standards and rating conditions for various equipment cooling IEERs and IPLVs. Note that water-cooled equipment is allowed to be rated at a lower dry-bulb ambient at higher part loads. This is to reflect the lower heat-sink temperature to which this equipment can reject heat, the wet-bulb temperature. Water-cooled equipment will be more efficient because of this capability. Also note that Standard 1230 allows lower ambient rating conditions for water-cooled VRF units than for water-cooled chillers.

To arrive at a single IPLV or IEER, the EERs at various part loads and ambient conditions have to be averaged to a single number. This average should be weighted for the hours the equipment operates. This is a function of climate. AHRI has attempted to arrive at a weighted average "based on the weighted average of the most common building types and operating hours using average U.S. weather data." Table 14-2 lists the weighting factors for each operating condition.

It is still difficult to compare heat pumps with the preceding equipment because the operating temperatures of the heat sinks they reject to and extract heat from different, especially geothermal heat pumps. However, one can construct a weighted-average operating efficiency for this equipment similar to IEERs for the preceding compressorized equipment in order to make a reasonable comparison of heat-pump efficiencies versus other equipment.

AHRI has published Standard 13256 for rating water-source heat pumps. The heat-sink or entering-water temperatures for cooling that are defined by the standard are 86°F for (closed) loop water-source heat pumps, 77°F for geothermal closed-loop systems, and 59°F for geothermal (open) groundwater systems. Assuming the heat-sink

Equipment	AHRI Standard	Rating Designation	Ambient Testing Conditions (F) Weighting Factor			
			100% Part Load	75% Part Load	50% Part Load	25% Part Load
Chillers, Air Cooled	550/590	IPLV	0.01	0.42	0.45	0.12
Chillers, Water Cooled	550/590	IPLV	0.01	0.42	0.45	0.12
Air Source Condensing Unit	365	IPLV	0.01	0.42	0.45	0.12
Air Source Heat Pump	340/360	IEER	0.02	0.617	0.238	0.125
Variable Refrigerant Flow, Air Cooled	1230	IEER	0.02	0.617	0.238	0.125
Variable Refrigerant Flow, Water Cooled	1230	IEER	0.02	0.617	0.238	0.125

Table 14-2 Weighting Factors for Cooling-Part-Load IEER and IPLV Ratings

temperature remains constant throughout the cooling season, the same weighting factors for IEERs can be used to calculate the IEER of a water-source heat pump. Closed-loop water-source heat pump systems, however, can employ a sequence that "chases the wet bulb" to achieve higher operating efficiencies at lower ambient temperatures. These temperatures would be the same as defined by Standard 550/590 for water-cooled chillers. This sequence would reset the cooling set point at which the closed-circuit tower comes on to reject heat.

Table 14-3 shows the heat-sink or entering-water temperatures that can be used to calculate IEERs for water-source heat pumps.

The other adjustment that has to be made is in distribution energy. IPLV ratings for chillers do not include chilled-water pump horsepower for air- and water-cooled chillers. The ratings also do not include the heat-rejection energy for water-cooled chillers for cooling-tower fans and pumps and condenser-water pumps. Ratings for water-cooled heat pumps include distribution energy for evaporator fans but do not include distribution energy for condenser water pumps. Ratings for air-cooled condensing units do not include distribution energy for evaporator fans. Table 14-4 is a summary of what is included or not included for distribution and heat-rejection energy for each of the rating standards.

However, reasonable estimates can be made for this equipment. For chiller systems, chilled-water pump horsepower is approximately 3 to 5 percent of the chiller horsepower. For water-cooled chiller systems, cooling-tower fans and pumps are approximately 3 to 5 percent of the chiller horsepower, and condenser water pumps are approximately 5 to 7 percent of the chiller horsepower. For water-source heat pumps,

Heat Pump Equipment	AHRI Standard	Rating Designation	Heat Sink/Entering Water Conditions (F)			
			100% Part Load	75% Part Load	50% Part Load	25% Part Load
(Closed) Water Loop	Same as 550/590	IEER	85	75	65	65
Geothemal (Closed) Ground Loop	13256	IEER	77	77	77	77
Geothemal (Open) Ground Water	13256	IEER	59	59	59	59

Table 14-3 Water-Source Heat-Pump Cooling Heat-Sink/Entering-Water Temperatures

Equipment	AHRI Standard	Rating Designation	Energy Source Inclusion			
			Evaporator Fan	Chilled Water Pump	Condenser Water Pump	Cooling Tower Fan and Pump
Chillers, Air Cooled	550/590	IPLV	N	N		
Chillers, Water Cooled	550/590	IPLV	N	N	N	N
Air Source Condensing Units	365	IPLV	N			
Air Source Heat Pump	340/360	IEER	Y			
(Closed) Water Loop	13256	IEER	Y		N	N
Geothermal (Closed) Ground Loop	13256	IEER	Y		N	
Geothermal (Open) Ground Water	13256	IEER	Y		N	
Variable Refrigerant Flow, Air Cooled	1230	IEER	Y			
Variable Refrigerant Flow, Water Cooled	1230	IEER	Y			

N = No, Y-Yes

Table 14-4 Energy Source Inclusion

cooling-tower fans and pumps are approximately 3 to 5 percent of the chiller horsepower, and the condenser water pumps are approximately 3 to 5 percent of the heat-pump horsepower. For air-cooled condensing units, evaporator fans are approximately 10 to 15 percent of compressor horsepower.

Ratings for VRF systems include distribution energy for evaporator fans, heat-rejection energy for condenser fans, and some distribution energy for refrigerant piping. For example, Standard 1230 requires 100 ft of refrigerant piping for (nonducted) systems over 135,000 Btu but less than 350,000 Btu. For a typical 20-ton system using a cooling load of 30 Btu/ft^2, the building would be 8000 ft^2. This is approximately a 90- × 90-ft building. If the condensing unit is 25 ft from the building, there could be over 300 ft of refrigerant pipe from the condensing unit to an evaporator on the far side of the building and back again, not 100 ft as required by Standard 1230.

For heating, AHRI Standard 210/240 developed an average or seasonal EER for heating, the *heating season performance factor* (HSPF). It again is an attempt to rate compressorized equipment for various climate (ambient) conditions and part loads. Table 14-6 shows the AHRI standards and rating conditions for various air-source equipment HSPFs.

Again, AHRI has published Standard 13256 for rating water-source heat pumps. For heating, the heat-sink or entering-water temperatures that are defined by the standard are 68°F for (closed) loop water-source heat pumps, 32°F for geothermal closed-loop systems, and 50°F for geothermal (open) groundwater systems.

The AHRI rating conditions for a geothermal closed-loop system are too low. The condition of 32°F represents an extreme northern U.S. location, not an average, "based on the weighted average of the most common building types and operating hours using average U.S. weather data," as stated by the cooling rating conditions. An entering-water temperature of 40°F is more reasonable, although this is low for the middle of the United States with groundwater temperatures in the middle 50s. A properly designed geothermal closed-loop system will generate entering-water conditions approximately 10°F below the groundwater temperature. Using a groundwater temperature of 50°F by Standard 13256 for an (open) groundwater system, 40°F would be a more reasonable ground-loop temperature condition. Again, assuming that the heat-sink temperature remains constant throughout the heating season, the same weighting factors for HSPFs can be used to calculate the HSPF of a water-source heat pump.

Table 14-6 shows the heat-sink or entering-water temperatures that can be used to calculate HSPFs for water-source heat pumps.

			Ambient Testing Conditions (F)			
Equipment	**AHRI Standard**	**Rating Designation**	**High Capacity**	**Medium Capacity**	**Medium Capacity**	**Low Capacity**
Unitary and Air Source Heat Pump	210/240	HSPF	62	47	35	17
Variable Refrigerant Flow, Air Cooled	1230	HSPF	62	47	35	17
Variable Refrigerant Flow, Water Cooled	1230	HSPF	62	47	35	17

Table 14-5 Heat-Sink Temperatures for Heating-Part-Load IEER and IPLV Ratings

Equipment	AHRI Standard	Rating Designation	Heat Sink/Entering Water Conditions (F)			
			High Capacity	Medium Capacity	Medium Capacity	Low Capacity
(Closed) Water Loop	550/590	HSPF	68	68	68	68
Geothermal (Closed) Ground Loop	13256	HSPF	32	32	32	32
Geothermal (Closed) Ground Loop	US Average	HSPF	40	40	40	40
Geothermal (Open) Ground Water	13256	HSPF	50	50	50	50

TABLE 14-6 Water-Source Heat-Pump Heating Heat-Sink/Entering-Water Temperatures

Table 14-7 is a summary of HVAC equipment cooling and heating efficiencies at the AHRI rating conditions for IEERs and IPLVs for cooling and HSPFs for heating. The U.S. chiller and heat-pump manufacturers are now offering variable-speed compressors similar to VRF systems. All variable-speed equipment has similar performances. The differences are in the heat-sink temperatures to which the equipment rejects heat, the result of the second law of thermodynamics. Geothermal open-loop systems are the most efficient, followed by geothermal closed-loop systems, water-cooled chillers and heat pumps, air-cooled chillers, VRF and rooftop units, and air-cooled condensing units.

The EER of a constant speed chiller is approximately 12. However, using the AHRI part load rating conditions for chillers at lower ambient yields a substantial increase in IPLV for constant speed chillers to 16. A VRF unit has an EER of approximately 13 and an IEER of 19. Therefore the increase in the IEER for VRF is due primarily to being able to rate part loads at lower ambients, not variable speed operation. Approximately 2/3 of a VRF's higher IEER is the result of this lower ambient rating for part load, not variable speed efficiency.

Another way to look at this is that the increase in efficiency of variable speed over constant speed is 2 points, (6 minus 4). This is 2 points out of 12 or less than 20 percent. Therefore the increase in efficiency of a variable speed unit over a constant speed unit is approximately 20 percent, a nice increase, but certainly not the amount being claimed by VRF manufacturers.

This can be seen in Fig. 14-3 from a chiller manufacturer showing the efficiency of their air cooled chillers. This chiller is offered as a constant speed (left bar) and variable speed (right bar) with a VFD. Note the full load EER is slightly over 11 for both units. The IPLV's are 16.2 and 19.4 respectively for the constant and variable speed units. The constant speed unit has a significant increase in part load IPLV vs. its full load. The majority of increase in efficiency of the variable speed unit is again due to being able to rate the part load efficiency at lower ambient or heat sink temperatures, not variable speed.

Obviously, based on the Table 14-7, data for VRF systems show that they are not "the most energy efficient systems ever developed," as claimed by a VRF manufacturer. It can be argued that these data are test data and are not actual operating conditions; therefore, actual operating data may be different. However, a real-world comparison exists

Equipment	EER	IEER	IPLV	HSPF
Air-cooled condensing units				
Constant speed	11	12[a]	14	—
Air-cooled rooftop units				
Constant speed	11	13	—	—
Variable speed	13	19	—	—
Air-cooled chiller units				
Constant speed	12	15[b]	16	—
Variable speed	12	18[b]	20	—
Water-cooled chiller units				
Constant speed	24	25[d]	30	—
Variable speed	25	33[d]	40	—
Water-to-air heat pumps				
Constant speed	22	26[c]	19[c]	—
Variable speed	22	31[c]	19[c]	—
Geothermal heat pumps				
Constant speed closed loop	22	21[b]	14[b]	—
Constant speed open loop	34	33[b]	15[b]	—
Variable speed closed loop	22	32[b]	14[b]	—
Variable speed open loop	34	44[b]	15[b]	—
Air-cooled VRF units				
Variable speed	13	19	8	—

[a]IEER includes distribution energy for chilled evaporator fans.
[b]IEER includes distribution energy for chilled-water or condenser water pumps.
[c]IEER includes distribution energy for chilled-water pumps and heat-rejection energy for cooling-tower fans and pumps and condenser pumps.
[d]IEER includes distribution energy for condenser water pumps and heat-rejection energy for cooling-tower fans and pumps.

Sources: Data obtained from McQuay, Carrier, York, WaterFurnace, ClimateMaster, and Mitsubishi.

Table 14-7 HVAC Equipment IEER and IPLV Part-Load Comparisons

for comparing hydronic and VRF systems. This is the ASHRAE Headquarters building in Atlanta, which compares a geothermal heat-pump system with a VRF system.

Several years ago, the Atlanta building went through an HVAC retrofit to upgrade its heating and cooling systems. A geothermal ground-source heat-pump system with constant-speed compressors was installed to serve the second floor, and a VRF system with variable-speed compressors was installed to serve the ground floor. Both systems use no backup heat and rely totally on the electrical energy to the compressors to both heat and cool the building, affording an apples-to-apples comparison.

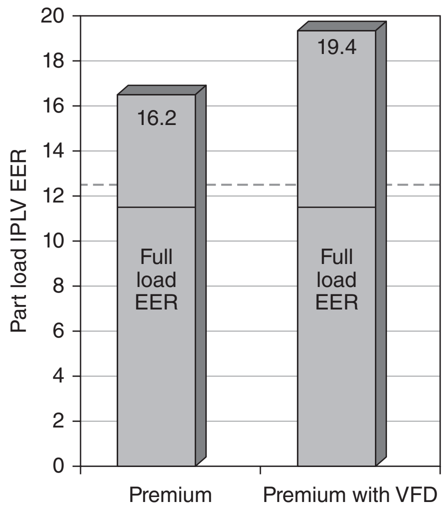


Figure 14-3 Constant speed and variable speed chiller IPLV.

Figure 14-4 shows the energy consumption of the two systems for the years 2010 to 2012. Figure 14-5 is a breakdown by month for a typical year, 2011.

The data show that the VRF system is approximately 60% to 85% higher energy consumption than the geothermal heat-pump system in the building. The reason for this is the energy consumption in heating. The AHRI ratings show that the constant-speed geothermal heat-pump system is slightly more efficient than the variable-speed VRF system in cooling. This can be seen in the monthly breakdown for 2011 for the cooling months.

VRF systems claim that even in heating climates, they do not need backup heat. This is the case. However, they achieve this by speeding up the compressor, up to double the speed, to produce higher heating capacities at lower ambient temperatures.

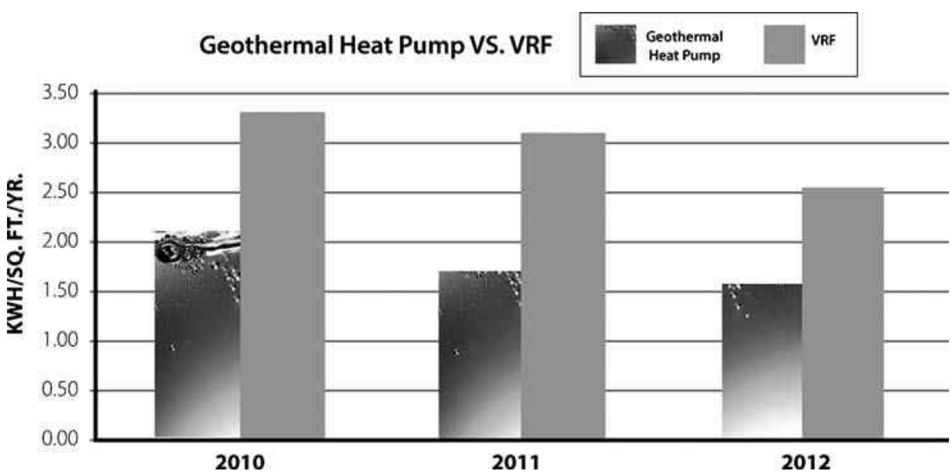


Figure 14-4 ASHRAE Headquarters energy consumption, 2010–2012.

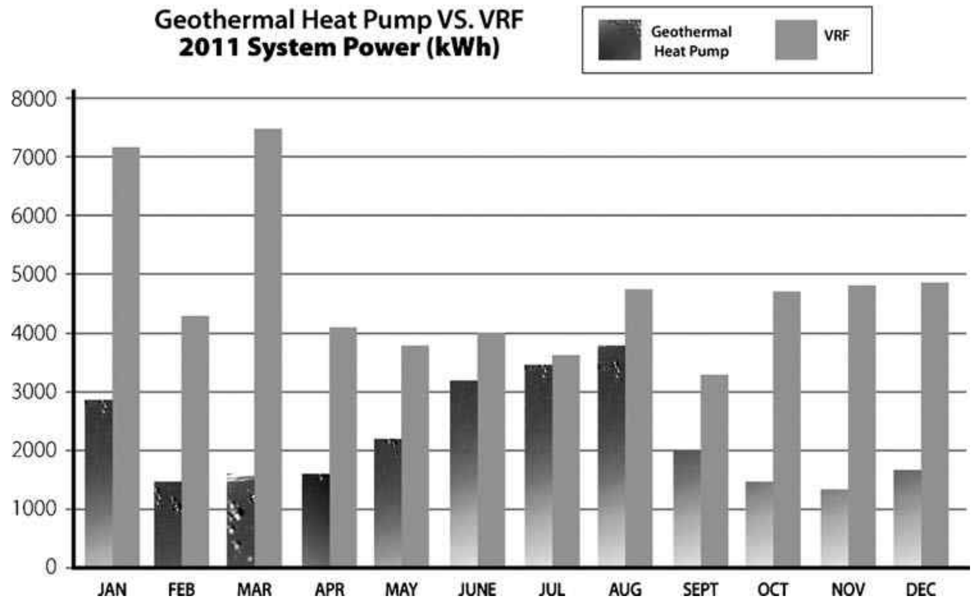


Figure 14-5 2011 ASHRAE Headquarters energy consumption, 2011 monthly breakdown.

This is at the expense of efficiency. If a variable-speed compressor has a higher efficiency at reduced speed, it will have a lower efficiency at increased speed. This information is not published by the VRF manufacturers. However, this can be seen in the monthly breakdown for 2011 for the heating months. The difference in heating consumption is more than the AHRI HSPF ratings would indicate. The biggest difference in energy consumption of the geothermal and VRF systems is not cooling, but heating.

Comparing energy consumption of heating for water, air and refrigerant systems is not as simple as comparing different HSPFs for compressorized equipment, as can be done for the ASHRAE Headquarters building. Most heat-generating equipment for water and air systems uses natural gas–fired boilers. Comparisons should be done on the basis of the cost of producing a Btu of heat, taking into account the local climate (heating hours), local cost of electricity, and local cost of natural gas.

For example, a VRF system with an HSPF of 8 using electricity at an average cost of \$0.11/kWh (energy costs per the U.S. Energy Information Agency), the unit cost of delivered heat is \$13.74 per million Btu. For a 90 percent efficient boiler using natural gas at an average cost of \$8.50/million ft^3 (\$0.85 per therm), the unit cost of delivered heat is \$9.44 per million Btu. This is a savings of 30 percent in heating costs.

The VRF manufacturers have recognized this difference in heating costs between air source heat pumps and natural gas boilers for heating climates. The problem is that the HSPF for an air source VRF unit decreases with lower ambient's and higher heating loads. The heating COP of an air source heat pump decreases with decreasing heat sink or outside air temperatures. The COP of a VRF unit decreases even faster because the compressor is speeded up to maintain heating capacity. The VRF manufacturer's claim they don't need back up heat. They do, it is actually electric heat,

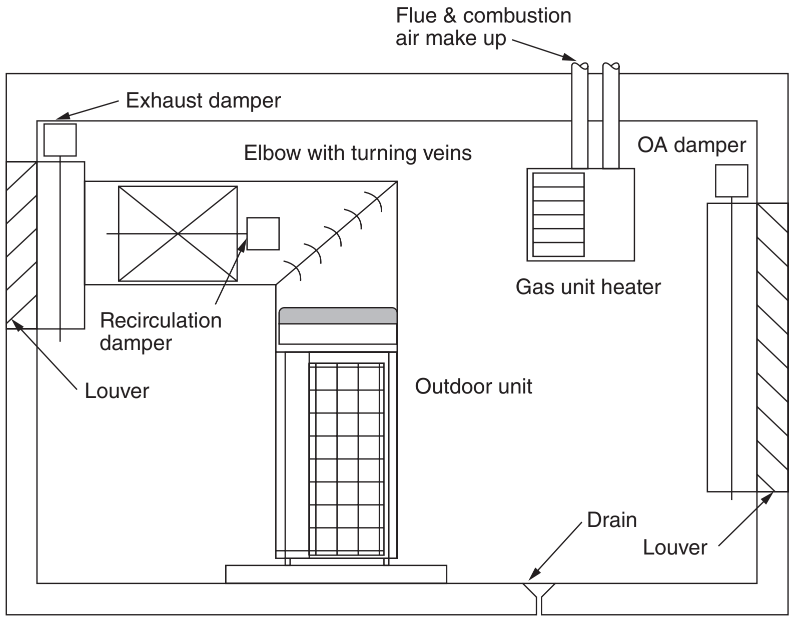


FIGURE 14-6 Outside VRF condensing unit installed indoors.

but run through the compressor at decreasing COP's rather than through an electric strip heater.

To get over this hurdle the VRF manufacturers have suggested that their outside condensing units be installed inside in a heated space using natural gas unit heaters as the back up heating source. As an example, if the space can be maintained at 40°F then the COP of the condensing unit remains high. The cost of heating is lower since cheaper natural gas heat replaces the higher cost electric heat from the lower COP at lower ambient's. Figure 14-6 is an example of how this could be installed.

In this example the outside air dampers are open in the summer for heat rejection to the outside air and closed in the winter for heat addition from the natural gas unit heater. This configuration negates one of the advantages claimed by the VRF manufacturers, they don't need inside mechanical rooms for their equipment, and it is mounted outside.

Review Questions

1. Which of the following is *not* one of the systems covered in this chapter?
   a. Variable refrigerant flow
   b. Oil fired
   c. Water/hydronic
   d. Forced air

2. VRF systems use a method of cooling and heating called
   a. geothermal sourced.
   b. air source.
   c. direct expansion.
   d. chilled water.
3. Chilled-beam cooling can be easily adapted to systems using
   a. variable refrigerant flow/direct expansion.
   b. chilled water/geothermal.
   c. air-source heat pumps.
   d. natural gas boilers.
4. Efficiencies for systems rated by AHRI do *not* include which of the following designations?
   a. IPLV
   b. IEER
   c. IVRF
   d. HSPF
5. Which of the following systems loses the greatest measure of efficiency incrementally in heating mode?
   a. Water-to-air heat pumps
   b. Water-cooled chillers
   c. Geothermal heat pumps
   d. Air-cooled VRF heat pumps
6. The letter designation used by AHRI, "IEER" is used to determine
   a. the energy-efficiency rating part-load values on heat pumps.
   b. the energy-efficiently rating on chillers.
   c. the heating capacity of VRV systems.
   d. the cooling capacity of air-source heat pumps.
7. AHRI Standard 13256 is used for rating
   a. chillers.
   b. boilers.
   c. water-source heat pumps.
   d. air-source heat pumps.
8. IPLV ratings for chillers do *not* include
   a. fan distribution power.
   b. chilled-water pump horsepower.
   c. compressor power.
   d. condenser pump horsepower.
9. The ASHRAE Headquarters building in Atlanta reported that VRF systems used approximately __________ of geothermal heat-pump systems in the same building under the same conditions.
   a. half the energy
   b. one-third the energy
   c. double the energy
   d. 30 percent more of the energy

10. VRF systems are able to create heat in low ambient conditions by
    a. turning on backup electrical resistance heating.
    b. speeding up the compressor to double the speed to produce higher heating capacities of lower ambient.
    c. installing the condenser in an equipment room with backup heating.
    d. Both a and c
11. New AHRI standards have attempted to simplify the effort required by energy-simulation programs to compare system efficiencies by
    a. averaging the performance along the lines of all similar equipment within each manufacturer's equipment line.
    b. coming up with an efficiency number that is necessarily a weighted seasonal average of efficiency for various climate (ambient) conditions and part loads.
    c. allowing manufacturers to do their own testing and providing real-world numbers for evaluation.
    d. simultaneously testing all defective equipment in the lab.
12. Programs such as McQuay's Energy Analyzer (MEA) and Taco's Systems Analysis Tool (SAT) offer the opportunity
    a. to save an experienced user between 4 and 8 hours of analysis time on system modeling.
    b. to model multiple systems with only a few minutes of input.
    c. on only one screen of input for each system
    d. All the above
13. Water and refrigerant both have much higher specific heats and densities than air. This results in
    a. a greater need for heat-absorbing coils.
    b. more effective water-to-refrigerant exchangers.
    c. less horsepower to move Btus.
    d. All the above
14. Water is a favorable method of transferring Btus from one place to another compared with refrigerant because
    a. water is not considered toxic to humans.
    b. refrigerant costs more than water.
    c. water is unlikely to be phased out in favor of a more environmentally friendly compound.
    d. All the above

CHAPTER 15

Geothermal Rebates, Incentives, and Renewables Legislation

> Individual commitment to a group effort—that is what makes a team work, a company work, a society work, a civilization work.
>
> —*Vince Lombardi*

It is clear that the manufacturing leaders of the geothermal HVAC industry have reached the level we now enjoy through their investment into the legislative processes that promote geothermal technologies. Geothermal manufacturing companies such as ClimateMaster, WaterFurnace, Trane, Carrier, Spectrum, Entertech, and other greats of the industry have spent millions upon millions of dollars through their affiliations with GeoExchange and other industry associations. If not for the investment over previous decades of these good manufacturers and others like them, geothermal would still be a speck on the map, and the economic and environmental geothermal benefits would not have reached the consumer.

It is fortunate that there are manufacturers coming into the industry that are aware of financial investments of these good companies. It is wonderful when industry veterans choose to support the promotion of legislation that benefits the industry and in turn begin to reap the benefits of increased sales from legislative promotion. As discussed in the previous chapters, financial commitment has also resulted in an increase in commitment to geothermal knowledge. The result is a perception of geothermal, and better performing geothermal projects.

The geothermal heating, ventilation, and air-conditioning (HVAC) industry has long been overlooked as a renewable technology partner. Technologies such as solar photovoltaic and wind power have been much more visible, both literally and figuratively.

If you were to do a Google search of solar projects, wind projects, and geothermal HVAC projects, you would find that geothermal has a small slice of the pie. However, geothermal has a much greater opportunity to remove many more kilowatthours per dollar invested from the electrical grid than any other technology available (Fig. 15-1).

For example, Dr. Xiaobing Liu, in a report titled, "Assessment of National Benefits from Retrofitting Existing Single-Family Homes with Ground Source Heat Pump

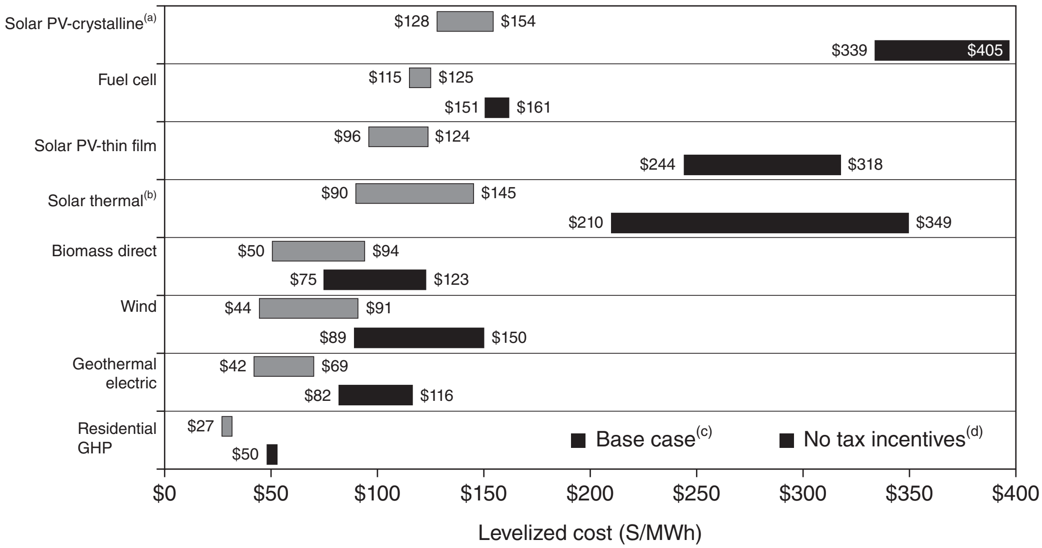


Figure 15-1 Geothermal HVAC projects cost far less per kilowatthour generated to install than any other renewable technology. (*LCEO Source Lazard/ClimateMaster*.)

Systems," dated August 2010, concluded, based on observations and scientific analysis using a cross section of 600,000 geothermal heat-pump (GHP) units in the United States, that the market penetration of GHPs in the United States would provide a reduction of *215.9 GW in summer-peak electrical demand* and a *56.1 percent reduction* in summer-peak electrical demand for straight-cool (SC) air-conditioners in existing U.S. single-family homes. Although it is not feasible to attain a 100 percent market penetration, there is no other technology that provides this type of energy reduction with a relatively small investment.

The single most important consideration for utility rebates is demand-side management (DSM). This is the reduction in peak demand in both summer and winter electrical consumption loads. Electrical utilities need to sell electricity to make money. However, when they have to design their power plants for that single day in which every home is drawing the maximum amount of energy to cool or heat the home, that peak is often 300 percent more than the standard load. Thus utilities are regularly looking for ways to reduce peak electrical demand or facilitate DSM.

A recent report titled, "The Importance of SEER and EER in Utility Air Conditioning Demand Side Management Programs," by Mark Faulkenberry and Kalun Kelley, shows that comparison of air-source air conditioners and geothermal-source air conditioners using current figures is misleading. SEER has been the federal efficiency standard for residential air conditioners since the late 1980s, with many utilities basing their efficiency-program incentives on SEER, and the majority of manufacturers focusing on units with ever higher SEER ratings. The result of this study shows a stark difference from the projected kilowatthour reduction to the actual kilowatthour reduction (Fig. 15-2).

As a result of this test, Western Farmers Electric Cooperative , Oklahoma the utility has implemented a program reversing its original assumptions and shooting for an 80 percent geothermal and a 20 percent air-source mix instead of the same ratio favoring air-source heat pumps, as originally planned. According to the authors of this report,

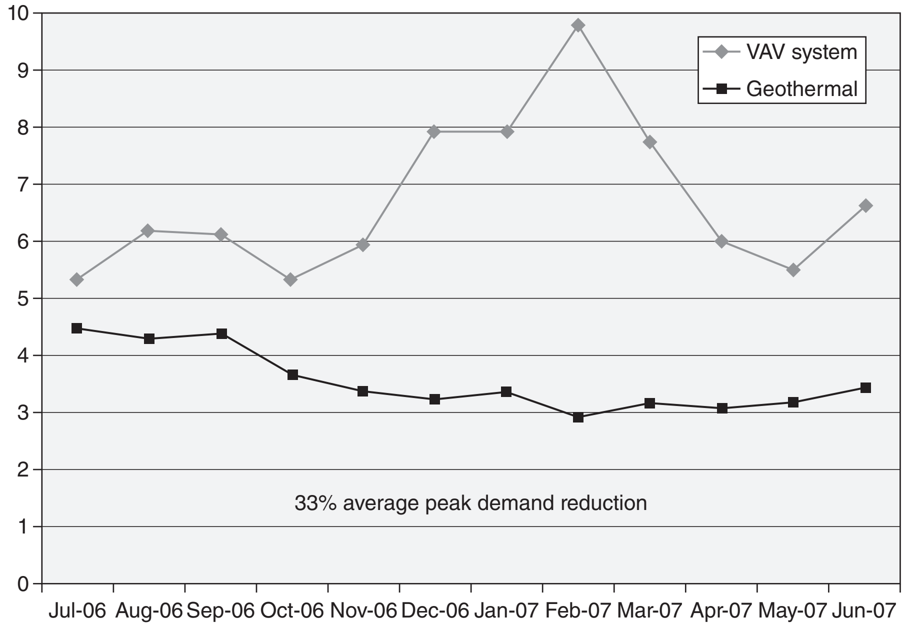


FIGURE 15-2 SEER versus EER comparison in peak kilowatthour reduction.

the result is that a more accurate measure of peak demand affects cooling equipment, and energy-efficiency ratio (EER) has been overlooked, especially by utilities seeking to reduce peak power demand.

It is often overlooked that 73 percent of home energy consumption is used for HVAC systems on average. The stumbling blocks faced by the GHP industry include a perceived high initial cost, a lack of knowledge and/or trust in GHP systems (AKA "Geo-Jitters"), and limited design and installation infrastructures. A lack of knowledge seems to be the most significant barrier to the wide application of GHP systems, a barrier that is quickly being overcome with this book and other industry and academic training throughout the country.

Is It Shiny?

Going back to the successful television series, *Home Improvement*, people are more concerned with how things look than with how well they perform. Of the three big renewable technologies that can be used most effectively in buildings—solar, wind, and geothermal—only geothermal remains hidden from view. When a person spends $25,000 or more on an investment, he or she normally would like something to show for it. He or she would like something to point to, such as a solar array or a windmill. It is not attractive enough to bring somebody into the basement, attic, or mechanical room and point to a GHP and say, "That's it." Usually, this result in a whimsical response from the guest, something like, "Wow, I guess you couldn't get a solar panel installed here?" With further explanation, your guest typically becomes more distant, until the subject is changed. Geothermal just does not have that "Will you look at that!" appeal.

Thankfully, manufacturers banded together to educate our legislators on the merits of GHPs. Through the efforts of GeoExchange, legislation has been implemented that is furthering efforts and benefiting everyone in the United States. Similar efforts are being made globally.

In the following story, the efforts of ClimateMaster WaterFurnace over the past years show what a little bit of cooperation can do: In early 2009, the construction company the lead author used to run, called Egg Commercial Systems, was just finished with another residential geothermal job. This job was no different from the hundreds of geothermal projects before it, with one exception. In this case, the project manager came into the lead author's office to inquire about a tax credit for geothermal HVAC. The lead author laughed out loud and told the project manager that he did not believe that there was any chance of a tax credit for geothermal air conditioning and heating his lifetime.

The project manager said that he felt the same way. However, the customer had insisted that new legislation had been passed. The lead author asked him to research it and bring back any proof of such a program.

The next day, the customer came into the lead author's office with a sizable stack of paper on which the following wording was affixed: "The American Recovery and Reinvestment Act of 2009." He quickly guided the lead author to a page in the document that had a short but sweet summary statement:

> A taxpayer may claim a credit of 30 percent of qualified expenditures for a system that serves a dwelling unit located in the United States that is owned and used as a residence by the taxpayer. Expenditures with respect to the equipment are treated as made when the installation is completed. If the installation is at a new home, the "placed in service" date is the date of occupancy by the homeowner. Expenditures include labor costs for on-site preparation, assembly or original system installation, and for piping or wiring to interconnect a system to the home.

If the federal tax credit exceeds tax liability, the excess amount may be carried forward to the succeeding taxable year. The excess credit may be carried forward until 2016, but it is unclear whether the unused tax credit can be carried forward after then.

In summary, all the components needed for the installation of a geothermal HVAC system are included. Some of those items are

1. Geothermal heat pump
2. Pumps
3. Ground loop and associated pipe system
4. Air-distribution system (duct work)
5. Thermostat and control system
6. Electrical upgrades
7. Structural upgrades

With regard to new construction, these tax credits penetrate beyond just the GHP, providing a significant reduction in cost by credits on the duct and control systems, a substantial portion of the cost of an HVAC system.

The efforts of the industry have been put squarely behind the industry's legislative arm, GeoExchange. As a result, contractors, engineers, and trades people are choosing to support the manufacturers that are putting their efforts and their money behind forward-moving legislation for the geothermal HVAC industry. In short, the GHP manufacturers, distributors, designers, and installers that retain membership in GeoExchange are supported by the authors of this book and the industry.

Commercial Geothermal HVAC Tax Incentives

Federal tax credits and incentives for commercial GHP systems seem to be a bit more elusive on the surface. Appearances are not what they seem. The credit is described on the Database of State Incentives for Renewables and Efficiency (DSIRE) website as

> The federal business energy investment tax credit available under 26 USC § 48 was expanded significantly by the Energy Improvement and Extension Act of 2008 (H.R. 1424), enacted in October 2008. This law extended the duration—by eight years—of the existing credits for solar energy, fuel cells and microturbines; increased the credit amount for fuel cells; established new credits for small wind-energy systems, geothermal heat pumps, and combined heat and power (CHP) systems; allowed utilities to use the credits; and allowed taxpayers to take the credit against the alternative minimum tax (AMT), subject to certain limitations. The credit was further expanded by the American Recovery and Reinvestment Act of 2009, enacted in February 2009.

Basically, this says that for GHPs, the credit is equal to 10 percent of expenditures with no maximum credit limit stated. This statement is so broad that it also includes high-temperature geothermal systems (hot-rock or steam-generating systems) with equipment qualifying up to the electric transmission stage.

By the time you get through all this legal verbiage, it looks as if commercial systems get only 10 percent credit. The lead author was not impressed, figuring that contractors and engineers should focus more on residential customers. Then one day as the lead author was reading on the forum hosted by GeoExchange, and the conversation peaked his interest. A gentleman stated, "It's too bad that the federal government saved the real tax incentives for the business owners. Again, the rich get richer."

The lead author was intrigued and determined to find out what he was missing. Then he saw the Maximum Accelerated Cost Recovery System (MACRS) spreadsheet on a manufacturer's website and downloaded it to decipher the benefits (Fig. 15-3).

The geothermal system also may be eligible for the Section 179 deductions, in which a small business can immediately write off 100 percent spending in lieu of depreciation to a maximum of $250,000. It's important to note that if the tax credit exceeds income tax liability, the loss can be carried back one taxable year, and any remaining balance can be carried forward into future years.

Section 179 also allows for taxable development interests to take advantage of tax credits on nontaxable projects such as municipal, state, and other projects for government buildings, school, and religious organizations. Note that businesses that cannot use the tax credits can explore other options, such as the sale of leasebacks, partnership flip structures, or energy-purchase contracts.

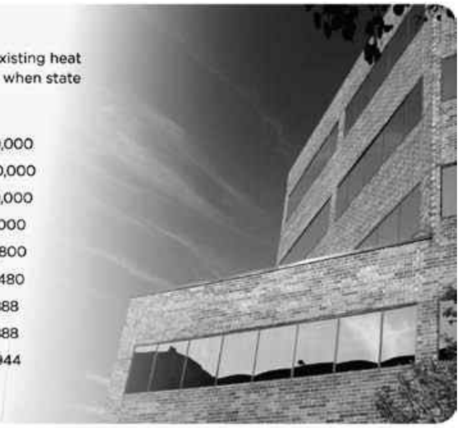
As with residential systems, these credits apply to expenditures for both the labor and equipment to install geothermal HVAC systems, but they must be located within the United States and be placed in service before December 31, 2016. Tax-exempt entities are not eligible.

New Construction

$2,000,000 spent to install geothermal heat pump systems in a new construction. Building occupied August 2009. 40% tax bracket when state income tax is included.

2009 Tax Credit:	$2,000,000 x 10% Credit	= $200,000
Depreciable Basis:	$2,000,000 - ($200,000/2)	= $1,900,000
2009 Bonus Tax Benefit:	$1,900,000 x 50% bonus x 40% tax rate	= $380,000
2009 MACRS Tax Benefit:	$190,000 x 40% tax rate	= $76,000
2010	$304,000 x 40% tax rate	= $121,600
2011	$182,400 x 40% tax rate	= $72,960
2012	$109,440 x 40% tax rate	= $43,776
2013	$109,440 x 40% tax rate	= $43,776
2014	$54,720 x 40% tax rate	= $21,888

Total tax savings including 10% credit: $960,000

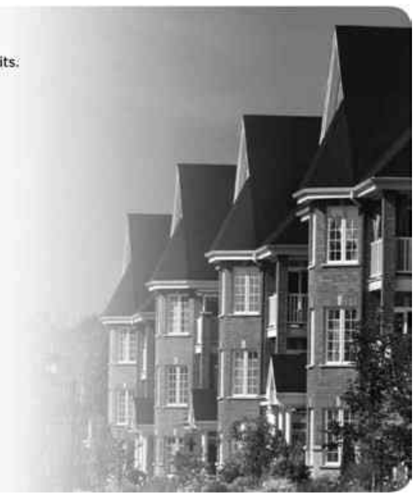


Retrofit Example

$1,000,000 spent to remove boilers, install geothermal loops, and upgrade existing heat pumps to geothermal equipment. Completed August 2009. 40% tax bracket when state income tax is included.

2009 Tax Credit:	$1,000,000 x 10%	= $100,000
Depreciable Basis:	$1,000,000 - ($100,000 / 2)	= $950,000
2009 Bonus Tax Benefit:	$950,000 x 50% bonus x 40% tax rate	= $190,000
2009 MACRS Tax Benefit:	$95,000 x 40% tax rate	= $38,000
2010	$152,000 x 40% tax rate	= $60,800
2011	$91,200 x 40% tax rate	= $36,480
2012	$54,720 x 40% tax rate	= $21,888
2013	$54,720 x 40% tax rate	= $21,888
2014	$27,360 x 40% tax rate	= $10,944

Total tax savings including 10% credit: $480,000



Replacement Example

$250,000 spent to replace existing geothermal heat pumps with new geothermal units. Completed August 2009. 40% tax bracket when state income tax is included.

2009 Tax Credit:	$250,000 x 10%	= $25,000
Depreciable Basis:	$250,000 - ($25,000 /2)	= $237,500
2009 Bonus Tax Benefit:	$118,750 x 40% tax rate	= $47,500
2009 MACRS Tax Benefit:	$23,750 x 40% tax rate	= $9,500
2010	$38,000 x 40% tax rate	= $15,200
2011	$22,800 x 40% tax rate	= $9,120
2012	$13,680 x 40% tax rate	= $5,472
2013	$13,680 x 40% tax rate	= $5,472
2014	$6,840 x 40% tax rate	= $2,736

Total tax savings including 10% credit: $120,000

Figure 15-3 The federal tax incentives for commercial geothermal HVAC equipment can have a total value of up to 48 percent of the cost of the system. This is often less than the cost of a standard HVAC system. Commercial tax credits are more favorable than residential credits in certain circumstances, as depicted in this chart from WaterFurnace.

Energy-Efficient Commercial Building Tax Deductions

The owners of new or existing buildings who install heating, cooling, ventilation, or hot-water systems that reduce the building's total energy and power costs by 50 percent or more in comparison with minimum requirements set by the American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 90.1-2001 are eligible for a tax deduction of up to $1.80/ft^2.

If this energy reduction is not attained, a consolation of $0.60/ft^2 is available for heating and cooling systems that provide at least one-third of the 50 percent savings target. Energy savings must be calculated using software approved by the Internal Revenue Service (IRS) in each of these cases. There are many companies that specialize in this tax credit opportunity currently in the marketplace.

The best source available for determining rebates and credits available, if any, is the Database of State Incentives for Renewables and Efficiency (DSIRE) website maintained by the U.S. Department of Energy (DOE): www.dsireusa.org/.

Barriers to Geothermal HVAC Funding

As with any technology that is perceived to be new, the barriers to geothermal HVAC are the lack of

- Knowledge
- Infrastructure
- Equipment
- Training
- Financing
- Personnel

Many of these obstacles have been overcome, but the obstacle of funding seems to be the most persistent. With regard to funding, there are two main obstacles:

1. Split incentive
2. Leverage barrier

Split incentive might be better described as "owner pays, tenant saves." Many times in a commercial building, the owner is responsible for all costs of capital improvements. So, if the owner installs a geothermal HVAC system, the tenant is the primary beneficiary in the form of reduced energy consumption and reduced energy dollars.

Because building owners seek to maximize net operating income (NOI) for their assets, it would seem that any reduction in operating expenses would increase the NOI for the building owner and help to finance energy-saving projects. This is not entirely correct. Operating expenses tend to rise, and most leases have clauses that state that the increases in expenses will be proportionally passed onto the tenant in the form of higher rents. Because of this typical scenario, a dollar saved in operating expenses produces a reduction in other income and does not create a dollar increase in the NOI.

Leverage barrier is the other issue preventing private owners from investing in geothermal HVAC projects. Access to the funds to do an energy-efficiency project is an insurmountable obstacle to many property owners, more so than the issue of split incentive. Vendor-sponsored project financing or performance-based contracting may be available. Mortgage covenants, however, are generally written to prohibit any secured secondary debt under penalty of default.

The economic climate in 2013 has made access to funds even more difficult. Building refinancing for properties that may need to face foreclosure in the future are no longer in the crosshairs of bank loan officers.

Some Current Funding Options

Energy Services Companies

Performance-based contracting has been used since the 1980s through energy services companies (ESCOs). The program is what it sounds like—a project supplier provides a turnkey energy-efficiency solution with an energy-savings guarantee. The energy savings are shared between the ESCO and the building owner. This is a sort of insurance policy for the building owner in that if project savings are not realize, he or she is not on the hook for the investment.

If you think about performance-based contracting just a little bit, you will certainly come to the conclusion that this does not solve the split incentive issue for the multitenant owner. Oh well.

Property Assessed Clean Energy Funding

In the lead author's first book, *Geothermal HVAC: Green Heating and Cooling*, he wrote about Property Assessed Clean Energy (PACE) that bears repeating here, and it goes something like this (changed a little for fun): A typical family in the United States consisting of a mom, dad, and four children lives in a 2000-ft^2 house in Anytown, USA. This family has a 10 SEER heat pump with a backup gas furnace. This family is able to pay all the normal expenses each month that a typical U.S. family has. But the parents notice that the air-conditioning bill has crept up to around $450 a month in the middle of the summer and close to the same in the winter.

About this time, they are watching television, and they hear of a fantastic technology, which, of course, is geothermal heat pumps. They investigate this for their home and find that they can reduce their energy consumption by an average of about $150 per month. This is done through the integration of the geothermal heating, geothermal cooling, and domestic hot-water generation.

The estimate for the installation of this 60,000 Btu, or 5 ton, GHP system comes in at $35,000. This is too much money; it simply cannot be raised by the family. They are, of course, aware that at some point they're going to have to replace their existing air-conditioning system because it will only last between 8 and 12 years. A reasonable cost estimate is about $10,000 to replace the existing system.

In this case, however, the sales representative explains that there is a new type of funding called PACE. In this program, the entire cost of the installation is applied to a 20-year loan, which is applied to the property through an assessment and is paid back through an increase in property taxes on the particular property on which it's installed. This will increase the family's taxes by approximately $150 per month.

In this scenario, the family has been offered a solution that doesn't cost taxpayers any money. Additionally, there is no out-of-pocket cost to the family because the increased amount of property taxes is offset by the decrease in electrical consumption.

This is all favorable, but there are many other benefits that have not been touched on yet. Among these are the following:

1. The family has saved the $10,000 that would have to come out of pocket for replacement of the air-conditioning system.
2. The family has increased the comfort of their home.
3. The family has increased the value of their home.
4. The family has increased the longevity of their HVAC equipment.
5. The family has added a renewable-energy device that reduces demand on the grid.
6. Until 2016, the family is eligible for a 30 percent tax credit applied to their federal taxes. This amounts to $10,500, which most likely will be applied to reducing the amount of funding. This will put more money in their pocket each month (perhaps $40 per month).
7. The family has increased the infrastructure of their home so that in 20 or 30 years, when the GHP equipment is in need of replacement, the cost will not be $35,000. It will be more along the lines of $10,000 because the entire infrastructure is in place. All that is needed is the heat-pump equipment, typically.

PACE for residential applications has not materialize owing to concerns about who gets "made whole" first in the case of default. Freddie Mac and Fannie Mae continue to claim the "prime position."

Many states and local jurisdictions have incentives for GHP systems. Many of these are in the range of 30 percent of the installed cost of the system. Many utilities are giving such a large incentive because of the mandate that has been placed on electrical utilities to have about 20 percent of their entire electrical consumption provided by renewable-energy generation.

Energy-Efficiency Power Purchase Agreements

The Photovoltaic Power Purchase Agreement and the Energy-Efficiency Power Purchase Agreement (EEPPA) are the framework of this comprehensive program. The EEPPA provider hires a third party, which is often an ESCO, to develop a project that is intended to be energy efficient in that it saves the owner on utility costs. The owner then pays the ESCO a set unit cost from the utility savings generated. This is typically based on an agreed-on amount for the unit cost of energy. Under this agreement, the EEPPA provider holds the rights to the equipment provided until termination or fulfillment of the contract. The EEPPA is also responsible for equipment maintenance and repairs until expiration of the contract, at which time the owner has the option to purchase the equipment at fair market value. Often the advantage of 'no maintenance worries' is equal to the operational cost advantage.

Managed Energy Services Agreement

This particular strategy for funding is based on the ESCO world. However, the ESCO model falls short of being what is called an *off-balance-sheet solution*. Managed Energy Services Agreement (MESA) arrangements have been implemented to provide a true off-balance-sheet solution for building owners. Under this program, the building owner assumes responsibility for the cost and payment of the building energy usage historically for an extended period, typically 10 years. The services provider procures the right, with permission of the owner, to install various energy-conservation products and to profit from any resulting reduction in energy usage. The energy services provider has a responsibility to procure investments to fund the project and uses outside equipment vendors, contractors, engineers, and so on. The energy services provider actually designs and commissions the project. This type of project has been completed for the last 10+ years, with more than two dozen projects currently being billed through MESA.

Utility Involvement: On-Bill Financing by Electric Utilities

Innovative financing programs, such as on-bill financing, have significant potential to address the upfront cost barrier to more widespread GHP installations. By financing the installation on the utility bill, the installation costs are converted into a small monthly payment that is more than offset by the monthly energy savings realized by the project. Programs such as on-bill financing will allow the GHP industry to expand rapidly, generating substantial energy savings for consumers and reductions in carbon emissions. Expanding the industry also will create thousands of new jobs. These are U.S.-based jobs—from manufacturing to drilling to installation.

Legislative and Political Progress

In May 2012, Maryland Governor Martin O'Malley signed the Renewable Energy Portfolio Standard—Geothermal Heating and Cooling Bill (Maryland SB 652) into law. New Hampshire Gevernor, John Lynch followed on June 15, 2012 with a similar renewable energy bill. States like Maryland, New Hampshire and California have recognized GHPs as an accepted technology toward earning renewable-energy credits (RECs). Many states have adopted renewable portfolio standards (RPS) that require 20 percent or more of all energy to be produced by renewable-energy sources. Buildings in the United States account for more than 70 percent of the nation's electricity usage, and GHPs have the potential to reduce energy use by as much as 40 to 70 percent in a typical building.

Doug Dougherty, president of the Geothermal Exchange Organization (GEO), lent support and written testimony that were crucial to the success of Maryland's legislation. As the first in the country, many are following Maryland's lead, and one expects to see all states fall in line within the next two to three years. California followed suit in just a few months, passing similar legislation into law in July 2012. California has the task of increasing the renewables dependence from 18 to 33 percent in just 10 years.

Rhode Island and several New Hampshire towns allow property tax–neutral residential geothermal property. Basically, this allows for the geothermal upgrade to be added without development of increased property taxes due to increased property value. Of note, even states such as Massachusetts, where competing natural gas interests have stalled geothermal incentives and rebates, there are low- or no-interest loans for geothermal as part of state-based energy-efficiency programs (Fig. 15-4).

A major dynamic of PACE legislation and funding is the issue of how to pay the contractors/suppliers. Although the property-taxing authority for the area has the ability to collect the taxes, the money won't be available right away to pay the contractors.

That's where companies such as District Management Services (DMS) in Florida come in. These entities basically bridge the loan for the consumer to the contractor. Then they are able to work with the legislative taxing body, and for a fee, they obtain the return on their investment.

Figure 15-4 Martin Orio, president of Water Energy Distributors in New Hampshire, stays politically active as president of the local geothermal chapter. People such as Martin are the primary movers in political activity promoting the forward movement of geothermal HVAC technologies throughout the country and the world.

Geothermal Exchange Organization

The Geothermal Exchange Organization (GEO) is a nonprofit trade group that represents the government affairs and business interests of its member companies across the United States (Fig. 15-5). GEO advocates the economic, energy security, and environmental benefits of GHP systems to elected officials, government institutions, and the public. GEO offers important outreach services to geothermal heating and cooling system manufacturers and related businesses, including

- An aggressive government affairs program that has gained major tax and other advantages for the GHP industry
- A robust public outreach program that includes GeoExchange branding and consumer awareness efforts

Figure 15-5 GeoExchange is the geothermal HVAC industry's legislative arm in Washington. (*GeoExchange*.)

- Strong alliances and collaboration with allied organizations on vital legislative and regulatory issues and with government agencies in support of energy efficiency, security, and environmental protection.
- GEO also supports quality training, certification, and accreditation for GHP system designers and installers.

For more information, visit the GEO website: www.geoexchange.org.

GEO's Focus: Federal and State Levels

GEO's efforts to expand and grow the U.S. GHP industry focus on both federal and state issues. GEO has a lobbying team in Washington that helps to set an annual agenda with the GEO board of directors and president. GEO also works with state agencies and state-based GHP organizations in support of their efforts for the industry (Fig. 15-6).

GEO recognizes that changing state laws and regulations that remove impediments to GHP installations is of utmost importance for the industry. Among these are energy-efficiency mandates and RPS. GHPs are an obvious leader in energy efficiency but have been left out of various state laws or ignored because of narrow definitions and/or formulas for qualifications. GEO is working in select states to begin turning those definitions in favor of GHPs.

Overcoming the hurdle of first cost is paramount in helping to guarantee new market share for GHPs. Utility involvement is key to this effort through promotions, rebates, financing programs, and outright loop ownership. GEO is working with regulators, public utility commissioners, and electric providers to urge their participation in the GHP marketplace. In addition, GEO is working to change renewable-energy purchase mandates across the country to include GHPs as a compliance measure for utilities.

Thirty-seven states have RPS laws that mandate that certain percentages of electricity provided by utilities must come from renewable generators such as wind, solar, and biomass. Few states recognize thermal energy as an equivalent to electricity. GEO is working to amend RPS laws to allow thermal energy production as a compliance measure for utilities in meeting renewable electricity purchase mandates, specifically the thermal energy produced by GHPs. In this way, GEO hopes to reinvigorate utility interest in—and promotion of—the technology for demand-side management. GEO contends that GHPs can help utilities to avoid the cost of building new power-generation facilities while shaving peaks in demand during periods of heavy power use, such as air conditioning on hot summer days. In essence, a geothermal heat pump is a "Renewable Energy Amplifier."

Figure 15-6 WaterFurnace CEO Tom Huntington (*right*) with GEO board of directors veteran Keith Swilley. It takes dedication and resources to keep legislators aware of the incredible benefits of geothermal HVAC technologies.

GEO's 2012 Federal Legislative Issues

During the GEO Second Annual Legislative Fly-In to Washington, DC, in late February 2012, the GEO board of directors, members, staff, and lobbyists pursued the following five key issues for the U.S. GHP industry:

1. *Ensure that GHPs qualify under federal renewable purchase requirements.* In 2005, the Energy Policy Act required that a certain percentage of electricity used by the federal government come from renewable sources. For fiscal years 2007–2009, the act required at least 3 percent of electricity used by the government to come from renewable sources. The requirement increased to 5 percent for fiscal year 2010 and will increase to 7.5 percent for fiscal year 2013. Unfortunately, the way *renewable energy* is defined excludes GHPs. The act defines renewable energy as "electrical energy generated from solar, wind, biomass, landfill gas, ocean, geothermal, municipal solid waste, or new hydroelectric generation capacity." GHPs do not qualify under the Energy Policy Act because they technically do not generate electricity—even though they can reduce energy use by as much as 40 to 70 percent in a typical building. GEO believes that the thermal energy use avoided with the installation of GHPs should count toward the law's renewable energy purchase requirement. GEO supports legislation introduced by Senators

Jeanne Shaheen (D-NH) and Rob Portman (R-OH)—the Energy Savings and Industrial Competitiveness Act (S. 1000)—to improve the energy efficiency of buildings. S. 1000 already includes a provision to clarify that thermal energy produced can count toward the renewable purchase requirements, but the language needs to be amended to also count thermal energy avoided by technologies such as GHPs. *This goal was accomplished in September with passage of H.R. 4850.**

2. *Include GHPs in clean energy standard (CES) legislation.* A *clean energy standard* (CES) is a policy that requires covered electricity retailers to supply a specified share of their electricity sales from qualifying clean-energy resources. GHPs should be included in any CES. This technology captures a distributed thermal form of renewable energy that can be measured, metered, and verified. Senator Jeff Bingaman (D-NM) introduced legislation to implement a federal CES. GEO asked legislators to encourage the senator to ensure that utilities can get credit under the legislation for the thermal energy avoided by installing GHPs.

   In testimony to the committee last June, GEO said, "Ensuring that utilities get credit under a CES for the thermal energy avoided by GHPs will create an incentive for utilities to actively promote this proven technology. Every electric utility in the country can improve its load factor, mitigate the need for price increases, lessen the strain on the transmission grid, forestall future generation needs, reduce carbon emissions, and provide consumers with improved conditioned space by promoting GHPs. In fact, a review of existing studies done by DOE labs suggests that GHPs could avoid more than 130 billion kWh of retail electricity sales by 2035" (data from Liu). *This legislation was stalled during this election year, as of November 2012.*

3. *Encourage the U.S. Department of Energy to promote GHPs.* Despite the potential of GHPs, the industry lacks a home at the U.S. Department of Energy (DOE). The DOE needs dedicated staff to promote the technology and provide technical assistance to other federal agencies that are pursuing GHP projects. The Consolidated Appropriations Act of 2012 (H.R. 2055), which was signed into law on December 23, 2011, directs DOE to produce a strategic plan for developing innovative GHP technologies and promoting them in residential and commercial applications. GEO asked for help to ensure that DOE completes and ultimately implements the plan (Fig. 15-7). *GEO urged legislators to contact DOE to inquire about the status of the strategic plan and to encourage them to do more to promote this effective and proven technology.*

**Senate Passes Bill Recognizing GHPs for Federal Clean Energy Purchases.* In September, the U.S. Senate unanimously approved H.R. 4850, which amends the Energy Policy Act of 2005 to specifically include thermal technologies (read: GHPs) for achieving federal energy-efficiency goals. The language was a product of GEO work with 30 senators, Senate Energy Committee staff, and GEO testimony on the benefits of GHPs. U.S. Senators Jeanne Shaheen (D-NH) and Rob Portman (R-OH) got their energy-efficiency legislation (originally S. 1000, also supported by GEO) passed as an amendment tacked onto H.R. 4850. Among other things, the amendment expands the definition of federal renewable-energy consumption requirements to include thermal as well as electrical renewable energy. Thanks to GEO and supporters such as the National Ground Water Association, those new technologies now include GHPs. H.R. 4885 now goes back to the U.S. House of Representatives for the postelection lame duck session, where more work will be needed to ensure its final passage.

4. *Support on-bill financing programs.* Innovative financing programs, such on-bill financing, have a significant potential to address the upfront cost barrier to more widespread GHP installations. By financing the installation on the utility bill, the installation costs are converted into a small monthly payment that is more than offset by the monthly energy savings realized by the project. Programs such as on-bill financing will allow the GHP industry to rapidly expand, generating substantial energy savings for consumers and reductions in carbon emissions. Expanding the industry also will create thousands of new jobs. These are U.S.-based jobs—from manufacturing to drilling to installation. GEO estimates that one new job will be created in this country for every 18 heat-pump installations—and that is a conservative estimate. GEO strongly supported a provision added to the Consolidated Appropriations Act of 2012 (H.R. 2055), signed into law on December 23, 2011, that directs the Economic Development Administration to use $1 million of its existing funds to support innovative on-bill financing programs for small businesses. GEO encouraged legislators to seek ways to expand this effort and to eventually ensure that all consumers have access to on-bill financing options. *The pilot program was initiated later in the year.*[†]
5. *Support for DOE research to reduce GHP cost.* GEO strongly supports the Geothermal Exploration and Technology Act (S. 1142), which was introduced by Senators Jon Tester (D-MT) and Lisa Murkowski (R-AK). The legislation directs the secretary of energy to implement a research program to help make GHPs more affordable and further demonstrate the efficiency of the technology

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[†]*On-Bill Financing Program Pilot in Vermont.* In October, Senator Bernie Sanders (I-VT) announced that a $1 million federal grant will help the Burlington Electric Department provide on-bill financing (OBF) to small-business customers for energy-efficiency projects, *including geothermal heat-pump installations.* Burlington's proposed OBF targets outdated and inefficient lighting, refrigeration, heating, and air-conditioning systems. Those loads drive the city's summer peak consumption of electricity. GHPs are the most efficient replacement for outdated heating and air-conditioning equipment. The idea of OBF was offered by GEO President and CEO Doug Dougherty following testimony to the Senate Energy and Natural Resources Committee in June 2011 for another bill. He noted that OBF was a way to help reduce the upfront cost of GHP. Dougherty subsequently met with Senator Sanders to further discuss the concept, which led to a hearing specific to the issue, where GEO Board Member Phil Schoen (Geo Enterprises, Tulsa, OK) testified on its behalf. GEO strongly supported Sanders' provision for an OBF pilot program for small business until it was passed as an amendment to the Consolidated Appropriations Act of 2012 (H.R. 2055). President Barack Obama signed the bill into law on December 23, 2011. The Sanders amendment directs the Economic Development Administration (EDA) to use $1 million of its existing funds to support OBF programs for small businesses. As part of the U.S. Department of Commerce, EDA awarded the grant to the Burlington Electric Department. OBF is a utility-run program that offers upfront funds to small businesses to make improvements that save energy and lower bills. It has great potential to address the upfront cost barrier to GHPs. By financing GHP systems with payments on monthly utility statements, installation costs are converted into small payments that are more than offset by the monthly energy savings realized by the projects. And since defaults on such loans have on average been less than 2 percent, the new OBF pilot program essentially leverages the $1 million now offered by EDA into $50 million worth of loans for energy-efficiency installations. The Burlington pilot program could take effect in early 2013 and will help to reduce waste of electricity. Many of the energy-efficiency measures installed under the new program could be paid back within 4 years. Energy savings then would directly benefit a business's bottom line. The pilot program in Vermont has the potential to expand beyond approximately its initial participants to more business owners—and ultimately to benefit home owners. Sanders said that he has "more comprehensive" legislation in the works that will extend the benefits of OBF to more Americans.

in large-scale projects. The legislation also includes provisions for exploration and development of high-temperature "hot-rock" geothermal resources. (This legislation was stalled during the election year.) S. 1142 authorizes a new grant program that will help to drive down the cost of this proven technology. The legislation, among other things, would direct research at

- Improving ground-loop efficiency through more efficient heat-transfer fluids and thermal grouts, better loop design, and improved variable pumping rates; this expenditure might be better spent on open and standing-column-well implementation.
- Reducing ground-loop installation cost through improved drilling techniques and equipment.
- Exploring innovative uses of wastewater and mine water for geothermal systems, dewatering of subways.
- Demonstrating the viability of large-scale commercial and residential neighborhood projects (as in Clearwater, FL).
- Integrating geothermal with solar systems to balance loads and store energy.

GEO successfully promoted an amendment to appropriations that directed $10 million in research by DOE directed at GHPs.[‡]

Successful Outcomes for the Industry

Companies such as Lend Lease, one of the largest construction management companies in the world, continue to spearhead major geothermal HVAC projects throughout the world. Principal partner Joe Potter, based in Tampa, FL, states that his company, Lend Lease, has been sustainable in design practice since long before the construction industry knew what *sustainable* was. It is because of Joe Potter's good work and the openness of the Pinellas County Commissioners in Florida that the new Pinellas Safety Complex (Emergency Operations Center) is going forward with the largest geothermal construction project thus far in the Southeast (Fig. 15-9).

[‡]*GEO Recommends DOE Research Projects for GHPs.* In April, the Senate Appropriations Committee approved a funding bill for the U.S. Department of Energy (DOE) for fiscal year (FY) 2013. The legislation encourages DOE to provide no less than $10 million "to support research, development, and strategic deployment of GHP technology." The bill has since been approved. Following a request from DOE for industry input into how the funds might be spent, GEO provided the following ideas for their consideration:

- Standardized method to measure thermal load avoided by GHPs
- Development of improved ratings method for GHP and HVAC systems
- Establishment of utility-owned ground-loop ownership program
- Integrated renewable-energy measurement of GHP systems
- Employment impacts of the U.S. GHP industry
- Performance analyses of HVAC systems—ASHRAE Headquarters
- In-depth analysis of GHP costs and maintenance at Fort Polk
- Updated GHPC data and studies, with new cost/efficiency analyses
- Analysis of utility GHP incentives, with strategies for renewed support
- GHP outreach, awareness, and education

Figure 15-7 The U.S. Department of Energy is important in the promotion, support, and research for the full implementation of geothermal HVAC systems in the United States and the world.

Figure 15-8 Dan Ellis, president of ClimateMaster, Doug Dougherty, president of GeoExchange, and Tom Huntington, president of WaterFurnace, are all among the giants of the industry working toward a successful outcome.

Figure 15-9 Jay Egg and Joe Potter, principal at Lend Lease, stand in front of the rig that is constructing one of the 1300 gal/min geothermal wells to provide cooling and heating needs for the massive $81 million Emergency Operations Center located in Pinellas County, FL.

The 2600 ton, $81 million Emergency Operations Center for Pinellas County will eliminate the need for cooling towers and boilers by using the sustainable, renewable geothermal-source chillers.

Stan Newton of Engineering Matrix states that elimination of outdoor equipment will considerably increase the life expectancy of the system. Stan would like to see water- and chemical-hungry cooling towers go away all over the southeastern United States and beyond.

GEO Supports State Geothermal Initiatives

GEO is pressing forward at the state level to get public policy implemented or changed to acknowledge GHPs as both efficient *and* renewable.

California: On September 27, 2012 Governor Jerry Brown signed into law AB 2339, Energy Geothermal Technologies. The legislation directs the California Energy Commission (CEC) to evaluate policies and implementation strategies that will promote widespread deployment of GHPs and geothermal ground-loop technologies as key components of a clean California energy future. The newly formed CaliforniaGeo championed AB 2339 with industry stakeholders and a coalition of allied organizations, including the California Groundwater Association, GEO, USGBC California, and the California Geothermal Energy Collaborative.

Illinois: GEO held informational meetings with the Illinois Power Agency (IPA) and the Illinois Commerce Commission (ICC) to discuss the value that GHPs provide to the state's renewable- and efficient-energy policies. In September, GEO registered with the Illinois Secretary of State and hired a lobbyist to legislatively include GHPs in the state's Energy Efficiency Portfolio Standard (EEPS) and Renewable Energy Portfolio Standard (REPS). The Illinois EEPS significantly limits the inclusion of GHPs as an energy-efficient technology under current law. Unless a GHP replaces electrical resistant heat, no credit is assigned to it for the heating load of a building, and therefore, it fails the EEPS payback test. It's clearly a flaw in the policy, and it will take legislative action and ICC intervention to change it.

Iowa: On May 25, 2012 Iowa Governor Terry Branstad signed SF 2432 into law, providing a state tax credit for residential GHP installations equal to 20 percent of the federal residential energy-efficient property tax credit. It can be used for tax liability for 10 years or until depleted. Considering that the federal GHP tax credit of 30 percent for residential installations, the Iowa GHP credit is equivalent to 6 percent of system cost. The law is applicable to any new or refitted construction or installation of a geothermal heating or cooling system on or after July 1, 2012, on property classified as residential. An important part of the bill is a property tax exemption for 10 years on additional appraised cost of real estate by installing geothermal systems. Installing a GHP in an Iowa residence typically increased the dwelling property tax by $300 to $350 per year. *The Iowa Geothermal Association is solely responsible for the success of the bill.* It will take some time for new forms to be developed by the Iowa Department of Revenue for filing with the county assessor and for the Department of Revenue to develop appropriate rules to implement the new law.

Ohio: In June, 2012 GEO met with the Ohio Public Utilities Commission (PUC) to discuss the value of GHPs in economic development, energy-efficiency, and renewable-energy initiatives. GEO presented documents that demonstrated how GHP installations can create jobs, reduce peak electrical generation, improve load factors, and lessen the strain on the electrical transmission grid. Ohio PUC officials were very receptive to the benefits of the technology and pledged to examine their authority under state statute to determine their options for promoting GHPs.

Maryland: In May, 2012 Governor Martin O'Malley (D) signed the Renewable Energy Portfolio Standard: Geothermal Heating and Cooling Bill (SB 652) into law, making Maryland the first state in the nation to allow utilities to claim credits for the installation of GHPs. The Maryland legislation makes GHPs eligible for renewable-energy credits under the state's RPS. The law makes GHPs an accepted technology for utilities to use toward earning RECs under the state's RPS. Under the Maryland model, the thermal energy avoided by installing GHPs in the residential setting will be estimated using modeling tools. For commercial installations, a meter would be installed on site to measure the thermal energy saved. In both cases, the Btu energy savings attributable to GHPs are converted into annual megawatthours that utilities can claim for credit under the Maryland RPS.

Among many industry and agency stakeholders, GEO lent support and written testimony that were crucial to the success of the measure. The Maryland GHP legislation is the first of its kind in the United States. The Maryland RPS stipulates that electricity suppliers (utilities and competitive retail suppliers) use renewable sources of energy such as wind, solar, and biomass to generate a portion of their retail sales in annual percentage increments to a level of 20 percent by the year 2022. Electricity suppliers demonstrate compliance with the RPS by accumulating RECs, which are issued by the state according to the renewable power they provide to their ratepayers. With the new law, GHPs offer yet another option for utilities to meet their renewable-energy purchase requirements and earn RECs under the state's RPS mandate. Maryland and regional government and industry stakeholders are now forming the Mid-Atlantic Geothermal Industry Consortium (MAGIC) to educate surrounding states about the value of GHPs, a compliance measure for their renewable-energy purchase requirements. GEO will use the Maryland GHP law as a model for nearly 40 other states that have mandated RPSs. More information about SB 652 can be found in an *Air Conditioning, Refrigeration and Heating News* feature article. http://www.achrnews.com/articles/120191-maryland-legislature-passes-geothermal-heat-pump-bill

New Hampshire: In June, 2012 New Hampshire Governor John Lynch signed SB 218, which allows thermal renewable energy sources to be used by electric utilities to meet energy purchase requirements under the state's RPS. The New Hampshire RPS requires power providers to source 23.8 percent of their electricity from renewable resources such as wind, solar, and biomass by 2025. The law says that renewable thermal energy from biomass, solar, and GHPs qualifies for incentives under the state's RPS mandate. It offers Renewable Energy Certificates (RECs) to biomass, solar, and GHP developers that are equivalent in value to those offered for renewable electricity power projects. The RECs will be worth up to $29 per megawatthour of thermal energy produced. GEO member and New England Geothermal Professionals President Martin Orio (Water Energy, Hampstead, NH) was instrumental in garnering support for the bill by GHP companies across the region.

The New Hampshire thermal energy program will be available to residential, commercial, and industrial projects. Qualified projects can use revenue generated from the sale of RECs that they earn to finance capital costs, helping to reduce payback time on investment. Thermal projects will qualify for the new REC incentives after January 1, 2013. The New Hampshire Public Utilities Commission will forge an administrative rule to implement the law. *The Biomass Thermal Energy Council (BTEC) developed the concept and led efforts with the legislature, governor's office, and the state Public Utilities Commission to pass the new law.*

The geothermal HVAC industry has many dedicated proponents that give back to the industry in huge ways. Through the financial sport of Taco HVAC in Cranston, RI, and the hard work of its chief applications engineer, Greg Cunniff, great strides are being made across the HVAC industry (Fig. 15-10). Because of the efforts of selfless manufacturers such as Taco and many others, books such as this are made possible.

Many dedicated organizations provide extraordinary design and engineering services for geothermal HVAC system construction. Figure 15-11 shows coauthor Carl

Figure 15-10 Coauthors Greg Cunniff (*left*) and Jay Egg (*right*) pose with Jerry Baker in front of the $14 million Taco Learning Center in Cranston, RI, a major contributor to this book.

Figure 15-11 Coauthor Carl Orio (*seated second from left*) founder of Water Energy Distributors, together with others in the company he founded.

Orio with the company he founded, Water Energy Distributors, which provides good, solid, engineering advice to the hundreds of geothermal contractors installing systems in the Northeast.

Review Questions

1. Geothermal tax incentives for commercial applications
   a. are clearly defined in Section 179 of the United States Internal Revenue Service tax code depend on the tax bracket of the nonprofit organization.
   b. should be reviewed by an accounting professional for optimal return.
   c. are lower than for residential applications.
2. Of the following potential barriers to full implementation of geothermal HVAC applications, which is *not* a legitimate barrier?
   a. consumer knowledge.
   b. trade-related infrastructure.
   c. equipment efficiency.
   d. university/technical education.
3. Support of organizations politically active in forwarding geothermal HVAC applications must be shouldered by
   a. manufacturers.
   b. contractors.
   c. engineers.
   d. All the above
4. Which of the following technologies provides greater dependability and energy savings than geothermal HVAC applications?
   a. Solar photovoltaic
   b. Wind power
   c. LED lighting
   d. None of the above
5. The legislative arm of the geothermal HVAC industry is the organization known as
   a. the International Ground Source Heat Pump Association (IGSHPA).
   b. GeoExchange (GEO).
   c. the American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE).
   d. the Air Conditioning Heating and Refrigeration Institute (AHRI).
6. Two major financial barriers to implementation of geothermal HVAC systems in the commercial market are
   a. financial and political opposition.
   b. split incentives and leverage barriers.
   c. ESCOs and natural gas dominance.
   d. utility involvement and energy purchase agreements.

7. Geothermal HVAC installations for commercial applications are only financially favorable
   a. when electric utilities provide rebates for installation.
   b. with federal tax incentives.
   c. when they are financially favorable without incentives.
   d. when they are accomplished by performance-based contracting.
8. Support for the legislative efforts of GeoExchange is
   a. provided by all manufacturers of geothermal equipment.
   b. provided by a few manufacturers and representatives of geothermal equipment.
   c. provided by contractors and engineers.
   d. Both b and c

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APPENDIX A

Geothermal HVAC Resources

Government

U.S. Environmental Protection Agency Energy Star Hotline
1200 Pennsylvania Ave. NW
Washington, DC 20460
888-STAR-YES (888-782-7937)
www.energystar.gov

U.S. Department of Energy, Office of Energy Efficiency and
Renewable Energy (EERE)
877-EERE-INF (877-337-3463)
www.eere.energy.gov

Database of State Incentives for Renewable Energy (DSIRE)
Funded by the DOE, DSIRE is a useful source of information on state, local, utility, and federal incentives on renewable energy and energy efficiency.
www.dsireusa.org

Office of Energy Efficiency (Canada)
580 Booth Street
Ottawa, ON K1A 0E4, Canada
613-996-4397
http://oee.nrcan.gc.ca/english

Environment Agency (United Kingdom)
Oversees environmental issues in the United Kingdom, including the geothermal industry.
National Customer Contact Centre
P.O. Box 544
Rotherham S60 1BY, United Kingdom
08708 506 506
enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Advocacy and Professional

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
ASHRAE Headquarters
1791 Tullie Circle N.E.
Atlanta, GA 30329
404-636-8400
www.ashrae.org/home

Air Conditioning Contractors of America (ACCA)
The nonprofit standards-developing organization committed to high-quality, high-efficiency heating and cooling systems in buildings.
2800 Shirlington Road, Suite 300
Arlington, VA 22206
703-575-4477
www.acca.org

Air Conditioning, Heating and Refrigeration Institute (AHRI)
The trade association that represents more than 300 manufacturers of air-conditioning, heating, and commercial refrigeration equipment.
2111 Wilson Blvd, Suite 500
Arlington, VA 22201
703-524-8800
ahri@ahrinet.org
www.ahrinet.org

American Council for an Energy-Efficient Economy (ACEEE)
Nonprofit organization dedicated to advancing energy efficiency.
529 14th Street NW, Suite 600
Washington, DC 20045-1000
202-507-4000
ace3info@aceee.org
www.aceee.org

Earth Energy Society of Canada
Since 1985, the Earth Energy Society of Canada and its predecessor, the Canadian Earth Energy Association, have represented the geothermal heat-pump industry in that country.
124 O'Connor, Suite 504
Ottawa, ON K1P 5M9, Canada
613-371-3372
Eggertson@EarthEnergy.ca
www.earthenergy.ca

European Heat Pump Association (EHPA)
Represents the geothermal HVAC industry in Europe.
Renewable Energy House
Rue d'Arlon 63-67
B-1040 Brussels, Belgium
+32 24 00 10 17
info@ehpa.org
www.ehpa.org

Geothermal Exchange Organization (GEO)
GEO is the voice of the U.S. geothermal heat-pump industry. It is a 501(c)(6) nonprofit trade association of geothermal heat-pump manufacturers, utilities, trade associates (distributors, dealers, architects, designers, engineers, drilling companies, loop installers, and other related businesses), and nonprofit allied organizations. GEO's primary purpose is advocacy at the federal, regional, and state levels on legislative, regulatory, and tax issues. GEO forms partnerships with institutional and public organizations to help advance the industry, engages in public affairs and education about geothermal heat-pump technologies, and helps to craft and promote quality standards for the industry.

A national trade association of manufacturers, architects, engineers, heating and cooling businesses, drilling companies, earth-loop installers, and other associated businesses, it maintains a directory of industry professionals and active online forums.
1050 Connecticut Avenue NW, Suite 1000
Washington, DC 20036
888-ALL-4GEO
www.geoexchange.org

Ground Source Heat Pump Association (GSHPA) (United Kingdom)
The industry association for the geothermal HVAC industry in the United Kingdom.
National Energy Centre
Davy Avenue, Knowlhill
Milton Keynes, MK5 8NG, United Kingdom
01908 665555
info@gshp.org.uk
www.gshp.org.uk

Heat Pump Centre of the International Energy Agency
An international information service and advocate for heat-pumping technologies, applications and markets.
c/o SP Technical Research Institute of Sweden
P.O. Box 857
SE-501 15 Borås, Sweden
+46 10 516 5512
hpc@heatpumpcentre.org
http://heatpumpcentre.org

International Ground Source Heat Pump Association (IGSHPA)
Based at Oklahoma State University, IGSHPA is a leading professional association for the geothermal HVAC industry and maintains a list of qualified local installers.
374 Cordell South
Stillwater, OK 74078
405-744-5175
igshpa@okstate.edu
www.igshpa.okstate.edu

U.S. Green Building Council (USGBC)
The community of professionals—organized into regional chapters—working to spread green building by serving as a resource, administering the LEED certification program, and advocating policy.
2101 L Street NW, Suite 500
Washington, DC 20037
www.usgbc.org

Manufacturers

ClimateMaster
A world leader in geothermal HVAC systems.
7300 S.W. 44th Street
Oklahoma City, OK 73179
877-436-6263
www.climatemaster.com

Econar
Manufacturer of GeoSource geothermal heat pumps.
Suite 120, Meridian Business Center
7550 Meridian Circle
Maple Grove, MN 55369
800-4-ECONAR
www.econar.com

NIBE Energy Systems
A leading manufacturer of ground-source heat pumps and other HVAC equipment in northern Europe.
Box 14
Hannabadsvägen 5
28521 Markaryd, Sweden
+46 433-73000
info@nibe.se
www.nibe.eu

FHP-Bosch Group
A leading manufacturer of water-source and geothermal heat pumps.
601 NW 65th Court
Fort Lauderdale, FL 33309
www.BoschGeo.com
www.fhp-mfg.com

WaterFurnace International
Leading manufacturer of geothermal heat pumps.
9000 Conservation Way
Fort Wayne, IN 46809
800-GEO-SAVE
www.waterfurnace.com

Modine Manufacturing Company
Commercial Products Group
Geofinity
1500 DeKoven Avenue
Racine, WI 53403
877-679-4GEO
www.modinehvac.com

Search the GeoExchange directory for a manufacturer, distributor, dealer, or contractor near you: www.geoexchange.org.
Search the IGSHPA directory for an accredited installer near you:
www.igshpa.okstate.edu/directory/directory.asp.

Industry Geothermal and Hydronic Experts Referred To in This Book

Greg Cunniff, P.E., coauthor
Manager, Applications Engineering, Taco HVAC

Carl D. Orio, P.E., coauthor
Chairman, Water Energy Distributors, Inc.

Jay Egg, CMC, coauthor
President, Egg Geothermal

Jim Bose, Ph.D., P.E.
Executive Director, International Ground Source Heat Pump Association

Dave Hoffman, P.E., contributor
Executive Vice President, Hoffman Engineers

Martin Orio, geothermal HVAC activist
Vice President for Business Development, Water Energy Distributors, Inc.
President of New England Geothermal Professionals Association (NEGPA)

Jerry Baker, P.E., contributor
Retired Principal Engineer

Jay Holtzman, contributor
Taco HVAC Communications

Jeff Pitcairn, contributor
Taco HVAC Regional Manager

Dr. Xiaobing Liu
Principal Investigator, Oak Ridge National Laboratory

Dr. Yong Tao
Chairman, Mechanical and Energy Engineering, and Director, PACCAR Technology Institute, UNT

Dr. Daniel H. Yeh
Associate Professor, Department of Civil and Environmental Engineering, College of Engineering, University of South Florida

Pacia Hernandez, E.I., Ph.D. student
Department of Civil and Environmental Engineering, College of Engineering, University of South Florida

Daniel Ellis
President, ClimateMaster, Inc.

Tom Huntington
President, WaterFurnace, Inc.

Mike Alexander
Executive Vice President, WaterFurnace, Inc.

Some of the Industry Personnel Mentioned in This Book

Nicolas de Varreux
Geothermal expert/driller
Augsburger Forages SA
Route d'Yvonand 2
1522 Lucens (VD)
Suisse
+41 (0)21 906 17 17

Stan Newton
Engineering Matrix
2860 Scherer Drive
Suite 640
St. Petersburg, FL 33716
www.engmtx.com/default.php

Joseph Potter
Operations Director
Lend Lease
www.lendlease.com/americas/home.aspx

Jim Sloan
Finney Refrigeration, Inc.
1101 2nd St. NE
Canton, OH 44704
330-453-8008

Mike Mcvey
Paramount Geothermal
310-210-8046
http://paramountgeo.com

Tim Yoder
Yoder Drilling and Geothermal, Inc.
997 SR 93
Sugarcreek, OH 44681
330-852-4342
www.yodergeothermal.com

Josh Staley
Staley Mechanical Consulting, Inc.
13315 Lisbon Street
Paris, OH 44669
330-418-9502

Skillings and Sons Well Drilling
9 Columbia Drive
Amherst, NH 03031
603-459-2600

Wilmington Pump Company
639 Woburn Street
Wilmington, MA 01887
978-658-9111

Major Geothermal
Geothermal products, tools, and consulting for design and installation professionals
6285 W. 48th Ave.
Wheat Ridge, CO 80033
800-707-9479

James Thomas
Thomas Geothermal Engineering, LLC
17 Gate Road
Tabernacle, NJ 08088
609-268-2257

Richard W. Hottel, CEO, CGD
Harvey W. Hottel, Inc.
Certified GeoExchange Designer and Installer (IGSHPA and AEE)
18900 Woodfield Road
Gaithersburg, MD 20879
301-921-9599
dhottel@harveyhottel.com

APPENDIX B

Answers to Review Questions

Chapter 1

1-d, 2-d, 3-b, 4-d, 5-d, 6-d, 7-c, 8-d, 9-d, 10-b, 11-c, 12-c, 13-c, 14-d, 15-d, 16-d

Chapter 2

1-d, 2-d, 3-d, 4-b, 5-a, 6-c, 7-a, 8-c, 9-d, 10-c, 11-b, 12-c, 13-d

Chapter 3

1-d, 2-d, 3-c4-d, 5-a, 6-b, 7-b, 8-d, 9-b, 10-a, 11-b, 12-b, 13-b, 14-d, 15-d, 16-b

Chapter 4

1-c, 2-c, 3-c, 4-b, 5-b, 6-d, 7-a, 8-b, 9-b, 10-d, 11-c, 12-c

Chapter 5

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Chapter 6

1-a, 2-b, 3-d, 4-a, 5-d

Chapter 7

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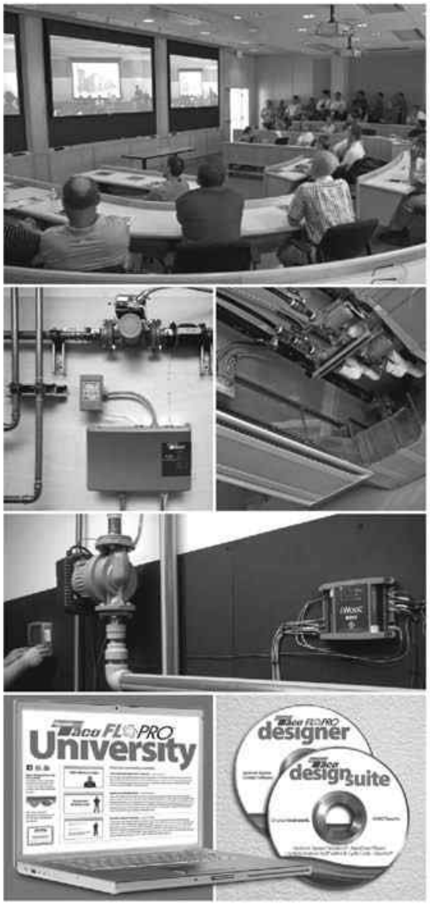
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