

Ground-Source Heat Pumps Applied to Federal Facilities—Second Edition

Technology for reducing heating and air-conditioning costs

The ground-source heat pump technology can provide an energy-efficient, cost-effective way to heat and cool Federal facilities. A ground-source heat pump is a unique means of using the thermodynamic properties of earth and groundwater for efficient operation throughout the year in virtually any climate. This Federal Technology Alert, one of a series on new technologies, describes the theory of operation, energy-savings mechanisms, range of applications, and field experience for the ground-source heat pump technology.

Energy Savings Mechanism

A ground-source heat pump system (shown below) uses the ground or groundwater as a heat source during winter operation and as a heat sink for summer cooling. The stability of subsurface temperatures results in year-round energy efficiency. In general, users have reported satisfaction with the operation and energy costs savings of the technology, and maintenance costs are reduced. Moreover, water-loop-based ground-source heat pumps use less refrigerant than conventional air-source heat pumps or air-conditioning systems, and the factory-sealed systems reduce the potential for leaking refrigerant. Space requirements for equipment, both interior

and exterior to the facility, are typically less than those for conventional systems.

Potential Application

The technology has been shown to be technically valid and economically attractive in many applications. It is efficient and effective. This Federal Technology Alert reports on the collective experience of heat pump users and evaluators and provides application guidance.

An estimated 400,000 ground-source heat pumps are operating in the private and public sector, although most of these systems operate in residential applications. A ground-source heat pump system can be applied in virtually any category of climate or building. The large number of installations testifies to the stability of this technology. The reported problems can usually be attributed to faulty design or installation of the ground-coupling system—emphasizing the importance of good design, documentation, installation and system commissioning.

Although local site conditions may dictate the type of system employed, the high first cost and its effect on the overall life-cycle cost are typically

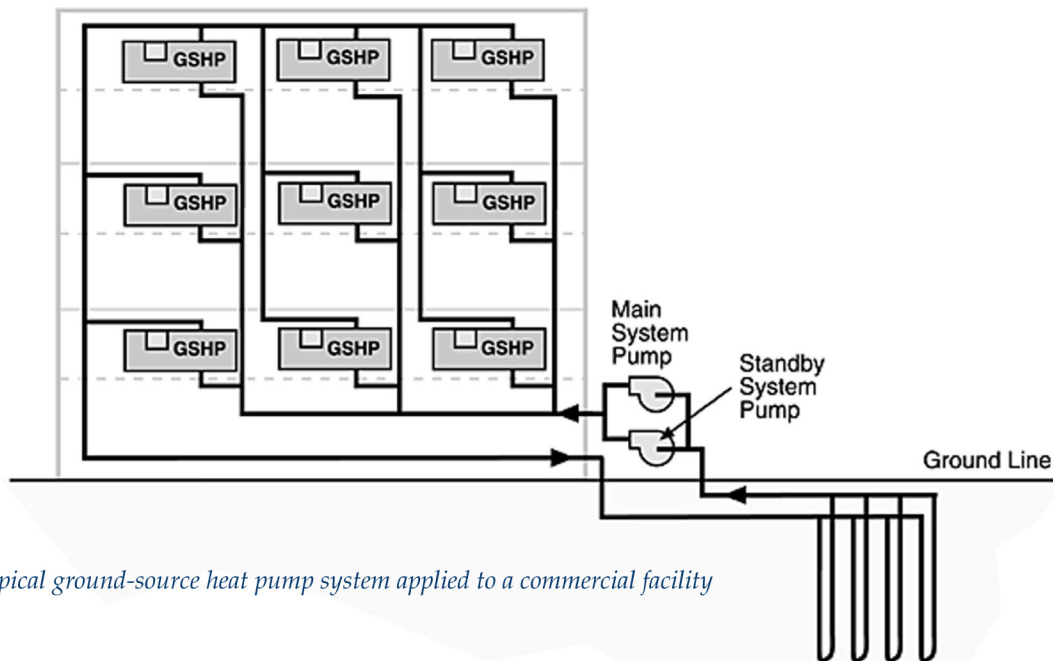


Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

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Typical ground-source heat pump system applied to a commercial facility



the constraining factors. Installation costs vary depending on the design and application, but typically range between \$1,500 and \$3,000/ton (\$425 and \$840/kW). Ground-source heat pumps have the potential to reduce cooling energy by 30 to 50% and reduce heating energy by 20 to 40%.

Ground-source heat pumps tend to be more cost-effective than conventional systems in the following applications:

- in new construction where the technology is relatively easy to incorporate, or to replace an existing system at the end of its useful life
- in climates characterized by high daily temperature swings, or where winters are cold or summers hot, and where electricity cost is higher than average

- in areas where natural gas is unavailable or where the cost is higher than electricity.

The following cautions are recommended for any ground-source heat pump application under consideration:

- install as a complete system, with the system and each unit properly designed and sized
- use only experienced and certified installers
- analyze soil type and thermal conductivity, if appropriate
- be aware that local water and well regulations may restrict some system types
- obtain equipment and installation warranties.

Implementation Barriers

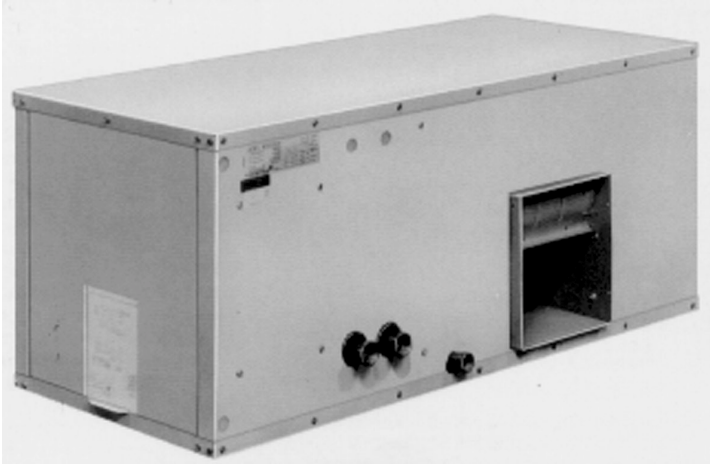
The major barriers to rapid implementation of this technology involve awareness and acceptance by users and HVAC designers (which is growing rapidly) and higher initial implementation costs than other options. In addition, there is a limited infrastructure and availability of skilled and experienced designers and installers of ground-source heat pump systems. Several Federal facilities that have ground-source heat pump systems are listed in this Federal Technology Alert. The reader is invited to ask questions and learn more about the technology.

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Technology for reducing heating and air-conditioning costs



Ground-source heat pump

Abstract

Ground-source heat pumps can provide an energy-efficient, cost-effective way to heat and cool Federal facilities. Through the use of a ground-coupling system, a conventional water-source heat pump design is transformed to a unique means of utilizing thermodynamic properties of earth and groundwater for efficient operation throughout the year in most climates. In essence, the ground (or groundwater) serves as a heat source during winter operation and a heat sink for summer cooling. Many varieties in design are available, so the technology can be adapted to almost any site. Ground-source heat pump systems can be used widely in Federal applications and, with proper installation, offer great potential for the Federal sector, where increased efficiency and reduced heating and cooling costs are important. Ground-source heat pump systems require less refrigerant

than conventional air-source heat pumps or air-conditioning systems, with the exception of direct-expansion-type ground-source heat pump systems. Installation costs are relatively high but are made up through low maintenance and operating expenses and efficient energy use. The greatest barrier to effective use is improper design and installation; employment of well-trained, experienced, and responsible designers and installers is of critical importance.

This Federal Technology Alert provides the detailed information and procedures that a Federal energy manager needs to evaluate most ground-source heat pump applications. The New Technology Demonstration Program (NTDP) selection process and general benefits to the Federal sector are outlined. Ground-source heat pump operation, system types, design variations, energy savings, and other benefits are explained. Guidelines are provided for appropriate application and installation. Two case studies are presented to give the reader a sense of the actual costs and energy savings. Current manufacturers, technology users, and references for further reading are included for prospective users who have specific or highly technical questions not fully addressed in this Federal Technology Alert. Sample case spreadsheets are provided in Appendix A. Additional appendixes provide other information on the ground-source heat pump technology.

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Contents

| | |
|---|----|
| Abstract | 1 |
| Background | 4 |
| Introduction to Ground-Source Heat Pumps | 4 |
| About the Technology | 5 |
| Application Domain | |
| Energy-Saving Mechanism | |
| Other Benefits | |
| Ground-Coupled System Types | |
| Variables Affecting Design and Performance | |
| Variations | |
| System Design and Installation | |
| Federal Sector Potential | 14 |
| Technology Screening Process | |
| Estimated Savings and Market Potential | |
| Laboratory Perspective | |
| Application | 15 |
| Application Screening | |
| Where to Apply Ground-Source Heat Pumps | |
| What to Avoid | |
| Design and Equipment Integration | |
| Equipment Warranties | |
| Energy Codes and Standards | |
| Utility Incentives and Support | |
| Technology Performance | 18 |
| Field Experience | |
| Energy Savings | |
| Maintenance | |
| Installation Costs | |
| Other Impacts | |
| Case Studies | 21 |
| Example 1: Upstate New York Facility | |
| Example 2: Oklahoma City Facility | |
| The Technology in Perspective | 26 |
| The Technology's Development | |
| Technology Outlook | |
| Manufacturers | 27 |
| Who is Using the Technology | 27 |
| For Further Information | 28 |
| Appendix A: Sample Case Spreadsheet Models | 33 |
| Appendix B: Federal Life-Cycle Costing Procedures and the BLCC Software | 40 |
| Appendix C: Performance and Efficiency Terminology Defined | 41 |
| Appendix D: Ground-Source Heat Pump Manufacturers | 43 |
| Appendix E: ARI Rating Conditions | 44 |

Background

This Federal Technology Alert updates the original ground-source heat pump Federal Technology Alert published in 1995. As with the previous document, the focus of this material is on commercial application of ground-source heat pumps (GSHPs) in the Federal sector. While GSHPs are well established in the residential sector, their application in the Federal sector is lagging, in part because of a lack of experience with the technology by those in decision-making positions. This Federal Technology Alert provides the information and procedures that Federal energy managers need to evaluate the potential for ground-source heat pump application at their facilities. The focus of this report is on the New Technology Demonstration Program (NTDP) selection process, and general benefits to the Federal sector are outlined. Ground-source heat pump operation, system types, design variations, energy-savings, and other benefits are explained. Guidelines are provided for appropriate application and installation. Two case studies are presented to give the reader a sense of the actual costs and energy savings potential of the technology. Current manufacturers, technology users, and references for further reading are included for prospective users who have specific or highly technical questions not fully addressed in this Federal Technology Alert. Sample case spreadsheets are provided in Appendix A. Several other appendixes provide additional information pertinent to ground-source heat pumps.

Introduction to Ground-Source Heat Pumps

Ground-source heat pumps are known by a variety of names: geoexchange heat pumps, ground-coupled heat pumps, geothermal heat pumps, earth-coupled heat pumps, ground-source systems, groundwater source heat pumps, well water heat pumps, solar energy heat pumps, and a few other variations. Some names are used to describe more

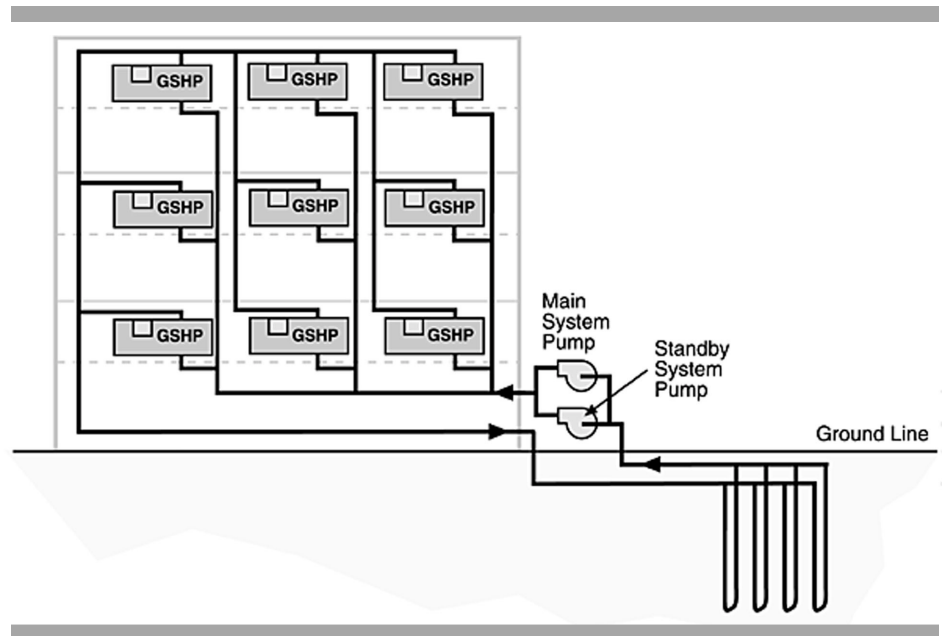


Figure 1. Typical ground-source heat pump system applied to a commercial facility.

accurately the specific application; however, most are the result of marketing efforts and the need to associate (or disassociate) the heat pump systems from other systems. This Federal Technology Alert refers to them as *ground-source heat pumps* except when it is necessary to distinguish a specific design or application of the technology. A typical ground-source heat pump system design applied to a commercial facility is illustrated in Figure 1.

It is important to remember that the primary equipment used for ground-source heat pumps are water-source heat pumps. What makes a ground-source heat pump different (unique, efficient, and usually more expensive to install) is the ground-coupling system. In addition, most manufacturers have developed extended-range water-source heat pumps for use as ground-source heat pumps.

A conventionally designed water-source heat pump system would incorporate a boiler as a heat source during the winter heating operation and a cooling tower to reject heat (heat sink) during the summer cooling operation. This system type is also sometimes called a boiler/tower water-loop heat pump system. The

water loop circulates to all the water-source heat pumps connected to the system. The boiler (for winter operation) and the cooling tower (for summer operation) provide a fairly constant water-loop temperature, which allows the water-source heat pumps to operate at high efficiency.

A conventional air-source heat pump uses the outdoor ambient air as a heat source during the winter heating operation and as a heat sink during the summer cooling operation. Air-source heat pumps are subject to higher temperature fluctuations of the heat source and heat sink. They become much less effective—and less efficient—at extreme ambient air temperatures. This is particularly true at low temperatures. In addition, heat transfer using air as a transfer medium is not as effective as water systems because of air's lower thermal mass.

A ground-source heat pump uses the ground (or in some cases groundwater) as the heat source during the winter heating operation and as the heat sink during the summer cooling operation. Ground-source heat pumps may be subject to higher temperature fluctuations than conventional water-source heat

pumps but not as high as air-source heat pumps. Consequently, most manufacturers have developed extended-range systems. The extended-range systems operate more efficiently while subject to the extended-temperature range of the water loop. Like water-source heat pumps, ground-source heat pumps use a water loop between the heat pumps and the heat source/heat sink (the earth). The primary exception is the direct-expansion ground-source heat pump, which is described in more detail later in this Federal Technology Alert.

Ground-source heat pumps take advantage of the thermodynamic properties of the earth and groundwater. Temperatures below the ground surface do not fluctuate significantly through the day or the year as do ambient air temperatures. Ground temperatures a few feet below the surface stay relatively constant throughout the year. For this reason, ground-source heat pumps remain extremely efficient throughout the year in virtually any climate.

About the Technology

Application Domain

In 1999, an estimated 400,000 ground-source heat pumps were operating in residential and commercial applications, up from 100,000 in 1990. In 1985, it was estimated that only around 14,000 ground-source heat pump systems were installed in the United States. Annual sales of approximately 45,000 units were reported in 1997. With a projected annual growth rate of 10%, 120,000 new units would be installed in 2010, for a total of 1.5 million units in 2010 (Lund and Boyd 2000).

In Europe, the estimated total number of installed ground-source heat pumps at the end of 1998 was 100,000 to 120,000 (Rybach and Sanner 2000).

Nearly 10,000 ground-source heat pumps have been installed in U.S. Federal buildings, over 400 schools and thousands of low-income houses and apartments (ORNL/SERDP, no date).

Although ground source heat pumps are used throughout the United States, the majority of new ground-source heat pump installations in the United States are in the southern and mid-western states (from North Dakota to Florida). Oklahoma, Texas, and the East Coast have been particularly active with new ground-source heat pump installations. Environmental concerns, particularly from the potential for groundwater contamination with a leaking ground loop, and a general lack of understanding of the technology by HVAC companies and installers have limited installations in the West (Lund and Boyd 2000). Usually the technology does well in an area where it has been actively promoted by a local utility or the manufacturer.

Ground-source heat pumps are not a new idea. Patents on the technology date back to 1912 in Switzerland (Calm 1987). One of the oldest ground-source heat pump systems, in the United Illuminating headquarters building in New Haven, Connecticut, has been operating since the 1930s (Pratsch 1990). Although ground-source heat pump systems are probably better established today in rural and suburban residential areas because of the land area available for the ground loop, the market has expanded to urban and commercial applications.

The vast majority of ground-source heat pump installations utilize unitary equipment consisting of multiple water-source heat pumps connected to a common ground-coupled loop. Most individual units range from 1 to 10 tons (3.5 to 35.2 kW), but some equipment is available in sizes up to 50 tons (176 kW). Large-tonnage commercial systems are achieved by using several unitary water-source heat pumps, each responsible for an individual control zone.

One of the largest commercial ground-source heat pump systems operating today is at Stockton College in Pomona, New Jersey, where 63 ground-source heat pumps totaling 1,655 tons

(5,825 kW) are connected to a ground-coupled loop consisting of 400 wells, each 425 feet (129 m) deep (Gahran September 1993).

Public schools are another good application for the ground-source heat pump technology with over 400 installations nationwide. In 1995, the Lincoln, Nebraska, Public School District built four new 70,000 square foot elementary schools. Space conditioning loads are met by 54 ground-source heat pumps ranging in size from 1.4 to 15 tons, with a total cooling capacity of 204 tons. Gas-fired boilers provided hot water for pre-heating of the outside air and for terminal re-heating. Compared with other similar new schools, these four geothermally conditioned facilities used approximately 26% less source energy per square foot of floor area (Shonder et al. 1999).

Multiple unitary systems are not the only arrangement suitable for large commercial applications. It is also possible to design large centralized heat-pump system consisting of reciprocating and centrifugal compressors (up to 19.5 million Btu/h) and to use these systems to support central-air-handling units, variable air-volume systems, or distributive two-pipe fan coil units.

Energy-Saving Mechanism

Heat normally flows from a warmer medium to a colder one. This basic physical law can't be reversed without the addition of energy. A heat pump is a device that does so by essentially "pumping" heat up the temperature scale, then transferring it from a cold material to a warmer one by adding energy, usually in the form of electricity. A heat pump functions by using a refrigerant cycle similar to the household refrigerator. In the heating mode, a heat pump removes the heat from a low temperature source, such as the ground or air, and supplies that heat to a higher temperature sink, such as the heated interior of a building.

In the cooling mode, the process is reversed and the heat is extracted from the cooler inside air and rejected to the warmer outdoor air or other heat sink. For space conditioning of buildings, heat pumps that remove heat from outdoor air in the heating mode and reject it to outdoor air in the cooling mode are common. These are normally called air-source or air-to-air heat pumps. Air-source heat pumps have the disadvantage that the greatest requirement for building heating or cooling is necessarily coincident with the times when the outdoor air is least effective as a heat source or sink. Below about 37°F, supplemental heating is required to meet the heating load. For this reason, air-source heat pumps are essentially unfeasible in cold climates with outdoor temperatures below 37°F for extended periods of time.

The efficiency of any heat pump is inversely proportional to the temperature difference between the conditioned space and the heat source (heating mode) or heat sink (cooling mode) as can be easily shown by a simple thermodynamic analysis (Reynolds and Perkins 1977). For this reason, air-source heat pumps are less efficient and have a lower heating capacity in the heating mode at low outdoor air temperatures. Conversely, air-source heat pumps are also less efficient and have a lower cooling capacity in the cooling mode at high outdoor air temperatures. Ground-source heat pumps, however, are not impacted directly by outdoor air temperatures. Ground-source heat pumps use the ground, groundwater, or surface water, which are more thermally stable and not subjected to large annual swings of temperature, as a heat source or sink.

Other benefits

The primary benefit of ground-source heat pumps is the increase in operating efficiency, which translates to reduced heating and cooling costs, but there are additional advantages. One notable benefit is that ground-source heat

pumps, although electrically driven, are classified as a renewable-energy technology. The justification for this classification is that the ground acts as an effective collector of solar energy. The renewable-energy classification can affect Federal goals and potential funding opportunities.

An environmental benefit is that ground-source heat pumps typically use 25% less refrigerant than split-system air-source heat pumps or air-conditioning systems. Ground-source heat pumps generally do not require tampering with the refrigerant during installation. Systems are generally sealed at the factory, reducing the potential for leaking refrigerant in the field during assembly.

Ground-source heat pumps also require less space than conventional heating and cooling systems. While the requirements for the indoor unit are about the same as conventional systems, the exterior system (the ground coil) is underground, and there are no space requirements for cooling towers or air-cooled condensers. In addition, the ground-coupling system does not necessarily limit future use of the land area over the ground loop, with the exception of siting a building. Interior space requirements are also reduced. There are no floor space requirements for boilers or furnaces, just the unitary systems and circulation pumps. Furthermore, many distributed ground-source heat pump systems are designed to fit in ceiling plenums, reducing the floor space requirement of central mechanical rooms.

Compared with air-source heat pumps that use outdoor air coils, ground-source heat pumps do not require defrost cycles or crankcase heaters and there is virtually no concern for coil freezing. Cooling tower systems require electric resistance heaters to prevent freezing in the tower basin, also not necessary with ground-source heat pumps.

It is generally accepted that maintenance requirements are also reduced,

although research continues directed toward verifying this claim. It is clear, however, that ground-source heat pumps eliminate the exterior fin-coil condensers of air-cooled refrigeration systems and eliminate the need for cooling towers and their associated maintenance and chemical requirements. This is a primary benefit cited by facilities in highly corrosive areas such as near the ocean, where salt spray can significantly reduce outdoor equipment life.

Ground-source heat pump technology offers further benefits: less need for supplemental resistance heaters, no exterior coil freezing (requiring defrost cycles) such as that associated with air-source heat pumps, improved comfort during the heating season (compared with air-source heat pumps, the supply air temperature does not drop when recovering from the defrost cycle), significantly reduced fire hazard over that associated with fossil fuel-fired systems, reduced space requirements and hazards by eliminating fossil-fuel storage, and reduced local emissions from those associated with other fossil fuel-fired heating systems.

Another benefit is quieter operation, because ground-source heat pumps have no outside air fans. Finally, ground-source heat pumps are reliable and long-lived, because the heat pumps are generally installed in climate-controlled environments and therefore are not subject to the stresses of extreme temperatures. Because of the materials and joining techniques, the ground-coupling systems are also typically reliable and long-lived. For these reasons, ground-source heat pumps are expected to have a longer life and require less maintenance than alternative (more conventional) technologies.

Ground-Coupled System Types

The ground-coupling systems used in ground-source heat pumps fall under three main categories: closed-loop, open-loop and direct-expansion. The type of ground coupling employed will

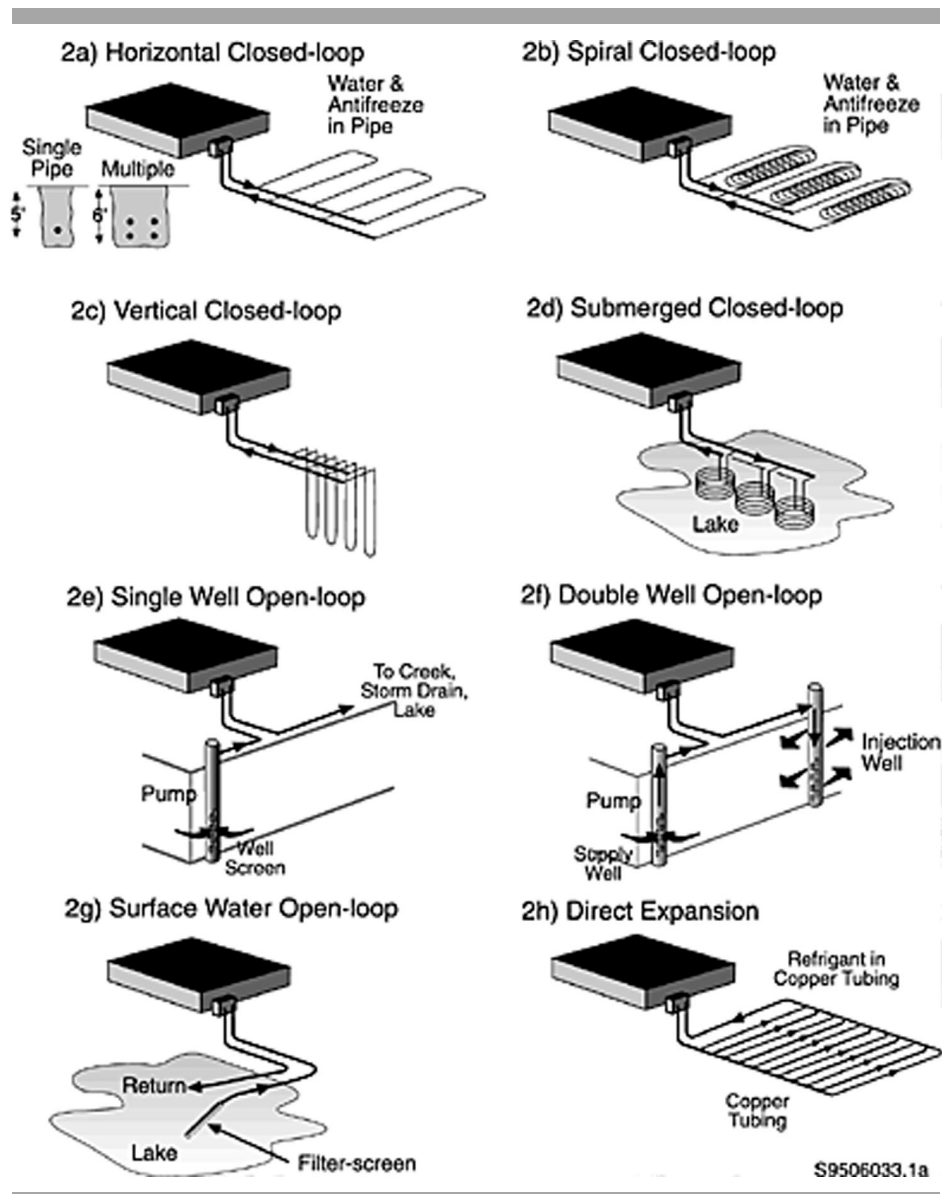


Figure 2. Ground-coupling system types.

affect heat pump system performance (therefore the heat pump energy consumption), auxiliary pumping energy requirements, and installation costs. Choice of the most appropriate type of ground coupling for a site is usually a

function of specific geography, available land area, and life-cycle cost economics.

Closed-loop systems. Closed-loop systems consist of an underground network of sealed, high-strength plastic pipe^(a) acting as a heat exchanger. The

loop is filled with a heat transfer fluid, typically water or a water-antifreeze^(b) solution, although other heat transfer fluids may be used.^(c) When cooling requirements cause the closed-loop liquid temperature to rise, heat is transferred to the cooler earth. Conversely, when heating requirements cause the closed-loop fluid temperature to drop, heat is absorbed from the warmer earth. Closed-loop systems use pumps to circulate the heat transfer fluid between the heat pump and the ground loop. Because the loops are closed and sealed, the heat pump heat exchanger is not subject to mineral buildup and there is no direct interaction (mixing) with groundwater.

There are several varieties of closed-loop configurations including horizontal, spiral, vertical, and submerged.

Horizontal loops. Horizontal loops, illustrated in Figure 2a, are often considered when adequate land surface is available. The pipes are placed in trenches, typically at a depth of 4 to 10 feet (1.2 to 3.0 m). Depending on the specific design, from one to six pipes may be installed in each trench. Although requiring more linear feet of pipe, multiple-pipe configurations conserve land space, require less trenching, and therefore frequently cost less to install than single-pipe configurations. Trench lengths can range from 100 to 400 feet per system cooling ton (8.7 to 34.6 m/kW), depending on soil characteristics and moisture content, and the number of pipes in the trench. Trenches are usually spaced from 6 to 12 feet (1.8 to 3.7 m) apart.

These systems are common in residential applications but are not frequently applied to large-tonnage commercial

(a) Acceptable piping includes high quality polyethylene or polybutylene. PVC is not acceptable in either heat transfer characteristics or strength.

(b) Common heat transfer fluids include water or water mixed with an antifreeze: sodium chloride, calcium chloride, potassium carbonate, potassium acetate, ethylene glycol, propylene glycol, methyl alcohol, or ethyl alcohol.

(c) Note that various heat transfer fluids have different densities and thermodynamic properties. Therefore, the heat transfer fluid selected will affect the required pumping power and the amount of heat transfer pipe. Furthermore, some local regulations may limit the selection and use of certain antifreeze solutions.

applications because of the significant land area required for adequate heat transfer. The horizontal-loop systems can be buried beneath lawns, landscaping, and parking lots. Horizontal systems tend to be more popular where there is ample land area with a high water table.

- **Advantages:** Trenching costs typically lower than well-drilling costs; flexible installation options.
- **Disadvantages:** Large ground area required; ground temperature subject to seasonal variance at shallow depths; thermal properties of soil fluctuate with season, rainfall, and burial depth; soil dryness must be properly accounted for in designing the required pipe length, especially in sandy soils and on hilltops that may dry out during the summer; pipe system could be damaged during backfill process; longer pipe lengths are required than for vertical wells; antifreeze solution viscosity increases pumping energy, decreases the heat transfer rate, and thus reduces overall efficiency; lower system efficiencies.

Spiral loops. A variation on the multiple pipe horizontal-loop configuration is the spiral loop, commonly referred to as the “slinky.” The spiral loop, illustrated in Figure 2b, consists of pipe unrolled in circular loops in trenches; the horizontal configuration is shown.

Another variation of the spiral-loop system involves placing the loops upright in narrow vertical trenches. The spiral-loop configuration generally requires more piping, typically 500 to 1,000 feet per system cooling ton (43.3 to 86.6 m/kW) but less total trenching than the multiple horizontal-loop systems described above. For the horizontal spiral-loop layout, trenches are generally 3 to 6 feet (0.9 to 1.8 m) wide; multiple trenches are typically spaced about 12 feet (3.7 m) apart. For the vertical spiral-loop layout, trenches are

generally 6 inches (15.2 cm) wide; the pipe loops stand vertically in the narrow trenches. In cases where trenching is a large component of the overall installation costs, spiral-loop systems are a means of reducing the installation cost. As noted with horizontal systems, slinky systems are also generally associated with lower-tonnage systems where land area requirements are not a limiting factor.

- **Advantages:** Requires less ground area and less trenching than other horizontal loop designs; installation costs sometimes less than other horizontal loop designs.
- **Disadvantages:** Requires more total pipe length than other ground-coupled designs; relatively large ground area required; ground temperature subject to seasonal variance; larger pumping energy requirements than other horizontal loops defined above; backfilling the trench can be difficult with certain soil types and the pipe system could be damaged during backfill process.

Vertical loops. Vertical loops, illustrated in Figure 2c, are generally considered when land surface is limited. Wells are bored to depths that typically range from 75 to 300 feet (22.9 to 91.4 m) deep. The closed-loop pipes are inserted into the vertical well. Typical piping requirements range from 200 to 600 feet per system cooling ton (17.4 to 52.2 m/kW), depending on soil and temperature conditions. Multiple wells are typically required with well spacing not less than 15 feet (4.6 m) in the northern climates and not less than 20 feet (6.1 m) in southern climates to achieve the total heat transfer requirements. A 300- to 500-ton-capacity system can be installed on one acre of land, depending on soil conditions and ground temperature.

There are three basic types of vertical-system heat exchangers: U-tube, divided-tube, and concentric-tube (pipe-in-pipe) system configurations.

- **Advantages:** Requires less total pipe length than most closed-loop designs; requires the least pumping energy of closed-loop systems; requires least amount of surface ground area; ground temperature typically not subject to seasonal variation.
- **Disadvantage:** Requires drilling equipment; drilling costs frequently higher than horizontal trenching costs; some potential for long-term heat buildup underground with inadequately spaced bore holes.

Submerged loops. If a moderately sized pond or lake is available, the closed-loop piping system can be submerged, as illustrated in Figure 2d. Some companies have installed ponds on facility grounds to act as ground-coupled systems; ponds also serve to improve facility aesthetics. Submerged-loop applications require some special considerations, and it is best to discuss these directly with an engineer experienced in the design applications. This type of system requires adequate surface area and depth to function adequately in response to heating or cooling requirements under local weather conditions. In general, the submerged piping system is installed in loops attached to concrete anchors. Typical installations require around 300 feet of heat transfer piping per system cooling ton (26.0 m/kW) and around 3,000 square feet of pond surface area per ton (79.2 m²/kW) with a recommended minimum one-half acre total surface area. The concrete anchors act to secure the piping, restricting movement, but also hold the piping 9 to 18 inches (22.9 to 45.7 cm) above the pond floor, allowing for good convective flow of water around the heat transfer surface area. It is also recommended that the heat-transfer loops be at least 6 to 8 feet (1.8 to 2.4 m) below the pond surface, preferably deeper. This maintains adequate thermal mass even in times of extended drought or other low-water conditions.

Rivers are typically not used because they are subject to drought and flooding, both of which may damage the system.

- **Advantages:** Can require the least total pipe length of closed-loop designs; can be less expensive than other closed-loop designs if body of water available.
- **Disadvantage:** Requires a large body of water and may restrict lake use (i.e., boat anchors).

Open-Loop Systems. Open-loop systems use local groundwater or surface water (i.e., lakes) as a direct heat transfer medium instead of the heat transfer fluid described for the closed-loop systems. These systems are sometimes referred to specifically as “groundwater-source heat pumps” to distinguish them from other ground-source heat pumps. Open-loop systems consist primarily of extraction wells, extraction and reinjection wells, or surface water systems. These three types are illustrated in Figures 2e, 2f, and 2g, respectively.

A variation on the extraction well system is the standing column well. This system reinjects the majority of the return water back into the source well, minimizing the need for a reinjection well and the amount of surface discharge water.

There are several special factors to consider in open-loop systems. One major factor is water quality. In open-loop systems, the primary heat exchanger between the refrigerant and the groundwater is subject to fouling, corrosion, and blockage. A second major factor is the adequacy of available water. The required flow rate through the primary heat exchanger between the refrigerant and the groundwater is typically between 1.5 and 3.0 gallons per minute per system cooling ton (0.027 and 0.054 L/s-kW). This can add up to a significant amount of water and can be affected by local water resource regulations. A third major factor is what to do with the discharge stream. The ground-

water must either be re-injected into the ground by separate wells or discharged to a surface system such as a river or lake. Local codes and regulations may affect the feasibility of open-loop systems.

Depending on the well configuration, open-loop systems can have the highest pumping load requirements of any of the ground-coupled configurations. In ideal conditions, however, an open-loop application can be the most economical type of ground-coupling system.

- **Advantages:** Simple design; lower drilling requirements than closed-loop designs; subject to better thermodynamic performance than closed-loop systems because well(s) are used to deliver groundwater at ground temperature rather than as a heat exchanger delivering heat transfer fluid at temperatures other than ground temperature; typically lowest cost; can be combined with potable water supply well; low operating cost if water already pumped for other purposes, such as irrigation.
- **Disadvantages:** Subject to various local, state, and Federal clean water and surface water codes and regulations; large water flow requirements; water availability may be limited or not always available; heat pump heat exchanger subject to suspended matter, corrosive agents, scaling, and bacterial contents; typically subject to highest pumping power requirements; pumping energy may be excessive if the pump is oversized or poorly controlled; may require well permits or be restricted for extraction; water disposal can limit or preclude some installations; high cost if reinjection well required.

Direct-Expansion Systems. Each of the ground-coupling systems described above uses an intermediate heat transfer fluid to transfer heat between the earth and the refrigerant. Use of an intermediate heat transfer fluid necessitates a higher compression ratio in the heat

pump to achieve sufficient temperature differences in the heat transfer chain (refrigerant to fluid to earth). Each also requires a pump to circulate water between the heat pump and the ground-couple. Direct-expansion systems, illustrated in Figure 2h, remove the need for an intermediate heat transfer fluid, the fluid-refrigerant heat exchanger, and the circulation pump. Copper coils are installed underground for a direct exchange of heat between refrigerant and earth. The result is improved heat transfer characteristics and thermodynamic performance.

The coils can be buried either in deep vertical trenches or wide horizontal excavations. Vertical trenches typically require from 100 to 150 square feet of land surface area per system cooling ton (2.6 to 4.0 m²/kW) and are typically 9 to 12 feet (2.7 to 3.7 m) deep. Horizontal installations typically require from 450 to 550 square feet of land area per system cooling ton (11.9 to 14.5 m²/kW) and are typically 5 to 10 feet (1.5 to 3.0 m) deep. Vertical trenching is not recommended in sandy, clay or dry soils because of the poor heat transfer.

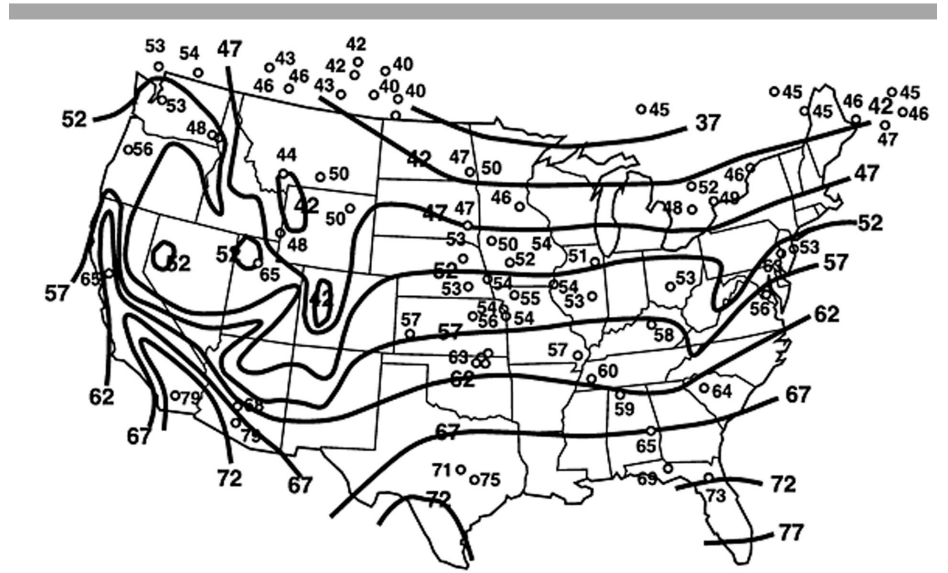
Because the ground coil is metal, it is subject to corrosion (the pH level of the soil should be between 5.5 and 10, although this is normally not a problem). If the ground is subject to stray electric currents and/or galvanic action, a cathodic protection system may be required. Because the ground is subject to larger temperature extremes from the direct-expansion system, there are additional design considerations. In winter heating operation, the lower ground coil temperature may cause the ground moisture to freeze. Expansion of the ice buildup may cause the ground to buckle. Also, because of the freezing potential, the ground coil should not be located near water lines. In the summer cooling operation, the higher coil temperatures may drive moisture from the soil. Low moisture content will change soil heat transfer characteristics.

Only one U.S. manufacturer currently offers direct-expansion ground-source heat pump systems. Systems are available from 24,000 to 60,000 Btu/h (heating/cooling capacity) (7.0 to 17.6 kW). Larger commercial applications require multiple units with individual ground coils.

- **Advantages:** Higher system efficiency; no circulation pump required.
- **Disadvantages:** Large trenching requirements for effective heat transfer area; ground around the coil subject to freezing (may cause surface ground to buckle and can freeze nearby water pipes); copper coil should not be buried near large trees where root system may damage the coil; compressor oil return can be complicated, particularly for vertical heat exchanger coils or when used for both heating and cooling; leaks can be catastrophic; higher skilled installation required; installation costs typically higher; this system type requires more refrigerant than most other systems; smaller infrastructure in the industry.

Annual air temperatures, moisture content, soil type, and ground cover all have an impact on underground soil temperature. In addition, underground temperature varies annually as a function of the ambient surface air temperature swing, soil type, depth, and time lag. Figure 3 contains a map of the United States indicating mean annual underground soil temperatures and

amplitudes of annual surface ground temperature swings. Figure 4, though illustrating a specific location, illustrates how the annual soil temperature varies with depth, soil type, and season. For vertical ground loop systems, the mean annual earth temperature (Figure 3a) is an important factor in the ground loop design. With horizontal ground loop systems, the ground surface annual

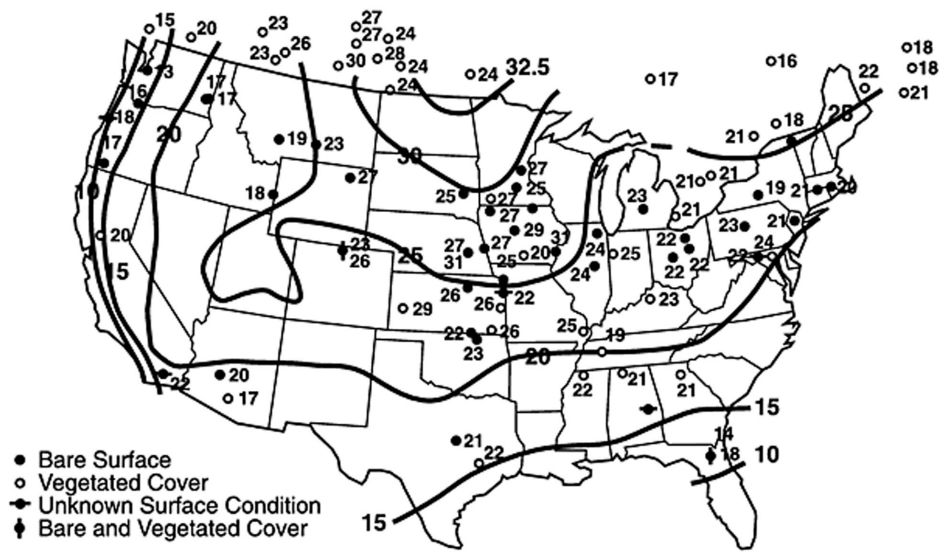


(a) Mean earth temperature, T_M (°F)

Variables Affecting Design and Performance

Among the variables that have a major impact on the sizing and effectiveness of a ground-coupling system, the importance of underground soil temperatures and soil type deserves special mention.

Underground Soil Temperature. The soil temperature is of major importance in the design and operation of a ground-source heat pump. In an open-loop system, the temperature of groundwater entering the heat pump has a direct impact on the efficiency of the system. In a closed-loop system and in the direct-expansion system, the underground temperature will affect the size of the required ground-coupling system and the resulting operational effectiveness of the underground heat exchanger. Therefore, it is important to determine the underground soil temperature before selecting a system design.



(b) Earth surface temperature amplitude, A_S (°F)

Figure 3. Mean annual soil temperatures. Source: OSU (1988).

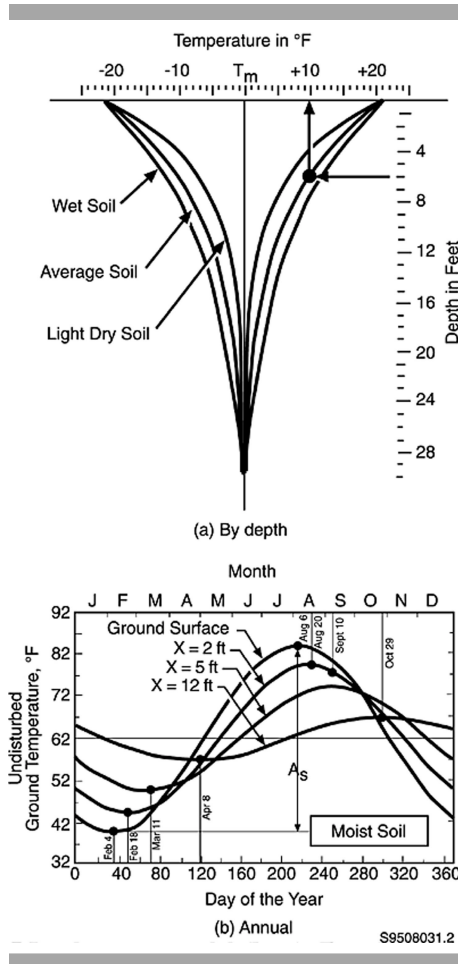


Figure 4. Soil temperature variation. Source: OSU (1988).

temperature variation (Figure 3b and Figure 4b) becomes an important design consideration.

Soil and Rock Classification. The most important factor in the design and successful operation of a closed-loop ground-source heat pump system is the rate of heat transfer between the closed-loop ground-coupling system and the surrounding soil and rock. The thermal conductivity of the soil and rock is the critical value that determines the length of pipe required. The pipe length, in turn, affects the installation cost as well as the operational effectiveness, which in turn affects the operating cost. Because of local variations in soil type and moisture conditions, economic designs may vary by location.

Soil classifications include coarse-grained sands and gravels, fine-grained silts and clays, and loam (equal mixtures of sand, silt, and clay). Rock classifications are broken down into nine different petrologic groups. Thermal conductivity values vary significantly within each of the nine groups. Each of these classifications plays a role in determining the thermal conductivity and thereby affects the design of the ground-coupling system. For more information on the thermal properties of soils and rocks and how to identify the different types of soils and rocks, see *Soil and Rock Classification for the Design of Ground-Coupled Heat Pump Systems* (STS Consultants 1989).

Series versus Parallel Flow. Closed-loop ground-coupled heat exchangers may be designed in series, parallel, or a combination of both. In series systems, the heat transfer fluid can take only one path through the loop, whereas in parallel systems the fluid can take two or more paths through the circuit. The selection will affect performance, pumping requirements, and cost. Small-scale ground-coupling systems can use either series or parallel-flow design, but most large ground-coupling systems use parallel-flow systems. The advantages and disadvantages of series and parallel systems are summarized below. In large systems, pressure drop and pumping costs need to be carefully considered or they will be very high. Variable-speed drives can be used to reduce pumping energy and costs during part-load conditions. Total life-cycle cost and design limitations should be used to design a specific system.

- **Series-System Advantages:** Single path flow and pipe size; easier air removal from the system; slightly higher thermal performance per linear foot of pipe because larger pipe size required in the series system.
- **Series-System Disadvantages:** Larger fluid volume of larger pipe in

series requires greater antifreeze volumes; higher pipe cost per unit of performance; increased installed labor cost; limited capacity (length) due to fluid pressure drop characteristics; larger pressure drop resulting in larger pumping load; requires larger purge system to remove air from the piping network.

- **Parallel-System Advantages:** Smaller pipe diameter has lower unit cost; lower volume requires less antifreeze; smaller pressure drop resulting in smaller pumping load; lower installation labor cost.
- **Parallel-System Disadvantages:** Special attention required to ensure air removal and flow balancing between each parallel path to result in equal length loops.

Variations

The ground-coupling system is what makes the ground-source heat pump unique among heating and air-conditioning systems and, as described above, there are several types of ground-coupling systems. In addition, variations to ground-source heat pump design and installation can save additional energy or reduce installation costs. Three notable variations are described below.

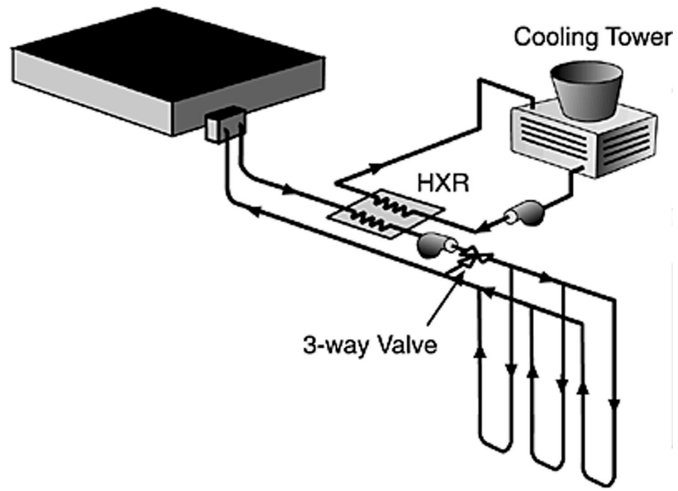
Cooling-Tower-Supplemented System.

The ground-coupling system is typically the largest component of the total installation cost of a ground-source heat pump. In southern climates or in thermally heavy commercial applications where the cooling load is the driving design factor, supplementing the system with a cooling tower or other supplemental heat rejection system can reduce the required size of a closed-loop ground-coupling system. The supplemental heat rejection system is installed in the loop by means of a heat exchanger (typically a plate and frame heat exchanger) between the facility load and the ground couple. A cooling tower system is illustrated in Figure 5. The

cooling tower acts to precool the loop's heat transfer fluid upstream of the ground couple, which lowers the cooling-load requirement on the ground-coupling system. By significantly reducing the required size of the ground-coupling system, using a cooling tower can lower the overall installation cost. This type of system is operating successfully in several commercial facilities, including some mission-critical facilities at Fort Polk in Louisiana.

Solar-Assisted System. In northern climates where the heating load is the driving design factor, supplementing the system with solar heat can reduce the required size of a closed-loop ground-coupling system. Solar panels, designed to heat water, can be installed into the ground-coupled loop (by means of a heat exchanger or directly), as illustrated in Figure 6. The panels provide additional heat to the heat transfer fluid. This type of variation can reduce the required size of the ground-coupled system and increase heat pump efficiency by providing a higher temperature heat transfer fluid.

Hot Water Recovery/Desuperheating. The use of heat pumps to provide hot water is becoming common. Because of their high efficiency, this practice makes economic sense. Most manufacturers offer an option to include desuperheating heat exchangers to provide hot water from a heat pump. These dual-wall heat exchangers are installed in the refrigerant loop to recover high temperature heat from the superheated refrigerant gas. Hot-water recovery systems can supplement, or sometimes replace, conventional facility water-heating systems. With the heat pump in cooling mode, hot-water recovery systems increase system operating efficiency while acting as a waste-heat-recovery device—and provide essentially free hot water. When the load is increased during the heating mode, the heat pump still provides heating and hot water more efficiently and less expensively than other systems.



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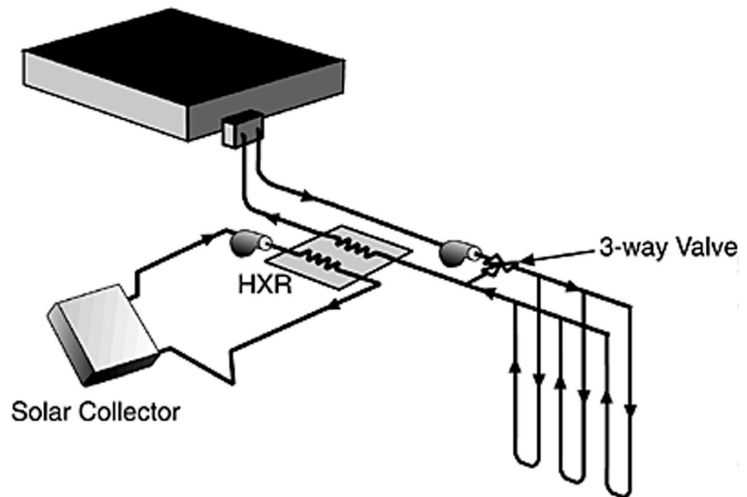
Figure 5. Cooling-tower-supplemental system for cooling dominated loads.

System Design and Installation

More is becoming known about the design and installation of ground-source heat pumps. Design day cooling and heating loads are determined through traditional design practices such as those endorsed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

Systems are also zoned using commonly accepted design practices.

The key issue that makes ground-source heat pumps unique is the design of the ground-coupling system. Most operational problems with GSHPs stem from the performance of the ground-coupling system. Today, software tools are available to support the design of the



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Figure 6. Solar-assisted system for heating dominated loads.

Ground Loop Design Software Review

Because of the diversity in loads in multizone buildings, the design of the ground-coupling heat exchanger (the ground loop) must be based on peak block load rather than the installed capacity. This is of paramount importance because ground coupling is usually a major portion of the total ground-source heat pump system cost, and over-sizing will render a project economically unattractive.

In the residential sector, many systems have been designed using rules-of-thumb and local experience, but for commercial-scale systems such practices are ill advised. For all but the most northern climates, commercial-scale buildings will have significantly more heat rejection than extraction. This imbalance in heat rejection/extraction can cause heat buildup in the ground to the point where heat pump performance is adversely affected and hence system efficiency and possibly occupant comfort suffer. Proper design for commercial-scale systems almost always benefits from the use of design software. Software for commercial-scale ground-source heat pump system design should consider the interaction of adjacent loops and predict the potential for long-term heat buildup in the soil. Some sources of PC-based design software packages that address this need are:

- GchpCalc Version 3.1, Energy Information Services, (205) 799-4591. This program includes built-in tables for heat pump equipment from most manufacturers. Input is in the form of heat loss/gain during a design day and the approximate equivalent full-load heating hours and equivalent full-load cooling hours. Primary output from the program is the ground loop length required. This program will also calculate the optimal size for a supplemental fluid cooler for hybrid systems, as discussed later.
- GLHEPRO, International Ground Source Heat Pump Association (IGSHPA), (800) 626-4747, <http://www.mae.okstate.edu/Faculty/spitler/glhewin/glhepro.html>. Input required is monthly heating/cooling loads on heat pumps and monthly peak loads either entered directly by user or read from BLAST or Trane System Analyzer and Trane Trace output files. The current configuration of the program has some constraints on selection of borehole spacing, depth, and overall layout that will be removed from a future version now being prepared.
- GS2000 Version 2.0, Caneta Research Inc., (905) 542-2890, email: caneta@compuserve.com. Heating/cooling loads are input as monthly totals on heat pumps or, alternatively, monthly loads on the ground loop may be input. Equipment performance is input at ARI rating conditions discussed in Appendix E. For operating conditions other than the rating conditions, the equipment performance is adjusted based on generic heat pump performance relationships.

Each of these programs requires input about the soil thermal properties, borehole resistance, type of piping and borehole arrangement, fluid to be used, and other design parameters. Many of the required inputs will be available from tables of default values. The designer should be careful to ensure that the values chosen are representative of the actual conditions to be encountered to ensure efficient and cost-effective designs. Test borings to determine the type of soil formations and aquifer locations will substantially improve design accuracy and may help reduce costs. Even with the information from test borings, some uncertainty will remain with respect to the soil thermal properties. These programs make it possible to vary design parameters easily within the range of anticipated values and determine the sensitivity of the design to a particular parameter (OTL 1999). In some instances, particularly very large projects, it may be advisable to obtain specific information on ground-loop performance by thermal testing of a sample borehole (Shonder and Beck 2000).

Ground loops can be placed just about anywhere—under landscaping, parking lots, or ponds. Selection of a particular ground-coupling system (vertical, horizontal, spiral, etc.) should be based on life-cycle cost of the entire system, in addition to practical constraints. Horizontal closed-loop ground-coupling systems can be installed using a chain-type trenching machine, horizontal boring machine, backhoe, bulldozer, or other earth-moving heavy equipment. Vertical applications (for both open and closed systems) require a drilling rig and qualified operators. Most applications of ground-source heat pumps to large facilities use vertical closed-loop ground-coupling systems primarily because of land constraints. Submerged-loop applications require some special considerations and, as noted earlier, it is best to discuss these directly with an experienced design engineer.

It is important to assign overall responsibility for the entire ground-source heat pump system to a single individual or contractor. Installation of the system, however, will involve several trades and contractors, many of whom may not have worked together in previous efforts. In addition to refrigeration/air-conditioning and sheet metal contractors, installation involves plumbers, and (in the case of vertical systems) well drillers. Designating a singular responsible party and coordinating activities will significantly reduce the potential for problems with installation, startup, and proper operation.

In heating-dominated climates, a mixture of antifreeze and water must be used in the ground-coupling loops if loop temperatures are expected to fall below about 5°C (41°F). A recent study (Heinonen et al. 1997) establishes the important considerations for antifreeze solutions for ground-source heat pump systems and provides guidance on selection.

One note of caution to the designer: some regulations, installation manuals,

ground-coupling system that meet the needs of designers and installers. These tools are available from several sources, including the International Ground-Source Heat Pump Association

(IGSHPA). In addition, several manufacturers have designed their own proprietary tools more closely tuned to their particular system requirements (see side-bar discussion on design software).

and/or local practices call for partial or full grouting of the borehole. The thermal conductivity of materials normally used for grouting is very low compared with the thermal conductivity of most native soil formations. Thus, grouting tends to act as insulation and hinders heat transfer to the ground. Some recent experimental work (Spilker 1998) has confirmed the negative impact of grout on borehole heat transfer. Under heat rejection loading, average water temperature was nearly 6°C (11°F) higher for a 16.5-cm (6.5-in.) diameter borehole backfilled with standard bentonite grout than for a 12.1-cm (4.75-in.) diameter borehole backfilled with thermally enhanced bentonite grout. Using fine sand as backfill in a 16.5-cm (6.5-in.) diameter borehole lowered the average water temperature over 8°C (14°F) compared with the same-diameter bore backfilled with standard bentonite grout. For a typical system (Spilker 1998) with a 16.5-cm (6.5-in.) diameter borehole, the use of standard bentonite grout would increase the required bore length by 49% over fine sand backfill in the same borehole. By using thermally enhanced grout in a smaller 12.1-cm (4.75-in.) borehole, the bore length is increased by only 10% over fine sand backfill in the larger 16.5-cm (6.5-in.) diameter borehole. Thus, the results of this study (Spilker 1998) suggest three steps that may be taken to reduce the impact of grout on system performance:

- Reduce the amount of grout used to the bare minimum. Sand or cuttings may be used where allowed, but take care to ensure that the entire interstitial space between the piping and the borehole diameter is filled.
- Use thermally enhanced grout wherever possible. For information on thermally enhanced grout consult ASHRAE (1997) and Spilker (1998).
- Reduce the borehole diameter as much as possible to mitigate the effects of the grout or backfill used.

The regulatory requirements for vertical boreholes used for ground-coupling heat exchangers vary widely by state. Current state and Federal regulations as well as related building codes are summarized at website <http://www.ghpc.com>, as are contacts within these regulatory bodies.

Federal Sector Potential

The ground-source heat pump technology applied to Federal and other large facilities has been assessed by the New Technology Demonstration Program as having significant potential for energy savings in the Federal sector.

Technology Screening Process

The new technologies presented in the Federal Technology Alerts are identified primarily through direct submittals from Federal agencies to the program's Interlaboratory Council (ILC). The ILC also identifies new technologies through trade journals, product expositions, trade associations, other research programs, and other interested parties. Based on these responses, the technologies are evaluated by the ILC in terms of Federal sector potential energy savings, procurement, installation and maintenance costs. Ground-source heat pumps applied to large facilities were judged to have notable potential and to be life-cycle cost-effective in the proper applications.

Estimated Savings and Market Potential

An assessment aimed at estimating the Federal sector potential for ground-source heat pumps applied to large facilities was performed by the Pacific Northwest National Laboratory. The energy savings and market potential of the technology was evaluated using a modified version of the FEDS software tool developed for the U.S. Department of Energy's Office of Federal Energy Management Program (FEMP), the U.S. Army Construction Engineering Research Laboratories (USA CERL), and the Naval Facilities Engineering Service

GSHP Super ESPC

DOE has established national GSHP Super Energy Savings Performance Contracts (Super ESPCs) with five energy service companies (ESCOs) that have demonstrated expertise in the application of GSHP systems through past performance and proposals for specific projects. Through this mechanism, every Federal site has access to at least five quality sources for the family of GSHP systems.

In an ESPC, an ESCO bears the costs of implementing energy-savings measures in exchange for fixed payments from the resulting cost savings. FEMP has implemented a "Super ESPC" to streamline the process of procuring GSHP-centered projects. A GSHP system must be the major focus, but other energy conservation measures (e.g., lighting improvements) can be included if they make the project more economical. FEMP has selected and pre-approved a pool of ESCOs with which Federal agencies can contract. Under the Super ESPC, delivery orders can be awarded and facility managers have the assurance that all of the selected ESCOs are qualified to deliver top-quality GSHP-centered energy efficiency projects.

The advantages of GSHP-centered projects under the Super ESPC include: (1) ensures alignment with ESPC statutory authority and full compliance with all Federal procurement regulations applying to performance contracting, (2) guarantees adequate operating budgets.

Additional information on the technology-specific GSHP Super ESPC can be found at www.eren.doe.gov/femp/financing/ghp.html.

Center (NFESC) by Pacific Northwest National Laboratory (Dirks and Wrench 1993).

The assessment, originally performed in 1997, used the economic basis required in 10 CFR 436. The results of the assessment indicated that the application of ground-source heat pumps applied to larger, non-residential, facilities in the Federal sector could yield cost-effective savings in excess of 120,000 million Btu per year over conventional HVAC technologies, for a net-present value of \$3.7 million. The initial cost of the technology installations in cost-effective Federal applications was estimated to total around \$15.6 million.

Laboratory Perspective

Through laboratory testing, field testing, and theoretical analysis, the ground-source heat pump technology has been shown to be technically valid and economically attractive in many applications. Performance and capacity of the technology do not degrade substantially as outside temperatures reach extremes, either high or low, as do air-source heat pumps. Therefore, efficiency remains high, and backup or supplementary systems are sometimes unnecessary. The only remaining barriers to rapid implementation involve user awareness and acceptance (which is growing rapidly), and higher initial implementation costs than other options. This Federal Technology Alert is intended to address these concerns by reporting on the collective experience of ground-source heat pump users and evaluators and by providing application guidance.

While ground-source heat pumps are making progress in residential markets, this technology can also be applied to any heating and/or cooling requirement. Application of ground-source heat pumps offers significant potential energy savings to a wide range of commercial-type facilities at Federal installations: administrative offices, hospitals and clinics, schools and training facilities, communications facilities, dormitories and hotels, clubs and recre-

ation buildings, restaurant and dining facilities, commissary and exchanges, and others. DOE, through FEMP, has provided \$500 million in contracting authority for Federal sites to procure ground-source heat pumps through private sector financing.

Application

This section addresses technical aspects of applying ground-source heat pumps. The range of applications and climates in which the technology has been installed are discussed. The advantages, limitations, and benefits are enumerated. Design and integration considerations for ground-source heat pumps are highlighted, including energy savings estimates, equipment warranties, relevant codes and standards, equipment and installation costs, and utility incentives.

Application Screening

A ground-source heat pump system is one of the most efficient technologies available for heating and cooling. It can be applied in virtually any climate or building category. Although local site conditions may dictate the type of ground-coupling system employed, the high first cost and its impact on the overall life-cycle cost are typically the constraining factors that can be offset by the ESPC.

The operating efficiency of ground-source heat pumps is very dependent on the entering water temperature, which, in turn, depends on ground temperature, system load, and size of ground loop. As with any HVAC system, the system load is a function of the facility, internal activities, and the local weather. Furthermore, with ground-source heat pumps, the load on the ground-coupling system may impact the underground temperature. Therefore, energy consumption will be closely tied to the relationship between the annual load distribution and the annual ground loop-temperature distribution (e.g., their joint frequency distribution).

There are several techniques to estimate the annual energy consumption of ground-source heat pump systems. The most accurate methodologies use computer simulation, and several software systems now support the analysis of ground-source heat pumps. These methods, while more accurate than hand techniques, are also difficult and expensive to employ and are therefore more appropriate when additional detail is required rather than as an initial screening tool.

The bin method is another analytical tool for screening technology applications. In general, a bin method is a simple computational procedure that is readily adaptable to a spreadsheet-type analysis and can be used to estimate the energy consumption of a given application and climate. Bin methods rely on load and ambient wet and dry bulb temperature distributions. This methodology is used in the case study presented in this Federal Technology Alert.

Where to Apply Ground-Source Heat Pumps

Ground-source heat pumps are generally applied to air-conditioning and heating systems, but may also be used in any refrigeration application. The decision whether to use a ground-source heat pump system is driven primarily by economics. Almost any HVAC system can be designed using a ground-source heat pump. The primary technical limitation is a suitable location for the ground-coupling system. The following list identifies some of the best applications of ground-source heat pumps.

- Ground-source heat pumps are probably least cost-prohibitive in new construction; the technology is relatively easy to incorporate.
- Ground-source heat pumps can also be cost-effective to replace an existing system at the end of its useful life, or as a retrofit, particularly if existing ductwork can be reused with minimal modification.

- In climates with either cold winters or hot summers, ground-source heat pumps can operate much more efficiently than air-source heat pumps or other air-conditioning systems. Ground-source heat pumps are also considerably more efficient than other electric heating systems and, depending on the heating fuel cost, may be less expensive to operate than other heating systems.
- In climates characterized by high daily temperature swings, ground-source heat pumps show superior efficiency. In addition, in climates characterized by large daily temperature swings, the ground-coupling system also offers some thermal storage capability, which may benefit the operational coefficient of performance.
- In areas where natural gas is not available or where the cost of natural gas or other fuel is high compared with electricity, ground-source heat pumps are economical. They operate with a heating coefficient of performance in the range of 3.0 to 4.5, compared with conventional heating efficiencies in the range of 80% to 97%. Therefore, when the cost of electricity (per Btu) is less than 3.5 times that of conventional heating fuels (per Btu), ground-source heat pumps have lower energy costs.
- Areas of high natural gas (or fuel oil) costs will favor ground-source heat pumps over conventional gas (or fuel oil) heating systems. High electricity costs will favor ground-source heat pumps over air-source heat pumps.
- In facilities where multiple temperature control zones or individual load control is beneficial, ground-source heat pumps provide tremendous capability for individual zone temperature control because they are primarily designed using multiple unitary systems.
- In areas where drilling costs are low, vertical-loop systems may be especially attractive.

The initial cost of the ground-source heat pump system is one of the prime barriers to the economics. In locations with a significant ground-source heat pump industry infrastructure (such as Oklahoma, Louisiana, Florida, Texas, and Indiana), installation costs may be lower and the contractors more experienced. This, however, is changing as the market for ground-source heat pumps grows.

What to Avoid

The following precautions should be followed when the application of ground-source heat pump technology is considered:

- Avoid threaded plastic pipe connections in the ground loop. Specify thermal fusion welding. Unlike conventional water-source heat pump systems where the water loop temperature ranges from 60° to 90°F (15.6° to 32.2°C), ground-source systems are subject to wider temperature ranges (20° to 110°F [-6.7° to 43.3°C]), and the resulting expansion and contraction may result in leaks at the threaded connection. It is also generally recommended to specify piping and joining methods approved by International Ground-Source Heat Pump Association (IGSHPA).
- Check local water and well regulations. Regulations affecting open-loop systems are common, and local regulations can vary significantly. Some local regulations may require reinjection wells rather than surface drainage. Some states require permits to use even private ponds as a heat source/sink.
- Have the ground-source heat pump system installed as a complete and balanced assemblage of components, each of which must be properly designed, sized, and installed (Giddings 1988). Also, have the system installed under the responsibility of a single party. If the entire system is installed by three different profes-

sionals, none of whom understands or appreciates the other two parts of the system, then the system may not perform satisfactorily.

- One of the most frequent problems cited is improper sizing of the heat pump or the ground-coupling system. Approved calculation procedures should be used in the sizing process—as is the case with any heating or air-conditioning system regardless of technology. ASHRAE has established one of the most widely known and accepted standards for the determination of design heating and cooling loads. Sizing the ground-coupling system is just as critical. Because of the uncertainty of soil conditions, a site analysis to determine the thermal conductivity and other heat transfer properties of the local soil may be required. This should be the responsibility of the designing contractor because it can significantly affect the final design.
- Avoid inexperienced designers and installers (see above). Check on the previous experience of potential designers and installers. It is also generally recommended to specify IGSHPA certified installers.

Design and Equipment Integration

The purpose of this Federal Technology Alert is to familiarize the Federal energy manager and Federal facility engineer with the benefits and liabilities of ground-source heat pumps in their application to Federal facilities. It is beyond the scope of this Federal Technology Alert to fully explain the design requirements of a ground-source heat pump system. It is, however, important that the reader know the basic steps in the design process.

The design of a ground-source heat pump system will generally follow the following sequence:

1. Determine local design conditions, climatic and soil thermal characteristics.

2. Determine local water, well, and grouting requirements
3. Determine building heating and cooling loads at design conditions.
4. Select the alternative HVAC system components, including the indoor air-distribution system type; size the alternatives as required; and select equipment that will meet the demands calculated in Step 2 (using the preliminary estimate of the entering water temperatures to determine the heat pump's heating and cooling capacities and efficiencies).
5. Determine the monthly and annual building heating and cooling energy requirements.
6. Make preliminary selection of a ground-coupling system type.
7. Determine a preliminary design of the ground-coupling system.
8. Determine the thermal resistance of the ground-coupling system.
9. Determine the required length of the ground-coupling system; recalculate the entering and exiting water temperatures on the basis of system loads and the ground-coupling system design.
10. Redesign the ground-coupling system as required to balance the requirements of the system load (heating and cooling) with the effectiveness of the ground-coupling system. Note that designing and sizing the ground-coupling system for one season (such as cooling) will impact its effectiveness and ability to meet system load requirements during the other season (such as heating).
11. Perform life-cycle cost analysis on the system design (or system design alternatives).

Although the design procedure for the ground-coupling system is an iterative and sometimes difficult process, several

sources are available to simplify the task. First, an experienced design contractor should be assigned responsibility for the heat pump and ground-coupling system designs. Several manufacturers of ground-source heat pump equipment have their own software tools to support the design of large, commercial-type systems. However, for those who typically design systems in-house, there are support tools available. Software programs are available to support the design of ground-source heat pump HVAC systems and the ground-coupling system. Several software tools are available through the IGSHPA, including an Earth-Coupled Analysis Program and a Ground-Loop Heat Exchanger Design Program. In addition, several technical design manuals also are available through IGSHPA, ASHRAE, and equipment manufacturers (refer to earlier section for an introduction to ground-loop design software).

There are several different approaches for incorporating ground-source heat pumps into the HVAC design. However, most applications in large facilities involve multiple smaller heat pump units (<20 ton) applied in a modular zone control system and connected to a common water loop and associated ground-coupling system. Although some agencies are experimenting with larger equipment sizes, most manufacturers are supporting the development of efficient smaller systems (1/2 ton to 15 tons [1.8 to 52.8 kW]).

Equipment Warranties

The prospective user should ask potential suppliers, contractors, and installers about equipment warranties. The heat pump equipment is typically guaranteed free from manufacturer defects from 1 to 5 years. Some manufacturers offer extended warranties up to 10 years. Residential applications have been found to have longer warranties than commercial applications.

Warranties should also be requested for the ground-coupling system, which is less common. Some installers and pipe manufacturers have offered limited ground-coupling system warranties as long as 50 years. Quality control in the installation of the ground-coupling system has been a concern in the industry. The IGSHPA now offers training and certification programs for installers. In addition, the IGSHPA also administers a registration program for those organizations in the industry. These services have gone far to improve quality control and customer satisfaction.

The track records reported in the literature for the ground-coupling systems are good. In cases where pipe joints were thermal welded and followed the standards recommended by IGSHPA, systems have proven reliable and resistant to system leaks.

Energy Codes and Standards

Applications of ground-source heat pumps are subject to building and facility energy codes and standards. In addition, the equipment used is subject to commercial equipment energy codes and standards. Most energy regulations that impact Federal facilities derive from ASHRAE standards, specifically ASHRAE Standard 90.1. The code that currently governs the selection of alternative energy technologies by life-cycle costing in Federal facilities is 10 CFR 436 Subpart A. Minimum equipment efficiency standards, as identified in ASHRAE Standard 90.1-1999, for commercial equipment relative to ground-source heat pumps are shown in Table 1.

Although codes and standards identify minimum efficiencies such as those identified above, they do not fully communicate the energy efficiency that is achieved by today's heat pumps. A review of manufacturer's literature on commercially available equipment indicates that cooling efficiencies (EERs) of 12.0 to 16.8 Btu/W-h and heating

Table 1. Minimum commercial equipment efficiency rating standards (ASHRAE 90.1-1999), effective 10/29/2001.

| Technology Application | Reference Standard | Category (capacity) | Rating Condition (enter water temperature) | Minimum Performance as of 10/29/2001 | |
|--------------------------------------|----------------------------|--------------------------|--|--------------------------------------|---------|
| | | | | Cooling | Heating |
| Water-Source Heat Pumps | ISO-13256-1 ^(a) | <17 kBtuh | Standard 86°F (30°C) | 11.2 EER | --- |
| | | | Standard 68°F (20°C) | --- | 4.2 COP |
| | | ≥17 kBtuh and <65 kBtuh | Standard 86°F (30°C) | 11.2 EER | --- |
| | | | Standard 68°F (20°C) | --- | 4.2 COP |
| | | ≥65 kBtuh and <135 kBtuh | Standard 86°F (30°C) | 12.0 EER | --- |
| | | | Standard 68°F (20°C) | --- | 4.2 COP |
| Groundwater- Source Heat Pumps | ISO-13256-1 | <135 kBtuh | Standard 59°F (15°C) | 16.2 EER | |
| | | | Standard 68°F (20°C) | 4.2 COP | |
| Ground-Source Closed-Loop Heat Pumps | ISO-13256-1 | <135 kBtuh | Standard 77°F (25°C) | 13.4 EER | --- |
| | | | Standard 32°F (0°C) | --- | 3.1 COP |

(a) ISO 13256-1 (1998) Water-Source Heat Pumps - Testing and Rating for Performance - Part 1: Water -to-Air and Brine-to-Air Heat Pumps.

efficiencies (COPs) of 3.0 to 4.3 are readily available.^(d) When comparing equipment efficiencies, it is important to make an appropriate comparison. The efficiency of any heating or cooling equipment varies with application, load, and related heat-source and heat-sink temperatures. Furthermore, standard ratings are for specific temperatures and operating conditions. Standard ratings do not necessarily reflect the efficiency of systems under true seasonal operating conditions. In determining the efficiency of heating or cooling equipment for estimating energy consumption or potential energy savings, the efficiency should be corrected for the appropriate operating conditions.

Utility Incentives and Support

Many utilities are promoters of ground-source heat pumps, and many offer incentive programs and support. Electric utilities are expected to offer Federal agencies private financing and expertise to implement GSHP projects through the existing Utility Energy Services Contracts UESCs).

In a recent publication reporting current demand-side management (DSM) programs, the Electric Power Research

Institute (EPRI) identified 136 utility programs specific to ground-source heat pumps and water-loop heat pumps (EPRI 1993). This report summarized a survey that identified 2,321 DSM programs from 666 utilities. Rebates for ground-source heat pumps identified in the survey ranged from \$15 to \$600 per ton, with an average of \$190/ton, and \$100 to \$2,000 per unit, with an average of \$538/unit. In addition to the technology-specific rebate programs, some utilities also offer custom rebate programs or programs that are not technology specific but are based on the energy savings regardless of the technology employed. Readers are encouraged to contact their local utility to find out more about what programs, services, and rebates may be offered by the utility to promote energy management and new energy-efficient technologies.

Technology Performance

In 1999, an estimated 400,000 ground-source heat pumps were operating in residential and commercial applications, up from 100,000 in 1990. With a projected annual growth rate of 10%, 120,000 new units would be installed in 2010, for a total of 1.5 million units in 2010 (Lund and Boyd 2000). The major-

ity of new ground-source heat pump installations in the United States are for residential applications in the southern and mid-western states. Environmental concerns and a general lack of understanding of the technology by HVAC companies and installers have limited installations in the west.

Field Experience

Observations about field performance of ground-source heat pumps obtained from Federal and private-sector users are summarized in this section.

The large number of reported installations testify to the stability of this technology. Most sites contacted report satisfaction with the overall performance (energy efficiency, maintenance, and comfort) of the technology. The world’s largest installation of ground-source heat pumps is at Fort Polk, Louisiana, where over 4000 units were installed in family housing as part of a major retrofit project (Hughes and Shonder 1998). They also have systems installed in several larger facilities, including some cooling-tower hybrid systems (discussed earlier in this Federal Technology Alert). Personnel at Fort Polk are obviously pleased with the performance of their ground-source heat

(d) For more information on the various terms used to define efficiency in HVAC systems (see Appendix C).

pumps, and the energy manager reports that the systems have performed better than expected and they plan to use the technology for all heating and cooling requirements on the base.

The maintenance engineer at the hospital in Love County, Oklahoma, reported that no problems have occurred since nine units were installed in their facility in the early 1990s. They perform routine maintenance on the system. They particularly like the technology because it takes up less space and gives better heating and cooling control than former systems.

An interview with the energy manager primarily responsible for the ground-source heat pump installation at the Oklahoma State Capitol Building revealed no problems with the heat pumps or the ground loop; however, the building was poorly zoned, which impeded effective temperature control. Approval from the local Water Resource Board for drilling the wells proved difficult but was primarily a matter of educating the board about the technology and the closed-loop system. The Capitol building system, which is a cooling-tower-supplemented design, contains 855 cooling tons (3,009.6 kW) connected to a common ground-loop system consisting of 372 250-foot (76.2 m) vertical wells.

One facility manager did report problems with the ground-source heat pump system installed in a facility at the Dugway Proving Grounds, Utah. The system contains 22.5-ton (8.8 kW) units. Although the actual problem has not been identified, the system is not performing up to expectations. The current belief is that the ground-loop is undersized. Sizing of the ground loop is one of the most important design factors and is a function of system load, ground temperature, and local soil conditions. As noted earlier in this Federal Technology

Alert, the type of soil and rock in contact with the pipe loop has serious implications for the length of ground loop required for adequate heat transfer. Inexperienced designers or installers are more likely to undersize the systems, resulting in inadequate system performance, or to oversize the systems, resulting in increased installation costs. The importance of good design, documentation, installation, and commissioning cannot be overemphasized.

In early 1995, at the National Training Center in Fort Irwin, California, 220 new single-family houses were built with an innovative ground-source heat pump system. The thermal sink/source for the heat pumps is geothermally heated 75°F groundwater. The groundwater is pumped into a storage reservoir adjacent to the housing project. The reservoir water is then circulated through a double-walled heat exchanger, transferring thermal energy to/from a secondary closed circulation loop connected to individual heat pumps in each residence. Operating conditions and problems with maintaining correct water flow through the central facility heat exchanger contributed to lower than expected energy savings during the first year of operation. There was no indication that the heat pumps themselves were not performing as designed. Limited anecdotal information from the occupants indicates that overall satisfaction with the level of thermal comfort from the system was high.^(e)

Vertical-bore, ground-coupled heat pump systems were installed in four new elementary schools in Lincoln, Nebraska, in 1995. Each school required 54 heat pumps ranging in size from 1.4 to 15 tons (204-tons total cooling capacity). With the heat pump systems, utility costs for these four schools and nearly half of that of other schools in the district, and the systems are providing a

comfortable, complaint-free environment (Shonder et al. 1999).

Additional case studies are identified on the Geothermal Heat Pump Consortium Web page (<http://www.ghpc.org/>).

Energy Savings

The most important reason to consider the application of ground-source heat pumps to Federal facilities is the potential energy savings and its impact on overall life-cycle cost of the heating and cooling system. Ground-source heat pumps save energy and money because the equipment operates more efficiently than conventional systems, the maintenance costs are lower (see next section for maintenance benefits), and the equipment has a longer life expectancy. In addition, a ground-source heat pump does not require a defrost cycle, or, in most situations, backup electric resistance heat, as do air source heat pumps.

By comparison, the average cooling efficiency at Federal commercial-type facilities is estimated to be an EER of 8.0 (2.33 COP) for existing facilities and an EER of 10.0 (2.93 COP) for new facilities. Ground-source heat pump systems have the potential to reduce consumption of cooling energy by 30% to 50% and to reduce heating energy by 20% to 40% compared with typical air-source heat pumps.

A review of manufacturing literature on commercially available systems indicates that cooling efficiencies (EERs) of 12.0 to 16.8 Btu/w-h and heating efficiencies (COPs) of 3.0 to 4.3 are readily available (ARI 330 ratings^(f)). A study prepared by DOE estimates energy-saving ranges of 17% to 42% comparing ground-source heat pumps to air-source heat pumps, depending on region (Calm 1987). Figure 7 illustrates the range of efficiencies typical of various heating and cooling equipment.

(e) D.L. Hadley and L. Lkevgard. August 1997. *Family Housing Energy Savings Verification, National Training Center, Fort Irwin, CA. Preliminary Findings: Cooling Season Energy Savings*. Letter Report, Pacific Northwest National Laboratory, Richland, Washington.

(f) ARI test rating conditions are described in Appendix E.

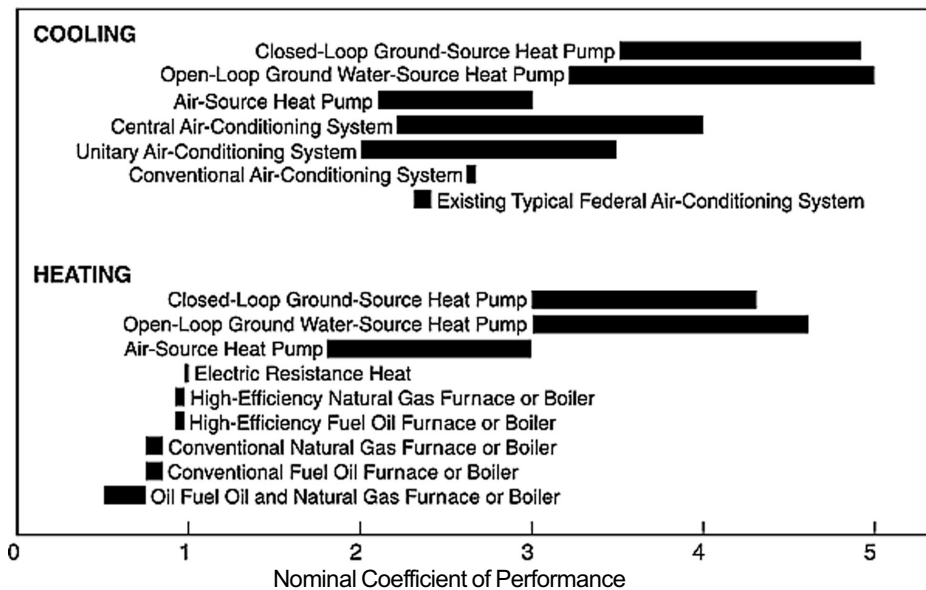


Figure 7. Typical heating and cooling equipment efficiencies.

Maintenance

The ground-source heat pump technology is mature and reliable. Systems have standard warranties ranging from 1 to 5 years. The heat pump units are self-contained, and maintenance requirements are relatively straightforward; no new maintenance skills are necessary. Because heat pump equipment is not exposed to outdoor elements, the units actually require less maintenance than typical air-source heat pumps. One site reported a problem with cottonwood trees clogging outside condenser units of the previous air-conditioning systems. This maintenance problem was eliminated with the application of ground-source heat pumps.

In closed-loop systems, the ground loop is virtually maintenance free. The circulating pump(s) requires routine maintenance, as with any pump and motor

system, and the water loop (a closed system) should be routinely monitored for temperature, pressure, flow, and antifreeze concentration. Unless there is a leak, no action is generally required.

In open-loop systems, the well requires maintenance similar to any water well. The system should be routinely monitored for temperature, pressure, and flow. Because groundwater is being supplied to the heat pump, the heat exchangers should be routinely inspected for potential fouling and scale buildup.

Maintenance costs for GSHPs are about the same or less than conventional equipment. For example, maintenance costs for four new schools in the Lincoln, Nebraska, equipped with GSHP systems have been thoroughly documented in recent years (Martin et al.

1999, 2000). The results of these studies are summarized in Table 2.

Another analysis, this one by the Geothermal Heat Pump Consortium, found that the average total preventive and corrective maintenance costs for 25 GSHP-equipped buildings were approximately 11 cents/ft², compared to 30 to 40 cents/ft² for conventional systems (Cane 1998).

Installation Costs

Application-specific parameters, such as equipment capacity, type, refrigerant, air-distribution system, control system, plumbing configuration, and ground-coupling system type, significantly affect the total cost of the overall system. While equipment costs are competitive, installation costs vary significantly.

To illustrate the potential range of installation costs, the following examples have been reported.

- Stockton State College in Pomona, New Jersey, retrofit a system that totaled 1,655 tons (5,826 kW) at a total cost of \$5,246,000 (Gahran 1993). The facility received grants and rebates reducing the capital outlay to \$135,000. The system included 63 rooftop units, 500 variable-air volume (VAV) boxes, and a 3,500-point energy management control system (EMCS). The unit cost was \$3,170/ton in 1993 dollars.
- WaterFurnace, a ground-source heat pump manufacturer, designed the technology using a submerged pond closed-loop system into its new office building located in Fort Wayne, Indiana. The system totaled 134 tons (471.7 kW) at a cost of \$239,800 (WaterFurnace WF639). The unit cost was \$1,790/ton in 1991 dollars.
- Salem Community College in Carney’s Point, New Jersey, retrofit a system that totaled 160 tons at a total cost of \$284,000 (Gahran 1994). The system included 32 heat pumps. The unit cost was \$1,775/ton in 1993 dollars.

Table 2. Maintenance costs for public schools in Lincoln, Nebraska.

| HVAC System Type | Preventive Maintenance (cents/yr-ft ²) | Repair (cents/yr-ft ²) | Total (cents/yr-ft ²) |
|---------------------|--|------------------------------------|-----------------------------------|
| GSHP system | 7.1 | 2.1 | 9.2 |
| Conventional system | 5.9 - 12.6 | 2.9 - 6.1 | 8.8 - 18.7 |

- Paint Lick Elementary School in Garrard County, Kentucky, designed the technology into the new school building. The system totaled 123 tons (433 kW) at a total cost of \$380,010 (WaterFurnace WF666). The unit cost was \$3,090/ton in 1992 dollars.
- Maywood Elementary School in Hammond, Indiana, designed the technology into a new school building. The unit totaled 250 tons (880 kW) at a total cost of \$1,277,190 (WaterFurnace WF925). The system consisted of 74 heat pumps and a ground-coupling system consisting of 244 vertical wells. The unit cost was \$5,110/ton in 1994 dollars.
- The Lincoln, Nebraska, school district installed ground-source heat pump systems in four new elementary schools. In each school, the system consisted of 54 heat pumps ranging in size from 1.4 tons to 15 tons, with a total cooling capacity of 180 tons (630 kW). Four gas-fired boilers with a capacity of 330,000 Btuh each provide hot water for pre-heat and terminal reheat. The total heat pump cost per school was approximately \$657,000 (\$3,650/ton) in 1995 dollars (Shonder et al. 1999).
- Kavanaugh (1995) concluded that the average cost of ground-source heat pumps (including unit, loop, duct, and installation) ranged from \$2360 per ton for a 5-ton horizontal loop to \$3000 per ton for a 3-ton vertical loop system. Compared to a 3-ton conventional system, the added cost was \$1250 to \$1550 per ton.

Installation costs are expected to drop as the ground-source heat pump industry infrastructure grows and designers and installers become more experienced. Reducing installation costs is one of the prime goals of the International Ground-Source Heat Pump Association and the Geothermal Heat Pump Consortium.

Other Impacts

There are no significant negative environmental impacts associated with ground-source heat pumps. There is, however, the potential for systems to be affected by some local codes and regulations. The most likely source of conflict, if any, lies with the installation of the ground-coupling system. Working with an experienced installer is the best advice. However, local electric utilities and other local sites with existing ground-source heat pump installations are other sources of information about local permit and regulation issues.

With the application of any electro-technology, there is a potential environmental benefit. Installing a ground-source heat pump system in lieu of a fossil-fuel heating system will reduce local emissions. Furthermore, installing a more efficient electro-technology such as a ground-source heat pump system for cooling will reduce source emissions at the utility power plant. Typical emission reductions per MWh of energy conserved are 0.3 pounds (0.14 kg) of particulates, 3.3 pounds (1.5 kg) of sulfur oxides, 5.3 pounds (2.4 kg) of nitrogen oxides, and 1,720 pounds (780 kg) of carbon dioxide. These numbers vary with time and region, depending on the power generation fuel mix (EPA 1994; Nemeth 1993).

Case Studies

The purpose of these case studies is to assist the Federal energy manager or facility engineer in estimating the energy consumption and costs associated with the construction and operation of ground-source heat pump systems and comparing them with those for conventional HVAC technologies. The goal is to estimate energy consumption and savings, not to design systems.

There are several methods for estimating energy consumption of HVAC

technologies, from simplistic degree-day calculations to sophisticated hour-by-hour energy modeling and simulation systems supported by computer programs. The examples used in this Federal Technology Alert are based on an outdoor temperature bin method. This method is described in more detail in *Closed-Loop/Closed-Source Heat Pump Systems: Installation Guide* (OSU 1988).

Two case studies were developed for this Federal Technology Alert. In both, estimates of the potential energy consumption and life-cycle costs of the ground-source heat pump technology are compared with conventional HVAC technologies. In each study, the facility is a hypothetical Federal administrative building of typical single-story construction. The facilities in each example operate continuously (no night setback temperature control). In the first example, the building is located in upstate New York; in the second example, the same building is located in central Oklahoma.

Example 1: Upstate New York Facility

The facility is in upstate New York near Griffiss Air Force Base. Mean local weather conditions are 7,331 (base 65°F) heating degree-days (4,073 heating Celsius degree-days) and 472 (base 65°F) cooling degree-days (262 cooling Celsius degree-days). The 97.5% heating design temperature is -5°F (-20.6°C) and the 2.5% cooling design temperature is 85°F (29.4°C). The mean annual earth temperature is 49°F (9.4°C).

The local utility in this region (for electric and natural gas) is Niagara Mohawk. The electric rate schedule for this example consists of a demand charge of \$5.51/kW-month and an energy charge of \$0.05/kWh. The gas rate schedule consists of an energy charge of \$0.54/therm.

The heating load for this facility during the design day is estimated to be 3,309 kBtu/h (970.6 kW). The design cooling

load is 1,273 kBtu/h (373.4 kW). The balance temperature for the facility is 60°F (15.6°C). The balance temperature is the temperature at which neither heating nor cooling is required to meet the comfort requirements of the facility.

Technology Description. Three technologies are compared in this example. The conventional technology is a rooftop air-conditioning system with integral natural gas furnace heaters. For this example, the capacity and input power are based on a commercially available rooftop unit with a rated heating capacity of 270 kBtu/h (79.2 kW) and a rated cooling capacity of 162 kBtu/h (47.5 kW) at ARI conditions. The equipment selected has a cooling efficiency of 8.2 EER and 10.1 IPLV^(g) at ARI conditions. The heating efficiency is rated at 80%. The indoor air fan is rated at 2.50 kW input and the outdoor air fans are rated at 2.67 kW input. To meet the heating requirements during the design day, 13 rooftop units are required. This number also meets the cooling load requirements. The estimated equipment life of this alternative, according to ASHRAE, is 15 years (ASHRAE 1995, p. 33.4).

The second alternative is a rooftop air-source heat pump system with electric resistance supplemental heaters. For this example, the capacity and input power are based on a commercially available air-source heat pump. The rooftop units have a rated cooling capacity of 162 kBtu/h (47.5 kW) and a rated heating capacity of 166 kBtu/h (48.7 kW) (high temperature) and 102 kBtu/h (29.9 kW) (low temperature) at ARI Standard 340 test conditions. The equipment selected has a rated cooling efficiency of 8.5 EER and a rated heating efficiency of 3.0 COP (high temperature) and 2.1 COP (low temperature). The indoor and outdoor air fan input power is included in the power input loads. To meet the cooling requirements during the design day, seven rooftop units are required. To meet the added load during the heating

design day, each rooftop unit is equipped with 125-kW supplemental heaters. The estimated equipment life of this alternative, according to ASHRAE, is 15 years (ASHRAE 1995, p. 33.4).

The third alternative is a ground-source heat pump system using extended-range water-source heat pumps and a vertical closed-loop ground-coupling system. For this example, the capacity and input power are based on a commercially available ground-source heat pump. The heat pumps have a rated cooling capacity of 57.5 kBtu/h (16.9 kW) and a rated heating capacity of 60.0 kBtu/h (17.6 kW) at ARI 330 conditions. The equipment selected has a rated cooling efficiency of 14.49 EER and a rated heating efficiency of 4.0 COP. The indoor air fan input power is included in the power input loads. To meet the cooling requirements during the design day, 22 units are required. To meet the added load during the heating design day, each unit is equipped with a 33-kW supplemental heater. It is also assumed that the water-loop system employs a variable-speed drive for added energy savings. The estimated equipment life of this alternative, according to ASHRAE, is 19 years (ASHRAE 1995, p. 33.4).

Savings Potential. Energy consumption for the three alternatives is estimated by an outdoor temperature bin method. The calculations are performed in a spreadsheet using 5°F bin data, because this is the form in which data are readily available to most Federal energy managers (TM 5-785).

The main assumption underlying this type of analysis is that the facility is “thermally light.” This implies that the heating and cooling loads on the building are proportional to the outside air temperature. A “thermally heavy” facility would be a building in which the cooling load on the building is not very proportional to the outside air temperature because of significant internal heat

loads or a thermally massive structure, which tends to “hold” the heat or cold. In the case of a “thermally heavy” facility, the building heating and cooling loads would have to be calculated using a methodology other than the one utilized in the following analysis.

The analysis shown in Table 3 begins with an estimate of the building load for each bin. Column 1 indicates the midpoint of each temperature bin, e.g., the bin from 95° to 99°F has a midpoint temperature of 97°F. Column 2 gives the number of hours that occur in each bin over a “typical” year. Column 3 estimates the corresponding building load. This is calculated by linear interpolation between no heating or cooling load at the facility balance temperature and the design heating or cooling load at the design heating or cooling temperature. The actual equations used in this analysis are listed in Appendix A, Table A.4.

The entering water temperature (EWT) is estimated in Column 4 of Table A.4. This is the temperature of the water entering the heat pump from the ground-coupling system. For initial estimating, the entering water temperature is a linear interpolation between two points for the heating cycle and again for the cooling cycle. During zero building load conditions, which occurs at the facility balance temperature, the entering water temperature is assumed to be equal to the ground temperature. During the peak load, the entering EWT is set to the maximum temperature desired during the peak cooling season load; similarly, it is set to the minimum temperature desired during the peak heating season load. Publications by the International Ground-Source Heat Pump Association recommend for initial calculations these temperatures be set to 100°F maximum (37.8°C) and 37°F (2.8°C) minimum, although in this example, the minimum temperature was set to 35°F (1.7°C). Today, most commercial systems are commonly designed at 90°F (32.2°C)

(g) EER and IPLV have units of Btu/w-h in this example.

FEDERAL ENERGY MANAGEMENT PROGRAM

Table 3. Griffiss AFB ground-source heat pump energy consumption bin method analysis.

| Avg. Bin Temp. ('F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Entering Water Temp. ('F) | Net GSHP Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | GSHP Eff'y. (EER or COP) | GSHP Input Power (kW) | Suppl. Heater Power (kW) | Pump Flow Rate (gpm) | GSHP Electric Energy (kWh) | Suppl. Heater Energy (kWh) | Circ. Pump Energy (kWh) | Circ. Pump Energy (kWh) | Total Electric Energy (kWh) |
|----------------------|------------------|---------------------|---------------------------|----------------------------|---------------------|---------------------|---------------------|--------------------------|-----------------------|--------------------------|----------------------|----------------------------|----------------------------|-------------------------|-------------------------|-----------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (15) | (16cv) | (16rad) | (17) |
| Cooling Mode: | | | | | | | | | | | | | | | | |
| 112 | 0 | 2,648 | 122 | 1,038.36 | 1.00 | 1.00 | 1.00 | 8.99 | 115.53 | n/a | 310 | 0 | 0 | 0 | 0 | 0 |
| 107 | 0 | 2,393 | 115 | 1,081.28 | 1.00 | 1.00 | 1.00 | 9.81 | 110.28 | n/a | 310 | 0 | 0 | 0 | 0 | 0 |
| 102 | 0 | 2,139 | 108 | 1,124.19 | 1.00 | 1.00 | 1.00 | 10.70 | 105.02 | n/a | 310 | 0 | 0 | 0 | 0 | 0 |
| 97 | 4 | 1,834 | 101 | 1,167.11 | 1.00 | 1.00 | 1.00 | 11.70 | 99.76 | n/a | 310 | 399 | 0 | 36 | 36 | 435 |
| 92 | 15 | 1,629 | 94 | 1,210.02 | 1.00 | 1.00 | 1.00 | 12.80 | 94.51 | n/a | 310 | 1,418 | 0 | 134 | 134 | 1,551 |
| 87 | 88 | 1,375 | 87 | 1,252.94 | 1.00 | 1.00 | 1.00 | 14.04 | 89.25 | n/a | 310 | 7,854 | 0 | 785 | 785 | 8,639 |
| 82 | 206 | 1,120 | 80 | 1,295.85 | 0.86 | 0.97 | 0.89 | 15.43 | 83.99 | n/a | 278 | 15,482 | 0 | 1,838 | 1,472 | 16,954 |
| 77 | 360 | 866 | 73 | 1,338.77 | 0.65 | 0.91 | 0.71 | 17.00 | 78.74 | n/a | 220 | 20,104 | 0 | 3,213 | 1,616 | 21,720 |
| 72 | 540 | 611 | 66 | 1,381.68 | 0.44 | 0.86 | 0.51 | 18.80 | 73.48 | n/a | 159 | 20,391 | 0 | 4,819 | 1,273 | 21,664 |
| 67 | 690 | 356 | 59 | 1,424.60 | 0.25 | 0.81 | 0.31 | 20.88 | 68.22 | n/a | 96 | 14,495 | 0 | 6,158 | 584 | 15,079 |
| 62 | 704 | 102 | 52 | 1,467.51 | 0.07 | 0.77 | 0.09 | 23.31 | 62.97 | n/a | 28 | 4,009 | 0 | 6,283 | 51 | 4,060 |
| Heating Mode: | | | | | | | | | | | | | | | | |
| 57 | 680 | 153 | 48 | 1,024.10 | 0.15 | 0.79 | 0.19 | 3.59 | 83.56 | 0.00 | 59 | 10,763 | 0 | 6,068 | 218 | 10,981 |
| 52 | 671 | 407 | 48 | 1,010.83 | 0.40 | 0.85 | 0.47 | 3.57 | 82.98 | 0.00 | 147 | 26,371 | 0 | 5,988 | 1,343 | 27,714 |
| 47 | 618 | 662 | 47 | 997.55 | 0.66 | 0.92 | 0.72 | 3.55 | 82.41 | 0.00 | 225 | 36,891 | 0 | 5,515 | 2,894 | 39,785 |
| 42 | 631 | 916 | 46 | 984.28 | 0.93 | 0.98 | 0.95 | 3.53 | 81.83 | 0.00 | 294 | 48,915 | 0 | 5,631 | 5,053 | 53,968 |
| 37 | 754 | 1,171 | 45 | 971.01 | 1.00 | 1.00 | 1.00 | 3.50 | 81.25 | 58.58 | 310 | 61,265 | 44,168 | 6,729 | 6,729 | 112,162 |
| 32 | 821 | 1,425 | 44 | 957.74 | 1.00 | 1.00 | 1.00 | 3.48 | 80.68 | 137.07 | 310 | 66,235 | 112,534 | 7,327 | 7,327 | 186,096 |
| 27 | 580 | 1,680 | 43 | 944.46 | 1.00 | 1.00 | 1.00 | 3.46 | 80.10 | 215.56 | 310 | 46,458 | 125,025 | 5,176 | 5,176 | 176,658 |
| 22 | 441 | 1,934 | 43 | 931.19 | 1.00 | 1.00 | 1.00 | 3.43 | 79.52 | 294.05 | 310 | 35,069 | 129,676 | 3,936 | 3,936 | 168,681 |
| 17 | 326 | 2,189 | 42 | 917.92 | 1.00 | 1.00 | 1.00 | 3.41 | 78.95 | 372.54 | 310 | 25,736 | 121,449 | 2,909 | 2,909 | 150,094 |
| 12 | 242 | 2,444 | 41 | 904.65 | 1.00 | 1.00 | 1.00 | 3.38 | 78.37 | 451.03 | 310 | 18,965 | 109,150 | 2,160 | 2,160 | 130,275 |
| 7 | 165 | 2,698 | 40 | 891.37 | 1.00 | 1.00 | 1.00 | 3.36 | 77.79 | 529.52 | 310 | 12,836 | 87,371 | 1,472 | 1,472 | 101,679 |
| 2 | 101 | 2,953 | 39 | 878.10 | 1.00 | 1.00 | 1.00 | 3.33 | 77.21 | 608.01 | 310 | 7,799 | 61,409 | 901 | 901 | 70,109 |
| -3 | 62 | 3,207 | 38 | 864.83 | 1.00 | 1.00 | 1.00 | 3.31 | 76.64 | 726.00 | 310 | 4,751 | 45,012 | 553 | 553 | 50,317 |
| -8 | 33 | 3,462 | 37 | 851.55 | 1.00 | 1.00 | 1.00 | 3.28 | 76.06 | 726.00 | 310 | 2,510 | 23,958 | 294 | 294 | 26,762 |
| -13 | 14 | 3,716 | 37 | 838.28 | 1.00 | 1.00 | 1.00 | 3.25 | 75.48 | 726.00 | 310 | 1,057 | 10,164 | 125 | 125 | 11,346 |
| -18 | 6 | 3,971 | 36 | 825.01 | 1.00 | 1.00 | 1.00 | 3.23 | 74.91 | 726.00 | 310 | 449 | 4,356 | 54 | 54 | 4,859 |
| -23 | 2 | 4,225 | 35 | 811.74 | 1.00 | 1.00 | 1.00 | 3.20 | 74.33 | 726.00 | 310 | 149 | 1,452 | 18 | 18 | 1,619 |
| Cooling | | | | | | | | | | | | 84,152 | 0 | 23,265 | 5,951 | 90,103 |
| Heating | | | | | | | | | | | | <u>406,219</u> | <u>875,724</u> | <u>54,856</u> | <u>41,162</u> | <u>1,323,105</u> |
| Total | | | | | | | | | | | | 490,371 | 875,724 | 78,122 | 47,113 | 1,413,207 |

maximum EWT. The estimated entering water temperatures are refined later in the design process as the ground-coupling system design is finalized.

Column 5 in Table A.4 is the net capacity of the ground-source heat pump equipment. This is taken from equipment specifications based on the entering water temperature. Columns 6, 7, and 8 are used to determine the loss in efficiency due to part-load operating characteristics of equipment, which result in increased

run-time on the units. The part-load factor is dependent on the equipment "degradation factor." The degradation factor is typically assumed to be 0.25 unless the equipment manufacturer has tested the unit and determined a lower value.

Column 10 is the input power of the ground-source heat pump equipment. Like the net capacity, this is taken from equipment specifications based on the entering water temperature. Column 9

is the efficiency of the ground-source heat pump alone and is determined by dividing the net capacity by the input power and correcting for the appropriate units of measure. The cooling efficiency is typically expressed as the Energy-Efficiency Ratio (EER) and has units of Btu/watt-h. Heating efficiency is typically expressed as the Coefficient of Performance (COP) and is a dimensionless measure.

Column 11 is the average input power required by the supplemental heaters to meet the estimated building heating load. It is estimated by taking the difference between the building heating load and the capacity of the heat pumps. When the ground-source heat pumps can meet the building load, there is no load on the supplemental heaters. The maximum load does not exceed the installed capacity of the supplemental heaters. Not included in this simplified example is an air-to-air heat recovery system that would reduce the need for supplemental heating. These recovery systems are common in cold region applications and are part of the basic rooftop unit.

The average pump flow rate in Column 12 is estimated based on the number of heat pumps, the actual run time (Column 8), and the rated flow per unit. Most ground-source heat pumps are rated at around 3 gpm per ton of cooling (0.054 L/s-kW), although manufacturers vary.

The ground-source heat pump energy consumption, Column 13, is the result of the input power multiplied by the run time multiplied by the number of hours in each bin (Column 10 x Column 8 x Column 2). The supplemental heater energy consumption is similarly estimated as the result of the supplemental heater power multiplied by the run time multiplied by the number of hours in each bin (Column 11 x Column 8 x Column 2).

The energy consumption of the ground-coupling loop is dependent on the configuration of the ground-coupling and control systems. For this example, it is assumed the net pressure rise of the circulation pump at full design flow is 48 psi and that, due to the control system, the variable-speed drive reduces the energy requirement as a square function of the flow rate. The total energy consumption (Column 16) is the sum of the component energy consumptions (Column 13 + Column 14 + Column 15). For the ground-source heat pump system in this example, the annual energy consumption

is estimated to be 1,413,207 kWh/yr. The monthly-billed demand is estimated by examining the corresponding temperature bin during the time the monthly peak demand is typically set for the facility. For this example, it is estimated that the demand is 4,355 kW-month/yr.

Not included in the sample equipment design is an air-to-air heat recovery system that would reduce the need for supplemental electric resistance heating. Heat pump manufacturers make these units available as part of the rooftop unit for installations in colder northern climates.

Similar spreadsheets were developed for each of the other technology alternatives using standard ASHRAE bin methods and are shown in Appendix A.

Life-Cycle Cost. The total installation cost, including material, labor, overhead, and profit, for the ground-source heat pump option is \$329,350 compared with the conventional system at \$454,100 and the air-source heat pump system

at \$213,000. The operations and maintenance cost for the ground-source heat pump system is estimated to be \$3,700/yr compared with \$8,775/yr for the conventional system and \$6,145/yr for the air-source heat pump system. Using the Building Life-Cycle Cost software (BLCC 4.0) available from the National Institute for Standards and Technology (NIST), the total life-cycle costs for the three alternatives are estimated at \$1,502,942 for the ground-source heat pump system, \$1,552,326 for the air-source heat pump system, and \$1,639,262 for the conventional system. A common life-cycle of 15 years was used in this analysis. More on Federal life cycle costing procedures and the BLCC software can be found in Appendix B.

A summary of the energy and cost factors from the three alternatives is shown in Table 4. A comparison of the air-source heat pump system with the ground-source heat pump alternative using BLCC is illustrated in Figure 8.

Table 4. Example 1: summary of results.

| Griffiss AFB, NY | Conventional System | Air-Source Heat Pump | Ground-Source Heat Pump |
|--|---------------------|----------------------|-------------------------|
| Number of units | 13 | 7 | 22 |
| Nominal capacity (tons) | | | |
| Each | 13.5 | 13.5 | 4.8 |
| Total | 175.5 | 94.5 | 105.6 |
| Supplemental heaters (kW) | | | |
| Each | n/a | 125 | 33 |
| Total | n/a | 875 | 726 |
| Equipment capacity (kBtu/h) (at design conditions) | | | |
| Summer | 2,535.0 | 1,360.1 | 1,270.1 |
| Winter | 3,510.0 | 3,395.0 | 3,336.6 |
| Energy Consumption (/yr) | | | |
| Electricity (kWh) | 252,908 | 1,656,555 | 1,413,207 |
| Demand (kW-mo) | 1,481 | 4,200 | 4,355 |
| Natural gas (therm) | 110,380 | 0 | 0 |
| Total energy (MBtu) | 11,901 | 5,562 | 4,822 |
| Energy Costs (\$/yr) | | | |
| Electricity | 12,645 | 82,828 | 70,660 |
| Demand | 8,160 | 23,142 | 23,996 |
| Natural gas | 59,605 | 0 | 0 |
| Total energy | 80,411 | 105,970 | 94,656 |
| O&M Costs (\$/yr) | 8,775 | 3,300 | 3,700 |
| Installed Cost (\$) | 454,100 | 212,500 | 329,300 |
| Equipment life (yr) | 15 | 15 | 15 |
| Total Life-Cycle Cost (\$) | 1,639,262 | 1,516,482 | 1,502,942 |

Example 2: Oklahoma City Facility

This example places the same building in a new environment. The location of the facility is in Oklahoma City, Oklahoma. Typical local weather conditions are 3,588°F-day/yr (base 65°F) heating degree-days (1,993 heating Celsius degree-days) and 2,068 (base 65°F) cooling degree-days (1,149 cooling Celsius degree-days). The 97.5% heating design temperature is 13°F (-10.6°C) and the 2.5% cooling design temperature is 96°F (35.6°C). The mean annual earth temperature is 62°F (16.7°C).

The local electric utility in this region is Oklahoma Gas & Electric Company (OG&E). The electric rate schedule for this example consists of a summer demand charge of \$12.35/kW-month, a winter demand charge of \$4.48/kW-month, and an energy charge of \$0.0236/kWh. The local natural gas utility is Oklahoma Natural Gas. The gas rate schedule consists of an energy charge of \$3.40/mcf (\$0.34/therm).

The corresponding heating load for this facility during the design day is estimated to be 2,392 kBtu/h (701.7 kW). The design cooling load is 1,832 kBtu/h (537.4 kW). The same balance temperature of 60°F (15.6°C) is estimated for the facility.

Technology Description. The same three technologies are compared in this example, but the number of units has changed because the building loads are now different. The conventional technology is a rooftop air-conditioning system with integral natural gas furnace heaters. To meet the cooling requirements during the actual cooling design day, 10 rooftop units are required. This number also meets the heating load requirements.

The second alternative is a rooftop air-source heat pump system with electric resistance supplemental heaters. To meet the cooling requirements during the actual cooling design day, 10 rooftop units are required. To meet the

```

NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS
BASE CASE: ASHP(a)
ALTERNATIVE: GSHP(b)

PRINCIPAL STUDY PARAMETERS:
ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
STUDY PERIOD: 15 YEARS (1995 THROUGH 2009)
DISCOUNT RATE: 3.0% Real (exclusive of general inflation)
BASE CASE LCC FILE: ASHP.LCC
ALTERNATIVE LCC FILE: GSHP.LCC

COMPARISON OF PRESENT-VALUE COSTS

```

| | BASE CASE: ASHP | ALTERNATIVE: GSHP | SAVINGS FROM ALT. |
|------------------------------------|--------------------|----------------------|----------------------|
| INITIAL INVESTMENT ITEM(S): | | | |
| CASH REQUIREMENTS AS OF OCCUPANCY | \$212,500 | \$329,300 | -\$116,800 |
| SUBTOTAL | \$212,500 | \$329,300 | -\$116,800 |
| FUTURE COST ITEMS: | | | |
| ANNUAL AND NON-AN. RECURRING COSTS | \$39,515 | \$46,170 | -\$6,656 |
| ENERGY EXPENDITURES | \$1,264,467 | \$1,129,472 | \$130,995 |
| SUBTOTAL | \$1,303,982 | \$1,173,642 | \$130,340 |
| TOTAL P.V. LIFE-CYCLE COST | \$1,516,482 | \$1,502,942 | \$13,540 |

```

NET SAVINGS FROM PROJECT GSHP COMPARED TO PROJECT ASHP

Net Savings = P.V. of non-investment savings $130,340
              - Increased total investment $116,800
              -----
Net Savings: $13,540

SAVINGS-TO-INVESTMENT RATIO (SIR)
FOR PROJECT GSHP COMPARED TO PROJECT ASHP

P.V. of non-investment savings
SIR = ----- = 1.12
Increased total investment

ADJUSTED INTERNAL RATE OF RETURN (AIRR)
FOR PROJECT RAK3LRP COMPARED TO PROJECT RAK3BAS
(Reinvestment rate = 3.00%; Study period = 15 years)

AIRR = 3.76%

ESTIMATED YEARS TO PAYBACK
Simple Payback occurs in year 11
Discounted Payback occurs in year 14

ENERGY SAVINGS SUMMARY

```

| Energy type | Units | ---Annual Consumption--- | | Energy Savings |
|-------------|-------|--------------------------|-------------|----------------|
| | | Base Case | Alternative | |
| Electricity | kWh | 1,656,555 | 1,413,207 | 243,348 |
| Natural Gas | Therm | 0 | 0 | 0 |

```

Note: the NS, SIR, and AIRR computations include differential capital
replacement costs and resale value (if any) as investment costs, per
NIST Handbook 135 (FEMP analysis only).

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- (a) File name for air-source heat pump (base case).
- (b) File name for ground-source heat pump alternative.

Figure 8. Building life-cycle cost (BLCC) output.

added load during the heating design day, each rooftop unit is equipped with a 50-kW supplemental heater.

The third alternative is a ground-source heat pump system using extended-range water-source heat pumps and a vertical closed-loop ground-coupling system. To meet the cooling requirements during the actual cooling design day, 35 units are required. To meet the added load during the heating design day, each unit is equipped with a 10-kW supplemental heater. The water-loop system employs a variable-speed drive for added energy savings.

Savings Potential. Energy consumption is estimated with the same spreadsheet temperature bin model as the previous case. The results are shown in Appendix A and summarized in Table 5.

Life-Cycle Cost. The total installation cost for the ground-source heat pump option (including material, labor, overhead, and profit) is estimated to be \$451,500, compared with the conventional system at \$349,300 and the air-source heat pump system at \$236,000. The operations and maintenance cost for the ground-source heat pump system is estimated to be \$5,880/yr, compared with \$6,750/yr for the conventional system and \$4,725/yr for the air-source heat pump system. Through BLCC, the total life-cycle costs for the three alternatives were estimated to be \$938,282 for the ground-source heat pump system, \$800,065 for the air-source heat pump system, and \$974,924 for the conventional system.

The fact that the ground-source heat pump system did not have the lowest life-cycle cost in this evaluation should not imply that ground-source heat pumps are never cost-effective in this region. On the contrary, the purpose of this example is to illustrate that the cost-effectiveness of ground-source heat pumps is a function of system heating and cooling load requirements, local

Table 5. Example 2: summary of results.

| Oklahoma City, OK | Conventional System | Air-Source Heat Pump | Ground-Source Heat Pump |
|---|---------------------|----------------------|-------------------------|
| Number of units: | 10 | 10 | 35 |
| Nominal capacity (tons) | | | |
| Each | 13.5 | 13.5 | 4.8 |
| Total | 135 | 13.5 | 168 |
| Supplemental heaters (kW) | | | |
| Each | n/a | 50 | 10 |
| Total | n/a | 500 | 350 |
| Equipment capacity (kBtu/h) (at design conditions) | | | |
| Summer | 1,848.0 | 1,822.7 | 1,864.6 |
| Winter | 2,700.0 | 2,621.0 | 2,611.5 |
| Energy Consumption (/yr) | | | |
| Electricity (kWh) | 467,708 | 850,469 | 687,333 |
| Demand (kW-mo) | | | |
| - Winter season | 455 | 2,748 | 1,931 |
| - Summer season | 842 | 770 | 770 |
| Natural gas (therm) | 54,081 | 0 | 0 |
| Total energy (MBtu) | 7,004 | 2,902 | 2,345 |
| Energy Costs (\$/yr) | | | |
| Electricity | 11,038 | 20,071 | 16,221 |
| Demand | 12,437 | 21,821 | 18,160 |
| Natural gas | 18,388 | 0 | 0 |
| Total energy | 41,863 | 41,892 | 34,381 |
| O&M Costs (\$/yr) | 6,750 | 4,725 | 5,880 |
| Installed Cost (\$) | 349,300 | 236,000 | 451,500 |
| Equipment life (yr) | 15 | 15 | 15 |
| Total Life-Cycle Cost (\$) | 974,924 | 800,065 | 938,282 |

utility costs, and most importantly, local installation costs. The reader is encouraged to perform similar calculations for a specific site.

The above examples assume that the facility will responsible for all costs associated with the construction and operation of the installed GSHP system. However, if the equipment were installed under the Super ESPC program, the installation cost could be zero and the economic justification for the project would be significantly different.

The Technology in Perspective

The future of ground-source heat pump technology in the Federal sector looks good because there are many potential commercial applications. Although installation costs are typically higher for ground-source heat pumps

than for other technologies, the decision criteria should be based on life-cycle costs rather than first costs (as required by 10 CFR 436); then, a ground-source heat pump system is frequently the most cost-effective alternative. According to the recent EPA study *Space Conditioning: The Next Frontier*, GSHPs are consistently the most energy-efficient, least polluting of all space conditioning technologies throughout the country (EPA 1993).

The limited industry volume has been one of the factors holding back the development of a broader contractor base. The technology has not enjoyed broad national promotion. According to the results of one survey on the barriers to ground-source heat pumps, HVAC, plumbing, and A/E contractors are conservative, and are therefore reluctant to commit to what they regard as innovative and (to some) unproven technology

and equipment (Technical Marketing Associates 1988). Installation of ground-source heat pump systems requires skills beyond those of most HVAC or plumbing contractors. Until recently, only a small number of contractors have performed enough installations to develop an extensive base of experience and expertise in ground-source heat pumps.

The Technology's Development

The ground-source heat pump technology has been shown through laboratory testing, field testing, and theoretical analysis to be technically valid and economically attractive in many applications. Energy savings have been verified in a large number of field tests over the past 30 years. In several installations, reductions in maintenance costs have also been verified. The technology has gained rapid acceptance from users.

The remaining barriers to rapid implementation include (1) acceptance from new users and engineers unfamiliar with the technology, (2) out-of-date cost estimating guides for construction and maintenance, (3) general lack of engineers able to design GSHP systems, and (4) lack of contractors to install and service GSHP systems. This Federal Technology Alert is intended to address some of these concerns by reporting on the collective experience of ground-source heat pump users and evaluators and by providing application guidance. For actual design guidance, readers should refer to any of the many publications available, some of which are listed at the end of this Federal Technology Alert.

Technology Outlook

The outlook for ground-source heat pumps is bright. In 1999, an estimated 400,000 ground-source heat pumps were operating in residential and commercial applications, up from 100,000 in 1990. In 1985, it was estimated that only around 14,000 ground-source heat pump systems were installed in the United States. Annual sales of approximately 45,000 units were reported in 1997. With a projected annual growth rate of 10%,

120,000 new units would be installed in 2010, for a total of 1.5 million units in 2010.

In Europe, the estimated total number of installed ground-source heat pumps at the end of 1998 was 100,000 to 120,000. Nearly 10,000 ground-source heat pumps have been installed in U.S. Federal buildings, over 400 schools, and thousands of low-income houses and apartments.

A government-industry-utility consortium (Geothermal Heat Pump Consortium, Inc.) was formed in 1994 to create a self-sustaining ground source heat pump market. The consortium consists of the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), the Edison Electric Institute (EEI), the National Rural Electric Cooperative Association, the Consortium for Energy Efficiency, electric utility companies, and most ground-source heat pump manufacturers. The goal of the consortium is to reach annual sales of 400,000 ground-source heat pumps by the year 2005.

The GSHP technology-specific Super ESPC allows Federal facilities to use private financing.

Manufacturers

There are a number of manufacturers of ground-source heat pumps and water-source heat pump that can be ground coupled. Appendix D contains a list of U.S. manufacturers provided by the Geothermal Heat Pump Consortium.

Who is Using the Technology

The list below identifies several Federal and private-sector contacts, agencies, and locations that already have ground-source heat pumps installed and operating. While not inclusive of all applications, it does provide a representative sample of the wide variety of existing GSHP projects. Many of the Federal energy managers are knowledgeable about ground-source heat pumps. The reader is invited to ask questions and learn more about the technology.

- YMCA
92-ton system
Bixby, OK
- Buckeye Power
58-ton system
Columbus, OH
- Fort Polk
several facilities
several sizes
Ft. Polk, LA
- Frank Knox School
114-ton system
Patuxent River Naval Air Station, MD
- Oklahoma State Capitol
855-ton system
Oklahoma City, OK
- Public School System
50 schools
Austin, TX
- Department of HUD
Apartment Complex
540-ton system
- Stockton State College
1,655-ton system
Pomona, NJ
- Paint Lick Elementary School
123-ton system
Garrard County, KY
- Salem Community College
2-80-ton systems
Carney's Point, NJ
- Love County Hospital
41-ton system
Marietta, OK
- Bachelor Enlisted Quarters
25-ton system
Marine Corps Air Station, NC
- Life Care Facility
840-ton system
Byrn Mawr, PA
- Yakima County Jail
300-ton system
Yakima, WA
- Lake City High School
503-ton system
Couer d'Alene, ID

For Further Information

Trade Associations

Electric Power Research Institute (EPRI)
P.O. Box 50490
3412 Hillview Ave.
Palo Alto, CA 94303
www.epri.com

Geothermal Heat Pump
Consortium, Inc.
Washington, D.C.
(202) 508-5222 Fax
www.ghpc.org

Geothermal Resource Council
P.O. Box 1350
Davis, CA 95617
www.geothermal.org

International Ground-Source Heat
Pump Association (IGSHPA)
498 Cordell South
Oklahoma State University
Stillwater, OK 74078
(800) 626-4747
(405) 744-5283 Fax
www.igshpa.okstate.edu

National Rural Electric Cooperative
Association (NRECA)
1800 Massachusetts Ave., NW
Washington, D.C. 20036
www.nreca.org

National Ground Water Association
601 Dempsey Road
Westerville, OH 43801
(800) 551-7379
www.ngwa.org

Michigan Geothermal Energy
Association
Lansing, MI
www.earthcomfort.com

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Oklahoma State University Ground
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Appendixes

Appendix A: Sample Case Spreadsheet Models

Appendix B: Federal Life-Cycle Costing Procedures and the BLCC Software

Appendix C: Performance and Efficiency Terminology Defined

Appendix D: Ground-Source Heat Pump Manufacturers

Appendix E: ARI Rating Conditions

Appendix A

Sample Case Spreadsheet Models

Table A.1. Griffiss AFB Conventional Air-Conditioning and Gas Furnace System Energy Consumption Bin Method Analysis.

| Avg. Bin Temp (°F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Net Equip. Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | A/C Effy. (EER) | A/C Input Power (kW) | A/C Electric Energy (kWh) | Fan Energy (kWh) | Total Electric Energy (kWh) | Nat. Gas Furnace Energy (therms) |
|----------------------|------------------|---------------------|------------------------------|---------------------|---------------------|---------------------|-----------------|----------------------|---------------------------|------------------|-----------------------------|----------------------------------|
| (1) | (2) | (3) | (5) | (6) | (7) | (8) | (9) | (10) | (13) | (14) | (17) | (18) |
| Cooling Mode: | | | | | | | | | | | | |
| 112 | 0 | 2,648 | 2,107.30 | 1.00 | 1.00 | 1.00 | 8.63 | 244.27 | 0 | 0 | 0 | n/a |
| 107 | 0 | 2,393 | 2,217.80 | 1.00 | 1.00 | 1.00 | 9.25 | 239.72 | 0 | 0 | 0 | n/a |
| 102 | 0 | 2,139 | 2,308.80 | 0.93 | 0.98 | 0.94 | 9.95 | 232.05 | 0 | 0 | 0 | n/a |
| 97 | 4 | 1,884 | 2,386.80 | 0.79 | 0.95 | 0.83 | 10.74 | 222.30 | 741 | 224 | 965 | n/a |
| 92 | 15 | 1,629 | 2,453.10 | 0.66 | 0.92 | 0.73 | 11.29 | 217.23 | 2,363 | 731 | 3,094 | n/a |
| 87 | 88 | 1,375 | 2,511.60 | 0.55 | 0.89 | 0.62 | 11.67 | 215.28 | 11,693 | 3,651 | 15,344 | n/a |
| 82 | 206 | 1,120 | 2,570.10 | 0.44 | 0.86 | 0.51 | 12.05 | 213.33 | 22,300 | 7,026 | 29,326 | n/a |
| 77 | 360 | 866 | 2,628.60 | 0.33 | 0.83 | 0.40 | 12.44 | 211.38 | 30,108 | 9,573 | 39,681 | n/a |
| 72 | 540 | 611 | 2,687.10 | 0.23 | 0.81 | 0.28 | 12.83 | 209.43 | 31,873 | 10,229 | 42,102 | n/a |
| 67 | 690 | 356 | 2,745.60 | 0.13 | 0.78 | 0.17 | 13.23 | 207.48 | 23,753 | 7,694 | 31,447 | n/a |
| 62 | 704 | 102 | 2,804.10 | 0.04 | 0.76 | 0.05 | 13.64 | 205.53 | 6,923 | 2,264 | 9,187 | n/a |
| Heating Mode: | | | | | | | | | | | | |
| 57 | 680 | 153 | 3,510.00 | 0.04 | 0.76 | 0.06 | n/a | n/a | n/a | 1,264 | 1,264 | 1,706 |
| 52 | 671 | 407 | 3,510.00 | 0.12 | 0.78 | 0.15 | n/a | n/a | n/a | 3,248 | 3,248 | 4,385 |
| 47 | 618 | 662 | 3,510.00 | 0.19 | 0.80 | 0.24 | n/a | n/a | n/a | 4,751 | 4,751 | 6,413 |
| 42 | 631 | 916 | 3,510.00 | 0.26 | 0.82 | 0.32 | n/a | n/a | n/a | 6,567 | 6,567 | 8,865 |
| 37 | 754 | 1,171 | 3,510.00 | 0.33 | 0.83 | 0.40 | n/a | n/a | n/a | 9,809 | 9,809 | 13,242 |
| 32 | 821 | 1,425 | 3,510.00 | 0.41 | 0.85 | 0.48 | n/a | n/a | n/a | 12,725 | 12,725 | 17,179 |
| 27 | 580 | 1,680 | 3,510.00 | 0.48 | 0.87 | 0.55 | n/a | n/a | n/a | 10,374 | 10,374 | 14,005 |
| 22 | 441 | 1,934 | 3,510.00 | 0.55 | 0.89 | 0.62 | n/a | n/a | n/a | 8,898 | 8,898 | 12,012 |
| 17 | 326 | 2,189 | 3,510.00 | 0.62 | 0.91 | 0.69 | n/a | n/a | n/a | 7,294 | 7,294 | 9,847 |
| 12 | 242 | 2,444 | 3,510.00 | 0.70 | 0.92 | 0.75 | n/a | n/a | n/a | 5,925 | 5,925 | 7,999 |
| 7 | 165 | 2,698 | 3,510.00 | 0.77 | 0.94 | 0.82 | n/a | n/a | n/a | 4,375 | 4,375 | 5,906 |
| 2 | 101 | 2,953 | 3,510.00 | 0.84 | 0.96 | 0.88 | n/a | n/a | n/a | 2,875 | 2,875 | 3,882 |
| -3 | 62 | 3,207 | 3,510.00 | 0.91 | 0.98 | 0.93 | n/a | n/a | n/a | 1,882 | 1,882 | 2,540 |
| -8 | 33 | 3,462 | 3,510.00 | 0.99 | 1.00 | 0.99 | n/a | n/a | n/a | 1,061 | 1,061 | 1,433 |
| -13 | 14 | 3,716 | 3,510.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | n/a | 455 | 455 | 614 |
| -18 | 6 | 3,971 | 3,510.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | n/a | 195 | 195 | 263 |
| -23 | 2 | 4,225 | 3,510.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | n/a | 65 | 65 | 88 |
| Cooling | | | | | | | | | 129,754 | 41,391 | 171,145 | 0 |
| Heating | | | | | | | | | 0 | <u>81,763</u> | <u>81,763</u> | <u>110,380</u> |
| Total | | | | | | | | | 129,754 | 123,154 | 252,908 | 110,380 |

FEDERAL ENERGY MANAGEMENT PROGRAM

Table A.2. Griffiss AFB Air-Source Heat Pump System Energy Consumption Bin Method Analysis.

| Avg. Bin Temp (°F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Net ASHP Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | ASHP Eff'y. (EER or COP) | ASHP Input Power (kW) | Suppl. Heater Power (kW) | ASHP Electric Energy (kWh) | Suppl. Heater Energy (kWh) | Total Electric Energy (kWh) |
|----------------------|------------------|---------------------|----------------------------|---------------------|---------------------|---------------------|--------------------------|-----------------------|--------------------------|----------------------------|----------------------------|-----------------------------|
| (1) | (2) | (3) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (13) | (15) | (17) |
| Cooling Mode: | | | | | | | | | | | | |
| 112 | 0 | 2,648 | 1,153.46 | 1.00 | 1.00 | 1.00 | 9.48 | 121.73 | n/a | 0 | 0 | 0 |
| 107 | 0 | 2,393 | 1,191.73 | 1.00 | 1.00 | 1.00 | 10.09 | 118.11 | n/a | 0 | 0 | 0 |
| 102 | 0 | 2,139 | 1,229.99 | 1.00 | 1.00 | 1.00 | 10.74 | 114.50 | n/a | 0 | 0 | 0 |
| 97 | 4 | 1,884 | 1,268.26 | 1.00 | 1.00 | 1.00 | 11.44 | 110.88 | n/a | 444 | 0 | 444 |
| 92 | 15 | 1,629 | 1,306.53 | 1.00 | 1.00 | 1.00 | 12.18 | 107.26 | n/a | 1,609 | 0 | 1,609 |
| 87 | 88 | 1,375 | 1,344.79 | 1.00 | 1.00 | 1.00 | 12.97 | 103.65 | n/a | 9,121 | 0 | 9,121 |
| 82 | 206 | 1,120 | 1,383.06 | 0.81 | 0.95 | 0.85 | 13.83 | 100.03 | n/a | 17,523 | 0 | 17,523 |
| 77 | 360 | 866 | 1,421.33 | 0.61 | 0.90 | 0.68 | 14.74 | 96.41 | n/a | 23,429 | 0 | 23,429 |
| 72 | 540 | 611 | 1,459.59 | 0.42 | 0.85 | 0.49 | 15.73 | 92.80 | n/a | 24,545 | 0 | 24,545 |
| 67 | 690 | 356 | 1,497.86 | 0.24 | 0.81 | 0.29 | 16.80 | 89.18 | n/a | 18,089 | 0 | 18,089 |
| 62 | 704 | 102 | 1,536.13 | 0.07 | 0.77 | 0.09 | 17.95 | 85.56 | n/a | 5,210 | 0 | 5,210 |
| Heating Mode: | | | | | | | | | | | | |
| 57 | 680 | 153 | 1,413.30 | 0.11 | 0.78 | 0.14 | 3.11 | 133.14 | 0.00 | 12,591 | 0 | 12,591 |
| 52 | 671 | 407 | 1,318.80 | 0.31 | 0.83 | 0.37 | 3.03 | 127.54 | 0.00 | 31,949 | 0 | 31,949 |
| 47 | 618 | 662 | 1,226.40 | 0.54 | 0.88 | 0.61 | 2.93 | 122.57 | 0.00 | 46,192 | 0 | 46,192 |
| 42 | 631 | 916 | 1,135.40 | 0.81 | 0.95 | 0.85 | 2.82 | 118.02 | 0.00 | 63,148 | 0 | 63,148 |
| 37 | 754 | 1,171 | 1,012.90 | 1.00 | 1.00 | 1.00 | 2.61 | 113.89 | 46.30 | 85,873 | 34,910 | 120,784 |
| 32 | 821 | 1,425 | 869.40 | 1.00 | 1.00 | 1.00 | 2.32 | 110.04 | 162.96 | 90,343 | 133,789 | 224,132 |
| 27 | 580 | 1,680 | 782.60 | 1.00 | 1.00 | 1.00 | 2.14 | 107.03 | 263.00 | 62,077 | 152,540 | 214,617 |
| 22 | 441 | 1,934 | 733.60 | 1.00 | 1.00 | 1.00 | 2.06 | 104.58 | 351.96 | 46,120 | 155,215 | 201,335 |
| 17 | 326 | 2,189 | 682.50 | 1.00 | 1.00 | 1.00 | 1.96 | 101.92 | 441.54 | 33,226 | 143,942 | 177,168 |
| 12 | 242 | 2,444 | 630.00 | 1.00 | 1.00 | 1.00 | 1.86 | 99.12 | 531.53 | 23,987 | 128,629 | 152,617 |
| 7 | 165 | 2,698 | 567.00 | 1.00 | 1.00 | 1.00 | 1.76 | 94.43 | 624.59 | 15,581 | 103,058 | 118,639 |
| 2 | 101 | 2,953 | 497.00 | 1.00 | 1.00 | 1.00 | 1.65 | 88.48 | 719.71 | 8,936 | 72,691 | 81,627 |
| -3 | 62 | 3,207 | 433.30 | 1.00 | 1.00 | 1.00 | 1.52 | 83.58 | 875.00 | 5,182 | 54,250 | 59,432 |
| -8 | 33 | 3,462 | 373.80 | 1.00 | 1.00 | 1.00 | 1.38 | 79.38 | 875.00 | 2,620 | 28,875 | 31,495 |
| -13 | 14 | 3,716 | 337.40 | 1.00 | 1.00 | 1.00 | 1.32 | 75.18 | 875.00 | 1,053 | 12,250 | 13,303 |
| -18 | 6 | 3,971 | 316.40 | 1.00 | 1.00 | 1.00 | 1.31 | 70.98 | 875.00 | 426 | 5,250 | 5,676 |
| -23 | 2 | 4,225 | 295.40 | 1.00 | 1.00 | 1.00 | 1.30 | 66.78 | 875.00 | 134 | 1,750 | 1,884 |
| Cooling | | | | | | | | | | 99,969 | 0 | 99,969 |
| Heating | | | | | | | | | | <u>529,437</u> | <u>1,027,149</u> | <u>1,556,586</u> |
| Total | | | | | | | | | | 629,406 | 1,027,149 | 1,656,555 |

FEDERAL ENERGY MANAGEMENT PROGRAM

Table A.3. Griffiss AFB Ground-Source Heat Pump System Energy Consumption Bin Method Analysis.

| Avg. Bin Temp. (°F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Entering Water Temp. (°F) | Net GSHP Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | GSHP Effy. (EER or COP) | GSHP Input Power (kW) | Suppl. Heater Power (kW) | Pump Flow Rate (gpm) | GSHP Electric Energy (kWh) | Suppl. Heater Energy (kWh) | Circ. Pump Energy (kWh) | Circ. Pump Energy (kWh) | Total Electric Energy (kWh) |
|----------------------|------------------|---------------------|---------------------------|----------------------------|---------------------|---------------------|---------------------|-------------------------|-----------------------|--------------------------|----------------------|----------------------------|----------------------------|-------------------------|-------------------------|-----------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (15) | (16cv) | (16vsd) | (17) |
| Cooling Mode: | | | | | | | | | | | | | | | | |
| 112 | 0 | 2,648 | 122 | 1,038.36 | 1.00 | 1.00 | 1.00 | 8.99 | 115.53 | n/a | 310 | 0 | 0 | 0 | 0 | 0 |
| 107 | 0 | 2,393 | 115 | 1,081.28 | 1.00 | 1.00 | 1.00 | 9.81 | 110.28 | n/a | 310 | 0 | 0 | 0 | 0 | 0 |
| 102 | 0 | 2,139 | 108 | 1,124.19 | 1.00 | 1.00 | 1.00 | 10.70 | 105.02 | n/a | 310 | 0 | 0 | 0 | 0 | 0 |
| 97 | 4 | 1,884 | 101 | 1,167.11 | 1.00 | 1.00 | 1.00 | 11.70 | 99.76 | n/a | 310 | 399 | 0 | 36 | 36 | 435 |
| 92 | 15 | 1,629 | 94 | 1,210.02 | 1.00 | 1.00 | 1.00 | 12.80 | 94.51 | n/a | 310 | 1,418 | 0 | 134 | 134 | 1,551 |
| 87 | 88 | 1,375 | 87 | 1,252.94 | 1.00 | 1.00 | 1.00 | 14.04 | 89.25 | n/a | 310 | 7,854 | 0 | 785 | 785 | 8,639 |
| 82 | 206 | 1,120 | 80 | 1,295.85 | 0.86 | 0.97 | 0.89 | 15.43 | 83.99 | n/a | 278 | 15,482 | 0 | 1,838 | 1,472 | 16,954 |
| 77 | 360 | 866 | 73 | 1,338.77 | 0.65 | 0.91 | 0.71 | 17.00 | 78.74 | n/a | 220 | 20,104 | 0 | 3,213 | 1,616 | 21,720 |
| 72 | 540 | 611 | 66 | 1,381.68 | 0.44 | 0.86 | 0.51 | 18.80 | 73.48 | n/a | 159 | 20,391 | 0 | 4,819 | 1,273 | 21,664 |
| 67 | 690 | 356 | 59 | 1,424.60 | 0.25 | 0.81 | 0.31 | 20.88 | 68.22 | n/a | 96 | 14,495 | 0 | 6,158 | 584 | 15,079 |
| 62 | 704 | 102 | 52 | 1,467.51 | 0.07 | 0.77 | 0.09 | 23.31 | 62.97 | n/a | 28 | 4,009 | 0 | 6,283 | 51 | 4,060 |
| Heating Mode: | | | | | | | | | | | | | | | | |
| 57 | 680 | 153 | 48 | 1,024.10 | 0.15 | 0.79 | 0.19 | 3.59 | 83.56 | 0.00 | 59 | 10,763 | 0 | 6,068 | 218 | 10,981 |
| 52 | 671 | 407 | 48 | 1,010.83 | 0.40 | 0.85 | 0.47 | 3.57 | 82.98 | 0.00 | 147 | 26,371 | 0 | 5,988 | 1,343 | 27,714 |
| 47 | 618 | 662 | 47 | 997.55 | 0.66 | 0.92 | 0.72 | 3.55 | 82.41 | 0.00 | 225 | 36,891 | 0 | 5,515 | 2,894 | 39,785 |
| 42 | 631 | 916 | 46 | 984.28 | 0.93 | 0.98 | 0.95 | 3.53 | 81.83 | 0.00 | 294 | 48,915 | 0 | 5,631 | 5,053 | 53,968 |
| 37 | 754 | 1,171 | 45 | 971.01 | 1.00 | 1.00 | 1.00 | 3.50 | 81.25 | 58.58 | 310 | 61,265 | 44,168 | 6,729 | 6,729 | 112,162 |
| 32 | 821 | 1,425 | 44 | 957.74 | 1.00 | 1.00 | 1.00 | 3.48 | 80.68 | 137.07 | 310 | 66,235 | 112,534 | 7,327 | 7,327 | 186,096 |
| 27 | 580 | 1,680 | 43 | 944.46 | 1.00 | 1.00 | 1.00 | 3.46 | 80.10 | 215.56 | 310 | 46,458 | 125,025 | 5,176 | 5,176 | 176,658 |
| 22 | 441 | 1,934 | 43 | 931.19 | 1.00 | 1.00 | 1.00 | 3.43 | 79.52 | 294.05 | 310 | 35,069 | 129,676 | 3,936 | 3,936 | 168,681 |
| 17 | 326 | 2,189 | 42 | 917.92 | 1.00 | 1.00 | 1.00 | 3.41 | 78.95 | 372.54 | 310 | 25,736 | 121,449 | 2,909 | 2,909 | 150,094 |
| 12 | 242 | 2,444 | 41 | 904.65 | 1.00 | 1.00 | 1.00 | 3.38 | 78.37 | 451.03 | 310 | 18,965 | 109,150 | 2,160 | 2,160 | 130,275 |
| 7 | 165 | 2,698 | 40 | 891.37 | 1.00 | 1.00 | 1.00 | 3.36 | 77.79 | 529.52 | 310 | 12,836 | 87,371 | 1,472 | 1,472 | 101,679 |
| 2 | 101 | 2,953 | 39 | 878.10 | 1.00 | 1.00 | 1.00 | 3.33 | 77.21 | 608.01 | 310 | 7,799 | 61,409 | 901 | 901 | 70,109 |
| -3 | 62 | 3,207 | 38 | 864.83 | 1.00 | 1.00 | 1.00 | 3.31 | 76.64 | 726.00 | 310 | 4,751 | 45,012 | 553 | 553 | 50,317 |
| -8 | 33 | 3,462 | 37 | 851.55 | 1.00 | 1.00 | 1.00 | 3.28 | 76.06 | 726.00 | 310 | 2,510 | 23,958 | 294 | 294 | 26,762 |
| -13 | 14 | 3,716 | 37 | 838.28 | 1.00 | 1.00 | 1.00 | 3.25 | 75.48 | 726.00 | 310 | 1,057 | 10,164 | 125 | 125 | 11,346 |
| -18 | 6 | 3,971 | 36 | 825.01 | 1.00 | 1.00 | 1.00 | 3.23 | 74.91 | 726.00 | 310 | 449 | 4,356 | 54 | 54 | 4,859 |
| -23 | 2 | 4,225 | 35 | 811.74 | 1.00 | 1.00 | 1.00 | 3.20 | 74.33 | 726.00 | 310 | 149 | 1,452 | 18 | 18 | 1,619 |
| Cooling | | | | | | | | | | | | 84,152 | 0 | 23,265 | 5,951 | 90,103 |
| Heating | | | | | | | | | | | | <u>406,219</u> | <u>875,724</u> | <u>54,856</u> | <u>41,162</u> | <u>1,323,105</u> |
| Total | | | | | | | | | | | | 490,371 | 875,724 | 78,122 | 47,113 | 1,413,207 |

FEDERAL ENERGY MANAGEMENT PROGRAM

Table A.4. Summary of Equations for Bin Method Energy Consumption Analysis.

| Column | Season | Description / Equation |
|---------|---------|---|
| (1) | both | Average bin temperature = Midpoint of temperature bin from weather data |
| (2) | both | Bin hours = Number of hours in temperature bin from weather data |
| (3) | cooling | Building load = (avg. bin temp. - fac. balance temp.) * [(fac. design load) / (fac. design temp. - fac. balance temp.)] |
| | heating | = (fac. balance temp. - avg. bin temp.) * [(fac. design load) / (fac. balance temp. - fac. design temp.)] |
| (4) | cooling | Entering water temperature = (ground temp.) + [(max. entering water temp. - ground temp.) / (max. bin temp. - fac. balance temp.)] * (avg. bin temp. - fac. balance temp.) |
| | heating | = (min. entering water temp.) + [(ground temp. - min. entering water temp.) / (fac. balance temp. - min. bin temp.)] * (avg. bin temp. - min. bin temp.) |
| (5) | both | Net equipment capacity = base on equipment specifications corrected for temperature |
| (6) | both | Theoretical run time = (column 3) / (column 5); maximum = 1.00 |
| (7) | both | Partial load factor = 1.00 - { degradation factor * [1.00 - (column 6)] }; maximum = 1.00 |
| (8) | both | Actual run time = (column 6) / (column 7) |
| (9) | cooling | Efficiency = (column 5) / (column 10) |
| | heating | = (column 5) / [(column 10) * 3.412] |
| (10) | both | HVAC equipment input power = based on equipment specifications corrected for temperature, may also include indoor and outdoor fan power |
| (11) | heating | Supplemental heater power = [(column 3) - (column 5)] / 3.412; minimum = 0, maximum = capacity |
| (12) | both | Average water-loop pump flow rate = [no. of units * flow rate per unit * (column 8)] |
| (13) | both | HVAC equipment energy = (column 2) * (column 8) * (column 10) |
| (14) | cooling | Fan energy = (column 2) * (column 8) * (total indoor air fan load + total outdoor air fan load); ignore if included in column 10 |
| | heating | = (column 2) * (column 8) * (total indoor air fan load); ignore if included in column 10 |
| (15) | heating | Supplemental heater energy = (column 2) * (column 11) |
| (16cv) | both | Constant-volume water-loop pump energy = [no. of units * flow rate per unit * pump pressure rise in p.s.i. * 0.746 * (column 2)] / [1715 * pump eff. * motor eff.] |
| (16vsd) | both | Variable-speed drive water-loop pump energy = (column 16cv) * [(column 8)^2] |
| (17) | both | Total electric energy = (column 13) + (column 14) + (column 15) + (column 16) |
| (18) | heating | Total natural gas furnace energy = (column 2) * (column 5) * (column 8) / [AFUE * 100] |

FEDERAL ENERGY MANAGEMENT PROGRAM

Table A.5. Oklahoma City Conventional Air-Conditioning and Gas Furnace System Energy Consumption Bin Method Analysis.

| Avg. Bin Temp ('F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Net Equip. Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | A/C Eff'y. (EER) | A/C Input Power (kW) | A/C Electric Energy (kWh) | Fan Energy (kWh) | Total Electric Energy (kWh) | Nat. Gas Furnace Energy (therms) |
|----------------------|------------------|---------------------|------------------------------|---------------------|---------------------|---------------------|------------------|----------------------|---------------------------|------------------|-----------------------------|----------------------------------|
| (1) | (2) | (3) | (5) | (6) | (7) | (8) | (9) | (10) | (13) | (14) | (17) | (18) |
| Cooling Mode: | | | | | | | | | | | | |
| 112 | 0 | 2,646 | 1,621.00 | 1.00 | 1.00 | 1.00 | 8.63 | 187.90 | 0 | 0 | 0 | 0 |
| 107 | 1 | 2,392 | 1,706.00 | 1.00 | 1.00 | 1.00 | 9.25 | 184.40 | 184 | 52 | 236 | 0 |
| 102 | 18 | 2,137 | 1,776.00 | 1.00 | 1.00 | 1.00 | 9.95 | 178.50 | 3,213 | 931 | 4,144 | 0 |
| 97 | 94 | 1,883 | 1,836.00 | 1.00 | 1.00 | 1.00 | 10.74 | 171.00 | 16,074 | 4,860 | 20,934 | 0 |
| 92 | 240 | 1,628 | 1,887.00 | 0.86 | 0.97 | 0.89 | 11.29 | 167.10 | 35,837 | 11,088 | 46,924 | 0 |
| 87 | 393 | 1,374 | 1,932.00 | 0.71 | 0.93 | 0.77 | 11.67 | 165.60 | 49,886 | 15,574 | 65,461 | 0 |
| 82 | 603 | 1,120 | 1,977.00 | 0.57 | 0.89 | 0.64 | 12.05 | 164.10 | 62,850 | 19,801 | 82,652 | 0 |
| 77 | 829 | 865 | 2,022.00 | 0.43 | 0.86 | 0.50 | 12.44 | 162.60 | 67,298 | 21,398 | 88,696 | 0 |
| 72 | 948 | 611 | 2,067.00 | 0.30 | 0.82 | 0.36 | 12.83 | 161.10 | 54,766 | 17,576 | 72,342 | 0 |
| 67 | 819 | 356 | 2,112.00 | 0.17 | 0.79 | 0.21 | 13.23 | 159.60 | 27,831 | 9,015 | 36,846 | 0 |
| 62 | 729 | 102 | 2,157.00 | 0.05 | 0.76 | 0.06 | 13.64 | 158.10 | 7,139 | 2,334 | 9,473 | 0 |
| Heating Mode: | | | | | | | | | | | | |
| 57 | 654 | 153 | 2,700.00 | 0.06 | 0.76 | 0.07 | n/a | n/a | 0 | 1,210 | 1,210 | 1,633 |
| 52 | 627 | 407 | 2,700.00 | 0.15 | 0.79 | 0.19 | n/a | n/a | 0 | 3,001 | 3,001 | 4,051 |
| 47 | 608 | 662 | 2,700.00 | 0.25 | 0.81 | 0.30 | n/a | n/a | 0 | 4,591 | 4,591 | 6,198 |
| 42 | 592 | 916 | 2,700.00 | 0.34 | 0.83 | 0.41 | n/a | n/a | 0 | 6,015 | 6,015 | 8,120 |
| 37 | 537 | 1,171 | 2,700.00 | 0.43 | 0.86 | 0.51 | n/a | n/a | 0 | 6,780 | 6,780 | 9,154 |
| 32 | 446 | 1,425 | 2,700.00 | 0.53 | 0.88 | 0.60 | n/a | n/a | 0 | 6,673 | 6,673 | 9,008 |
| 27 | 282 | 1,679 | 2,700.00 | 0.62 | 0.91 | 0.69 | n/a | n/a | 0 | 4,843 | 4,843 | 6,538 |
| 22 | 174 | 1,934 | 2,700.00 | 0.72 | 0.93 | 0.77 | n/a | n/a | 0 | 3,354 | 3,354 | 4,527 |
| 17 | 85 | 2,188 | 2,700.00 | 0.81 | 0.95 | 0.85 | n/a | n/a | 0 | 1,808 | 1,808 | 2,441 |
| 12 | 49 | 2,443 | 2,700.00 | 0.90 | 0.98 | 0.93 | n/a | n/a | 0 | 1,135 | 1,135 | 1,533 |
| 7 | 16 | 2,697 | 2,700.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | 0 | 400 | 400 | 540 |
| 2 | 9 | 2,952 | 2,700.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | 0 | 225 | 225 | 304 |
| -3 | 1 | 3,206 | 2,700.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | 0 | 25 | 25 | 34 |
| -8 | 0 | 3,461 | 2,700.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | 0 | 0 | 0 | 0 |
| -13 | 0 | 3,715 | 2,700.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | 0 | 0 | 0 | 0 |
| -18 | 0 | 3,970 | 2,700.00 | 1.00 | 1.00 | 1.00 | n/a | n/a | 0 | 0 | 0 | 0 |
| Cooling | | | | | | | | | 325,079 | 102,629 | 427,708 | 0 |
| Heating | | | | | | | | | 0 | 40,060 | 40,060 | 54,081 |
| Total | | | | | | | | | 325,079 | 142,688 | 467,768 | 54,081 |

FEDERAL ENERGY MANAGEMENT PROGRAM

Table A.6. Oklahoma City Air-Source Heat Pump System Energy Consumption Bin Method Analysis.

| Avg. Bin Temp (°F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Net ASHP Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | ASHP Eff'y. (EER or COP) | ASHP Input Power (kW) | Suppl. Heater Power (kW) | ASHP Electric Energy (kWh) | Suppl. Heater Energy (kWh) | Total Electric Energy (kWh) |
|--------------------|------------------|---------------------|----------------------------|---------------------|---------------------|---------------------|--------------------------|-----------------------|--------------------------|----------------------------|----------------------------|-----------------------------|
| (1) | (2) | (3) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (13) | (15) | (17) |
| Cooling Mode: | | | | | | | | | | | | |
| 112 | 0 | 2,646 | 1,647.80 | 1.00 | 1.00 | 1.00 | 9.48 | 173.90 | n/a | 0 | 0 | 0 |
| 107 | 1 | 2,392 | 1,702.47 | 1.00 | 1.00 | 1.00 | 10.09 | 168.73 | n/a | 169 | 0 | 169 |
| 102 | 18 | 2,137 | 1,757.13 | 1.00 | 1.00 | 1.00 | 10.74 | 163.57 | n/a | 2,944 | 0 | 2,944 |
| 97 | 94 | 1,883 | 1,811.80 | 1.00 | 1.00 | 1.00 | 11.44 | 158.40 | n/a | 14,890 | 0 | 14,890 |
| 92 | 240 | 1,628 | 1,866.47 | 0.87 | 0.97 | 0.90 | 12.18 | 153.23 | n/a | 33,143 | 0 | 33,143 |
| 87 | 393 | 1,374 | 1,921.13 | 0.72 | 0.93 | 0.77 | 12.97 | 148.07 | n/a | 44,808 | 0 | 44,808 |
| 82 | 603 | 1,120 | 1,975.80 | 0.57 | 0.89 | 0.64 | 13.83 | 142.90 | n/a | 54,759 | 0 | 54,759 |
| 77 | 829 | 865 | 2,030.47 | 0.43 | 0.86 | 0.50 | 14.74 | 137.73 | n/a | 56,798 | 0 | 56,798 |
| 72 | 948 | 611 | 2,085.13 | 0.29 | 0.82 | 0.36 | 15.73 | 132.57 | n/a | 44,709 | 0 | 44,709 |
| 67 | 819 | 356 | 2,139.80 | 0.17 | 0.79 | 0.21 | 16.80 | 127.40 | n/a | 21,942 | 0 | 21,942 |
| 62 | 729 | 102 | 2,194.47 | 0.05 | 0.76 | 0.06 | 17.95 | 122.23 | n/a | 5,426 | 0 | 5,426 |
| Heating Mode: | | | | | | | | | | | | |
| 57 | 654 | 153 | 2,019.00 | 0.08 | 0.77 | 0.10 | 3.11 | 190.20 | 0.00 | 12,234 | 0 | 12,234 |
| 52 | 627 | 407 | 1,884.00 | 0.22 | 0.80 | 0.27 | 3.03 | 182.20 | 0.00 | 30,706 | 0 | 30,706 |
| 47 | 608 | 662 | 1,752.00 | 0.38 | 0.84 | 0.45 | 2.93 | 175.10 | 0.00 | 47,611 | 0 | 47,611 |
| 42 | 592 | 916 | 1,622.00 | 0.56 | 0.89 | 0.63 | 2.82 | 168.60 | 0.00 | 63,254 | 0 | 63,254 |
| 37 | 537 | 1,171 | 1,447.00 | 0.81 | 0.95 | 0.85 | 2.61 | 162.70 | 0.00 | 74,223 | 0 | 74,223 |
| 32 | 446 | 1,425 | 1,242.00 | 1.00 | 1.00 | 1.00 | 2.32 | 157.20 | 53.64 | 70,111 | 23,924 | 94,035 |
| 27 | 282 | 1,679 | 1,118.00 | 1.00 | 1.00 | 1.00 | 2.14 | 152.90 | 164.56 | 43,118 | 46,407 | 89,525 |
| 22 | 174 | 1,934 | 1,048.00 | 1.00 | 1.00 | 1.00 | 2.06 | 149.40 | 259.66 | 25,996 | 45,181 | 71,176 |
| 17 | 85 | 2,188 | 975.00 | 1.00 | 1.00 | 1.00 | 1.96 | 145.60 | 355.63 | 12,376 | 30,229 | 42,605 |
| 12 | 49 | 2,443 | 900.00 | 1.00 | 1.00 | 1.00 | 1.86 | 141.60 | 452.20 | 6,938 | 22,158 | 29,096 |
| 7 | 16 | 2,697 | 810.00 | 1.00 | 1.00 | 1.00 | 1.76 | 134.90 | 500.00 | 2,158 | 8,000 | 10,158 |
| 2 | 9 | 2,952 | 710.00 | 1.00 | 1.00 | 1.00 | 1.65 | 126.40 | 500.00 | 1,138 | 4,500 | 5,638 |
| -3 | 1 | 3,206 | 619.00 | 1.00 | 1.00 | 1.00 | 1.52 | 119.40 | 500.00 | 119 | 500 | 619 |
| -8 | 0 | 3,461 | 534.00 | 1.00 | 1.00 | 1.00 | 1.38 | 113.40 | 500.00 | 0 | 0 | 0 |
| -13 | 0 | 3,715 | 482.00 | 1.00 | 1.00 | 1.00 | 1.32 | 107.40 | 500.00 | 0 | 0 | 0 |
| -18 | 0 | 3,970 | 452.00 | 1.00 | 1.00 | 1.00 | 1.31 | 101.40 | 500.00 | 0 | 0 | 0 |
| Cooling | | | | | | | | | | 279,589 | 0 | 279,589 |
| Heating | | | | | | | | | | <u>389,983</u> | <u>180,898</u> | <u>570,880</u> |
| Total | | | | | | | | | | 669,571 | 180,898 | 850,469 |

FEDERAL ENERGY MANAGEMENT PROGRAM

Table A.7. Oklahoma City Ground-Source Heat Pump Energy Consumption Bin Method Analysis.

| Avg. Bin Temp. (°F) | Bin Hours (h/yr) | Bldg. Load (kBtu/h) | Entering Water Temp. (°F) | Net GSHP Capacity (kBtu/h) | Theor. Run Time (%) | Partial Load Factor | Actual Run Time (%) | GSHP Eff'y. (EER or COP) | GSHP Input Power (kW) | Suppl. Heater Power (kW) | Pump Flow Rate (gpm) | GSHP Electric Energy (kWh) | Suppl. Heater Energy (kWh) | Circ. Pump Energy (kWh) | Circ. Pump Energy (kWh) | Total Electric Energy (kWh) |
|----------------------|------------------|---------------------|---------------------------|----------------------------|---------------------|---------------------|---------------------|--------------------------|-----------------------|--------------------------|----------------------|----------------------------|----------------------------|-------------------------|-------------------------|-----------------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (15) | (16c) | (16sd) | (17) |
| Cooling Mode: | | | | | | | | | | | | | | | | |
| 112 | 0 | 2,646 | 117 | 1,699.84 | 1.00 | 1.00 | 1.00 | 9.55 | 177.93 | n/a | 494 | 0 | 0 | 0 | 0 | 0 |
| 107 | 1 | 2,392 | 112 | 1,751.32 | 1.00 | 1.00 | 1.00 | 10.20 | 171.63 | n/a | 494 | 172 | 0 | 14 | 14 | 186 |
| 102 | 18 | 2,137 | 106 | 1,802.80 | 1.00 | 1.00 | 1.00 | 10.90 | 165.32 | n/a | 494 | 2,976 | 0 | 256 | 256 | 3,231 |
| 97 | 94 | 1,883 | 101 | 1,854.27 | 1.00 | 1.00 | 1.00 | 11.66 | 159.02 | n/a | 494 | 14,948 | 0 | 1,335 | 1,335 | 16,282 |
| 92 | 240 | 1,628 | 96 | 1,905.75 | 0.85 | 0.96 | 0.89 | 12.48 | 152.71 | n/a | 438 | 32,500 | 0 | 3,407 | 2,679 | 35,180 |
| 87 | 393 | 1,374 | 91 | 1,957.22 | 0.70 | 0.93 | 0.76 | 13.37 | 146.41 | n/a | 374 | 43,644 | 0 | 5,580 | 3,210 | 46,854 |
| 82 | 603 | 1,120 | 85 | 2,008.70 | 0.56 | 0.89 | 0.63 | 14.34 | 140.10 | n/a | 309 | 52,945 | 0 | 8,561 | 3,362 | 56,308 |
| 77 | 829 | 865 | 80 | 2,060.18 | 0.42 | 0.85 | 0.49 | 15.40 | 133.80 | n/a | 242 | 54,477 | 0 | 11,770 | 2,839 | 57,316 |
| 72 | 948 | 611 | 75 | 2,111.65 | 0.29 | 0.82 | 0.35 | 16.56 | 127.49 | n/a | 174 | 42,505 | 0 | 13,459 | 1,665 | 44,170 |
| 67 | 819 | 356 | 69 | 2,163.13 | 0.16 | 0.79 | 0.21 | 17.85 | 121.19 | n/a | 103 | 20,659 | 0 | 11,628 | 504 | 21,163 |
| 62 | 729 | 102 | 64 | 2,214.60 | 0.05 | 0.76 | 0.06 | 19.28 | 114.88 | n/a | 30 | 5,054 | 0 | 10,350 | 38 | 5,092 |
| Heating Mode: | | | | | | | | | | | | | | | | |
| 57 | 654 | 153 | 61 | 1,931.29 | 0.08 | 0.77 | 0.10 | 3.88 | 146.07 | 0.00 | 51 | 9,811 | 0 | 9,285 | 98 | 9,909 |
| 52 | 627 | 407 | 58 | 1,872.89 | 0.22 | 0.80 | 0.27 | 3.82 | 143.53 | 0.00 | 133 | 24,323 | 0 | 8,902 | 650 | 24,973 |
| 47 | 608 | 662 | 56 | 1,814.48 | 0.36 | 0.84 | 0.43 | 3.77 | 140.99 | 0.00 | 214 | 37,160 | 0 | 8,632 | 1,622 | 38,782 |
| 42 | 592 | 916 | 54 | 1,756.08 | 0.52 | 0.88 | 0.59 | 3.72 | 138.45 | 0.00 | 292 | 48,566 | 0 | 8,405 | 2,951 | 51,516 |
| 37 | 537 | 1,171 | 51 | 1,697.67 | 0.69 | 0.92 | 0.75 | 3.66 | 135.91 | 0.00 | 369 | 54,559 | 0 | 7,624 | 4,260 | 58,820 |
| 32 | 446 | 1,425 | 49 | 1,639.27 | 0.87 | 0.97 | 0.90 | 3.60 | 133.37 | 0.00 | 443 | 53,457 | 0 | 6,332 | 5,114 | 58,571 |
| 27 | 282 | 1,679 | 47 | 1,580.86 | 1.00 | 1.00 | 1.00 | 3.54 | 130.84 | 28.91 | 494 | 36,896 | 8,152 | 4,004 | 4,004 | 49,051 |
| 22 | 174 | 1,934 | 44 | 1,522.45 | 1.00 | 1.00 | 1.00 | 3.48 | 128.30 | 120.60 | 494 | 22,323 | 20,985 | 2,470 | 2,470 | 45,779 |
| 17 | 85 | 2,188 | 42 | 1,464.05 | 1.00 | 1.00 | 1.00 | 3.41 | 125.76 | 212.30 | 494 | 10,689 | 18,046 | 1,207 | 1,207 | 29,942 |
| 12 | 49 | 2,443 | 40 | 1,405.64 | 1.00 | 1.00 | 1.00 | 3.34 | 123.22 | 304.00 | 494 | 6,038 | 14,896 | 696 | 696 | 21,629 |
| 7 | 16 | 2,697 | 37 | 1,347.24 | 1.00 | 1.00 | 1.00 | 3.27 | 120.68 | 350.00 | 494 | 1,931 | 5,600 | 227 | 227 | 7,758 |
| 2 | 9 | 2,952 | 35 | 1,288.83 | 1.00 | 1.00 | 1.00 | 3.20 | 118.14 | 350.00 | 494 | 1,063 | 3,150 | 128 | 128 | 4,341 |
| -3 | 1 | 3,206 | 33 | 1,230.43 | 1.00 | 1.00 | 1.00 | 3.12 | 115.60 | 350.00 | 494 | 116 | 350 | 14 | 14 | 480 |
| -8 | 0 | 3,461 | 30 | 1,172.02 | 1.00 | 1.00 | 1.00 | 3.04 | 113.06 | 350.00 | 494 | 0 | 0 | 0 | 0 | 0 |
| -13 | 0 | 3,715 | 28 | 1,113.62 | 1.00 | 1.00 | 1.00 | 2.95 | 110.52 | 350.00 | 494 | 0 | 0 | 0 | 0 | 0 |
| -18 | 0 | 3,970 | 25 | 1,055.21 | 1.00 | 1.00 | 1.00 | 2.86 | 107.98 | 350.00 | 494 | 0 | 0 | 0 | 0 | 0 |
| Cooling | | | | | | | | | | | | 269,880 | 0 | 66,359 | 15,902 | 285,782 |
| Heating | | | | | | | | | | | | <u>306,932</u> | <u>71,179</u> | <u>57,926</u> | <u>23,441</u> | <u>401,551</u> |
| Total | | | | | | | | | | | | 576,812 | 71,179 | 124,284 | 39,342 | 687,333 |

Appendix B

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of \$0.10 per kWh, this fixture has an annual energy cost of \$20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where

PV(x) denotes "present value of cost stream x,"

IC is the installed cost,

EC is the annual energy cost,

OM is the annual nonenergy O&M cost, and

REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1) + PV(OM_0) - PV(OM_1) + PV(REP_0) - PV(REP_1) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where

subscript 0 denotes the existing or baseline condition,

subscript 1 denotes the energy cost saving measure,

IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),

ECS is the annual energy cost savings,

OMS is the annual nonenergy O&M savings, and

REPS is the future replacement savings.

Levelized energy cost (LEC) is the breakeven energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective ($NPV \geq 0$). Thus, a project's LEC is given by

$$PV(LEC \cdot EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS)) / PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

Appendix C

Performance and Efficiency Terminology Defined

There are many terms used in the heating, air-conditioning, and refrigeration industry that convey performance and efficiency. Many of these terms are synonymous, others are not. When comparing various systems, it is important to understand what the assorted terms are, how they are determined, and their relationship. The following provides a brief description of many (but not all) of the terms used to convey efficiency. Use of the terms is also summarized in Table C.1.

Annual Fuel Utilization Efficiency (AFUE): For fuel-fired systems such as boilers and furnaces, AFUE is defined as the ratio of annual output energy to annual input energy. This term is generally applied to systems $\leq 300,000$ Btu/h input. AFUE is a weighted average efficiency under standard rated conditions at various part-load conditions and also includes any non-heating-season pilot input losses. AFUE is a unitless term generally expressed as a percentage.

Coefficient of Performance (COP): The COP is the basic parameter used to report the efficiency of refrigerant-based systems. It is a unitless term. This term is universal in its use but not in its meaning. COP can be used to define both cooling efficiency or heating efficiency, such as for a heat pump. For cooling, COP is defined as the ratio of the rate of heat removal to the rate of energy input to the compressor, in consistent units. For heating, COP is defined as the ratio of rate of heat delivered to the rate of energy input to the compressor, in consistent units. COP can be used to define the efficiency at a single (standard or non-standard) rated condition or a weighted average (seasonal) condition. Depending on its use, the term may or may not include the energy consumption of auxiliary systems such as indoor or outdoor fans, chilled water pumps, or cooling tower systems. For purposes of comparison, the higher the COP the more efficient the system. For mathematical purposes, COP can be treated as an efficiency. (COP of 2.00 = 200% efficient) For unitary heat pumps, ratings at two standard (outdoor) temperatures (47°F and 17°F [8.3°C and -8.3°C]) are typically reported.

Combustion Efficiency (η_c or E_c): For fuel-fired systems, this efficiency term is defined as the ratio of the fuel energy input minus the flue gas losses (dry flue gas, incomplete combustion and moisture formed by combustion of hydrogen) to the fuel energy input. In the U.S., fuel-fired efficiencies are reported based on the higher heating value of the fuel. Other countries report fuel-fired efficiencies based on the lower heating value of the fuel. The combustion efficiency is calculated by determining the fuel gas losses as a percent of fuel burned. [$E_c = 1 - \text{flue gas losses}$]

Energy Efficiency Ratio (EER): The EER is a term generally used to define the cooling efficiency of unitary air-conditioning and heat pump systems. The term implies that the efficiency is determined at a single rated condition specified by the appropriate equipment standard and is defined as the ratio of net cooling capacity (heat removed in Btu/h) to the total input rate of electric energy required (watt). The units of EER are Btu/w-h. It is important to note that this efficiency term typically includes the energy requirement of auxiliary systems such as the indoor and outdoor fans. For purposes of comparison, the higher the EER the more efficient the system. To convert to a COP, divide the EER by 3.412. [$\text{COP} = \text{EER}/3.412$]

Heating Seasonal Performance Factor (HSPF): The term HSPF is similar to the term SEER, except it is used to signify the seasonal heating efficiency of heat pumps. The HSPF is a weighted average efficiency over a range of outside air conditions following a specific standard test method. The term is generally applied to heat pump systems less than 60,000 Btu/h (rated cooling capacity.) The units of HSPF are Btu/w-h. It is important to note that this efficiency term typically includes the energy requirement of auxiliary systems such as the indoor and outdoor fans. For purposes of comparison, the higher the HSPF the more efficient the system.

Integrated Part-Load Value (IPLV): The term IPLV is used to signify the cooling efficiency related to a typical (hypothetical) season rather than a single rated condition. The IPLV is calculated by determining the weighted average efficiency at part-load capacities specified by an accepted standard. It is also important to note that IPLVs are typically calculated using the same condensing temperature for each part-load condition and IPLVs do not include cycling or load/unload losses. The units of IPLV are not consistent in the literature; therefore, it is important to confirm which units are implied when the term IPLV is used. ASHRAE Standard 90.1 (using ARI reference standards) uses the term IPLV to report seasonal cooling efficiencies for both seasonal COPs (unitless) and seasonal EERs (Btu/w-h), depending on the equipment capacity category; and most chiller manufacturers report seasonal efficiencies for large chillers as IPLV using units of kW/ton. Depending on how a cooling system loads and unloads (or cycles), the IPLV can be between 5 and 50% higher than the EER at the standard rated condition.

kW/ton: The term kW/ton is generally used for large commercial and industrial air-conditioning, heat pump, and refrigeration systems. The term is defined as the ratio of the rate of energy consumption (kW) to the rate of heat removal (ton) at a rated condition. As the term suggests, the units are kW/ton. Because refrigeration systems of this capacity are typically custom designed, the reported kW/ton generally implies only the compressor and does not include the auxiliaries. However, for specific references, auxiliaries can be added to report the overall system efficiency using this term. It is important to note that this term is inverse to the other performance and efficiency terminology. Therefore, for purposes of comparison, the lower the kW/ton the more efficient the system. To convert to a COP, divide 12,000 by the product of 3,412 multiplied by the kW/ton. [COP = 12,000 / (3,412 (kW/ton))]

Seasonal Energy Efficiency Ratio (SEER): The term SEER is used to define the average annual cooling efficiency of an air-conditioning or heat pump system. The term SEER is similar to the term EER but is related to a typical (hypothetical) season rather than for a single rated condition. The SEER is a weighted average of EERs over a range of rated outside air conditions following a specific standard test method. The term is generally applied to systems less than 60,000 Btu/h. The units of SEER are Btu/W·h. It is important to note that this efficiency term typically includes the energy requirements of auxiliary systems such as the indoor and outdoor fans. For purposes of comparison, the higher the SEER the more efficient the system. Although SEERs and EERs cannot be directly compared, the SEERs usually range from 0.5 to 1.0 higher than corresponding EERs.

Thermal Efficiency (nt or Et): This efficiency term is generally defined as the ratio of the heat absorbed by the water (or the water and steam) to the heat value of the energy consumed. The combustion efficiency of a fuel-fired system will be higher than its thermal efficiency. See ASME Power Test Code 4.1 for more details on determining the thermal efficiency of boilers and other fuel-fired systems. In the U.S., fuel-fired efficiencies are typically reported based on the higher heating value of the fuel. Other countries typically report fuel-fired efficiencies based on the fuel's lower heating value. The difference between a fuel's higher heating value and its lower heating value is the latent energy contained in the water vapor (in the exhaust gas) which results when hydrogen (from the fuel) is burned. The efficiency of a system based on a fuel's lower heating value can be 10 to 15% higher than its efficiency based on a fuel's higher heating value.

Table C.1. Summary of Performance and Efficiency Terminology.

| Operating Mode | Design Rated Conditions | Seasonal Average Conditions |
|----------------|---|-----------------------------|
| Cooling | COP EER kW/ton | COP IPL SEER |
| Heating | COP E _c E _t | AFUE COP HSPF |

Appendix D

Ground-Source Heat Pump Manufacturers

Addison Products Company
 Mr. Dave Phillips
 7050 Overland Road
 Orlando, FL 32810
 Tel. 407-292-4400
 Fax 407-290-1329
www.addison-hvac.com

Advanced Geothermal Technologies
 Mr. Don Creyts
 P.O. Box 511
 Reading, PA 19607
 Tel: (610) 796-1450
 Fax: (610) 796-2070

American Geothermal, Inc.
 Mr. Chris Pamplin
 1037 Old Salem Road
 Murfreesboro, TN 37129
 Tel: (615) 890-6985
 Tel: (800) 776-8039
 Fax: (615) 890-6926
www.amgeo.com

American Thru Wall
 Manufacturing Corp.
 Mr. Richard W. Wright
 59 BC Remington Blvd.
 Ronkonkoma, NY 11779
 Tel 516-467-5252
 Fax 516-467-3452

Aqua Cal
 2737 24th Street North
 St. Petersburg, FL 33713
 Tel. 813-823-5642
 Fax 813-821-7471

Carrier Corporation
 Mr. Chuck Perry
 6752 Melrose Lane
 Oklahoma City, OK 73127
 Tel: (405) 789-2699
 Fax: (405) 789-8755
<http://www.carrier.com>

ClimateMaster
 Mr. Dan Ellis
 7300 SW 44th Street
 P.O. Box 25788
 Oklahoma City, OK 73125
 Tel: (405) 745-6000
 Fax: (405) 745-3629
www.climatemaster.com

DeMarco Energy Systems
 of America, Inc.
 Mr. Victor DeMarco
 P.O. Box 201057
 Austin, TX 78720
 Tel: (512) 335-1494
 Fax: (512) 335-6380
www.demarcoenergy.com

Econar Energy Systems Corp.
 Ms. Susie Overholser
 19230 Evans Street
 Elk River, MN 55330
 Tel: (612) 241-3110
 Tel: (800) 4-ECONAR
 Fax: (612) 241-3111
www.econar.com

ECR Technologies
 Mr. Joe Parsons, Jr.
 3536 DMG Drive
 Lakeland, FL 33811
 Tel: (863) 701-0096
 Fax: (863) 701-7796
 E-mail: jparsons@ecrtech.com

FHP Manufacturing
 Mr. Chris E. Smith
 601 NW 65th Court
 Ft. Lauderdale, FL 33309
 Tel: (954) 776-5471
 Fax: (954) 776-5529
<http://www.fhp-mfg.com>

HydroDelta Corporation
 Mr. Tim Burke
 10205 Gravois
 St. Louis, MO 63123
 Tel: (314) 849-5550
 Fax: (314) 849-8410
 E-mail: hydroheat@aol.com

Hydro-Temp Corporation
 Mr. Steve Hudson
 P.O. Box 566
 Pochontas, AR 72455
 Tel: (870) 892-8343
 Tel: (800) 382-3113
 Fax: (870) 892-8323
<http://www.hydro-temp.com>

Mammoth, Inc.
 Mr. Craig Fischbach
 101 West 82nd Street
 Chaska, MN 55318
 Tel: (612) 361-2644
 Fax: (612) 361-2700
 E-Mail: cfischbach@mammoth-inc.com
<http://www.mammoth-inc.com>

McQuay International
 Ms. Marilyn Linette
 13600 Industrial Park Blvd.
 P.O. Box 1551
 Minneapolis, MN 55440
 Tel: (612) 553-5168
 Fax: (612) 553-5177
<http://www.mcquay.com>

Millbrook Industries - Hydronic Division
 Mr. Michael Waldner
 RR #3, Box 265
 Mitchell, SD 57301
 Tel: (605) 995-0241
 Fax: (605) 996-9186

The Trane Company
 Mr. Robert Kim or Mr. Howard Newton
 182 Cotton Belt Parkway
 McGregor, TX 76657
 Tel: (254) 299-6329
 Fax: (817) 299-6671
<http://www.trane.com>

WaterFurnace International
 Mr. Tony Cooper
 9000 Conservation Way
 Fort Wayne, IN 46809
 Tel: (219) 478-5667
 Tel: (800) 222-5667
 Fax: (219) 478-3029
<http://www.waterfurnace.com>

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Appendix E

ARI Rating Conditions

When comparing the efficiency of various equipment, it is important to make an appropriate comparison. The efficiency of any heating or cooling equipment varies with application, load, and related heat-source and heat-sink temperatures. As noted in the beginning of this Federal Technology Alert, most ground-source heat pumps are specific applications of water-source heat pumps. There are three accepted standards for testing heat pump efficiency; these are briefly identified below.

Note that the difference among these standards is in application, not necessarily the equipment. Furthermore, standard ratings are for specific temperatures and operating conditions. Standard ratings do not necessarily reflect the efficiency of systems under true seasonal operating conditions. In determining the efficiency of heating or cooling equipment for the purpose of estimating energy consumption or potential energy savings, the efficiency should be corrected for the appropriate operating conditions.

ARI Standard 320 - Water-Source Heat Pumps. This standard applies to electrically driven mechanical-compression residential, commercial, and industrial water-source heat pumps. Heat pumps rated under this standard are tested under the following standard rating temperatures:

- Cooling: Indoor entering^(a) air conditions 80°F_{db} (26.7°C_{db}) and 67°F_{wb} (19.4°C_{wb}). Entering water^(b) temperature 85°F (29.4°C). Leaving water temperature 95°F (35.0°C).
- Heating: Indoor entering air conditions 70°F_{db} (21.1°C_{db}) and 60°F_{wb, max} (15.6°C_{wb, max}). Entering water temperature 70°F (21.1°C). Water flow rate same as standard rating cooling test.

ARI Standard 325 - Ground Water-Source Heat Pumps. This standard applies to electrically driven mechanical-compression residential, commercial and industrial water-source heat pumps. Heat pumps rated under this standard are tested under the following standard rating temperatures:

- Cooling (high-temperature): Indoor entering air conditions 80°F_{db} (26.7°C_{db}) and 67°F_{wb} (19.4°C_{wb}). Entering water temperature 70°F (21.1°C). Water flow rate as specified by manufacturer.
- Cooling (low-temperature): Indoor entering air conditions 80°F_{db} (26.7°C_{db}) and 67°F_{wb} (19.4°C_{wb}). Entering water temperature 50°F (10.0°C). Water flow rate as specified by manufacturer.
- Heating (high-temperature): Indoor entering air conditions 70°F_{db} (21.1°C_{db}) and 60°F_{wb, max} (15.6°C_{wb, max}). Entering water temperature 70°F (21.1°C). Water flow rate as specified by manufacturer.
- Heating (low-temperature): Indoor entering air conditions 70°F_{db} (21.1°C_{db}) and 60°F_{wb, max} (15.6°C_{wb, max}). Entering water temperature 50°F (21.1°C). Water flow rate as specified by manufacturer.

ARI Standard 330 - Ground-Source Closed-Loop Heat Pumps. This standard applies to electrically driven mechanical-compression residential, commercial, and industrial water-source heat pumps. Heat pumps rated under this standard are tested under the following Standard Rating Temperatures (the fluid for the test is based on a 15% solution by weight of sodium chloride and water):

- Cooling: Indoor entering air conditions 80°F_{db} (26.7°C_{db}) and 67°F_{wb} (19.4°C_{wb}). Entering fluid temperature 77°F (25.0°C). Fluid flow rate as specified by manufacturer.
- Heating: Indoor entering air conditions 70°F_{db} (21.1°C_{db}) and 60°F_{wb, max} (15.6°C_{wb, max}). Entering fluid temperature 32°F (0.0°C). Fluid flow rate same as standard rating cooling test.

(a) This is the ventilation air entering the indoor coil to be conditioned.

(b) This is the water entering the heat pump from the ground-coupling or boiler/tower system.

About FEMP's New Technology Demonstration Program

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in Federal buildings be reduced by 35% from 1985 levels by the year 2010. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of publications that are designed to disseminate information on new and emerging technologies. New Technology Demonstration Program publications comprise three separate series:

Federal Technology Alerts—longer summary reports that provide details on energy-efficient, water-conserving, and renewable-energy technologies that have been selected for further study for possible implementation in the Federal sector. Additional information on Federal Technology Alerts is provided in the next column.

Technology Installation Reviews—concise reports describing a new technology and providing case study results, typically from another demonstration program or pilot project.

Technology Focuses—brief information on new, energy-efficient, environmentally friendly technologies of potential interest to the Federal sector.

More on Federal Technology Alerts

Federal Technology Alerts, our signature reports, provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Federal Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector.

The goal of the Federal Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

The information in the Federal Technology Alerts typically includes a description of the candidate technology; the results

of its screening tests; a description of its performance, applications and field experience to date; a list of manufacturers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal sector savings, the Federal Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Furthermore, the Federal Technology Alerts do not attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the Federal Technology Alerts as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Federal Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over \$8 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), Executive Order 12902 in 1994, and Executive Order 13123 in 1999.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

Log on to FEMP's New Technology Demonstration Program Website

<http://www.eren.doe.gov/femp/prodtech/newtechdemo.html>

You will find links to

- An overview of the New Technology Demonstration Program
- Information on the program's technology demonstrations
- Downloadable versions of program publications in Adobe Portable Document Format (PDF)
- A list of new technology projects underway
- Electronic access to the program's regular mailing list for new products when they become available
- How Federal agencies may submit requests for the program to assess new and emerging technologies

For More Information

FEMP Help Desk

(800) 363-3732
 International callers please use
 (703) 287-8391
 Web site: www.eren.doe.gov/femp

General Contacts

Ted Collins

New Technology Demonstration
 Program Manager
 Federal Energy Management
 Program
 U.S. Department of Energy
 1000 Independence Ave., SW, EE-92
 Washington, D.C. 20585
 Phone: (202) 586-8017
 Fax: (202) 586-3000
theodore.collins@ee.doe.gov

Steven A. Parker

Pacific Northwest National
 Laboratory
 P.O. Box 999, MSIN: K5-08
 Richland, WA 99352
 Phone: (509) 375-6366
 Fax: (509) 375-3614
steven.parker@pnl.gov

Technical Contacts

Donald L. Hadley

Pacific Northwest National
 Laboratory
 P.O. Box 999, MSIN: K5-16
 Richland, WA 99352
 Phone: (509) 375-3708
 Fax: (509) 375-3614
don.hadley@pnl.gov

Gary Phetteplace

U.S. Army Cold Regions Research
 and Engineering Laboratory
 72 Lyme Road
 Hanover, NH 03755
 Phone: (603) 646-4248
 Fax: (603) 646-4380
gephet@cr102.crel.army.mil

John A. Shonder

Oak Ridge National Laboratory
 P.O. Box 2008 MS6070
 Oak Ridge, TN 37831
 Phone: (865) 574-2015
 Fax: (865) 574-9338
shonderja@ornl.gov



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