Commercial Earth Energy Systems:
A buyer's Guide



Natural Resources Canada Ressources naturelles Canada

Canada

Preface

Photo Credits

All photos (excluding the cover) courtesy of the Geothermal Heat Pump Consortium, Inc., 701 Pennsylvania Avenue, N.W., Washington D.C. 20004-2696.

This publication was prepared by the CANMET Energy Technology Centre – Varennes and by CANETA Research and by TECHNOSIM Consulting Group, for the Renewable and Electrical Energy Division, Energy Resources Branch, Natural Resources Canada.

ISBN 0-662-32808-6
Cat. No. M92-251/2002E
Aussi disponible en français sous le titre :
Les systèmes géothermiques commerciaux : Guide de l'acheteur

About This Guide

Commercial Earth Energy Systems: A Buyer's Guide is intended to assist building owners, facility managers, building asset planners, architects, engineers, energy utilities, energy service companies, energy consultants, decision support system (DSS) tool designers, mechanical contractors, hydrologists, geologists and excavation and drilling companies with information needed to understand, plan, oversee, design, build and manage an earth energy system (EES) for heating and cooling applications in commercial and institutional buildings.

This guide has two main parts. Part 1 contains basic information intended to address the questions of decision-makers with little or no knowledge of EESs. Part 1 is divided into the following sections:

Part 1

- Chapter 1 provides an introduction to EESs, what they are, where they make the most sense, how they work and the economics compared to other heating, ventilating and air-conditioning (HVAC) systems. The reader will find this information a useful starting point.
- Chapter 2 describes the different configurations or types of EESs and the factors to be considered when selecting an EES. This chapter also introduces the energy efficiency descriptors for heat pumps used in EESs and discusses the importance of energy efficiency in other aspects of buildings.
- Chapter 3 provides a brief overview of an EES design.
- Chapter 4 discusses other important considerations that are unique to EESs, including environmental and legal considerations, planning, installation and warranty and maintenance issues.

More advanced topics and technical details are discussed in Part 2, which is divided into the following sections:

Part 2

- Chapter 5 provides a detailed examination of topics pertaining to heat pump performance and efficiency.
- Chapter 6 discusses the evaluation and calculation of building loads and energy use.

- Chapter 7 explains the requirements for sizing heat pumps and ground heat exchangers. A number of sample calculations and rules of thumb for sizing heat exchangers are also provided in this chapter.
- Chapter 8 outlines factors to consider in the analysis of an earth energy system investment and provides an economic and financial calculation example.
- Chapter 9 addresses practical issues that should be considered in the design and installation of EESs. A sample performance specification is provided in this chapter, to be used as a general guide. It also provides a list of important information to obtain from suppliers and contractors.

The appendices of this guide contain earth energy case studies, other sources of information that will be useful at various stages of the decision-making and implementation process, a glossary and a conversion factor table to help with calculations.

A Note About "Rules of Thumb"

A number of "rules of thumb" appear throughout this guide. They are provided to help evaluate orders of magnitude and should serve as guidelines only.

Table of Contents

Part 2: Advanced Topics and Technical Details

Chapter 5: Understanding Heat Pump Performance and Efficiency

Chapter 6: Evaluating Heating, Cooling Loads and Energy Use

Chapter 7: Sizing Heat Pumps and Ground Heat Exchangers

Chapter 8: Analysing an Earth Energy System Investment

Chapter 9: Practical Considerations

Appendices

Part 1
Earth Energy Systems – The Basics

Chapter 1: Introduction

History

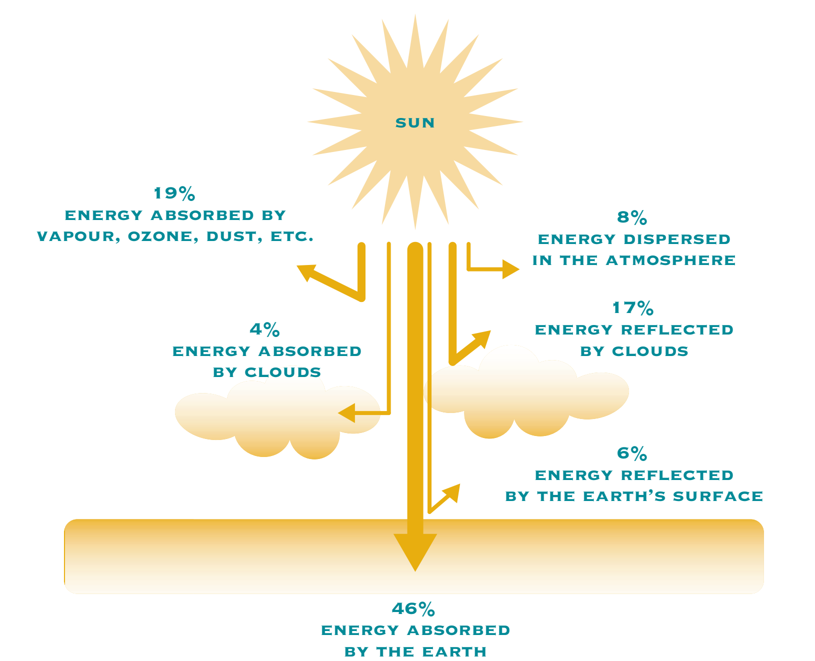
An earth energy system (EES) is a type of heat pump system that uses the ground or ground water as a source of energy. The earliest EES applications date as far back as 1912, when the first patent of a system using a ground loop was recorded in Switzerland. However, it was not until the 1970s that EESs gained significant market acceptance. The first commercial EESs were designed for the residential sector and were ground-water-type systems. By the mid-1980s, advances in heat pump efficiencies and operating ranges, combined with better materials for ground loops, allowed ground-coupled heat pumps to enter the market. At about the same time, commercial-type applications started to gain popularity. Currently, more than 40 000 heat pump units are sold each year in North America. The largest commercial installation to date (a ground-water-type system) has a total cooling capacity that exceeds 15 800 kW, clearly demonstrating that EESs are not limited to small-scale applications.

Abbreviations

Earth energy systems are known under various names, often in the form of abbreviations. The more common names are as follows:

GSHP: ground-source heat pump
GeoExchange™ systems (term used in the U.S.)
EES: earth energy system
GCHP: ground-coupled heat pump
GWHP: ground-water heat pump
GHP: geothermal heat pump
SWHP: surface-water heat pump

Figure 1. Solar Energy Distribution



What is an Earth Energy System?

An EES is a heating and cooling technology which transfers heat from an earth or water source to provide space conditioning at greater efficiencies than those of conventional systems. EESs can also be used to heat domestic water.

Natural heat from the earth or water source is absorbed into a liquid, heat transfer medium and is carried through a system of buried pipes to a building, where in heating mode, it is upgraded to the required temperature level via a heat pump unit. The heat is then circulated via ductwork or through radiant heating. In cooling mode, the system is reversed and the excess building heat is rejected back into the cooler ground.

Like a conventional heat pump, a ground-source heat pump is essentially an air-conditioner that can also run in reverse in the winter. However, unlike conventional air-source heat pumps, EESs can maintain high efficiencies and capacities even when ambient air temperatures hit extreme values in the winter or summer because the components of the system are not exposed to the outdoors.

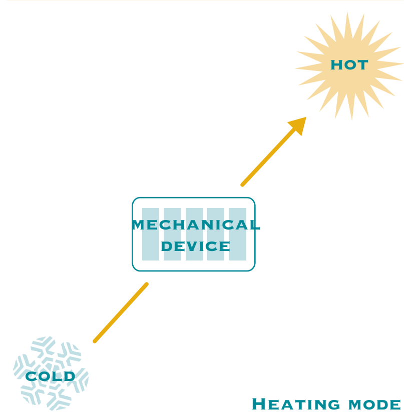
Many EESs on the market have the ability to provide domestic hot water heating through a device called a desuperheater, further increasing their operating efficiency. Alternately, EESs may provide domestic hot water through a dedicated water-to-water heat pump.

Significant energy savings can be achieved through the use of EESs. Compared to conventional systems, typical reductions in energy consumption of 30 to 70 percent in the heating mode and 20 to 95 percent in the cooling mode can be obtained.

EESs come in a wide variety of configurations that use the ground, ground water or surface water as a heat source and sink. Examples are:

- ground-coupled heat pumps, which use the ground as a heat source and sink either with vertical or horizontal ground heat exchangers (GHXs);
- ground-water heat pumps, which use underground (aquifer) water as a heat source and sink; and
- surface-water heat pumps, which use surface-water bodies (lakes, ponds, etc.) as a heat source and sink.

Figure 2. Basic heat pump principle



Heat Pump Fundamentals of Earth Energy Systems

Heat naturally flows "downhill" from higher to lower temperatures. A heat pump is a machine that causes heat to flow in a direction opposite to its natural tendency, or "uphill" in terms of temperature. Because work must be done to accomplish this (i.e., going uphill), the name heat "pump" is used to describe the device.

The heat pumps that are in an EES operate following the same basic principles as those of most cooling and refrigerating equipment. Most of these systems are based on two physical phenomena:

- When a liquid evaporates, it absorbs energy, and when it condenses it releases energy.
- Any liquid will evaporate or condense at a lower temperature when the pressure decreases and will condense or evaporate at a higher temperature when the pressure increases.

These two principles are the basis of the mechanical vapour compression cycle, which is behind most EES heat pumps. This cycle uses the two principles to transfer energy from a colder source to a warmer sink.

Therefore, a heat pump is nothing more than a refrigeration unit. The only differences between a heat pump and a refrigeration unit are the temperature levels at which they operate and the fact that heat pumps are reversible and can provide either heating or cooling.

The Right Conditions

Commercial and institutional buildings that are best suited to EESs include the following:

- new buildings, which allow for more ready adoption of EES designs. There have also been a number of applications where major renovations were undertaken or where new additions to existing buildings were made that allowed EES designs to be considered;
- buildings with large space heating and water heating energy use. Extended care facilities, retirement communities and health care facilities are excellent candidates for EESs;
- buildings that are located in areas where natural gas is unavailable for heating purposes;
- buildings that require simultaneous, year-round heating and cooling that can be readily provided by a two-pipe distribution EES;
- buildings where it is important to maintain exterior aesthetics, such as heritage building restorations; and
- buildings where space for a mechanical room is at a premium.

How Earth Energy Systems Work

Basic Operating Principle

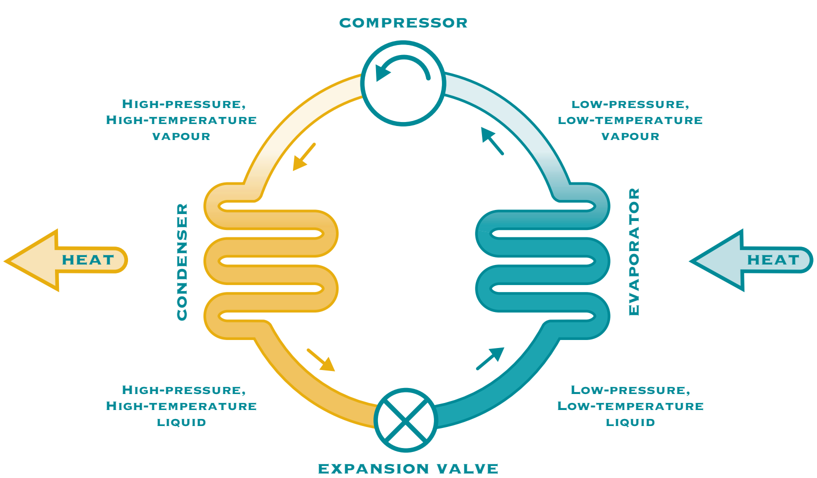
Energy in the form of heat is present even at very low temperatures. Provided the temperature of an object is above absolute zero (–273°C), there is some heat energy present in the object. The temperature of the ground is too low to heat a building directly (in Canada, the ground temperature ranges from 4 to 10°C), but the ground still holds a vast store of heat. A heat pump is required to upgrade this energy extracted from the ground to a convenient level for heating, or to reject heat to the ground effectively. This ground heat source and sink has a near constant temperature, which is well suited to a heat pump, giving predictable performance and lower thermal and mechanical stress. An EES can provide space heating and cooling and much of the hot water requirements for most institutional/commercial buildings.

The Refrigeration Cycle: An Overview

The vast majority of heat pumps work on the principle of the vapour compression cycle. The main components in such a heat pump system are the compressor, the expansion valve and two heat exchangers referred to as the evaporator and the condenser. The components are connected to form a closed circuit, as shown in Figure 3. A fluid, known as the working fluid or refrigerant, circulates through the four components.

In the evaporator, refrigerant enters in a cool, mostly liquid state. The temperature of the liquid is lower than the temperature of the heat source, such as the surrounding ground in heating mode of a ground-coupled heat pump or the room air in cooling mode. The warmer ground or air then causes the liquid refrigerant to evaporate, thus absorbing heat. Refrigerant vapour from the evaporator travels to the compressor where it is compressed to a higher pressure and temperature. Once it passes through the compressor, the refrigerant is said to be on the "high" side of the system. The hot vapour then enters the condenser, where it condenses and gives off heat (i.e., heating up the building when in heating mode). Finally, the pressure of the warm liquid refrigerant exiting the condenser is reduced through the expansion valve. The expansion process also reduces the refrigerant temperature before it re-enters the evaporator. The whole process can be reversed to cool the building.

Figure 3. The Refrigeration Cycle (heating mode)



Digging a trench to lay ground loops

Earth Energy System Components

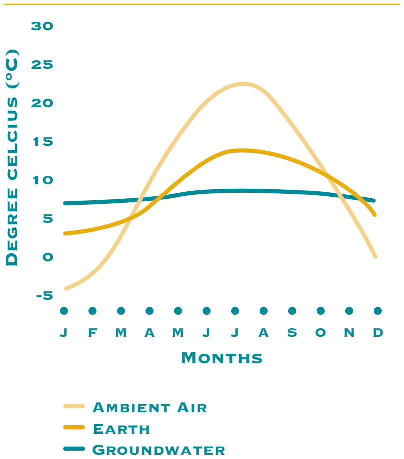
The basic function of an EES is to provide heating and cooling for a building. In addition, it may provide water heating, sometimes supplemented by a conventional water heater. To perform these functions, EESs are made up of the following three primary sub-systems, which are discussed more fully in Chapter 2, "Selecting an Earth Energy System."

- an earth connection (also known as ground or ground-water loops) that extracts heat from the earth or discharges heat to the earth;
- a heat pump that transfers heat between the distribution system and the ground or ground-water loops; and
- a distribution system to deliver the heating or cooling to the building's various spaces.

Why Earth Energy Systems Make Sense

An EES offers numerous benefits to building owners and tenants, many of which lead to lower owning and operating costs.

Figure 4. Average Monthly temperatures in Canada



Constant Ground Temperature

At a depth of eight to nine metres or more, the ground temperature is virtually constant throughout the year, having a value close to that of the average annual air temperature. This constant temperature environment is well suited to earth energy heat pumps, giving them consistent performance, regardless of the outdoor temperature. In climates with temperature extremes such as in Canada, this is very beneficial. Earth energy can play an important role in Canada's response to climate change as both a renewable form of energy and as an energy-efficient technology, resulting in low greenhouse gas (GHG) emissions.

Renewable Energy

EESs are a renewable energy option. Like most renewable energy systems, EESs make use of the sun's energy. EESs are environmentally friendly because approximately two-thirds of the energy they deliver comes from renewable energy within the ground. This indirect use of solar energy comes from the capability of the earth's crust to store solar energy. In fact, the earth is a massive solar energy collector that absorbs 46 percent of the sun's energy that radiates to earth, which amounts to more than 500 times more energy than earth's population needs every year. EESs can retrieve some of the energy stored in the ground to heat buildings during the winter and, during the summer, reverse the process to reject the building's heat to the ground for cooling purposes. A recent climate change analysis showed that EESs in commercial and institutional buildings had the lowest GHG emissions of all heating, ventilating and air-conditioning (HVAC) systems.

Flexibility

A decentralized EES has built-in flexibility that allows the heat pumps to be installed only when the tenant or owner occupancy is imminent. Tenants can control comfort levels, and the thermostat control is simple to use. The heat pumps can be located out of the occupied space (in ceiling space above corridors, for example). This permits flexibility in partitioning and layout of the occupied space and easily allows for tenant space expansions. Careful planning by the owners and design engineers will provide inherent flexibility and cost efficiency.

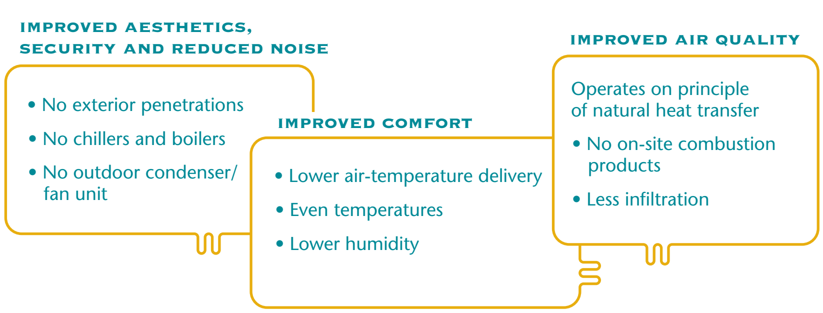
Benefits of Earth Energy Systems in Commercial Buildings

- lowest life-cycle cost
- sometimes has a lower first cost
- lower operating and maintenance costs
- improved comfort (individual room control)
- small mechanical room
- aesthetic design (no roof penetrations)
- may reduce building's height requirements

Space and Cost Savings

An EES can be all-electric, which eliminates the need for multiple utility service entrances, fuel storage tanks, etc. The system requires less mechanical room space than central heating and cooling systems, meaning more space in occupied and leased areas and possibly lower floor-to-ceiling heights. There is much less outdoor equipment, which results in lower maintenance and security costs. With no outdoor equipment on the roof, there are less penetrations, maintenance decks and architectural blinds and less of a need to protect equipment from vandalism. Exterior noise is significantly reduced, and building aesthetics are excellent. EESs also last longer, with the GHX lasting more than 30 years and the heat pumps themselves lasting typically 20 years.

Figure 5. Advantages of Choosing Earth Energy Systems



Energy Efficiency and Environmental Benefits

Since EESs involve the transfer of natural heat and no combustive process occurs, the only harmful environmental emissions attributable to their use is related to the electricity required for the system's operations, if the source of electrical generation is from fossil fuels. EESs are also energy efficient because for every unit of energy (electricity) required to operate the system, the system transfers three to four times that amount of energy (heat). Hence, the use of EESs can contribute significantly to the mitigation of GHG emissions, impacting on climate change because there are little or no carbon dioxide emissions associated with the operation of EESs.

Earth Energy Systems Make Environmental Sense

- low or no GHG emissions (associated with climate change)

Earth Energy Systems Make Economic Sense

- lower power requirements
- secure, stable heat supply
- lower resource intensity
- lower maintenance, more profitability
- less susceptible to energy price fluctuations
- initial cost is not always higher than conventional systems and may even be lower

Societal Benefits

Using EESs has a positive impact on society as a whole as they use a significant portion of renewable energy in their operation, have long lives, and are comprised of equipment that can be recycled. The resource is plentiful and readily available from one's own land. The use of an EES should always be a part of a holistic approach to building design.

Economics

An EES generally costs more than a conventional HVAC system to install but can yield substantial annual energy cost savings. Lower maintenance costs and the displacement of fuel costs for conventional systems by free, natural heat from a ground or water source, together with a longer equipment life, gives EESs a lower life cycle cost than conventional options.

The initial cost of an EES is not always higher than that of a conventional HVAC system because the costs of chillers, boilers and cooling towers, which are part of conventional systems, are eliminated with the EES choice. The costs associated with the earth loop and heat pump components of an EES would have to be weighed against the equipment costs for alternative HVAC systems.

Typical Cost of EESs

Capital Cost

The capital cost of EESs is generally higher than that of conventional systems, but this is offset by lower operating and maintenance costs. In addition, an EES will often reduce electrical demand for the building, thus reducing electrical equipment and installation costs. Compared to an all-electric heating system, the savings are even greater. The additional cost of an EES will vary considerably depending on the site, building type, size and alternative HVAC systems. In a sample of nine EES-equipped commercial buildings, the average installed capital cost of the EES was $105/m^2 compared to $89/m^2 for a conventional system (about an 18 percent average cost premium for an EES). Often, as the project gets larger, the premium for an EES becomes smaller. The capital cost of each individual project should be carefully assessed.

Operating Cost

Offsetting the increased capital costs are the energy cost savings available with an EES. Total building energy cost reduction can be significant and can amount to up to 60 percent. The higher the ratio for heating and cooling over the total building energy cost, the higher the potential for energy cost reduction. Peak demand can be reduced by up to 35 percent.

As with capital cost differences, savings will vary considerably with individual projects and specific locations, and these should be adequately assessed in advance. Operating cost is specific to the site and to the system's usage; a comprehensive analysis that includes a cost breakdown and a sensitivity analysis should be requested from your design team.

Maintenance Cost

In addition to savings in energy costs, there is evidence indicating that EESs can also save in maintenance costs. Where in-house labour is used, a typical average maintenance cost is $0.95/m² per year compared to an average cost of $2.33/m² per year for a water-source heat pump system. Other savings can be factored into the maintenance cost. Your design team should be able to provide a comprehensive analysis, upon request.

Financing Earth Energy Systems

Financing approaches to offset the higher initial cost of an EES include the following:

- **a standard loan** from a financing institution for the initial cost of the system, less any down payment;
- **a standard loan** with a shared savings feature. This is a loan for the initial cost of the system in which the customer pays a fixed monthly fee for a preset period. A financing operator covers all operating and maintenance costs for the preset period;
- **a lease**, whereby the customer pays both equipment and maintenance costs through lease payments while paying operating costs separately;
- **end-use pricing**, in which the customer pays the cost of equipment, maintenance and operating by fixed payments over a prescribed period; and
- **energy performance contracting**, where a third party incurs the cost of the equipment, maintenance and operating and is repaid through the energy savings.

These forms of financing are available from banks, financial organizations, utilities and third-party financing.

Payback and Life-Cycle Analysis

A life-cycle analysis enables one to select from among competing options. The investment that has the lowest total life-cycle cost (LCC) while meeting the investor's goal is the preferred investment. The LCC technique sums the net cost of the EES and the competing scenarios together with the energy and other operating costs during the useful life of the system. The net cost includes purchase and installation, maintenance, repair, replacement and all other costs attributable to the EES. LCC analysis gives a more meaningful economic result than a simple payback period and integrates the concept of sustainable development.

The trade-off between capital cost and operating savings can be determined using the simple payback period. This indicator will provide an evaluation of the time it takes to recuperate the initial investment.

EESs provide an average simple payback period of about six to eight years. The payback periods range between immediate (in some cases where an EES costs less than a conventional system) to just over 12 years. The average internal rate of return for an EES is about 20 percent.

For example, studies indicate a payback period range of four to 10 years for a high-rise condominium compared to a gas boiler or hydronic heat base case scenario. The period depends on location, usage and base case scenario.

Natural Resources Canada's RETScreen® software can facilitate the LCC analysis as part of a pre-feasibility assessment. Table 1 presents the payback periods obtained in a typical LCC analysis when comparing an EES with a gas base case scenario.

TABLE 1. PAYBACK PERIODS FOR EES (IN YEARS) COMPARED WITH GAS BASE CASE*

	Montréal	Toronto	Vancouver
New elementary school (3000 m^2)	13.6	18.3	1.3
Seniors' complex (7800 m^2)	7.6	10.8	1.8
High-technology facility (7000 m^2)	–	Immediate	–
Curling rink/hockey arena (1100 m^2)	4.8	Immediate	–
Mid-size hotel (10 500 m^2)	5.9	9.5	6.1
Motel (2050 m^2)	5.4	8.3	5.7
Suburban office building (5200 m^2)	Immediate	Immediate	Immediate
Strip mall	4.9	5.4	–

* LCC results are based on 1999 prices. As fuel prices rise, payback periods become shorter.

Table 2 presents payback periods obtained in a typical LCC analysis when comparing an EES with an oil base case scenario.

TABLE 2. PAYBACK PERIODS FOR EES (IN YEARS) COMPARED WITH OIL BASE CASE*

	Montréal	Toronto	Vancouver
New elementary school (3000 m^2)	6.6	8.5	0.8
Seniors' complex (7800 m^2)	3.5	4.7	1.1
High-technology facility (7000 m^2)	–	Immediate	–
Curling rink/hockey arena (1100 m^2)	4.0	Immediate	–
Mid-size hotel (10 500 m^2)	2.8	4.2	3.6
Motel (2050 m^2)	2.7	4.0	3.5
Suburban office building (5200 m^2)	Immediate	Immediate	Immediate
Strip mall	2.9	3.1	–

* LCC results are based on 1999 prices. As fuel prices rise, payback periods become shorter.

The immediate payback period is a result of the EES having a lower initial cost than the alternative HVAC system. It is important to take into account space savings and lower HVAC system complexity, which can often result in lower initial costs as well as maintenance savings, which lower operational costs.

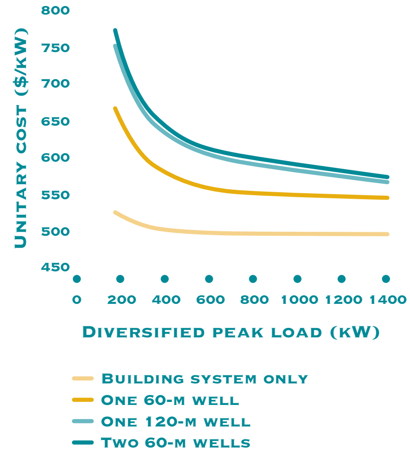
Rules of Thumb on Cost

Studies of various types of EESs indicate that vertical ground-coupled heat pumps (GCHPs) usually have the highest initial cost compared to hybrid or ground-water heat pump (GWHP) systems. Cost reductions of 20 to 80 percent can be achieved using the latter two options under specific conditions. GWHPs generally have a significantly lower initial cost but are subject to more stringent regulatory and practical constraints with regard to water use and disposal. In addition, overall efficiency and longer-term economic advantages of GWHP systems may be less attractive than those of GCHPs or hybrid systems due to their pumping power demand.

The typical total cost for a GWHP system depends on the ground-water temperature, system size and depth required for the wells, as shown in Figure 6. GWHP systems that are smaller have a sharp cost increase. GCHP and hybrid systems do not demonstrate as sharp a cost increase for smaller systems.

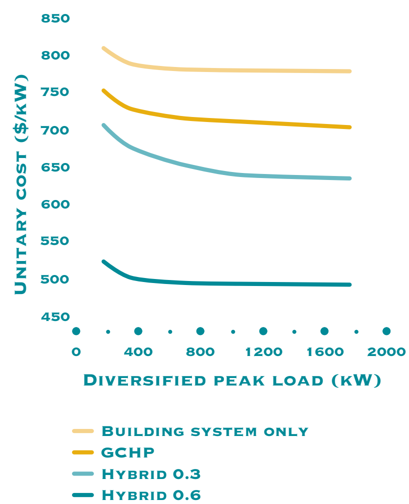
In general, when the required borehole (vertical hole) length for cooling exceeds that for heating, a hybrid system will reduce the system's initial cost without a large performance penalty. The smaller the ratio of heating length to cooling length, the greater the initial cost reduction will be, as shown in Figure 7.

Figure 6. Typical cost of GWHP system



Source: Kavanaugh, S., *A Capital Cost Comparison of Commercial Ground-Source Heat Pump Systems*, 1994.

Figure 7. Typical cost of GCHP and Hybrid systems



Source: Kavanaugh, S., *A Capital Cost Comparison of Commercial Ground-Source Heat Pump Systems*, 1994.

Chapter 2: Selecting an Earth Energy System

Selecting a Type of Earth Energy System

Selecting a cost-effective EES depends on many factors, although some guidelines can help with the process. Consideration must be given to each of the three primary sub-systems (earth connection, heat pump and distribution system) when selecting an EES.

The Earth Connection

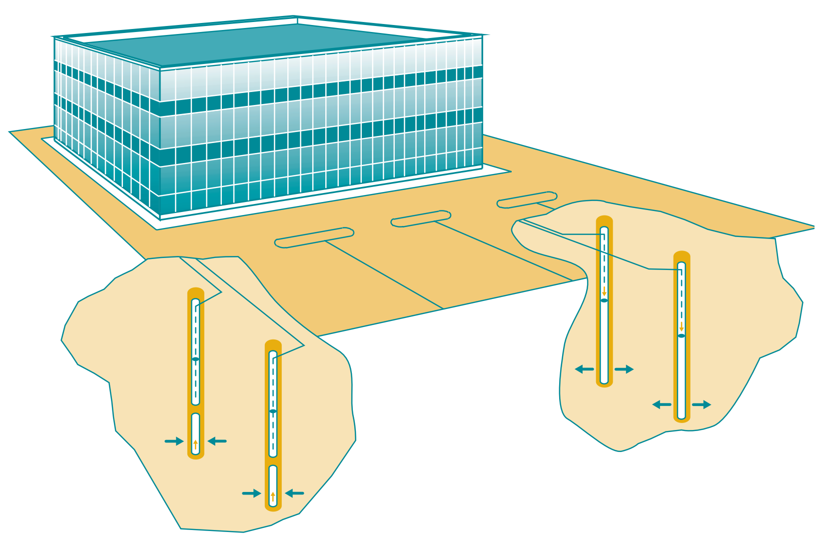
An EES can use either the ground or water as a heat source and heat sink. In a ground-coupled system, a series of buried pipes carry the fluid, often an antifreeze solution. Ground-water systems usually consist of water wells from which the water is pumped either directly to the heat pump's water-to-refrigerant heat exchanger or, commonly, to an intermediate heat exchanger that is connected to a building loop. This configuration facilitates cleaning by reducing fouling of heat pump components, provides heat recovery between the heat pumps on multi-zone systems and reduces well pump-head requirements.

A wide variety of earth connections are available for EESs. The following is an overview of the most common types.

Ground-Water Heat Pump Systems

Where ground water is available in sufficient quantities with adequate quality and environmental regulations permit this type of installation, such a system should be considered. GWHP systems will generally be more economically attractive for larger buildings, since the cost of the ground-water wells (supply and injection) does not rise linearly with capacity.

Figure 8. Ground-water heat pump system



GWHP systems were the first to appear on the market. These systems have been used successfully for decades. However, local environmental regulations and insufficient water availability may limit their use in some areas. A GWHP earth connection consists simply of water wells where ground water from an aquifer is pumped directly from the well to the building and, commonly, returned to the aquifer by another well. In such cases, the supply and return wells should be spaced to avoid thermal interference. As described earlier, an intermediate heat exchanger may be used to isolate the heat pumps from the well water. This is done to protect the heat exchanger from the fouling, abrasive or corrosive action of the well water. After leaving the building, the water can be pumped back into the same aquifer via a second well, called an injection well. Pumping power requirement is often an important factor to consider when evaluating ground-water systems.

Vertical Ground-Coupled Heat Pump Systems

Vertical GCHP systems are well suited for most commercial buildings and are usually the least expensive GCHP option for larger buildings. The GHX can be located under the building footprint or parking lot, making optimal use of available land. It has minimal environmental impact, and the earth connection in such systems can also be used, when properly designed, as a heat storage medium (i.e., for free cooling and sometimes free heating).

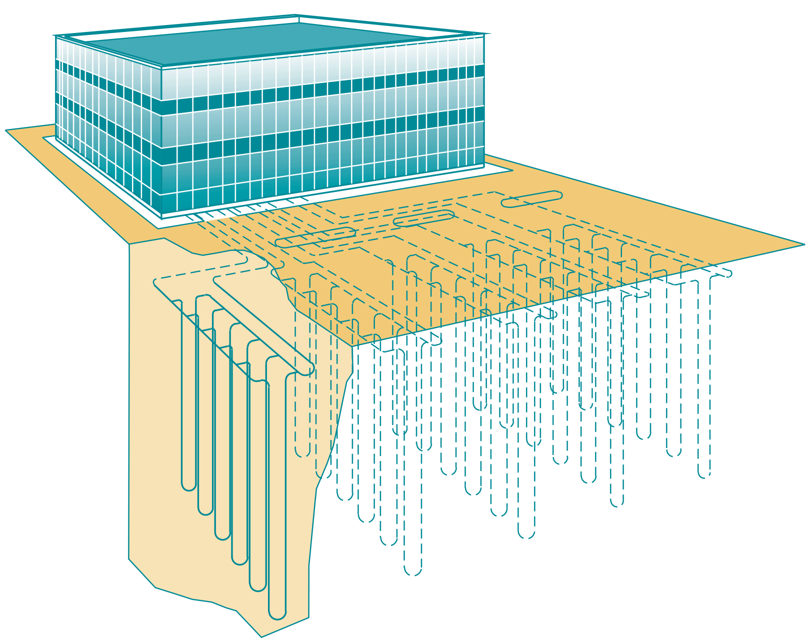
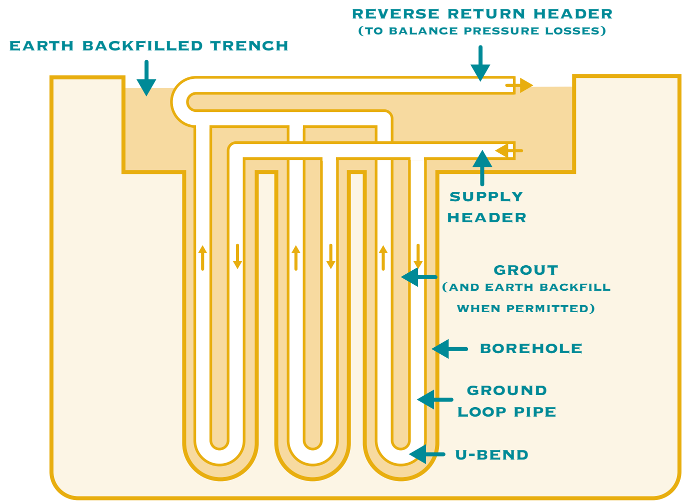


FIGURE 9. VERTICAL GROUND-COUPLED HEAT PUMP SYSTEM

Figure 10. Vertical ground-source heat exchanger

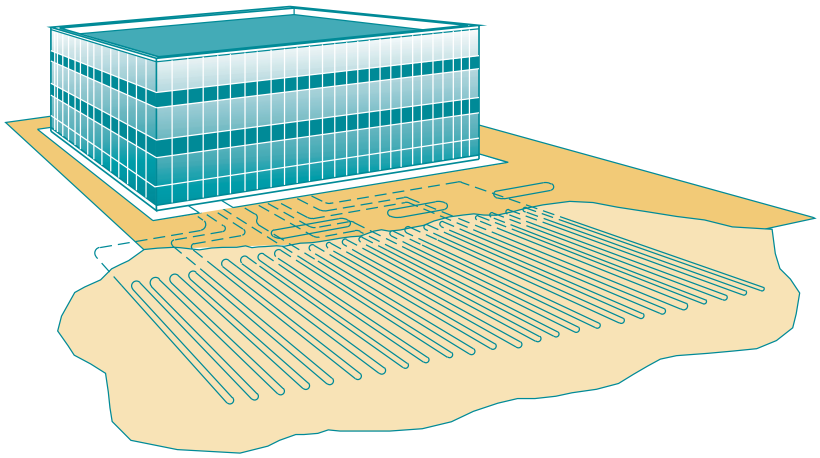


This type of system is well suited for most soil conditions and when minimum disruption of the landscaping is desired. The system consists of a series of vertical holes (boreholes) in the ground at 45 to 150 metres deep, into which one or two high-density polyethylene U-tubes (one down-flow tube and one up-flow tube in the same well) are placed. After the pipe is inserted, the hole is backfilled and grouted. The grouting process consists of filling the borehole with a special material that will prevent surface water from penetrating the aquifer or prevent the water from one aquifer from leaking into an adjacent one. Grouting materials usually have poorer heat-transfer characteristics than common backfill material and cost more, but thermally enhanced grout is also available (i.e., bentonite). Grouting the boreholes from top to bottom is often recommended for adequate protection from water seepage from one aquifer to another. In all cases, local regulations must also be consulted. Following backfilling and grouting, the vertical pipes are connected to a horizontal underground header pipe. The header pipe carries the GHX fluid to and from the heat pumps. Vertical loops are generally more expensive to install than horizontal ones (for small projects), but require less piping due to the higher efficiency obtained at greater depths.

Horizontal Ground-Coupled Heat Pump Systems

A horizontal ground-coupled system configuration is often the most economical to install, offering the lowest initial cost. However, these systems will also often have lower seasonal efficiencies because of lower ground temperatures and they require a larger land area. Generally, when the system's cooling capacity exceeds 70 kW, the surface of a typical parking lot will not be sufficient to accommodate the GHX without supplemental heat rejection. For these reasons, horizontal GCHP systems are usually more suited for smaller applications such as residential and small commercial buildings. Imbalances between the heating and cooling loads must be properly addressed in these systems to ensure that the ground surrounding the loop will offer a stable, long-term source and sink for the EES.

FIGURE 11. HORIZONTAL GROUND-COUPLED HEAT PUMP SYSTEM



Horizontal GHXs consist of a series of pipes laid out in trenches, usually one to two metres below the ground surface. Up to six pipes per trench can be specified, with adequate spacing between them. Typically, about 35 to 55 metres of pipe is installed per kW of heating and cooling capacity. Many variations of the horizontal GHX can be used. When land area is limited, a coiled pipe – also called a "slinky" or spiral – may be used in order to fit more piping into a trench area. Although this reduces the amount of land used, it will require more pipe, which results in additional costs. Once the pipe is laid out, the trench is then backfilled.

About Thermal Imbalance

All the information provided in this guide assumes that the earth connection will remain approximately at the same temperature year after year. This will be the case for all properly designed systems. However, when a building's cooling load differs significantly from its heating load, the earth connection will always have either a significant net energy gain or a significant energy loss. This is what is called "thermal imbalance." In the first case (energy gain), the average ground temperature may start warming up over the years if the GHX was not properly designed (e.g., ground with low water movement and closely packed boreholes). In the second case, the average ground temperature will gradually fall. When designing a GHX, thermal imbalance must always be considered in the final design to insure that long-term performances will be maintained.

Typical Land Area Required

The typical land area required for a ground-water system is usually not a critical factor. An estimate based on a 6-m radius per well, including the presence of injection wells, can be calculated.

The typical land area for vertical closed-loop systems can be based on an average borehole depth of 91 m and a spacing of 5 m between the boreholes. Common land areas required for vertical systems can vary significantly but are usually around 5 to 10 m^2/kW.

Horizontal systems require the most land area. The amount of land required varies with the GHX layout and piping arrangement required to minimize the pumping power. Typical values for land area for horizontal systems are as follows:

Table 3. Typical Land Area required for Horizontal EES (m^2/kW)

Configuration	Northern Climate Regions of North America	Southern Climate Regions of North America
One-pipe	79	79
Two-pipe	53	93
Four-pipe	40	66
Six-pipe	40	66

Source: *Commercial/Institutional Ground-Source Heat Pump Engineering Manual.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1995.

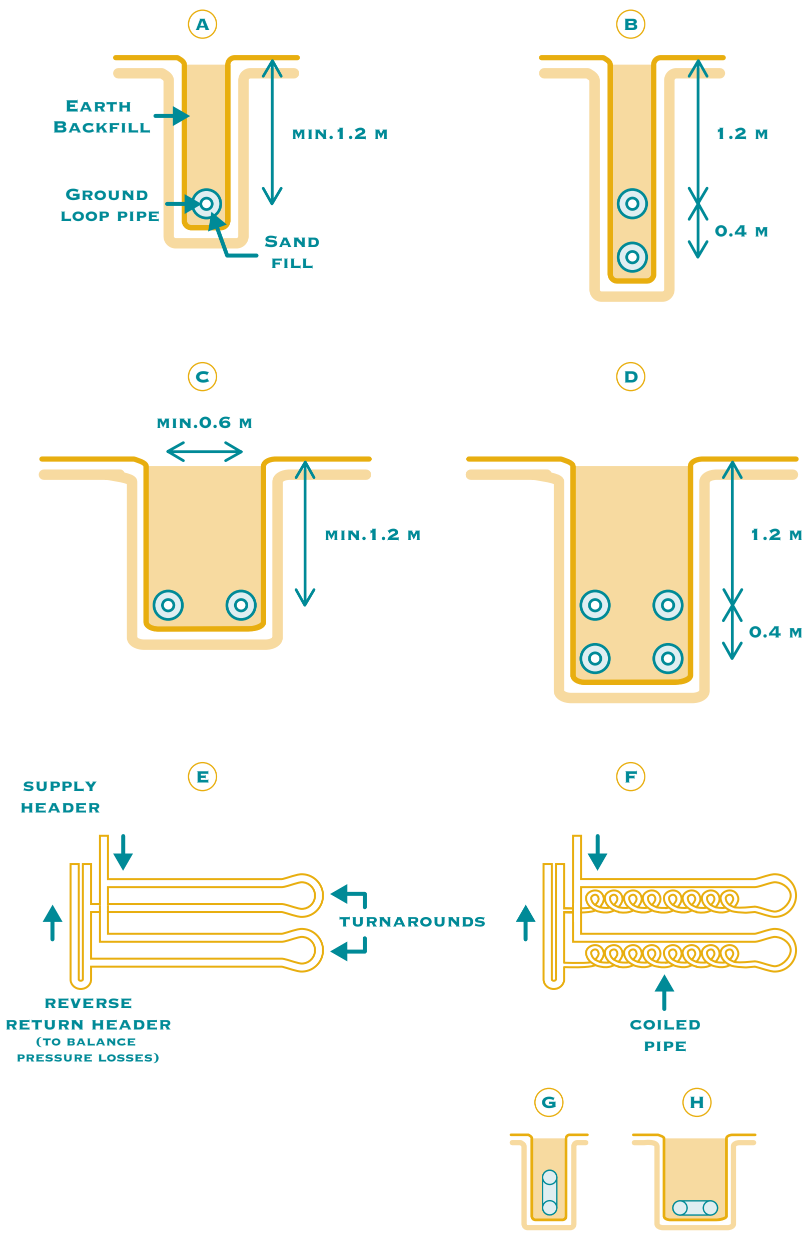
Direct-Expansion (DX) System

Each of the ground-coupling systems already described utilizes an intermediate fluid to transfer heat between the ground and the refrigerant. Use of an intermediate heat-transfer fluid necessitates a higher compression ratio in the heat pump in order 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 loop. Direct-expansion systems 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 ground. The result is improved heat-transfer characteristics and thermodynamic performance. However, the systems require a large amount of refrigerant and, 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.

Surface-Water System

A surface-water system is a viable and relatively low-cost EES option. When a building is near a pond or lake, submersing a series of coiled pipes beneath the surface will constitute the heat exchanger. This system requires minimum piping and excavation, but the pond or lake must be deep enough and must also have sufficient surface area to accommodate this type of system. The fluid is pumped through the pipe, just as it is in a ground-coupled system. Properly designed pond loops used in a closed system result in negligible impacts on the aquatic ecosystem. Piping should be buried at the shoreline to avoid damage from marine traffic and ice.

Figure 12. Various types of horizontal GHX



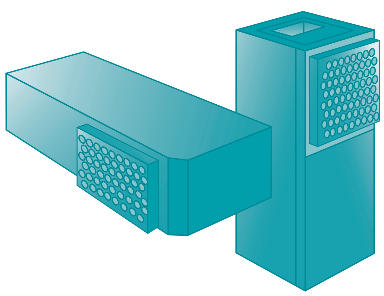
A. Single Pipe
B. Stacked two-pipe (sand fill is required only if rocks larger than 5 cm across are present.)
C. Parallel two-pipe
D. Stacked parallel four-pipe
E. Layout of parallel two-pipe showing turnarounds and header
F. Coiled pipe laid either horizontally in a wide trench or vertically in a narrow trench
G. Coiled pipe laid vertically in a narrow trench
H. Coiled pipe laid horizontally in a wide trench

Another factor to consider when selecting an EES type may be the availability of local contractors and installers familiar with the proposed technology. Long-term performance as well as a number of crucial practical considerations in designing and installing EESs can usually be thoroughly addressed by experienced personnel.

The Heat Pump

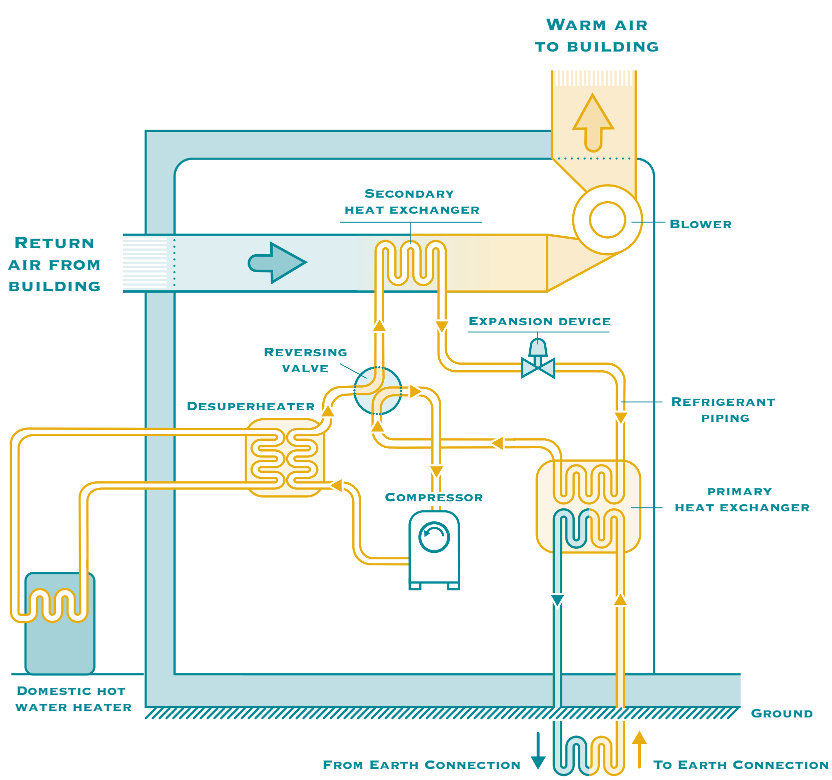
Heat Pumps

FIGURE 13. HEAT PUMP UNIT



One of the basic building blocks of any EES is the heat pump unit itself. Heat pumps used in an EES are either water-to-air units or water-to-water units, depending on the distribution system of the building. The most common type used is the single package water-to-air heat pump, typically ranging in size from 3.5 to 105 kW of cooling capacity. EESs should typically use extended-range units, which allow lower entering fluid temperatures in heating mode (liquid entering the liquid-to-refrigerant heat exchanger), and higher entering fluid temperatures in cooling mode. In these units, all the components are contained in a single enclosure. The unit typically includes the compressor, an earth loop-to-refrigerant heat exchanger, controls and a small air-distribution system that contains the air handler, duct fan, filter, refrigerant-to-air heat exchanger and a condensate removal system for air conditioning. A simplified schematic of a packaged heat pump unit is illustrated below.

FIGURE 14. SIMPLIFIED EES HEAT PUMP UNIT LAYOUT



The desuperheater shown on the schematic provides domestic hot water when the compressor is operating. The desuperheater is a small auxiliary heat exchanger at the compressor outlet. It transfers excess heat from the compressed gas to a water line that circulates water to a hot water tank. During the cooling season, when the air conditioning runs frequently, a desuperheater may provide all the hot water needed in certain applications.

In the last few years, the EES market has come of age, and manufacturers now offer a wide range of products, from split systems, water-to-water heat pumps, multi-speed compressors and dual compressors, to rooftop versions of this equipment to suit various applications.

Typical configurations include the following:

- vertical up-flow air discharge;
- vertical counter-flow air discharge;
- horizontal ceiling-mounted;
- dual compressor units;
- split systems (compressor/water heat exchanger and air-handling sections);
- large commercial vertical up-flow air-discharge units;
- two speed units, horizontal and vertical;
- floor-mounted console units;
- large commercial vertical variable air-volume units;
- rooftop packages;
- schoolroom ventilator units; and
- water-to-water (radiant hydronic systems).

Experienced and knowledgeable professionals should provide the proper selection of heat pump units.

Tons, Btu/h and Watts

Different units are commonly used in the industry to designate heat pumps' heating and cooling capacities. Generally, cooling capacity is expressed in tons, while heating capacity is expressed in Btu/h or kW. Converting from one unit to another is easily achieved using the following conversion factors:

- 1 ton = 12 000 Btu/h
- 1 kW = 3412 Btu/h
- 1 ton = 3.517 kW

Figure 15. Horizontal heat pump unit

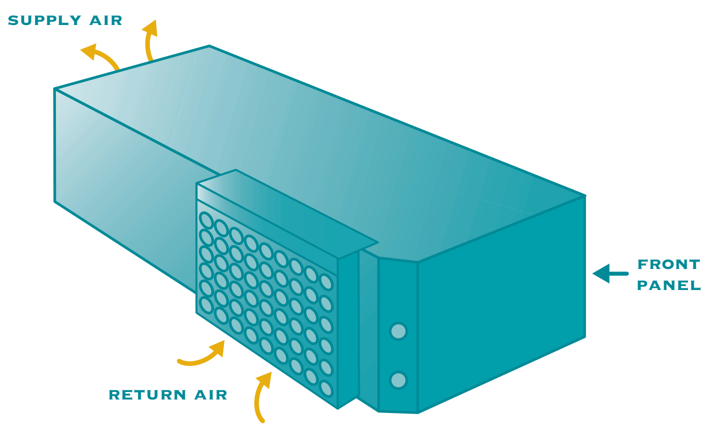
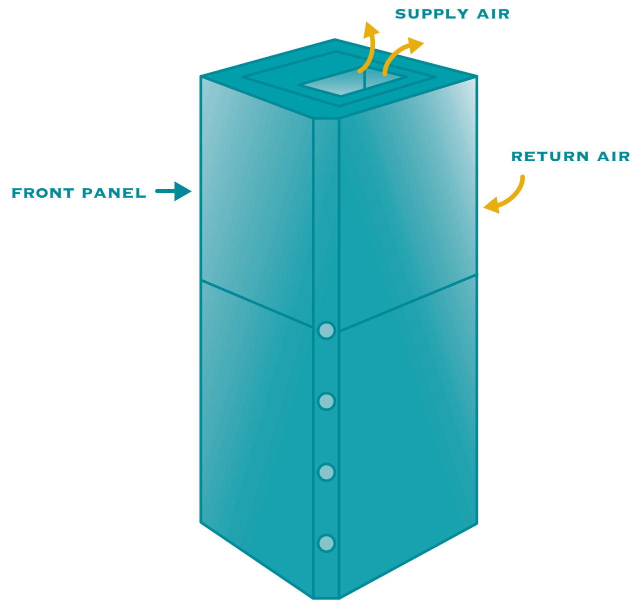


Figure 16. Vertical heat pump unit



EES heat pumps are available at different levels of efficiencies. High-efficiency equipment generally contains a high-efficiency compressor, a larger air coil, a higher-efficiency fan motor and sometimes a larger refrigerant-to-water heat exchanger. High-efficiency equipment comes with a higher price tag but may be the better economic option for a given project. It is difficult to state a general rule about selecting equipment on the basis of efficiency, because the economic considerations and merits of each system will vary depending on the application.

Table 4. Typical Cost of EES Heat Pumps

Heat Pump Efficiency Level	Typical Cost (per kW cooling)
Standard	$235
Medium	$270
High	$330

Tips on Heat Pump Sizing and Selection

- An EES heat pump should be sized so that, at its minimum capacity, the equipment does not exceed 125 percent of the cooling load. If this limit is exceeded, improper dehumidification and operation may result.
- Extended-range heat pumps should be used.
- A minimum energy efficiency ratio (EER) of 13, as per the Canadian Standards Association or the Air-Conditioning and Refrigeration Institute (ARI), is recommended.
- EER and COP ratings for multi-speed or variable-speed units must be carefully interpreted. Always look at the full-speed EER.

Care should be taken to ensure that the controls used on the heat pumps are easily integrated with the building and can be serviced by regular HVAC maintenance personnel.

Heat Pump Sizing

Heat pumps in distributed EESs will normally be sized according to the peak loads of each individual zone. This ensures that every room will maintain its temperature at any given time. The diversified (block) load should be used only to size central equipment, which can benefit from the potential load diversity (heating loads cancelling out cooling loads) to reduce its required size. For an EES, the earth connection should thus be sized according to the diversified load to help minimize its size and cost. If centralized heat pumps are used, these can also be sized using the diversified loads. Therefore, the type of distribution system used in a building will impact the final size of the heating and cooling equipment.

Pumping Concerns

EES performance can be greatly penalized if inadequate pumps, pumping controls and piping designs are used.

GCHP and GWHP systems require the use of pumps. GCHPs need pumps to circulate the fluid (water or antifreeze solution) throughout the building and the earth connection. GWHPs need pumps to circulate the fluid through the building loop, as well as separate pumps for the ground water.

GWHP projects can sometimes become uneconomical due to excessive pumping requirements (i.e., if the water table is too low or if the system's overall pressure drop is too high).

There are many options possible to optimize the pumping energy requirements for GCHPs and GWHPs. EES designers are the primary resource in selecting the proper pumping and piping layout that will optimize the economic performance of an EES.

As a general rule, GCHP systems should have an installed pumping capacity of less than 16 W per kW of peak diversified load. It is important to consider the peak block load and not the installed heat pump capacity when judging the adequacy of the pumping capacity. Cutting the flow to the heat pumps that are not in operation (solenoid-valve and variable-speed pumping) is highly recommended.

GWHP pumping capacity should be judged on the merit of each project. Optimal ground-water flow and associated pumping capacity should always be considered in an overall system performance analysis (i.e., heat pump performance and the well pump). This is required because the heat pump's performance will generally be significantly affected by the selected ground-water flow rate. As for GCHP systems, diversified load – not installed capacity – should be considered in the calculations.

Evaluation of Heating and Cooling Loads

Evaluating the building's loads is a critical step in an EES project. Given the usually higher initial cost of an EES, over-sizing the heat pumps or the earth connection may significantly reduce its economic attractiveness.

To determine the heating and cooling loads, the building should first be divided into thermal zones. The zone loads are then evaluated based on envelope thermal transmission, solar gains, internal gains (lights, people, equipment), infiltration and ventilation.

Heating loads for the zones should be determined using the winter design temperature for the locale. Cooling loads for the zones can be calculated using the most recent methods of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). These calculation methods include the effect of solar heat gain, thermal storage in building materials and indoor/outdoor temperature differences. Cooling load calculations should be made for three different times during the design day (usually July 31).

Block heating and cooling loads are needed to size the central equipment and GHX. Block loads are the sum of the individual zone loads at the time of the peak building load. The heating block loads should be evaluated at night conditions, and the cooling block loads evaluated at the same three different times used for the zone load determination. The highest of these should be selected as the design block load for cooling.

Controls

Water-Source Heat Pump

Controls for water-source heat pumps consist of low-voltage, wall-mounted thermostats for each unit. These may have night set-back capabilities. Operating fault conditions should be reset through the thermostat rather than at the unit. Fan operation is also controlled through the thermostat.

When an individual heat pump unit is off due to too high or low refrigerant temperature, an alarm or indicator light on the thermostat alerts the occupants. If there is a failure of the central pump, an alarm in the equipment room is activated, even if the standby pump is available.

Circulating Pump

A two-pump arrangement can be controlled from a time clock to automatically shut down the pumps during scheduled unoccupied periods. The pumps run continuously in many applications. A manual switch is normally provided to alternate pump operation in order to balance run times and wear. A variable-speed drive can also be used for the pumps to save energy.

Central Control/Energy Management System

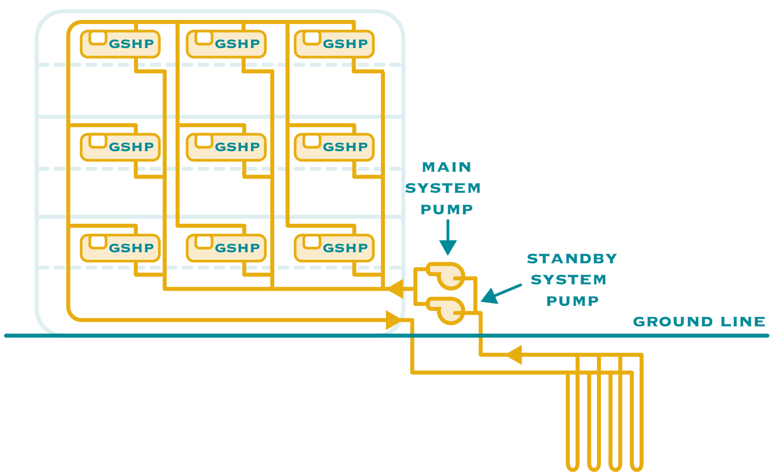
Larger systems may have central control panels with individual heat-pump-unit monitoring and controls. With such a system, a night set-back can be controlled centrally, as can morning start-up. Operation of the heat pumps can also be controlled from a central location (scheduling) as can the ventilation system.

The air-handling system is typical of any forced-air heating or cooling system. A fan moves heated or cooled air through ducts to the individual rooms and returns air to the earth energy system.

The Distribution System

Commercial EESs can be adapted to a wide variety of distribution systems, including air-based, hydronic (water-based), central and distributed systems. However, the most common system is based on the conventional water-loop heat pump system. In this type of system, each zone has one or more water-to-air heat pumps. All units, both in the perimeter area and the core area, are connected to a common hydronic system. For GCHP systems, the ground loop is normally used directly in the heat pump's building loop. GWHP systems will usually isolate the building's hydronic loop from the ground-water loop through an intermediate plate-type heat exchanger.

Figure 17. Typical Ground-Source Heat Pump Distribution System



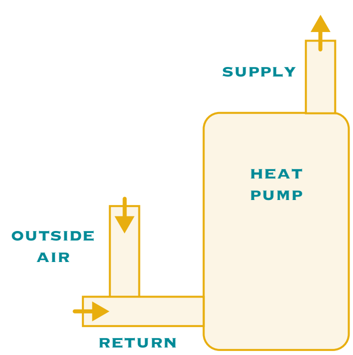
The heat pumps in a typical system, illustrated in Figure 17, are connected in parallel with a two-pipe water loop that circulates continuously. Thus, one heat pump can be rejecting heat to the loop while another takes heat from the loop, allowing heat recovery between the units. Any net heat gain or loss in the loop is transferred to the ground, lake or ground water. The heat pumps in such distributed systems are usually packaged units in single cabinets that include the compressor, heat exchangers, fan, filter and controls. These cabinets may be hung above the ceiling, installed in a closet or used as self-contained consoles on the perimeter of the building. Common areas such as lobbies or meeting rooms can use larger heat pumps.

A common centralized system uses a two-pipe system connected to one or more large heat pumps, which cool or heat water that feeds the two-pipe distribution system. This will typically supply fan coil units in the various zones of the building. A two-pipe fan coil system cannot cool and heat simultaneously, precluding heat recovery for space heating. A central four-pipe distribution system allows simultaneous heating and cooling. It consists of supply and return piping to both the condenser and the evaporator of the heat pump, which gives both chilled water and hot water for use throughout the building. This configuration is also readily adaptable to use the cool summer ground for free cooling purposes. Hydronic in-floor radiant systems are another common central system used with EESs.

A variation of the distributed system is the modular system, which has dedicated heat pumps, water pumps and loops for specific parts of a building. This type of system allows for independent individual control, operation and maintenance but limits the amount of load diversity available to size the earth connection.

As mentioned earlier, by linking all heat pumps through a common liquid loop, the ground connection of the EES can be designed using the diversified building load. However, for buildings where night set-back is to be used, the morning pickup load must be considered in sizing the ground connection because, at that time, all heat pumps are likely to be operating in the same mode.

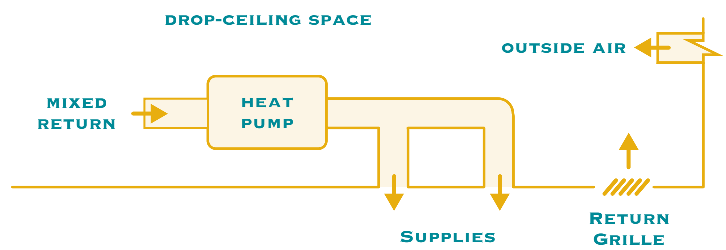
FIGURE 18. OUTSIDE AIR MIXED AT THE HEAT PUMP



Fresh Air Delivery

Regardless of the distribution system, fresh air quantities should meet or exceed local regulations, often developed following ASHRAE Standard 62, "Ventilation for Acceptable Indoor Air Quality." For the common water-loop system, the fresh air is often delivered to the return air plenum. In many buildings, ceiling space is used as the return air plenum. In such cases, fresh air is supplied to the ceiling space where individual zone heat pumps get their supply air. In some instances, fresh air is ducted directly to the heat pump's fan inlet where it is mixed with return air. Another possibility is to diffuse the fresh air directly into the room. Caution is required to ensure proper diffusion and to prevent cold drafts. Corridors can also be used to supply outside air to adjacent rooms that have mechanical exhaust. Regardless of the configuration selected, sufficient ductwork for fresh air distribution must be provided to ensure that all units receive adequate outside air and that short-circuiting to washroom exhausts is avoided. In all cases, if the fresh air quantity causes an entering air temperature to the heat pumps (after mixing with the return air) of less than 10°C, the fresh air will have to be heated. A heat recovery ventilator (HRV), which warms the incoming fresh air using heat from the outgoing general exhaust air, is an energy-efficient way of achieving this.

Figure 19. Ceiling Space Used as Return Air Plenum



Domestic Hot Water

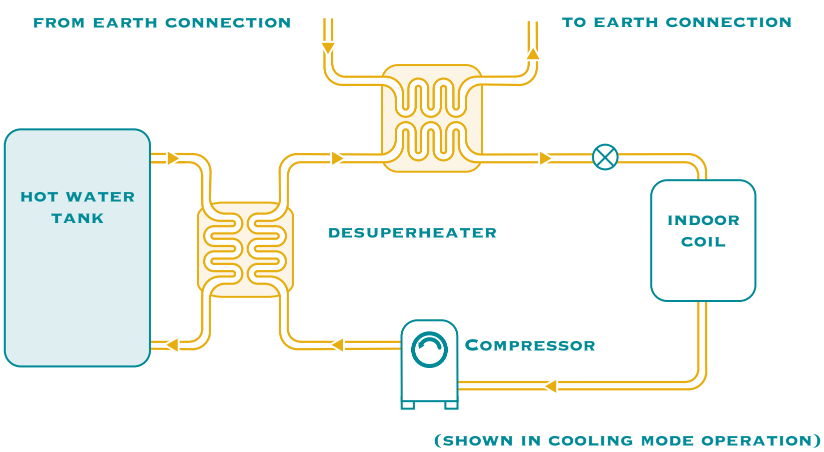
Water heating can be provided much more efficiently with vapour-compression technology than with electrical resistance or fossil-fuel-fired water heating.

Typically, an EES can provide domestic hot water using one of two main configurations. It should be noted that double-wall heat exchangers are usually required by local regulations for both of the configurations in Figure 20 and 21.

Desuperheaters

Using a desuperheater is a common factory-installed option for EES heat pumps. They can be easily adapted to a variety of situations, and they are highly efficient. However, they heat water only when the heat pumps are operating to satisfy heating or cooling space demand and therefore need auxiliary heating. This system will seldom meet the entire domestic hot water needs for commercial buildings.

Figure 20. Desuperheater



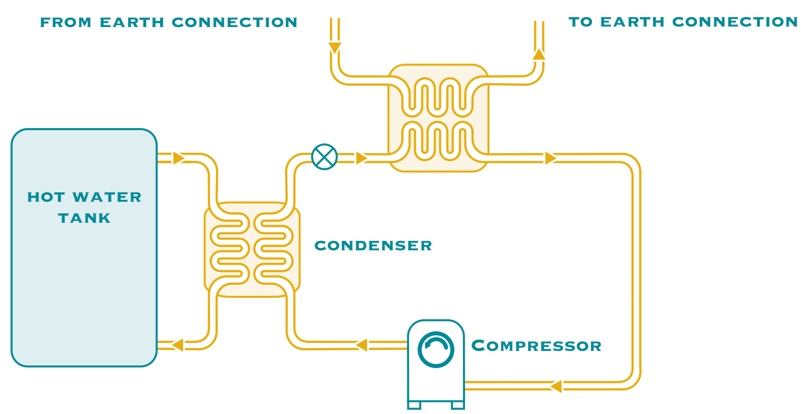
The operating principle behind a desuperheater is quite simple. Desuperheaters make use of the hot refrigerant vapour leaving the compressor to heat the water through a relatively small liquid-to-refrigerant heat exchanger. A desuperheater can transfer 5 to 15 percent of the energy that would otherwise be dissipated by the condenser.

The hot water generated by the desuperheater during cooling operation is virtually free, whereas it is provided at the system's coefficient of performance (COP) during heating operation mode.

Dedicated Heat Pump Water Heaters

Dedicated heat pump water heaters are specifically designed to heat water. Unlike desuperheaters, they can provide a building's total domestic hot water requirements without the use of an auxiliary system.

FIGURE 21. DEDICATED HEAT PUMP WATER HEATER



In an EES, dedicated heat pump water heaters consist of water-to-water heat pumps. These heat pumps use the earth connection (or building loop) as a year-round heat source and the domestic water tank as a heat sink. During the cooling season, the heat pump gets its energy from the heat rejected in the earth connection from other heat pumps cooling the building.

The hot water generated by the dedicated heat pump system is provided at the system's COP regardless of the operating mode. The maximum water temperature obtained with dedicated heat pumps or desuperheaters is about 55°C.

Building Considerations

The primary function of an EES is to provide space conditioning to a building. Therefore, the requirements of the building will dominate the EES design, as shown in the technical section describing earth connection sizing (see Chapter 7). The main parameters that need to be known about a building in order to proceed with an EES design are as follows:

- the peak cooling and heating load of individual sections of the building;
- the peak cooling and heating load of the building as a whole (also called block load or diversified load); and
- an estimate of the annual heating and cooling energy use (for GCHP).

The individual sections are defined as the building's zones, as shown in Figure 22, Sample Building Floor Plan. Zones in a building can be described as groups of spaces (or rooms) that have similar

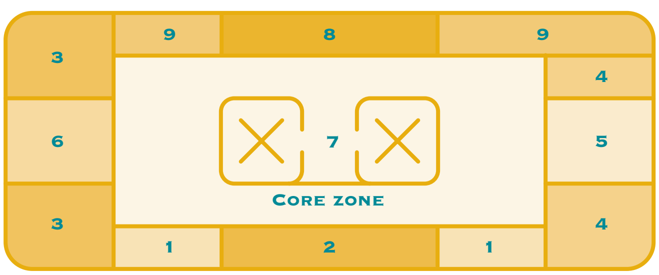
- usage and function (e.g., office space vs. coffee room);
- heating and cooling systems and thermostat set-points (e.g., rooms that have windows that face north vs. south); and/or
- periods of heating and cooling (e.g., perimeter rooms vs. interior or core rooms).

Diversified Loads vs. Peak Loads

At any given time, different zones in a building will experience varying thermal loads. Some spaces may require cooling while others may need heating. The total instantaneous load of the building will often be less than the sum of the design loads for each space, because they do not happen coincidentally.

Designing the ground connection using the diversified load allows for a reduction of the size and cost of the EES without compromising its efficiency.

Figure 22. Sample building floor plan



Note: Numbers 1-9 represent zones.

Energy Efficiency Considerations

As with air-source heat pumps, EESs are available with widely varying efficiency ratings. EESs intended for ground-water or open-system applications have heating COP ratings ranging from 3.0 to 4.0 and cooling energy efficiency ratings (EERs) between 11.0 and 17.0. Those intended for closed-loop applications have heating COP ratings between 2.5 and 4.0 and EERs from 10.5 to 20.0.

Energy Efficiency

EES heat pump efficiencies are defined by two parameters: the coefficient of performance (COP) and the energy efficiency ratio (EER). The steady state EER is defined as cooling output in Btu/h divided by the power input in watts. This gives the cooling load performance, usually available at a standard rating condition. In the heating mode, the descriptor is COP-defined as heating output divided by power input in the same units. The EER and COP do not include **central** pump/tower pump and fan power input. EER is also referred to as COP_c, which means COP in cooling mode.

The minimum efficiency in each range is regulated in the same jurisdictions as the air-source equipment. There has been a dramatic improvement in EES efficiency over the past five years. Today, the same new developments in compressors, motors and controls that are available to air-source heat pump manufacturers are resulting in higher levels of efficiency for EESs.

In the lower to middle efficiency range, EESs use single-speed rotary or reciprocating compressors, relatively standard refrigerant-to-air ratios and oversized enhanced-surface refrigerant-to-water heat exchangers. Mid-range efficiency units employ scroll compressors or advanced reciprocating compressors. Units in the high-efficiency range tend to use two-speed compressors and/or variable-speed indoor fan motors or both, with more or less the same heat exchangers.

Figure 23. Open System Earth Energy System Efficiency (at an entering water temperature of 10°C)

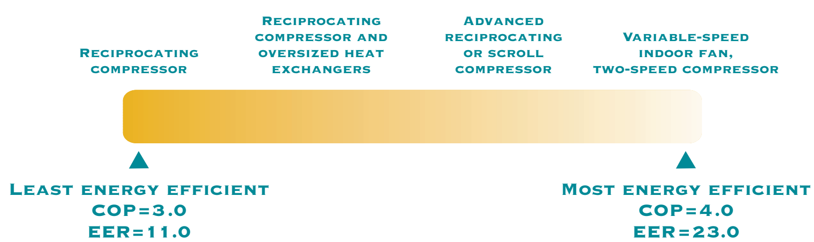
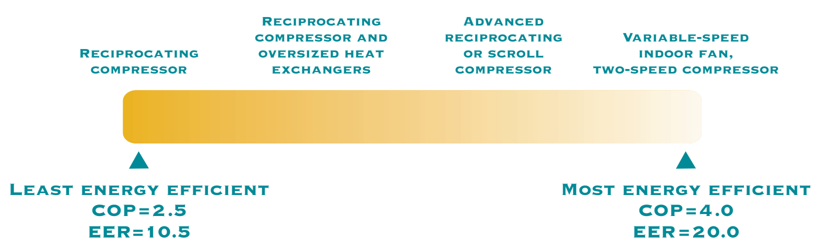


Figure 24. Closed-Loop Earth Energy System Efficiency (at an entering antifreeze water temperature of 0°C)



Chapter 3: Designing the Earth Connection

An overview of the design requirements of EESs is provided in this chapter. Design considerations are discussed more fully in Part 2 of this guide.

Typical Design Sequence

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

1. Determine local design conditions and climatic and soil thermal characteristics.
2. Determine building heating and cooling loads at design conditions.
3. Select the alternative HVAC system components, including the indoor air-distribution system type, and size the alternatives as required. Also 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).
4. Determine the monthly and annual building heating and cooling energy requirements.
5. Make a preliminary selection of a ground-coupling system type.
6. Determine a preliminary design of the ground-coupling system.
7. Determine the thermal resistance of the ground-coupling system.
8. 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.
9. Redesign the ground-coupling system as required to balance the requirements of the system load (heating and cooling) with the effectiveness of the system. Note that designing and sizing the 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).
10. Perform a life-cycle cost analysis on the system design (or system design alternatives).

Evaluating the building loads adequately is the initial stage and one of the most important steps in an EES project.

Earth Connection Design

Regardless of the EES earth connection selected, the specifications and size of the earth connection will depend on a number of design choices, such as the type of distribution system (see the section on distribution systems on pages 23–24), efficiency of the heat pumps, etc. One of the most predominant of the choices is whether the earth connection is to meet the heating or the cooling load. The cooling and heating loads will usually require different capacities from the earth connection, which may sometimes be significantly different. In these instances, it may not be economically optimal to design for the greater of the two capacities, and a designer must select which of the cooling or heating loads will serve as a basis for the EES design. In all cases, the loads attributable to the presence of pumps and domestic water heating must be considered in the final sizing calculations for the earth connection.

When an EES earth connection is not designed to entirely meet one of the building's loads, auxiliary systems are required to assist the earth connection. For example, many buildings in moderate to warm climates – and to a lesser extent in colder climates – have cooling loads that typically dominate heating loads. Selecting an earth connection to entirely meet this load could lead to an excessively large system that could make the EES uneconomical. In such a situation, the earth connection could be sized to meet only the heating load and have a supplemental heat rejector to compensate for the excess cooling demand (i.e., a cooling tower). In cold climates, this situation can be reversed, and sizing the earth connection for cooling loads can result in a smaller system but will require the use of auxiliary heat in the winter. A better option would be to reduce the heating load by optimizing the overall building design (i.e., by using a heat recovery device on the exhaust air).

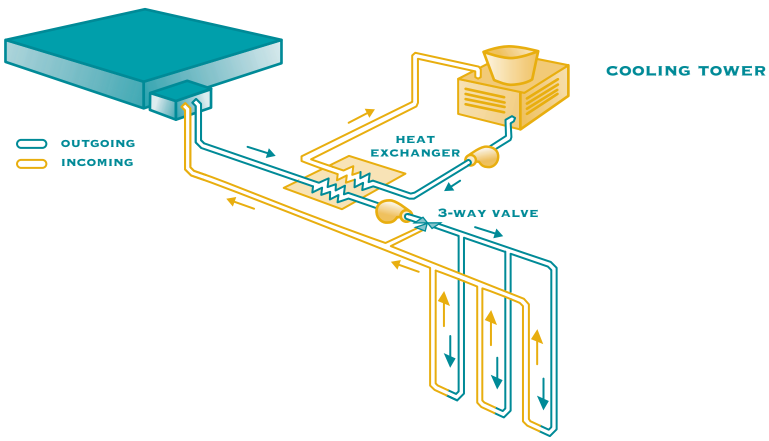
The choice of designing the system based on cooling or heating loads will be closely linked to the economics of each project and should be evaluated by the designer during the pre-feasibility analysis through sensitivity studies.

Finally, sizing the earth connection for closed-loop systems also involves greater uncertainty 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 professional because it can significantly affect the final design. A CSA standard with regard to EES design and installation has been developed and should be consulted (CAN/CSA-C448 Series-02) when analysing a potential project.

Supplemental Heat Rejector: Cooling Tower

When the earth connection is sized for the heating requirement, a cooling tower may serve to help meet the summer load. When needed, both the earth connection and the cooling tower are operated to reject the excess heat. Since the cooling tower is usually an open water circuit, an intermediate plate heat exchanger is often required to separate the earth connection or building loop fluid from the water circulated in the cooling tower.

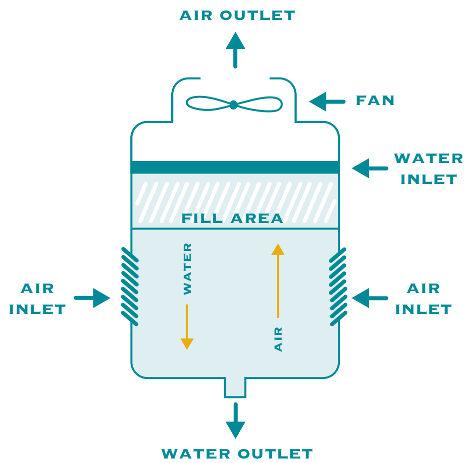
Figure 25. Supplemental heat rejector – Cooling tower



Furthermore, the building's core areas often require cooling well into the heating season. The heat pumps in these sections can then make use of free cooling by using separate coils, called economizer coils. When the outdoor temperature is low enough, the cooling tower can keep the building-loop fluid cold enough to allow cooling of the core areas using these coils, without operating the compressors. The loop temperature could be reduced to the proper temperature if the water bypasses the earth connection through a three-way valve. The core zones can be cooled without using the compressors, while the perimeter heat pumps can still operate in the heating mode. Economic viability of this option requires a case-by-case analysis.

Another alternative to the cooling tower is the closed circuit evaporative cooler. In this design, the heat exchanger is eliminated, and the loop water flows directly through the cooler's internal coil. If using the building/earth connection directly in a cooling tower is a problem, this design can also be achieved with a dry cooler instead.

Figure 26. Cooling tower principle



These towers utilize large fans to force air through circulated water. The water falls downward over fill surfaces, which helps increase the contact time between the water and the air. This helps maximize heat transfer between the two. The transfer of sensible and latent heat from the water droplets to the surrounding air allows cooling of the water.

A variation to the cooling tower system is the night evaporative system, in which cooling towers are used at night to expel excess heat that builds up in the ground loop as a result of heavy daytime use of the EES. This prevents the temperature of the fluid in the loop from losing its efficiency as a heat sink. Such systems may be ideal in climates where the days are unusually hot but the nights are cool, or where time-of-use rates are available from the local utility.

Supplemental Heat

Supplemental heat can be a viable option to reduce the size of the earth connection for heating-dominated buildings.

In many commercial systems, a packaged water heater installed in the building loop, much as in a closed-loop water-source heat pump system, provides the supplemental heat. This method allows some diversity in sizing the boiler as it lowers the installed capacity, compared to individual unit duct heaters or room baseboard heaters. Boiler operation is controlled to maintain a set minimum loop temperature going to the heat pumps. An optional feature is a reset control to keep the water heater from coming on unless the outdoor temperature falls below a certain set point.

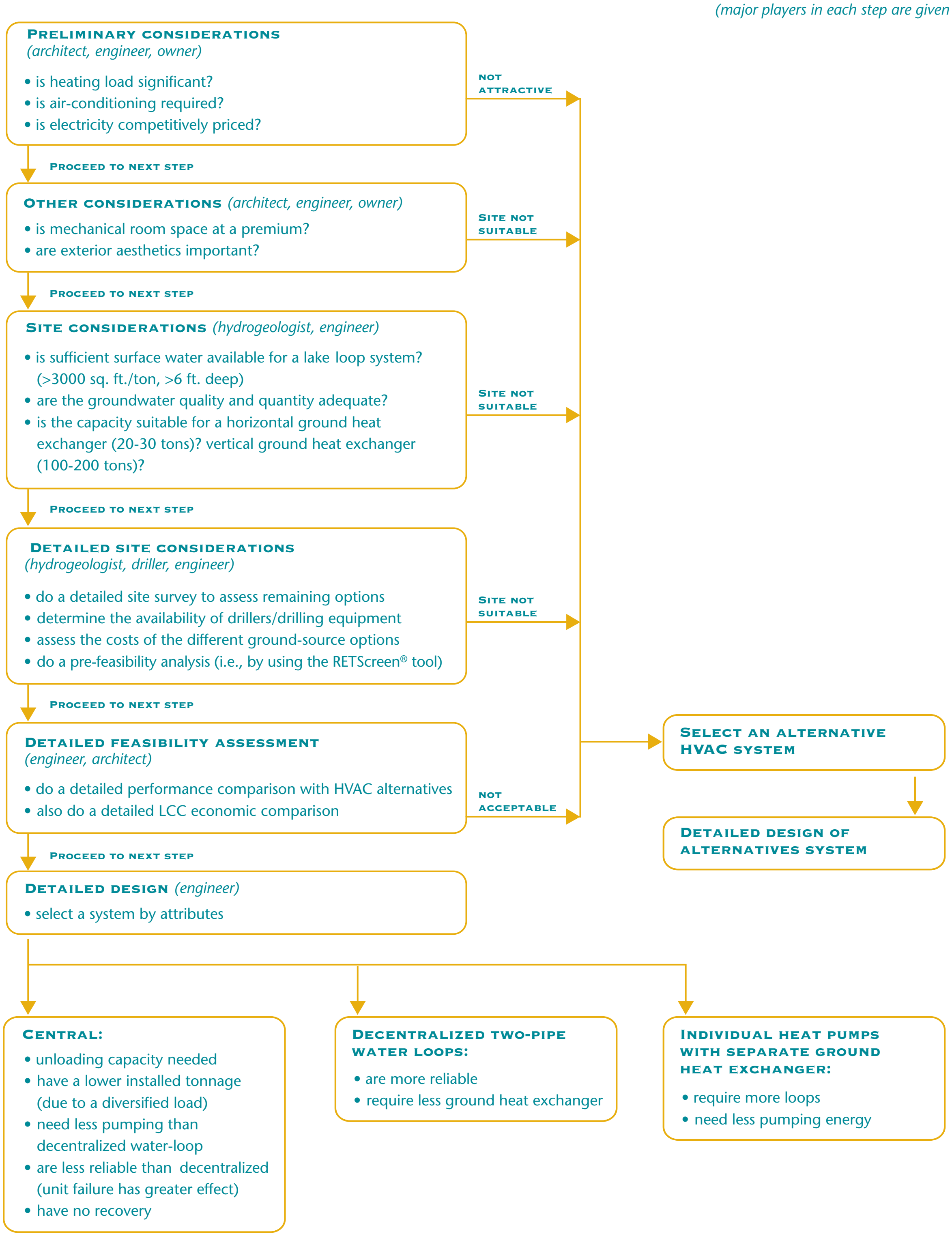
Using supplemental heat should be avoided whenever possible, because it reduces the overall system efficiency. Good building design with regard to its envelope, fresh air system, etc., can allow an EES to meet the entire heating load without relying on supplemental heating, even in cold climates.

Typical Steps in an Earth Energy System Project

Figure 27 is an outline of the typical steps when installing an EES.

Figure 27. Typical steps in an earth energy system project

(major players in each step are given in italics)



Chapter 4: Important Considerations

Environmental Factors

Ground loop or "slinky"

Ground-Loop Fluids

Antifreeze solutions are required in closed-loop EESs in colder climates to prevent freezing during heating operation. It is important to be aware of the potential impacts and risks of the available antifreeze alternatives, given that some antifreeze agents are toxic, corrosive or flammable.

Ethanol is an efficient thermal fluid with low toxicity and is biodegradable. Propylene glycol is non-toxic, non-corrosive and non-flammable but is less efficient as a thermal fluid. From an environmental standpoint (and for low risk of health, fire and corrosion) propylene glycol is an attractive antifreeze. Potassium acetate and methanol have the highest water and underground pollution impact. Methanol, although a very efficient thermal fluid, is highly toxic and non-biodegradable. Its use is limited in many areas; check with local authorities. Potassium acetate, although efficient and biodegradable, is prone to leakage problems and corrosion in systems that have threaded joints.

Therefore, caution must be exercised when using methanol (fire, health and environmental risks) and potassium acetate (leakage and environmental risks). The heat pump supplier should approve the choice of antifreeze solution.

EES designers and engineers should always evaluate the risk and impact of the selected ground-loop fluid.

Effect of Ground Temperature on the Environment

There is little or no documented evidence of negative impacts on organisms or plants resulting from the lower (and higher) ground temperatures associated with the operation of EESs.

Open-water or well-water systems are limited in use for large scale commercial and industrial installations, due to the need for a sustainable yield of high-quality ground water equal to just over three litres per minutes for each kW of rated heat pump system output. EES water discharge must return to the source aquifer to avoid depletion and/or contamination of other water-bearing zones.

Ground-water and surface-water extraction and usage are subject to the provisions of provincial and territorial acts and regulations intended to protect water resources. In accordance with CAN/CSA-C448 Series-02, due consideration should be given to:

- easements or rights of access to equipment by persons or agencies;
- quality and chemical composition of ground water;

- evidence of peak sustainable yield (including for other domestic services); and
- location and sustainable capacity of discharge wells.

Refrigerants: Ozone Layer and Regulation

As described in the overview of the refrigeration cycle (see page 5), EES heat pumps usually require the use of a refrigerant. Traditionally, the most common working fluid for heat pumps has been HCFC-22 (R-22).

However, HCFC-22 contains chlorine, and even though it has much lower ozone-depletion potential (ODP) than chlorofluorocarbons (CFCs) – typically 2 to 5 percent of CFC-12 – its production and use will be prohibited. This is the reason why hydrochlorofluorocarbons (HCFCs) are sometimes called transitional refrigerants. The phase-out schedule of HCFCs for industrialized countries, which was agreed to under the Montréal Protocol and its amendments, is shown in Table 5. HCFC-22 should be phased out for industrialized countries by the year 2010 and should be phased out entirely by 2020.

Table 5. Phase-Out Schedule for HCFCs

Date	Control Measure
1 January 1996	• CFCs phased out • HCFCs frozen at 1989 levels of HCFC + 2.8 percent of 1989 consumption of CFCs (base level)
1 January 2004	• HCFCs reduced by 35 percent below base levels
1 January 2010	• HCFCs reduced by 65 percent
1 January 2015	• HCFCs reduced by 90 percent
1 January 2020	• HCFCs phased out, allowing for a service tail of up to 0.5 percent until 2030 for existing refrigeration and air-conditioning equipment

Most EES heat pumps currently being marketed still use HCFC-22 as the refrigerant, although units using R-404a and R-410a are available.

HCFC-22 Alternatives

Research and development are underway to develop substitutes for HCFC-22 since it is the predominant refrigerant used in heat pumps and air conditioners.

The long-term substitutes will probably be blends of various hydrofluorocarbon (HFC) refrigerants since they have little or no ozone-depletion potential.

HFCs

HFCs can be considered long-term alternative refrigerants. This means that they are chlorine-free refrigerants, such as HFC-134a, HFC-32 and HFC-125. Since they do not contribute to ozone depletion, these are the major components of alternatives to HCFC-22.

Lubricants

Special attention must be given to the use of lubricants with new refrigerants. Mineral oils are non-miscible with these refrigerants. Normally only ester-based lubricant oils recommended by the refrigerant manufacturer should be used. Mineral oil residues must be completely removed during retrofitting.

However, they do contribute to climate change. Direct use of HFCs in ground-source heat pump systems is not possible, so refrigerant manufacturer devise "mixtures" of HFC to mimic HCFC-22 characteristics.

For instance, R-410A is a blend of HFC-32 and HFC-125. Another example is R-407C, a blend of HFC-134a, HFC-32 and HFC-125. They are mixed in such a way that they behave closely like HCFC-22 and possess similar thermodynamic properties.

Legislation

Federal legislation applying to EESs is limited to mechanical safety requirements and performance certification under the *Energy Efficiency Act,* except

- when installed in buildings owned by the Government of Canada (Public Works and Government Services Canada);
- lake loops in navigable waterways or fishery habitats (Transport Canada); and
- installations in national parks or Indian reserves (Indian and Northern Affairs Canada).

Application of Provincial/Territorial Building Codes

Regional limitations are intended to protect special interests. One must also ensure compliance with national standards. Municipal authorities are required to implement the provincial or territorial regulations where the responsibility is assumed by a third party, such as a conservation authority, and to ensure compliance with the proper provincial or territorial building code.

National Standards

Like requirements for other HVAC systems, all EESs are subject to national standards for performance certification and installation. The following standards are referenced in most technical and regulatory publications, with full recognition by industry, engineers and regulators.

- CAN/CSA-C448 Series-02 – a design and installation standard for earth energy systems, comprised of three parts:
  1) C448.1-02 – *Design and Installation of Earth Energy Systems for Commercial and Institutional Buildings*, which contains requirements applicable to any system within the scope of this standard.
  2) C448.2-02 – *Design and Installation of Earth Energy Systems for Residential and Other Small Buildings*, which has alternative requirements for houses and small buildings.

.

3) C448.3-02 – *Design and Installation of Underground Thermal Energy Storage Systems for Commercial and Institutional Buildings*, which applies to the intentional storage of energy in the earth for later use.

The CAN/CSA-C448 series supercedes standard CAN/CSA-C445-M92 (R1998) (*Design and Installation of Earth Energy Heat Pump Systems for Residential and Other Small Buildings*) and CAN/CSA-C447-94 (R1999) (*Design and Installation of Earth Energy Heat Pump Systems for Commercial and Institutional Buildings*). Installation and maintenance manuals are provided to support these standards with approved industry practice.

- CAN/CSA-C748-94 (R1999) – a standard for the performance of direct-expansion ground-source heat pumps.

- CAN/CSA-C13256-01 – a performance rating standard for earth energy heat pumps providing COP (heating) and EER (cooling) data, as required by the *Energy Efficiency Act* of Canada. Certified performance data for each eligible make and model is clearly visible on every unit offered for sale in Canada. Standard CAN/CSA-C13256 is comprised of two parts:
  - Part 1 (CAN/CSA-C13256-1-01): *Water-to-air and brine-to-air heat pumps*; and
  - Part 2 (CAN/CSA-C13256-2-01): *Water-to-water and brine-to-water heat pumps*.

Parts 1 and 2 together supersede CAN/CSA-C446-94 (*Performance of Ground Source Heat Pumps*) and CAN/CSA-C655-M91 (*Performance Standard for Internal Water-Loop Heat Pumps*).

Planning, Installation and Security

Unlike most other heating and cooling systems, the installation of an EES requires significant exterior civil works. This will require a geotechnical evaluation of the site and a careful definition of existing services to avoid accidental damage or personal injury. A detailed plan and specification referencing CAN/CSA-C448.1-02 (see above reference to national standards) must be submitted to the local inspection authority for prior approval.

In many jurisdictions, the replacement of a heating and cooling system using the same source of energy does not normally require a formal application under the *National Building Code of Canada*. All earth energy retrofits and first-time installations, however, require a formal application due to provincial and territorial regulations and the need for exterior civil works. Work should not proceed until formal approval has been received with a schedule of proposed inspections. The use of heavy equipment such as drill rigs, excavators and other civil work machinery will require a hard-hat zone to comply with provincial and territorial occupational safety regulations and general work safety practices. It would be prudent to rope off the affected land area with appropriate notices and maintain a 24-hour security guard until all operations cease and the original ground profile is reinstated. The installation or retrofit of all internal systems must be conducted with diligence to ensure maximum performance according to design. Extra precautions should be taken to avoid injury and protect health while recharging the refrigerant or antifreeze solution to the ground loop.

Warranty and Life Expectancy

Look for a warranty that clearly states the terms involved and the responsibilities of the players. Equipment warranties can be invalidated by lack of routine maintenance such as filter changes, and these conditions should be clearly understood from the outset. Typical warranty periods for heat pump units are one year (for the entire unit) and five years for the compressor. For warranties on installation quality and other equipment, consult with your general contractor.

Water-source heat pumps have a life expectancy of 20 years; ground loops have a life expectancy of more than 30 years.

Maintenance

Like other commercial heating and cooling systems, there are maintenance tasks to be performed periodically. These include the following:

- changing air filters;
- lubricating motors;
- changing fan belts;
- checking antifreeze concentration and inhibitors;
- cleaning open-loop heat exchangers (where applicable);
- cleaning grilles/registers;
- cleaning ducts; and
- checking air vents.

Cooling tower maintenance (which can be extensive) is eliminated, unless the system is a hybrid.

Little Known Facts About the Maintenance of EES Systems

The reliability of EESs is evident in a recent study of service and maintenance on 38 commercial installations, where a total of 723 corrective actions were taken for 2238 heat pumps. This represents only six corrective actions per 100 unit years of operation. The average age of the buildings was 5.6 years. The most frequent corrective action was compressor repair or replacement, representing 29 percent of all corrective actions. This translates into replacing only 1.7 percent of the compressors per year, compared to 3.3 percent for conventional water-loop systems.

Part 2

Advanced Topics and Technical Details

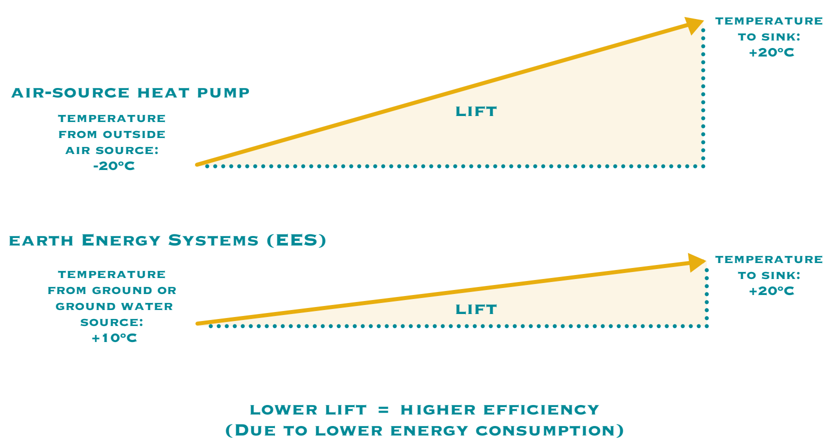
Part 2 of this guide elaborates upon the technical and economic aspects governing the design, sizing and installation of an EES.

Chapter 5: Understanding Heat Pump Performance and Efficiency

About Heat Sources, Sinks and Heat Pump Lift

One of the most important characteristics of heat pumps is that the efficiency of the unit and the energy required to operate it are directly related to the temperatures between which it operates. In heat pump terminology, the difference between the temperatures where the heat is extracted – the "source" – and the temperature where the heat is delivered – the "sink" – is called the "lift." The smaller the lift, the higher the efficiency will be. This is important because it forms the basis for the efficiency advantage of the EES heat pumps over air-source heat pumps. An air-source heat pump, or air-source air conditioner for that matter, must remove heat from cold outside air in the winter and reject heat to hot outside air in the summer. In contrast, the EES heat pumps extract heat from relatively warm ground (or ground water) in the winter and reject heat to the same relatively cool ground (or ground water) in the summer.

Figure 28. Air-source heat pump lift vs. EES lift



As a result, EESs, regardless of the season, are always "lifting" the heat over a shorter temperature differential than the air-source heat pump. This leads to higher efficiency and lower energy use. Also, less energy is required to move a liquid (in an EES) than to move air (in an air-source heat pump system).

Typical Heat Sources and Sinks

As previously mentioned, the performance of a heat pump is closely related to the characteristics of the heat source and sink. Ideally, the heat source should be as warm and stable as possible during the heating season and the heat sink as cool as possible during the cooling season.

For a heat pump, the typical sources and sinks available translate into typical pressure differentials between which the compressor will have to work. The higher the pressure differential, the greater the required work per unit mass of refrigerant.

Table 6. Typical Minimum Temperature Levels for Common Heat Sources in Heating Mode

Heat Source	Typical Minimum Temperature (°C)
Ambient air	-30°C to -15°C
Ground water	4°C to 10°C
Surface water	0°C to 10°C
Ground	4°C to 10°C

A heat pump that uses air as its source and sink is often called an air-to-air heat pump or air-source heat pump (ASHP). EES heat pumps, which use water or an antifreeze solution as its cooling sink, are generally referred to as water-to-air or water-source heat pumps.

Defining Heat Pump Efficiency

Heat pump efficiency is defined as the useful energy delivered, divided by the energy supplied to perform that function. The heating energy delivered by a heat pump is the sum of the heat extracted from the heat source and the energy needed to drive the cycle (i.e., compressor motor energy). The cooling effect delivered by a heat pump includes only the energy extracted from the source.

The coefficient of performance (COP) is used to define the heating performance of heat pumps. COP is defined as the ratio of heat delivered by the heat pump and the electricity supplied to the heat pump to deliver the useful heat. Therefore, the overall COP should include an allowance for pumping and fan energy, as indicated in the following equation:

$$COP_{heating} = \frac{\text{Useful Heating Energy}}{\text{Compressor and Fan and Pump Energy}}$$

Example – Using the COP

If equipment heating capacity and COP are known, the equipment power input can be estimated. For example, if the equipment has a heating capacity of 20 kW at a COP of 3.0, the power input would be:

20 kW/(3.0 COP) = 6.7 kW

COP can also be used to define a heat pump's cooling efficiency. In this case, the only difference is that the compressor and fan energy are not present in the useful cooling energy term. However, it is common in the industry to express the cooling efficiency in terms of its energy efficiency ratio (EER). The EER is equivalent to the COP with the exception that the heat from the source is expressed in Btu/h instead of W or kW.

EER vs. COP

⇒ *EER = COP X 3.413*

$$COP_{cooling} = \frac{\text{Useful Cooling Energy*}}{\text{Compressor and Fan and Pump Energy}}$$

** Useful cooling energy = heat removed from room.*

Example – Using the EER

If equipment cooling capacity and EER are known, the power can be estimated. For example, if the equipment has a total cooling capacity of 60 MBtu/h* at an EER of 12, the power input would be

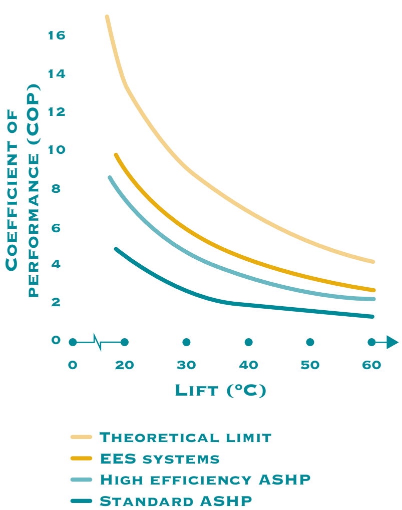
60 000 Btu/h / (12 Btu/h/W X 1000 W/kW) = 5 kW

* MBtu/h = 1000 Btu/h

Both the COP and EER values for EES heat pumps are single-point values only: i.e., they are valid only at the specific test conditions used in the rating. These conditions are usually more advantageous than those met in the field. In addition, COPs and EERs are usually reported without consideration for pump energy. These values are useful mainly for comparing equipment.

The COP or EER of a heat pump is closely related to the temperature lift of the heat pump. The greater the lift, the lower the efficiency.

Figure 29. Lift Effect on Heat Pump Performance



Factors Affecting Heat Pump Performance

A heat pump EER and COP depend on many factors, such as the temperature of the entering liquid, water flow rate through the unit, airflow rate and the temperature of the entering air. In general, the main factors affecting the performance of heat pumps include the following:

- the temperatures of the heat source and heat distribution system;
- the auxiliary energy consumption (pumps, fans, supplementary heat for hybrid system, etc.);
- the efficiency level of the heat pump;
- the sizing of the heat pump in relation to the heat demand and the operating characteristics of the heat pump; and
- the heat pump control system.

Rating Heat Pumps

Different types of heat pumps are tested and rated according to different standards. This is a potentially confusing aspect of EES heat pump rating. Rated heating and cooling performance values should be used only for comparing units of the same type (i.e., ASHP to ASHP or GSHP to GSHP). The ratings used for different types of equipment (i.e., ASHP, GSHP) are not generally comparable.

In Canada, the Canadian Standards Association (CSA) has published Standard CAN/CSA-C13256 upon which EES heat pumps are to be rated. In the United States, the American Refrigerant Institute (ARI) rates EES heat pumps using two different standards. Equipment rated as per CSA standards is listed in the CSA's *Energy Efficiency Directory*. ARI results are published every six months in the *Directory of Certified Applied Air-conditioning Products* (for GSHPs) and the *Directory of Certified Unitary Products* (for ASHPs).

Table 7. Applicable Standards for Different Types of Heat Pumps

Type	CSA	ARI
GCHP	C13256	330
GWHP	C13256	325
WLHP[1]	C13256	320
ASHP[2]	C273.31	210/2402

[1] Water-loop heat pump

[2] Unitary ASHP of less than 19 kW capacity

Rating conditions for the GSHP equipment are shown in the following table:

Table 8. Rating Conditions for EES Heat Pump Equipment

Type	Standard	EFT[1] Cooling (°C)	EFT Heating (°C)	Standard (°C)	EFT Cooling (°C)	EFT Heating (°C)
GCHP	C13256	25	10	ARI	25	10
GWHP	C13256	10	10	ARI	21	10

[1] Entering fluid temperature

Published ratings incorporate the effect of fans. GWHP ratings also include a pump penalty, given the greater pumping head that GWHPs usually have.

In Canada, federal regulations authorized by the *Energy Efficiency Act* apply to GCHPs and GWHPs. The regulations set the minimum efficiency that these products must meet to be imported into or manufactured in Canada. The reported efficiencies have to be established according to the appropriate CSA standard. The current minimum efficiency requirements for EES heat pumps are found in Table 9.

Table 9. Minimum Efficiency Requirements for EES Heat Pumps

Type	Standard	Cooling EER	Heating COP
GCHP	C13256	10.5	2.5
GWHP	C13256	11.0	3.0
WLHP	C13256	10.0	3.9

ASHP Ratings

The major difference between ratings for ASHPs and EESs is that the air-source values are seasonal. They are intended to reflect the total heating or cooling output for the season, divided by the total electrical input for the season. It takes into account the variable heating and/or cooling demands, the variable heat source and sink temperatures over the year, and includes the energy demand for defrosting.

Chapter 6: Evaluating Heating, Cooling Loads and Energy Use

Evaluating Building Loads

The design of any commercial building HVAC system requires a licensed professional engineer and must be done according to all other aspects of the building as a system. An EES is no exception.

One of the most frequent problems encountered with EES is improper sizing of the heat pumps or the earth connection. Rigorous building load calculation procedures should be used in the EES-sizing process; rules of thumb should never serve for sizing purposes. ASHRAE has established one of the most widely known and accepted standards for the determination of design heating and cooling loads. CSA standard CAN/CSA-C448.1-02 recommends using the ASHRAE heating and cooling load methods (*ASHRAE Handbook Fundamentals*, 2001).

Evaluating commercial building loads is complex and usually time consuming. A number of software programs are available to help designers proceed with this evaluation. However, preliminary design for simple buildings can still be evaluated using hand calculations or rudimentary spreadsheet programs. In all cases, one must be aware that evaluating the building load is one of the most important steps in designing an EES. Also, since an EES can benefit from a building's diversified load, this load needs to be evaluated in addition to calculating the individual zone's heating and cooling load for heat pump design purposes.

Heating and Cooling Load Calculation

The first step in the sizing process usually involves calculating each zone's peak heating and cooling load as well as the whole-building peak loads. The following factors typically need to be considered when performing these calculations:

- Solar gains through windows: Standard double-glazed windows can let up to 75 percent of this energy penetrate the building, where it becomes a cooling load. Additional window treatments such as tinted and reflective glazing, shading and draperies can further reduce solar gains.
- Internal gains from occupants (including latent heat for cooling purposes): Each adult will typically generate about 75 W of sensible energy and 55 W of latent energy.

Latent Loads

Latent load is the term used to define the energy attributable to humidity injection in a space. Removing 1 kg of humidity requires 0.7 kWh of energy. This load comes into play only under cooling conditions, when the heat pumps are actually removing some of that humidity.

- Internal gains from lighting and equipment: Lighting power is often about 20 W/m^2 in office buildings but can be as high as 40 to 50 W/m^2. The equipment load (also called plug-load) is often in the 2- to 5-W/m^2 range but can be as high as 15 to 20 W/m^2.
- Outside air loads (sensible and latent) from ventilation and infiltration: All buildings should meet at least the minimum outside air requirements imposed in their local jurisdiction. The amount of outside air is often taken from ASHRAE Standard 62. A typical value for outside airflow rate is 15 L/s/occupant.
- Heat gains or losses through windows, walls, floors and roofs: These gains are mostly important for heating load calculation but may still have some impact for the cooling load, especially the windows, and heat gain. The amount of heat transfer through these components can be estimated using the following formula:

  Heat gain/loss = Area X (surface temperature outside – surface temperature inside)/RSI value.

For typical RSI values, or effective thermal resistance in the International System of Units (SI), see Table 10.

Table 10. Typical RSI Values

Insulation Level	Wall RSI-Value (m^2·°C)/W*	Roof RSI-Value (m^2·°C)/W	Window RSI-value (m^2·°C)/W
Low	1.5	2.0	0.2
Medium	3.0	4.0	0.3
High	5.0	7.0	0.5

* (m^2·°C)/W denotes square metre by degree Celcius, per watt.

Using the very simplified values and formulas presented here can help in getting a rough estimate of a zone heating and cooling load. Some other important points to know about load calculations are as follows:

- The heating load calculation must be done without credit for occupants and internal gains, since this load usually occurs at night.
- Zone loads are calculated with consideration only to the zone's peak gains (i.e., solar) or losses (for heating).
- Each zone's peak loads may occur at different moments. However, for hand calculations, cooling loads are usually calculated during the hottest day of the summer for three different times for each zone. The greatest of the calculated loads are selected as the zone peak loads.
- Heating loads need only to be evaluated at the heating design temperature, since no credit for solar gain or internal gain is considered. However, since some areas in the core of a building may require cooling at all times, these zones may need to consider internal gain even under winter design conditions.

- Whole-building loads are calculated considering all zones' loads. The whole-building peak loads may not occur at the same moment as that of any of its zones. Precise determination of the time of occurrence of the whole-building load requires either extensive hand calculations or, more realistically, an hourly computer simulation. Approximate cooling block load can be estimated using the greatest of the sum of all zone loads for the three time periods previously considered.
- Design temperatures must be obtained from a reliable source, such as *ASHRAE Handbook Fundamentals, 2001*.

Typical values for building heating load range from 20 to 120 W/m^2. Cooling loads generally vary from 50 W/m^2 for buildings in cool climates with little internal gains to 200 W/m^2 or more for commercial buildings in hot climates with high internal gains.

For a thorough calculation of the zones and whole-building loads, one of the following three methods presented in ASHRAE should be employed:

- Transfer Function Method (TFM): This is the most complex of the methods proposed by ASHRAE and requires the use of a computer program or advanced spreadsheet.
- Cooling Load Temperature Differential/Cooling Load Factors (CLTD/CLF): This method is derived from the TFM method and uses tabulated data to simplify the calculation process. The method can be fairly easily transferred into simple spreadsheet programs but has some limitations due to the use of tabulated data.
- Total Equivalent Temperature Differential/Time-Averaging (TETD/TA): This was the preferred method for hand or simple spreadsheet calculation before the introduction of the CLTD/CLF method.

These three methods are well documented in *ASHRAE Handbook Fundamentals, 2001*. When designing an EES, the method used for obtaining the zones and whole-building loads should always be documented to ensure its adequacy.

Energy-Use Calculation

Long-term EES performance can be influenced by the amount of energy rejected in the cooling mode compared to that in the heating mode. If a large imbalance exists in these annual values, it can reduce GHX performance, and its design should take this into consideration. To evaluate the energy extracted and rejected to the ground, an annual energy-use calculation is required. For a commercial building, this type of calculation can rarely, if ever, be performed manually to obtain a reliable estimate. There are a few simplified methods that are still used today to obtain ballpark figures, but these should be treated with caution given their extremely simplistic approach to commercial building energy use.

Energy calculations can be done using one of three basic methods:

- Degree-day method: This simple procedure requires knowing only two parameters to estimate the annual energy use. Its value is extremely limited for commercial buildings. Crude estimates may be derived from it, but these can hardly serve in any estimating procedures, even at an early stage. Its use is limited to the residential sector.
- Bin method: Bin methods represent the best way to obtain early estimates for annual energy consumption. The method accounts for the changing outdoor temperature and partial load conditions. It can be automated easily in a spreadsheet program and can be used to treat multiple-zone buildings. Hand calculations of simple, residential-type buildings are feasible. Commercial buildings would be more difficult to treat using hand calculations.
- Hour-by-hour method: This is one of the most advanced methods for performing annual energy use calculations. It is arguably the best, but most complex method to select. Many commercial programs are available for performing hourly simulation, one of the better known being DOE2 and its derivatives. Care must be taken when performing a detailed hourly simulation. Easy to use software interfaces must not preclude a thorough validation of the input data and verification of the outputs. Validity of the results, even with the best hourly simulation model, will depend to a greater extent on its adequate use rather than on its various capabilities.

The "Energy Estimating Methods" chapter of *ASHRAE Handbook Fundamentals, 2001* describes in detail these methods and includes examples.

Typical commercial buildings in Canada will use between 100 and 400 kWh/m^2/year (kilowatt-hours per square metre, per year).

Chapter 7: Sizing Heat Pumps and Ground Heat Exchangers

Sizing the Heat Pumps

Once the cooling and heating loads are known, a decision must be made with regard to equipment selection. Should the equipment size be based on the heating load or the cooling load?

A common heat pump design guideline is that the cooling capacity should not exceed 125 percent of the peak sensible cooling load. Otherwise, dehumidification may not be adequate, and occupant comfort may be compromised. Using multiple compressor units or variable-speed fans may help circumvent this limit. The heat pump should be sized based on a sensible cooling capacity within 10 percent of the sensible space load. In cases where heating loads largely dominate the cooling loads, preconditioning the outside air may help balance out the loads. In such cases, the earth connection must be sized according to the loads actually met by the heat pumps and not the total loads. By reducing the gap between heating and cooling loads, preconditioning the outside air may also help reduce the need for hybrid systems. As in other industries, knowledge and methods evolve over time. Other methods and principles are used and provide adequate results. The buyer should refer to a trained designer for further information.

Humidity Considerations

EES heat pumps are usually designed to operate with a sensible heat ratio (SHR) typically of 0.75. The SHR is defined as the ratio of the sensible cooling capacity over the total capacity.

An SHR of about 0.75 is sufficient to maintain adequate humidity levels (i.e., meeting the latent load) in most Canadian locations.

In general, when estimating the cooling loads one should verify the zone's SHR. This value should be equal or superior to the heat pump's SHR.

Outside Air Preconditioning

If the temperature going into the heat pumps, after mixing with the outside air, can go below 10°C, preheating the outside air is required. Also, as mentioned above, outside air preheating may be desired to avoid large imbalances between design heating and cooling loads. There are several ways for preconditioning outside air. The most common options are as follows:

- Heat recovery ventilator (HRV) or total recovery ventilator (TRV): The HRV is an energy-efficient method for preheating outdoor air. The HRV extracts some of the heat in the exhaust air to precondition the outside air. A TRV will not only exchange heat between the exhaust and fresh air stream, but also exchange humidity. In humid climates, this will reduce the latent load on the heat pumps. In cold climates, it will reduce humidification needs.
- Water-to-water heat pumps: Another option that integrates itself naturally in an EES is the use of a water-to-water heat pump to precondition the outside air. This system uses a dedicated water-to-water heat pump that can heat and cool the outside air. Therefore, this system may also help reduce the latent load under cooling conditions.

HRVs in Cold Climates

In cold climates, HRVs may require supplemental heating, usually electric, to ensure that on the coldest days the incoming mixed air does not fall below 10°C. Also, in cold climates, a defrost mechanism on HRVs is usually required.

- Conventional heat source: Preheating may be performed by standard electric heaters, hot water or steam. These options are less energy efficient than the previous two but may turn out to be part of an overall optimal economic design.
- Other types of recovery systems: There are many more heat recovery systems that may play the same role as an HRV. Heat pipe systems, air-to-air heat pumps between the air stream and others may also be used.

Sizing Ground Heat Exchangers (GHXs)

The design of a GHX is in a few ways similar to that of a conventional heat exchanger. The load on the heat exchanger will drive the sizing process. For GHXs under specific soil conditions, the building load (cooling or heating) is the primary factor that influences its size. However, as for its conventional counterpart, the final size of the GHX is determined by design choices. When designing a conventional heat exchanger, both the inlet and outlet temperatures and flow rates are usually provided to determine its size. The final size will depend on the designer's requirement with regard to the temperature of the fluids coming out of the heat exchanger. This also applies for a GHX. The final size of the GHX will be determined by the designer's requirements for the minimum or maximum temperatures allowed at the GHX's outlet during the course of the year.

However, the maximum and minimum GHX outlet temperatures have a limited range of acceptable values. Practical constraints, mainly from the heat pumps, tend to make this design decision more straightforward. For example, extended-range heat pumps will usually have a recommended minimum entering fluid temperature (EFT) of –6°C , and a recommended maximum EFT of 43°C , with values in the 27 to 32°C range primarily being used. Specific designs may go below and above these temperatures but would not be common.

A designer can vary these values to optimize first cost against performance. Typically, the higher the value for the minimum temperature allowed at the GHX outlet, the higher the system's annual performance. However, the resulting GHX will be longer, and the initial cost will be higher. This applies to lower values for the maximum GHX outlet temperature.

Other factors affecting the length of a GHX include the following:

- type and properties of fluid circulated;
- GHX layout (distances between boreholes and trenches);
- depth of boreholes and trenches;
- net annual energy transfer to the ground;
- heat exchanger configuration, i.e., horizontal one-pipe or two-pipe, series and/or parallel;
- mean ground temperature;
- properties of the ground (and grout, if present);
- local hydrogeology (water movement in the ground);
- diameter of the pipe and flow rate for turbulence in the pipe over the extreme of operating temperatures; and
- heat pump's efficiency and pumping energy use.

Separation Distances

When designing a GHX, land area is often a concern. The required land area is not only dictated by the size of the GHX but also by the minimum spacing between boreholes and trenches. Typical values are shown in the following table but are always project-specific, and these values should only be considered in early estimates.

Table 11. Typical Distances Between Boreholes and Trenches in Soil

Type of GHX Layout	Borehole Separation (m)	Trenches Separation (m)
Standard	6.0	4.0
Minimum recommended	4.5	1.5

Although a smaller separation distance will reduce the typical land area required, it will increase the total length of ground heat exchanger required. Moreover, long-term heat imbalance on the GHX (cooling loads much greater than heating loads or vice-versa) will reduce to a greater extent the efficiency of closely packed GHXs. When a large difference exists between the heating and cooling loads, long-term effects on non-standard layouts should be thoroughly investigated. Specialized design tools are available to conduct this type of analysis (see the Web site at http://www.ghpc.org).

Rules of Thumb and Simple GHX-Sizing Guide for Vertical Systems

Initial estimates for a vertical GHX can be obtained through simple sizing rules of thumb or by using correlated formulas for typical systems. The size obtained using these guidelines can serve to obtain ballpark figures for the required length and cost of a GHX. However, these extremely simplified methods do not account for varying soil properties, long-term thermal imbalances or any of the other factors that influence the final size of a GHX. Therefore, they should be used only to gauge a potential system's size. Many public and commercial tools offer refined estimates for GHX size. These should always be used, or an experienced designer consulted, when going further than just a general overview of a potential project.

A simple estimating rule is presented in *ASHRAE's Commercial/Institutional GSHP Engineering Manual*, 1995. This rule is based on the net energy extracted from the ground for heating purposes or rejected to the ground during the cooling season. As will be presented later on, the designer must choose between designing a GHX according to the heating need of the building or its cooling need. Estimating a vertical GHX size using cooling data is then based on using 31.8-mm-diameter pipes. It is particularly important for commercial EESs to emphasize the limits of such simplified methods. These can be used only for very early estimates, and the cited references should be consulted for further validation of the following rule of thumb:

Length of GHX for cooling

$$= 0.05105 \times \frac{\text{Annual energy rejected to the ground (MJ)}}{\text{Maximum entering liquid temperature (°C)} - \text{Deep ground temperature (°C)}} \quad \text{(in metres)}$$

Estimating a vertical GHX size using heating data is based on the following:

Length of GHX for heating

$$= 0.05506 \times \frac{\text{Annual energy absorbed from the ground (MJ)}}{\text{Deep ground temperature (°C)} - \text{Minimum entering liquid temperature (°C)}} \quad \text{(in metres)}$$

These length estimates can vary significantly with a number of parameters, the most important being the soil conditions. Hence, for soils with poor thermal properties (such as most clay-rich soils), the length predicted by these simple rules could double.

Initial estimates for the energy extracted from and rejected to the ground can be obtained from whole-building peak cooling and heating loads combined with estimates of the equivalent full load (EFL) hours of the systems.

Heat extracted from the ground = Peak heating load X EFL_h X $(COP_h – 1)/COP_h$

Heat rejected to the ground = Peak cooling load X EFL_c X $(1 + COP_c)/COP_c$

The formulas include a term for the average annual heat pump efficiency. This term is required since the compressor motor power will be rejected to the ground, along with the building load, in the cooling season, while it will offset part of the building load in the heating season.

This simple formulation for the heat transfer to and from the ground can be replaced by better estimates if the building has been modeled using detailed simulation tools.

Other even simpler rules of thumb for obtaining an order of magnitude for a vertical GHX size are based only on the building's diversified loads and a general guidance as per its location.

Table 12. Vertical GHX Sizing Guideline (in nominal pipe size)

Location	Northern Climate Regions of North America (m/kW load)	Southern Climate Regions of North America (m/kW load)
3/4" and 1" nominal pipe size – length range	26	52
1" to 2" nominal pipe size – length range	17	39

Reference: *Commercial/Institutional GSHP Engineering Manual*, ASHRAE, 1995.

Sample Sizing Calculation: Vertical GHX

A building has a diversified peak cooling load of 100 kW and a diversified peak heating load of 84 kW. The building is located in Halifax, Nova Scotia. The building owners wish to have an idea of what size of GHX would roughly be required if they were to install an EES.

Local weather data indicate that the average yearly temperature in Halifax is 9°C. This is a good estimate for the deep-ground temperature. From their current energy bills, the owners estimate that the EFL of the cooling system is approximately 1100 h and the EFL of the heating system is 2200 h. The average cooling COP typical of vertical systems is considered to be 3.5 when cooling and 2.5 when heating. The annual energy that would be rejected to the ground would then be as follows:

Energy rejected = 100 kW X 1100 h X (1 + 3.5)/3.5
= 141 429 kWh X 3.6 MJ/kWh
= 509 144 MJ

Energy extracted = 84 kW X 2200 h (2.5 – 1)/2.5
= 110 880 kWh X 3.6 MJ/kWh
= 399 168 MJ

Since this is a first look at an EES for this building, typical temperature values for the entering liquid are used (i.e., 1.7°C minimum and 29.4°C maximum).

The resulting length for heating and cooling are as follows:

Cooling length = 0.05105 X 509 144/(29.4 – 9)
= 1274 m

Heating length = 0.05506 X 399 168/(9 – 1.7)
= 3011 m

The heating length is much longer in this case because of the fairly low ground temperature. This length would be reduced to 1998 metres if the acceptable minimum entering liquid temperature were reduced to –2°C. This, however, would reduce the overall system efficiency. The actual efficiency value, and its variation, cannot be as easily determined. If this first approximation is within reasonable limits for the owners, a more detailed pre-feasibility approach should then be considered to capture interactions such as changes to the COP with changing GHX length. Another interesting aspect of GHX design under a heating-dominated load is that the GHX size will increase for heat pumps that are more efficient. This is because less heating energy is supplied by the heat pump compressors and more by the ground. If the heating COP in the example were 3.5 instead of 2.5, the required length would be 3584 metres instead of 3011 metres. Selecting the optimal economic solution requires a well-planned approach.

Evaluating the GHX size using the simple rule of thumb presented in the previous table would lead to the following general estimate:

Length from cooling load = 100 kW X 17 or 26
= 1700 to 2600 m

Length from heating load = 84 kW X 17 or 26
= 1428 to 2184 m

The differences between the sizes from the equations and the tables are a good indication of the possible variations for any given GHX design using simple methods and rules of thumb. In this case, the owners could estimate that a GHX for their building may be around 2100 metres under a specific set of design choices (i.e., entering water temperature, heat pump efficiencies).

Part Load Factor (PLF)

Determining the horizontal GHX length using the formulas requires the evaluation of the building's design month's part load factor. The PLFs represent the fraction of equivalent full load hours during the design month to the total number of hours in that month. The PLF can be evaluated as follows:

$$PLF_m = \frac{\sum \text{Building Load} \times \textit{hours}}{\text{Peak Load} \times \text{No. of hours in month}}$$

The PLF is evaluated for the design-cooling and the design-heating months, typically July and January in the Northern Hemisphere.

Rules of Thumb and Simple GHX-Sizing Guide for Horizontal Systems

Unlike vertical systems, horizontal systems experience temperature fluctuation due to their shallow ground location. Sizing the GHX must therefore account for this additional parameter. Simplified formulas can also be used for initial estimates for horizontal GHXs, or simple rules of thumb can suffice to obtain these ballpark figures. However, as for vertical systems, such estimates are subject to a high degree of uncertainty and should always be considered with caution.

A simple method for sizing horizontal GHX sizes is available in *Closed-Loop/Ground-Source Heat Pump Systems: Installation Guide* (Oklahoma State University, 1988). This method can be further simplified by using approximate pipe resistance of 51 (m^2°C/kW) to allow easy use for rough estimates (loads in kW).

$$\text{Length of GHX for heating} = \frac{\text{Heating Load} \times [(COP_h - 1)/COP_h] \times (51 + R_s \times PLF_h)}{\text{Minimum ground temperature} - \text{Miminum entering temperature}} \text{ (in metres)}$$

$$\text{Length of GHX for cooling} = \frac{\text{Cooling Load} \times [(COP_c + 1)/COP_c] \times (51 + R_s \times PLF_c)}{\text{Maximum entering temperature} - \text{Maximum ground temperature}} \text{ (in metres)}$$

The terms in these equations are similar to those for vertical systems, but a few additional parameters need to be estimated, namely:

- the soil/field resistance, R_s (m^2°C/kW);
- the minimum and/or maximum ground temperature (°C); and
- the design months' part load factors (PLFs).

The soil/field resistance is an indication of the amount of energy that can be transferred to the ground. High values of resistance indicate that more pipe length will be required to reject or absorb a given amount of energy. The resistance is affected by the soil conditions and the GHX layout (i.e., one pipe system vs. a stacked two-pipe system). Typical values for common layout and a medium soil condition (i.e., dry heavy soil or damp light soil) follow in Table 13.

Table 13. Typical Soil/Field Resistance (in m^2°C/kW)

One-Pipe System	Stacked Two-Pipe System	Four-Pipe (2x2) System
742	970	1369

As for the ground temperature, an initial estimate for the minimum ground temperature can be based on the average air temperature for the heating season (October to March); the maximum ground temperature can be estimated based on the average air temperature for the cooling season (April to September). Better estimates that account for the depth of the pipe and soil conditions can be calculated using an analytical formulation. Alternately, the chart at the right can be used to determine the minimum and maximum temperatures based on the yearly average temperature at any given depth.

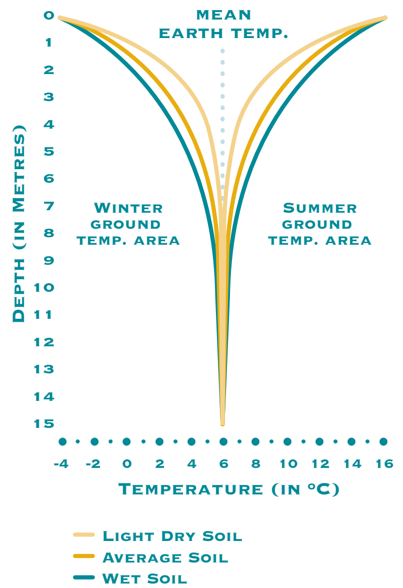
The rules of thumb for a horizontal GHX are available in Table 14.

Table 14. Required Pipe Length (m/kW Diversified Peak Load)

Configuration	Northern Climate Regions of North America	Southern Climate Regions of North America
One-pipe	30	30
Two-pipe	43	74
Four-pipe	52	87
Six-pipe	65	104

Reference: *Commercial/Institutional Ground-Source Heat Pump Engineering Manual,* ASHRAE, 1995.

Figure 30. Soil Temperature Variation (°C)



Source: *Closed-Loop/Ground-Source Heat Pump Systems: Installation Guide*, Oklahoma State University, 1988.

Sample Sizing Calculation: Horizontal GHX

Building owners in Halifax, Nova Scotia, have estimated the size of a vertical GHX and now want to obtain similar estimates for a horizontal GHX. They have already estimated the ground temperatures for their proposed GHX layout. Their building has an estimated diversified peak cooling load of 100 kW and a diversified peak heating load of 84 kW.

From current energy bills, the owners estimate that the EFL of the cooling system is approximately 1100 hours and that the EFL of the heating system is 2200 hours. The average cooling COP typical of horizontal systems is considered to be 3.5 when cooling and 2.5 when heating. The owners estimate that the design months' (summer and winter) part load factors (PLFs) are about double that of the annual average, as follows:

$$PLF_c = 1100 \text{ h}/8760 \text{ h} \times 2$$
$$= 0.252$$

$$PLF_h = 2200 \text{ h}/8760 \text{ h} \times 2$$
$$= 0.502$$

Since this is a first look at an EES for this building, typical temperature values of the entering liquid are used (i.e., –1 °C minimum and 29.4°C maximum). The soil resistance is estimated at 51.

The resulting length for heating and cooling are as follows:

Cooling length = {100 kW X [(3.5 + 1)/3.5 X (51 + 970 X 0.252)]}/(29.4 – 14.2*)
= 2500 m (of pipe) or 1250 m of trench

Heating length = 84 kW X (2.5 – 1)/2.5 X (51 + 970 X 0.502)/[3.8 –(– 1)**]
= 5648 m of pipe or 2824 m of trench

* 14.2°C is the maximum ground temperature.
** -1°C is the minimum ground temperature.

The heating length is once again much longer because of the low minimum ground temperature. This length would be reduced to 3583 metres if the acceptable minimum entering liquid temperature were reduced to –3.9 °C (low temperature limit of equipment). This, however, would reduce the overall system efficiency. The actual efficiency value, and its variation, cannot be as easily determined. If this first approximation is within reasonable limits for the owners, a more detailed pre-feasibility approach should then be considered to capture interactions such as changes to the COP with changing GHX length. As for the vertical GHX, the required heating length will increase for more efficient heat pumps, and selecting the optimal economic solution requires a sensitivity analysis.

Evaluating the GHX size using the simple rules of thumb presented in Table 14 would lead to the following general estimates:

Length from cooling load = 100 kW X 43
= 4300 m

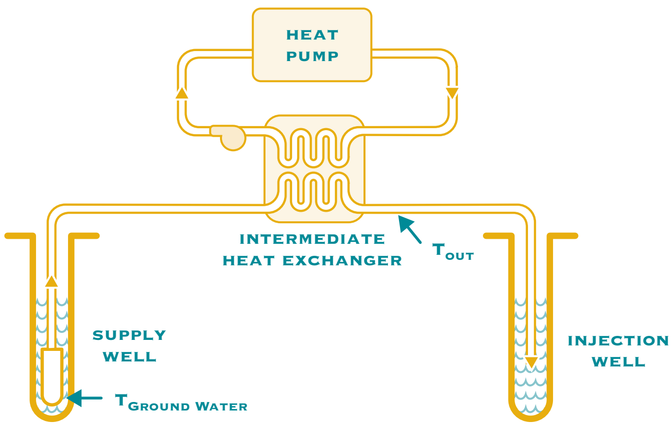
Length from heating load = 84 kW X 43
= 3612 m

The differences between the sizes from the equations and the tables are a good indication of the possible variations for any given GHX design choice. In this case, the owners could evaluate that a horizontal GHX for their building may be around 4000 metres under a specific set of design choices (i.e., entering water temperature, heat pump efficiencies and configuration).

Rules of Thumb and Simple GHX-Sizing Guide for Ground-Water Systems

The ground-water system considered here uses an intermediate heat exchanger to isolate the building fluid loop from the ground water. This is required whenever the building-loop fluid is not water and is recommended in many cases to prevent damage to the heat pump's heat exchanger due to scaling or corrosion from the ground water. Intermediate heat exchangers are also valued as a means to protect ground-water quality by isolating the ground-water loop from the heat pump equipment and refrigerant circuits.

Figure 31. Indirect Ground-Water Heat Pump System



Required ground-water flow rate depends on the ground-water temperature and the effectiveness of the building's loop heat exchanger. Using an approach temperature of 3°C at the heat exchanger, between the ground-water loop and the building loop, is reasonable to estimate the required flow rate. The temperature of ground water remains relatively constant throughout the year. The ground-water temperature for an area is approximately equal to an area's annual average air temperature.

Ground-water flow can be estimated by the greater of the flow for cooling or the flow for heating using the following formulas (loads in kW):

Heating flow rate (in litres per second) =

$$\frac{\text{Diversified heating load}}{4.18 \times (T_{groundwater} - T_{out})} \times \frac{(COP_h - 1)}{COP_h}$$

Cooling flow rate (in litres per second) =

$$\frac{\text{Diversified cooling load}}{4.18 \times (T_{out} - T_{groundwater})} \times \frac{(COP_c + 1)}{COP_c}$$

To complete the evaluation for the flow rates, the leaving temperature on the ground-water side of the intermediate heat exchanger, T_{out}, has to be evaluated. This temperature is based on the design decision concerning the approach temperature and is also dependent on the building-loop water-flow rate and heat pump efficiencies.

Values of T_{out} can be estimated using the typical 0.054 L/s/kW flow rate value recommended by ground-water-source heat pump manufacturers for the building loop.

Heating: $T_{out} = T_{groundwater} - 5°C$

Cooling: T_{out} = *Summer entering temperature + 2°C*

The summer entering temperature used in the previous equation represents the maximum building loop temperature at the inlet of the GWHPs.

Typical values for the ground-water-flow rate are usually 0.05 L/s/kW or less.

Sample Sizing Calculation: Ground-Water System

Building owners in Halifax have estimated the size of a vertical and horizontal GHX but would also like to estimate the required flow if they were to select a ground-water EES. Their building has an estimated diversified peak cooling load of 100 kW and a diversified peak heating load of 84 kW.

The ground-water temperature in Halifax is estimated at 9°C. The building owners choose a summer maximum entering temperature of 24°C at the inlet of the GWHP. They use estimated COPs of 4.0 in cooling and 3.0 in heating. The ground-water flow rate for both loads can then be estimated as follows:

Heating: T_{out} = 9 – 5 = 4°C

Heating flow rate = 84/4.18/(9 – 4.5) X (2/3)
= 2.98 L/s

Cooling: T_{out} = 24°C + 2°C
= 26°C

Cooling flow rate = 100/4.18/(26 – 9) X (5/4)
= 2.0 L/s

The heating ground-water flow is significantly higher than the cooling flow. Lowering the selected minimum entering fluid temperature could reduce the difference, but this would also lower the system's efficiency.

Chapter 8: Analyzing an Earth Energy System Investment

Investment Criteria

Three of the most-used measures for evaluating an investment are the simple payback period, the net present value (NPV) and the internal rate of return (IRR). Each indicator has a different meaning and should be used accordingly.

Simple Payback Period

The simple payback period is by far the simplest and most basic financial indicator. It provides an indication of a project's risk and short-term capital cost recovery potential. However, it does not account for varying economies or expenses occurring past the payback period and does not consider the cost of borrowing money or revenue made on investing money. The simple payback period is calculated as the ratio of the additional cost of installing an EES over the annual economies it will bring. Many EES projects present simple payback periods between four and six years but demonstrate even better life-cycle economic values.

Net Present Value

The word "net" in the term "net present value" indicates that this parameter includes the initial costs as well as the subsequent economies or losses incurred by the EES, including maintenance costs throughout the lifetime of the system. The NPV of an EES project shows how this investment compares with an alternative system. A positive NPV means the EES investment is better. A negative NPV means that the alternative system is a better option. The NPV represents the net worth of a project in today's dollars. Therefore, it is the sum of all future savings (or losses), corrected to discount for the interest rate (or the amount you need today to have the same savings in the future), minus the added initial cost.

$$\text{Net present value} = \sum_{\text{Year}=1}^{\text{System's life}} \frac{\text{Net annual savings}}{(1 + \text{Interest rate})^{\text{Year}}} - \text{Initial cost}$$

Internal Rate of Return

The IRR represents the true interest rate provided by the project over its life. It is also referred to as the return on investment (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the NPV of the project to be equal to zero. Thus, if the savings are high, a higher discount rate (i.e., IRR) is required to make the NPV equation equal to zero. The IRR can be thought of as the interest rate that would have applied to the incremental cost of the EES if it had been invested otherwise.

Economic and Financial Calculation Example

A building's owners in Halifax, Nova Scotia, have estimated the size of a vertical system and want to evaluate the initial cost, type of savings and financial indicators that would be typical for this type of system. The average energy rate for their 2500-m^2 building is $0.10/kWh on average (including demand charge).

Using $/kW Rule of Thumb

The vertical-system size is used for this early estimate is based on a 100-kW peak load and 1000 metres of borehole. The total cost could be estimated using the previous tables as follows:

EES Initial Cost

Borehole: 1000 m X $20/m = $20,000
Piping: 2000 m X $2.5/m = $5,000
Valves and fittings: 100 kW X $10/kW = $1,000
Heat pumps: 100 kW X $350/kW = $35,000
Internal piping and insulation = $20,000
Circulating pumps = 100 kW X 0.017 W/kW X $1000/kW
= $1,700
Total = $82,700

The conventional system cost, based on rooftop units at a cost of $500/kW, would be $50,000.

The annual energy use and cost for the building are estimated from the utility bills as follows:

Conventional System

Cooling (conventional COP = 3.0) = 40 000 kWh X $0.10/kWh
= $4,000

Heating (all-electric) = 184 000 kWh X $0.10/kWh
= $18,400

EES Estimate

The solution indicates a short-term investment recovery period. In such a case, long-term financial indicators may not be necessary in an early project phase. The payback period should incite the owners to push forward with a more thorough evaluation of the EES design and costing. The simple payback could also be corrected to account for additional feasibility costs for an EES and for other savings, such as demand charge savings. Using a pre-feasibility tool such as RETScreen® would allow these kinds of details to be included in the analysis.

Cooling (COP = 3.5) = 40 000 kWh X 3.0/3.5
= 34 285 kWh X $0.10/kWh
= $3,429

Heating (COP = 2.5) = 184 000 kWh/2.5
= 73 600 kWh X $0.10/kWh
= $7,360

Energy Savings = $11,611/year

Simple Payback = 2.8 years on the differential cost

Chapter 9: Practical Considerations

Earth Connections

Since all earth connections in an EES are usually very difficult to reach after installation, the materials and workmanship used in their construction must be of the highest quality. Pipe material used is almost exclusively high-density polyethylene, and pipe connections are fusion-bonded. When installing a GHX or water wells, experienced EES installers should be involved.

Horizontal, Closed Ground Loop

Trenching for a horizontal GHX can be done with a backhoe, a chained excavator, a vibratory plough or even a bulldozer for large fields. The unit cost of trenching and backfilling can be influenced by factors such as trench depth, soil type, presence of obstacles (i.e., boulders) and the number of turnarounds. The backfilling process is critical for good GHX performances and integrity. Large rocks should not be present in the backfill material, and sand should be used in the vicinity of the pipes.

New types of digging equipment that allow horizontal boring are making it easier to use horizontal loops with minimal disturbance to landscaping. Horizontal boring machines can even allow loops to be installed under existing buildings or parking lots.

The pipe connections, using CSA-approved pipes, should be fusion-bonded, which make them stronger than the original pipes themselves. Some manufacturers offer warranties of up to 50 years.

To ensure good results, the piping should be installed by accredited installers who have experience in horizontal-loop systems. Improper installation could lead to problems. For example, failure to bury the loop below the frostline could cause the piping to shift during winter freezes and thaws.

Soil characterization for a horizontal GCHP system is usually recommended, since the soil properties have a significant influence on the size and performance of the system. Horizontal-system geotechnical investigations usually consist of test pits to provide knowledge of the sub-surface conditions. For a GHX of less than one hectare in area, a minimum of four test pits is recommended. For a GHX that is larger than two hectares, two test pits per hectare is recommended.

Vertical, Closed Ground Loop

Drilling for vertical GCHP or GWHP systems can be done with conventional drilling equipment such as rotary drills, cable tool drills and air drills. The unit cost of drilling is closely linked to soil type. Drilling in hard rock formations will be more costly and require more time. Wellbore or borehole diameter also influences the cost of drilling and grouting. Vertical boreholes can be smaller in diameter (typically 0.10 to 0.15 metres) than water wells, which can range anywhere from 0.15 to 0.40 metres depending on flow rates.

Grouting of wells and vertical holes is done by using special material, the most common being high-solids bentonite. The grout is used to prevent surface water from contaminating aquifers or to prevent one aquifer from contaminating an adjacent aquifer. All the heat transferred to and from the borehole pipes must pass through the bentonite-sealed medium. Unfortunately, typical bentonite grouts have poor thermal properties. Thermal enhancement techniques are available that can be used to significantly increase the thermal performance of the grout while maintaining its environmental protection properties. The economic benefits of employing the thermal enhancement techniques should be evaluated on a project-by-project basis.

It is often valuable for vertical GCHP systems to have a hydrogeological investigation undertaken. The information from the latter survey will also ensure that the ground-water quality is documented prior to the installation of the vertical GCHP. This should help prevent the system's owner from being held responsible for any ground-water contamination that predated the vertical GCHP installation.

A geotechnical survey for vertical GCHPs consists of test holes drilled at least 15 metres below the deepest planned GHX hole. The survey will provide a detailed report of the soil type, depth and formation found on the site. Another benefit of the test borehole is its use as a prototype borehole. Installing a specialized U-bend and conducting a long-term borehole thermal response test will provide valid information about the thermal characteristics of the ground and future borefield. The thermal response test will provide the designers with information used to optimize the borefield. For buildings of less than 3000 m^2, one test hole is sufficient. For larger buildings, two test holes should be drilled.

Water Issues: Wells

In some ground-water EESs, the water is pumped from the well(s), used once and then rejected to a surface well, lake or stream, continually removing water from the aquifer. Environmental concerns have been raised, because aquifers can be depleted if the water is not re-injected. In addition, the risk of contamination is an increasing concern. Improperly installed wells can be a path for surface-water run-off that carries pesticides, fertilizers, organic materials and other contaminants into underlying aquifers.

Some localities, provinces or territories may forbid or limit the use of ground-water systems. When considering a ground-water EES, inquiries to all relevant authorities (local, provincial/territorial and federal) should be made.

Re-Injection Wells

In locations where surface disposal of ground water is prohibited, the use of re-injection wells is required. The re-injection wells allow return of the ground water to the aquifer from which it was extracted. Again, some jurisdictions may consider returning warmer or colder water to an aquifer as "thermal pollution," and applicable regulations need to be checked.

The re-injection wells should be drilled at the same time as the supply well and be deep enough to receive the maximum amount of discharge water from the EES. They should be located at least 30 m (100 ft.) from the source well and should recharge directly into the same aquifer from which they came. Typically, re-injection wells will accept only 50 to 75 percent of the water they would yield. A number of design constraints apply to re-injection wells, and an experienced professional such as a hydrogeologist or an engineer should always be consulted to address points such as

- mineral encrustation;
- re-injection well overflow; and
- the possibility of using a reversible system (seasonal switchover between supply and re-injection wells).

GWHP systems will usually require the most extensive site investigation. In this case, a hydrogeological assessment has to be conducted. A typical study should be conducted by a qualified hydrogeologist and will cover areas such as

- establishing all regulations pertinent to the installation of a ground-water system at the proposed site;
- reviewing existing geological/hydrogeological information for the site location; and
- sub-surface investigation through test wells.

The number of test wells required is linked to the size of the proposed GWHP system. For buildings less than 3000 m^2, one test well is usually sufficient. For larger buildings, at least two test wells should be drilled.

Pumping Guidelines

Some general guidelines regarding pumping in EESs are as follows:

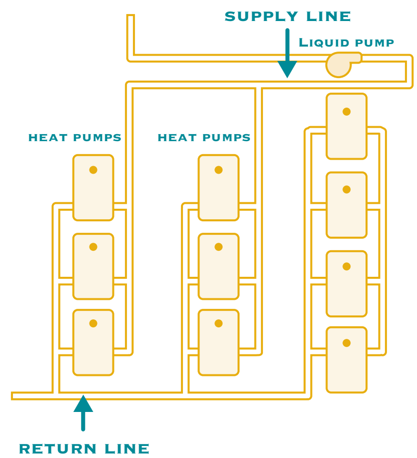
- Flow rate in GCHP systems should not exceed 0.054 L/s/kW of peak diversified load.
- Building-loop and ground-water flow rates should be based on diversified load.
- Pressure loss through the building loop should not exceed 1.5 metres of water column for every 30 metres of equivalent pipe length, to limit pumping energy use.
- Commercial systems usually employ a dual pump system on the building loop – a primary pump and an equivalent backup pump. Operation between the two pumps may be alternated to even out mechanical wear.
- Pressure loss through the heat pump should not exceed 4 m of water column.
- Pressure loss through the GHX should not exceed 1.5 m of water column for every 30.5 m of equivalent pipe length.
- Pumps should be selected to operate near their maximum efficiency. Avoid oversizing EES pumps.
- Keep the antifreeze concentration to a minimum, since it usually translates into increased pumping energy use.
- Examine various pump control options to optimize pump energy use (i.e., variable speed, multiple speed, primary/secondary pumps, etc.).

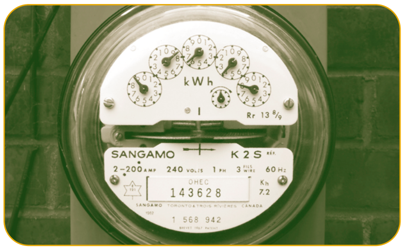
A pump's capacity can be evaluated once the flow rate and the head are known by using the following formula:

$$\text{Pump power} = \frac{\text{Flow rate X Head}}{\text{Pump efficiency}}$$

Complex control schemes and associated control devices (i.e., variable speed with pressure transducer, two-way solenoids and microprocessor controller) may be detrimental to ease of use and maintenance by regular HVAC personnel. When recommending an optimal pump control scheme, reliability and maintenance concerns should be properly addressed.

Figure 32. Ground-coupled heat pump system





Electricity Meter

A Word on Electricity Rates

Using an EES not only reduces a building's energy use; it usually also reduces electrical demand.

Electrical power use is metered in two ways: on maximum power use during a given time period (i.e., kilowatt demand) and on total cumulative energy use (kilowatt hours).

In determining demand charges, companies often use a meter that records kilowatt power use during either a 15- or 30-minute time window. The average power used during that window is used to calculate the peak kilowatt demand.

The peak demand used for billing purposes in any month can depend on the time of day, time of year or other local utility-related factors.

In determining energy charges, the meter recording kilowatt power used during the 15- or 30-minute time window also sums up the total energy use. The meter is read at roughly monthly intervals, and total energy use is billed according to applicable pricing schedules.

Electricity rate schedules can be very confusing and subject to misinterpretation. Always check with your local utility company representative for assistance in this area.

Commissioning

Proper commissioning of any HVAC system is crucial in achieving its optimal performance. However, this step is often handled in an expedited manner, often leading to systems underachieving their optimal efficiency. Since EES economic advantages rely heavily on the system's overall performance, the commissioning phase is that much more critical. The following general commissioning guidelines should be followed when going ahead with an EES project:

- Commissioning must go beyond simply "turning on" the system to make sure everything starts up correctly.
- A well-planned testing phase should be submitted to the building owner to verify functional and performance characteristics of the system.
- The control system should be tested under all operating modes (i.e., heating with and without auxiliary heater, free cooling, supplemental heat rejection mode, etc.).
- Power demand and energy use of all circulating pumps, well pumps and fans should be verified (accounting for power factors).

- Capacity and efficiency should be checked on all building-loop heat pumps.
- Verification of the water-side flow distribution and the air-side flow balancing should be performed.
- Special attention should be given to verifying the outside airflow rate, especially if no return fan is used. These tests should be done with and without local exhaust fans operating.
- Verify proper operation of all control and bypass valves.
- Verify the capacity of all auxiliary equipment (water heating, heat rejection, supplemental heat).
- Verify the concentration of the antifreeze solution.
- Verify the start-up and shutdown procedures and control sequences.
- Verify the accuracy of the main sensors (temperature, pressure).

The commissioning phase must always be scaled to the project's size. However, even small EES projects should have a minimum commissioning test plan. It is advisable that the owners or one of their representatives be present during the commissioning tests.

Sample Performance Specification for an Earth Energy System

When considering going ahead with an EES project, a number of key points should be addressed. One way to cover these key points without having to take on the actual design and selection process is to set up a performance specification requirement, which must be met by the designer/contractor who will be in charge of the project. The performance specification will state the various guidelines that must be applied during the EES design, installation and commissioning without having all of the details spelled out. It is up to the project's bidders to demonstrate how they will meet the performance specification. An example of such a performance specification follows. This short specification does not cover all possible aspects of EES projects but includes some important considerations.

Heat Pumps and Building Systems

- Installation of the EES shall comply with CSA Standard CAN/CSA-C448.1-02.
- All heat pumps shall be rated according to recognized standards such as CSA Standard CAN/CSA-C448.1 or equivalent and have a minimum full capacity efficiency of EER = 13 and heating COP = 3.5 or surpass local regulatory requirements.
- All heat pumps shall minimize pressure loss through their liquid-to-refrigerant heat exchanger and have a pressure loss of no more than 36 kPa at the flow rate.
- All heat pumps shall have sufficient capacity to meet the peak heating load in every zone, and no auxiliary zone heating system shall be employed.
- All heat pumps shall have adequate cooling capacity to ensure proper operation and dehumidification. If cooling capacities exceed 125 percent of design cooling loads, it shall be demonstrated that the equipment performance will not deteriorate due to the oversizing.
- Adequate volumes of outside air shall be supplied directly or indirectly to each heat pump to meet local regulations. In the absence of such regulations, minimum outside air volume shall be based on the *Model National Energy Code for Buildings* or the latest version of ASHRAE Standard 62.

- Adequate measures shall be taken to ensure that the air supplied to the heat pumps, after mixing with outside air, does not reach temperatures below 10°C.
- Direct use of electrical energy for tempering outside air shall be avoided, if possible.
- The building distribution system shall allow maintenance to be performed on individual heat pumps without compromising the operation of the entire EES.
- Heat pumps shall have the required accessories to dispose of any water condensate occurring during the cooling operation.
- It shall be demonstrated that the pumping power requirement for the building loop will be below 56 W per ton of diversified peak load.

Loads

- Heating and cooling loads shall be evaluated according to recognized methods, such as those recommended in CSA Standard CAN/CSA-C13256-01.
- Peak heating and cooling loads shall be evaluated for every zone that will be served by the EES and be adequately documented.
- Diversified heating and cooling loads shall be evaluated for every group of zones that will be served by a common EES earth connection.

Earth Connection

- Design of the earth connection shall be based on the diversified load of the building spaces that will be served by it.
- Installation of the earth connection shall comply with CSA Standard CAN/CSA-C448.1-02.
- It shall be demonstrated that proper consideration was given in evaluating hybrid system options as a function of their cost and performance.
- The method used for sizing the earth connection shall comply with recognized methods and be adequately documented. Approval by certified professionals, such as engineers, is always recommended and in many jurisdictions is mandatory.
- All necessary geotechnical survey information shall be collected prior to establishing the final earth connection size.

Important Information to Obtain from Suppliers and Contractors

Be sure to ask your EES suppliers and contractors about the following:

General

- references and satisfied customers;
- financial capability and/or bonding;
- evidence of the manufacturer's certification;
- the refrigeration certification of the contractor's employees;
- the pipe-fusion certification of the contractor's employees;
- the well-drilling/geothermal certification of the contractor's sub-trades;
- manufacturer and extended warranty provisions; and
- capital cost financing arrangements.

Specific

- a detailed heating and cooling load analysis;
- heat pump system design and specifications;
- predicted performance and cost savings;
- engineering design and specification of external civil works;
- regulatory approvals for internal and external work;
- safety provisions;
- an integrated hot water system in addition to space conditioning;
- specification of controls for system;
- internal finishing and landscaping on completion;
- maintenance and service manual and schedule;
- preventive maintenance schedule; and
- contractor's performance warranty.

Appendices

Appendix A: Case Studies

New Construction

Federally Sentenced Women's Facility

The Federally Sentenced Women's Facility is a 3800-m^2 complex in Truro, Nova Scotia. The facility is composed of 12 one- and two-storey buildings, including residential units, a gymnasium, a recreation building, an education building, office areas, health/food services and an enhanced security building. The full occupancy of the complex is approximately 35 inmates and staff.

Highlights

- saves $8,340 in annual energy costs
- simple payback period of nine years

The Federally Sentenced Women's Facility was constructed in 1994 to accommodate the Correctional Service of Canada's (CSC's) "Green Plan" initiatives. To help the facility meet its Green Plan's carbon dioxide reduction targets, a closed-loop ground-source heat pump system was installed.

A radiant floor heating system was selected by CSC for security purposes. Hot water pumps are used to circulate the water heated by the water-to-water heat pumps through piping located below the floors. CSC also desired supplemental propane heating in case of any problems with the heat pump system. The supplemental heating is provided by the solar hot water boilers through water-to-water heat exchangers.

The energy consumption of the heat pump system and the conventional HVAC system was obtained from an energy/environmental analysis performed before the heat pump system was constructed. The GSHP system provides $8,340 savings in annual energy costs. The simple payback period of the Federally Sentenced Women's Facility is approximately nine years.

Source: Adapted from *Operating Experiences with Commercial Ground-Source Systems,* with permission of the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE); www.ashrae.org.

Father Michael McGivney Secondary School

Father Michael McGivney Secondary School is a three-storey, 16 800-m^2 building in Markham, Ontario, just north of Toronto. Built in 1992, the school has 38 classrooms, 19 laboratories and workshops, a library, administrative offices, a chapel, a greenhouse, a cafeteria, three gymnasiums and a child-care centre. The full occupancy of the school is about 2400 staff and students.

The decision to install a ground-source system at the school was supported by two economic reasons:

- The electrical utility offered a very attractive ground-source incentive.
- The use of a ground-source system reduced the size of the required equipment room, freeing space for classroom areas, which is the basis for government grants to school boards.

The system is currently operating within the expectations of the owner. An indication of the school board's satisfaction with the ground-source heat pump system is the fact that such systems have been installed in seven new schools in recent years.

Based on an analysis of the utility bills, the ground-source system saves $9,420 annually in energy compared to a system that uses a central chiller and gas boiler.

Source: Adapted from *Operating Experiences with Commercial Ground-Source Systems,* with permission of the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE); www.ashrae.org.

Highlights

- saves $9,420 in annual energy costs
- reduced the size of equipment room required

Economical Water Heating System for Fish Farm

Alléghanys Inc., a Quebec agricultural company, tested a new heating system to increase its production. The heat is recovered in two steps: a passive heat recovery with the effluent via a heat exchanger and an active heat recovery via a heat pump between the incoming preheated water and the used water outlet. With a COP of 10.7, the energy consumption was reduced by 87 percent and resulted in an increase in production of 40 percent. The higher initial investment of $85,000 (compared to conventional systems) has been recovered in less than 1.5 years due to the high energy savings.

The heat pump operates with HCFC-22. The internal refrigerant loop is equipped with three compressors in parallel. This feature ensures a constant temperature of 12°C that helps avoid problems such as fouling.

The overall system reduced energy consumption to 184.6 MWh compared to a conventional (electrical or fuel oil) system that consumes about 1468 MWh. This is a savings of approximately 87 percent. Moreover, a

Highlights

- energy consumption reduced by 87 percent
- savings of $23,657 and $14,035 compared to electrical and fuel oil systems, respectively
- payback period less than 1.5 years

preliminary analysis from the ministère de l'Agriculture, des Pêcheries et de l'Alimentation estimated an increase in production of 40 percent due to the temperature differences of the breeding pools.

Some environmental benefits were also encountered. Using a heat pump instead of the conventional fuel oil system avoids the emission of greenhouse gases. There is a reduction of carbon dioxide emissions of about 218 tons per year compared to an electricity-type system, and 357 tons per year for the fuel oil equivalent.

Source: Adapted with permission from the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET).

Geothermal Mine Water as an Energy Source for Heat Pumps

Highlights

- reduced capital costs compared to a conventional system
- annual energy savings of $45,000
- energy source is non-polluting

Ropak Can Am Ltd., a manufacturer of plastic packaging products, is using geothermal energy from floodwater in abandoned mines to provide heating and cooling at the company's facility in Springhill, Nova Scotia. Ropak is the first industrial site in Canada to demonstrate the economic and technical viability of this energy source. Mine water at a temperature of 18°C is pumped at a rate of four litres per second from a flooded mine and passed through a heat pump system before re-injection into another separate (but linked) mine.

Gross annual energy savings (fuel oil and electricity) for the new plant are approximately $65,000 (compared to what costs would have been with a conventional system). After deducting operation and maintenance costs (including the cost of electricity for the new heat pumps), the net savings in the new plant are in excess of $45,000 annually, equivalent to a savings of about 600 000 kWh.

Many additional benefits resulted from the project. Because the new air-conditioning provides healthier working conditions, the plant's employees are absent less often. Reduced maintenance and downtime, improved production efficiency (up nine percent in 1989) and better staff morale have also resulted from the geothermal installation.

Source: Adapted with permission from the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET).

Southern Manitoba Town Simplifies Ice Making While Reducing Costs

The hockey arena is the centre of activity during long winters in the small town of Miami, in the southern part of Manitoba. Since construction of its arena in 1952, the community relied on cold prairie winds to make ice for hockey teams and figure skaters. In a typical prairie winter, the arena could be used for skating for 50 to 100 days, but often with interruptions during mid-January warm spells. As more and more surrounding towns built arenas with artificial ice, Miami was bypassed for tournaments and other events.

In 1998, the community devised a strategy to keep the ice pad reliably solid for a longer season and, at the same time, slash operating costs and keep maintenance to a minimum. Using a unique ice-pad design and a geothermal system, the Miami arena takes advantage of thermal storage to make ice and provide heating and air conditioning to the arena and an adjacent community hall.

Revenues have increased because ice is available up to six weeks sooner in the fall and up to a month later in the spring, and the comfort level in both buildings has been increased. The estimated payback of the geothermal heat pump strategy as opposed to the installation of a conventional ice plant is less than three years. When savings in maintenance costs are calculated, the payback for the geothermal system drops to less than two years.

Source: Adapted from *Southern Manitoba Town Simplifies Ice Making While Reducing Costs*, Natural Resources Canada Case Study Volume 1, Issue 4, April 2000.

Highlights

- phased approach spread out the capital cost
- $30,000 annual operating, maintenance and energy savings reduce payback to less than two years
- system avoids electrical service upgrade required for a conventional ice plant
- system includes HVAC upgrade by integrating the geothermal system
- simple maintenance without expensive training for operators
- eliminates annual fall start-up and spring shutdown costs of a conventional ammonia or Freon ice plant
- single system for ice making and space heating

Rehabilitation of an Old Industrial Building With Geothermal Heat Pumps

Built in 1923, a five-storey building in the city of Montréal has been transformed into a high-tech office building. To meet the new comfort requirements, installation of a decentralized HVAC system was necessary. A geothermal system was selected, providing annual savings between $30,000 and $35,000 from an initial investment of $375,000.

In addition to the building's HVAC system, other features such as a centralized control system were installed. Because the heat pump option was selected, other features did not need to be installed (such as a cooling tower and fan coils), making possible the construction of a terrace at the third and fourth floors (adding to the overall aesthetics of the building). With this system, immediate gain was encountered: flexibility of operation and temperature control, low noise level and the possibility of installation in occupied space only (leaving more space to rent).

Highlights

- savings of $175,000 (650 MWh) over a traditional system
- reduction of 66 percent in energy for heating
- installation in occupied space only

The energy consumption was reduced from 1000 MWh to 350 MWh per year. In other words, 66 percent of the energy consumption for heating was saved compared to a conventional system. This means that 6.5 tons of carbon dioxide are saved per year. Moreover, the design's simplicity results in easier maintenance (therefore less costs) and a significant space savings. Indeed, the mechanical room was reduced to the minimum (only the two plate-heat exchanger and five circulating pumps), and there is no outside equipment.

Source: Adapted with permission from the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET).

Appendix B: Resources

The following organizations offer further information on EESs.

In Canada:

Renewable and Electrical Energy Division
Energy Resources Branch
Natural Resources Canada
580 Booth Street, 17th Floor
Ottawa ON K1A 0E4
Fax: (613) 995-0087
Web site: http://www.nrcan.gc.ca/es/erb/reed

CANMET Energy Technology Centre – Varennes
Natural Resources Canada
1615, boul. Lionel-Boulet
C.P. 4800
Varennes QC J3X 1S6
Web site: http://www.lrdec.com/

CANMET Energy Technology Centre
Natural Resources Canada
580 Booth Street, 13th Floor
Ottawa ON K1A 0E4
Fax: (613) 996-9418
Web Site: http://www.nrcan.gc.ca/es/etb

Canadian Renewable Energy Network (CanREN)
Natural Resources Canada
Web site: http://www.canren.gc.ca

To find out about EES manufacturers, dealers, distributors, contractors or installers in your area, contact the following:

Earth Energy Society of Canada
124 O'Connor St., Suite 504
Ottawa ON K1P 5M9
Tel.: (613) 371-3372
Fax: (613) 822-4987
Web site: http://www.earthenergy.ca

In the United States:

Geothermal Heat Pump Consortium, Inc.
701 Pennsylvania Avenue, NW
Washington D.C. 20004-2696 U.S.A.
Tel.: 1 888 255-4436 (toll-free)
Web site: http://www.geoexchange.org

GEO-HEAT CENTER
Oregon Institute of Technology
3201 Campus Dr.
Klamath Falls OR 97601 U.S.A.

International Ground Source Heat Pump Association
490 Cordell
South Oklahoma State University
Stillwater OK 74078-8018 U.S.A.

We Have Free Software to Assist You!

Renewable energy technologies such as EESs can be a smart investment. RETScreen® has just made it easier. RETScreen® is a standardized renewable energy project analysis software that will help you determine whether an EES is a good investment for you. The software uses Microsoft® Excel spreadsheets and has as a comprehensive user manual and supporting databases to help your evaluation. RETScreen® software and a user manual can be downloaded free of charge from the Web site at http://retscreen.gc.ca. You can also obtain a copy from Natural Resources Canada by phone at (450) 652-4621 or by fax at (450) 652-5177.

Other Software Tools

A number of software packages are available to help designers and engineers with their tasks. The Geothermal Heat Pump Consortium has produced a comprehensive list of software tools that are EES-related. The Earth Energy Society of Canada can also provide guidance in this area. See the preceding page for contact information.

Additional Case Studies

Additional case studies are available at the following Web sites:

- http://www.canren.gc.ca
- http://www.ghpc.org

To order copies of the earth energy case studies highlighted on pages 72–76 or other case studies featuring earth energy or other renewable energy technologies, please contact Natural Resources Canada's publications line at 1 800 387-2000. In the National Capital Region, call 995-2943. You can also send a fax to (819) 779-2833, or write to the following:

Energy Publications
c/o DLS
1770 Pink Road
Aylmer, QC K1A 1L3

Appendix C: Glossary

Acoustic insulation: a sound-absorbent material installed inside the *plenum* and ductwork to reduce noise created by forced-air heating and cooling equipment.

Air coil: *see* Coil (air, water).

Air-Conditioning and Refrigeration Institute (ARI): the national trade association representing manufacturers of more than 90 percent of central air-conditioning and commercial refrigeration equipment produced in the United States. (www.ari.org)

Air-conditioning/heating system, conventional: *see* Conventional heating/air-conditioning system.

Air-to-air heat exchanger: *see* Heat recovery ventilator (HRV).

Antifreeze: a modifying agent added to water in a *closed-loop system* to lower the temperature at which the water freezes.

Approach temperature: the minimal temperature difference between the ground water and the building's loop fluid inside the heat exchanger.

Aquifer: a rock or granular (sand or gravel) formation in which water can collect and through which water can be transmitted; more fractured or porous formations can hold and transmit greater quantities of water and so provide a useful energy source for an *EES* (*also see* Ground water).

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Auxiliary heat, auxiliary heater: a secondary heat supply used to supplement the main source of heat. In a residential system, electric heating elements are most often used to supplement the heat supplied by an EES. Most *heat pump* manufacturers can install the auxiliary heat inside the *heat pump* cabinet.

Backhoe: a mechanized, heavy, self-propelled digging implement to excavate earth during the installation of an EES *loop*.

Blower door test: a method to measure how tightly a home is sealed by increasing the air pressure inside a home in relation to the outside.

Blower motor: electric motor used to turn the fan to move air through the ductwork in a heating and cooling system.

Borehole: a vertical hole drilled in the earth to insert pipe to transfer heat from the soil.

Btu/h: British thermal unit (Btu) per hour. One Btu is the amount of heat needed to raise the temperature of one pound of water by 1°F.

Building load (heating or cooling): the heating or cooling power required to maintain building indoor spaces at their selected temperatures. This power is calculated based on the heat transfer for each room, the simultaneous heat transfer for the whole building and the difference between the indoor and outdoor temperature.

Bypass, non-bypass humidifier: *see* Humidifier (bypass, non-bypass).

Canadian Standards Association (CSA): A division of CSA International, a Canadian organization that sets standards for safety, energy performance, procedures, etc., including those for the installation of an *EES*.

Cash-flow analysis: a study of the economics of owning an *EES* that takes into account the cost of purchasing the system (including interest paid on money borrowed to purchase it) and the cost of energy used to operate it.

CFC (chlorofluorocarbon): fluid used as a *refrigerant* in an *EES*; toxic if released into the air. Non-toxic refrigerants are now being produced (*also see* Refrigerant).

Chain trencher: mechanical, trench-excavating heavy equipment that can be used during the installation of an EES *loop*.

Circulation (or circulating) pump: in an *EES*, it pumps liquid through the *loop* and *heat pump*. The liquid transfers heat between the earth and the *heat pump*.

Climate change: a change in the average weather of a given region. Average weather includes all features associated with climate such as temperature, wind patterns, and precipitation. Climate change on a global scale refers to changes to the climate of the Earth as a whole.

Closed-loop system: *see* Loop: closed loop.

Coefficient of performance (cooling) (COP_c): a measure of the efficiency of an air-conditioning appliance, calculated by dividing the cooling output by the energy input.

Coefficient of performance (heating) (COP_h): a measure of the efficiency of a heating appliance, calculated by dividing the heat output by the energy input.

Coil (air, water): The *heat exchanger* that transfers heat between the air and *refrigerant* is sometimes called an air coil, while the one transferring heat between the *refrigerant* and the liquid circulated through the loop is often referred to as a water coil.

Combustion, products of: toxic particles produced by the burning of *fossil fuels* such as oil, natural gas, propane and coal; eliminated by the installation of an *EES* (*also see* Climate change; Emissions; Greenhouse gases).

Compressor: a device used to compress *refrigerant* gas in a *heat pump*. Compressing a gas raises its temperature and makes it more useable to heat either a home or domestic water.

Compression ratio: the ratio of absolute pressure after compression to absolute pressure before compression.

Condensate drain: water droplets (condensate) that form on an *air coil* in a *heat pump* while it is in air-conditioning mode are collected in a condensate pan and drained to waste through a condensate drain.

Condensing unit: part of a *conventional air-conditioning system*. Unnecessary where an EES is installed.

Console-type heat pump: a pump designed to heat or cool air without being connected to a *distribution system* (duct system) and used primarily for a single-room application (*also see* Heat pump).

Conventional heating/air-conditioning system: a system using the prevalent fuels (fossil fuel, electrical resistance, air-cooled condensing units) to provide heating and cooling to most homes is often referred to as conventional.

CSA: see Canadian Standards Association.

Cupro-nickel: a metal alloy, or mixture, of copper and nickel.

Desuperheater: a *heat exchanger* installed in a *heat pump* directly after the *compressor* and designed to remove a portion of the heat from hot, gas *refrigerant* in an EES *heat pump*. It is typically intended to heat domestic water.

Direct expansion (DX) system: a *closed-loop earth energy system* that uses *refrigerant* in a buried pipe *loop* as a *heat exchanger*, instead of a water/glycol solution.

Distribution system: a system that distributes the heated (or cooled) air (or water) supplied by a heating system in a home. Ductwork is normally used in a *forced-air system*, and water piping is used in a *hydronic heating system*.

Earth connection: a series of pipes, commonly called a *loop*, which carry a fluid used to connect the *EES*'s *heat pump* to the earth. Most commonly, the loops contain only water or a water and *antifreeze* mixture.

Earth Energy Society of Canada: an organization formed by contractors, manufacturers and designers of *earth energy systems* to promote the proper design and installation of systems in Canada.

Earth energy system (EES): a system designed to transfer heat to and/or from the soil and a building, consisting of a *heat pump* that is connected to a closed or open *loop* and a *forced-air* or *hydronic heat distribution system*.

Easement (also right-of-way): the legal right to enter or cross another person's property for the purpose of access, usually by a utility such as a hydro provider, pipeline, etc.

EES: *see* Earth energy system.

Electrical heating/air-conditioning system, conventional: *see* Conventional heating/air-conditioning system.

Emissions: toxic particles produced by the burning of *fossil fuels* such as oil, natural gas, propane and coal; eliminated by the installation of an *EES* (*also see* Climate change; Combustion, products of; Greenhouse gases).

Energy efficiency ratio (EER): a measure of the cooling or air-conditioning efficiency of an appliance, calculated by dividing the cooling output in *Btu/h* by the energy input in watts.

Expansion tank: a container connected to a liquid-filled system, such as an earth *loop* or a *radiant floor heating system*, that allows for expansion and contraction of the fluid with changes in temperature.

Fan coil unit: a water-to-air *heat exchanger* combined with a fan designed to heat or cool air by using hot or chilled water as a source.

Flexible connections: bendable connectors of ductwork or piping designed to prevent the transfer of vibration from heating or air-conditioning equipment such as a *heat pump* to the main ductwork or piping in the home.

Floor heating system: a heat *distribution system* in which the floor is warmed (usually by circulating warm water through pipes in the floor, or with electric elements built into the floor structure). Heat is radiated to the room by the entire floor surface. Water can be heated by any hot water heating system. Also known as in-floor or radiant floor heating.

Forced-air heating/air-conditioning systems, Conventional: *see* Conventional heating/air-conditioning system.

Fossil fuels: combustible fuels derived from the decay of organic material over long periods of time and under high pressure, such as natural gas, oil, propane or coal.

Greenhouse gases: the combustion of *fossil fuels* releases gases, such as carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrous oxides (NO_X) etc., that are commonly referred to as greenhouse gases because they allow the sun's radiation to pass through but block the radiation of the earth's heat back into space (*also see* Climate change; Combustion, products of; Emissions; Global warming).

Ground heat exchanger: *see* Heat exchanger.

Ground (or earth) loop: *see* Loop.

Ground water: water supply drawn from an underground *aquifer*.

Ground-loop heat pump (GLHP): a heat pump that extracts heat from the ground is sometimes referred to as a ground-loop heat pump (*also see* Earth energy system).

Ground-water heat pump (GWHP): when a *heat pump* extracts heat from an open *well-water system*, it is sometimes referred to as a ground-water heat pump.

Grout, grouting: placement of grout in a *borehole* from the bottom up, by means of a pipe or hose and pump, during the installation of a *loop* (*vertical*) for an *EES* (*also see* Tremie line).

Gypcrete: trade name for a concrete mix used to cover pipe in a *radiant floor heating system*. The main purpose of the Gypcrete is to transmit heat away from warm water circulated through the pipe to the air in the room.

HDPE (High-density polyethylene): long-lasting synthetic material used as a ground *heat exchanger* piping material.

Heat exchanger: a device designed to transfer heat between two different materials (hot and cold liquid, liquid and air, liquid and soil, hot and cold air, etc.) while maintaining a physical separation between the two materials.

Heat pump: a device at the heart of an *EES*, designed to extract heat from a low-grade source (such as the earth) by way of a *loop* (*open or closed*) and concentrate it for use to heat a space. Consists of a *compressor,* a *blower motor* and a *circulation pump*. A *reversing valve* enables it to switch functions to provide air-conditioning as well as heat for a home. May be either a *console-type* or *water-water heat pump*.

Heat recovery ventilator (HRV): a *heat exchanger* designed to recover heat from air being exhausted from the home and transfer it to fresh air being supplied to the home. Typically 60 to 75 percent of the heat from the exhaust air is recovered and transferred to the fresh air supply (*also see* Air-to-air heat exchanger; Size, sizing).

Heat sink: A *heat pump* is designed to take heat from a "heat source" and transfer it to a "heat sink." In an *EES*, the soil is a heat source when a home is being heated, and a heat sink when a home is being cooled.

Heating/air-conditioning system, Conventional: *see* Conventional heating/air-conditioning system.

Hot spot: the area in a home where the high temperatures produced by a *conventional heating/air-conditioning system* furnace make the air significantly warmer than the surrounding air in the home, usually near a warm air register.

Humidifier (bypass, non-bypass): a bypass humidifier circulates warmed air from the supply air of a heating system and circulates it through a dampened material back to the return air of a *forced-air heating system*. A non-bypass humidifier injects a mist of water or steam directly into the heated air stream that distributes air to the home.

Hydronic heating/air-conditioning system, Conventional: *see* Conventional heating/air-conditioning system.

In-floor heating systems: *see* Floor heating system.

Infrastructure: permanent large-scale engineering installations such as roads, sewers, energy pipelines, etc.

Joist: one of a series of parallel timber or metal beams installed from wall to wall in a house to support the floor or ceiling.

Life-cycle cost analysis: similar to a *cash-flow analysis*. Used to calculate the economics of owning an *EES*, the life-cycle cost analysis also takes into account the cost of maintaining and/or replacing the equipment as it deteriorates over time; probably the most accurate method of determining the true cost of owning an *EES*.

Load: *see* Building load.

Loop: a *heat exchanger* used to transfer heat between a *heat pump* and the earth, using liquid as a heat-transfer medium. Types of loops used in an *EES* include the following:

Closed loop: a continuous, sealed, underground or submerged system, through which a heat-transfer fluid (*refrigerant*) is circulated.

Ground (also earth) loop: a sealed underground pipe through which a heat-transfer fluid is circulated to transfer heat to and from the earth.

Horizontal: pipes are buried on a plane parallel to the ground.

Lake (also ocean, pond) loop: sealed pipes arranged in loops and submerged in a lake (ocean or pond), through which a *refrigerant* passes to absorb or release heat from or into the water.

Open loop: designed to recover and return ground or surface water with a liquid-source *heat pump*; usually requires two wells – one from which to draw the water (primary well) and a second to receive the circulated water (*return well*).

Vertical loop: pipes are buried on a plane at 90 degrees to the ground.

Low-grade heat: a source of heat that is not hot enough to heat a living space by itself.

Nominal Pipe Size: inch-pound names given to pipe products.

Non-bypass, Bypass humidifier: *see* Humidifier (bypass, non-bypass).

Non-CFC refrigerant: *see* CFC.

Ocean loop: *see* Loop.

Open loop: *see* Loop.

Outdoor reset control: *see* Reset control, outdoor.

Oversizing: a heating or cooling system that is oversized for a home will run for only a short period of time before the temperature of the home is satisfied. The system will not operate as efficiently as a system that is sized accurately, as most systems take several minutes to reach peak operating efficiency (*also see* Size, sizing).

Payback, simple: *see* Simple payback.

PEX tubing: cross-linked polyethylene pipes designed to withstand temperatures greater than *HDPE* pipe; used for *in-floor* (also known as *radiant floor*) *heating systems*, domestic water piping systems, etc.

Plenum: an enclosed space in which air pressure is higher than outside. The air from forced-air heating or cooling equipment is blown directly into the plenum. The main distribution ducts are connected to the plenum to distribute the air throughout the home.

Pond loop: *see* Loop.

Pressure tank: part of a well pump, used to prevent *short-cycling*.

Programmable thermostat: a device that controls the heat pump of an *EES* that can be set electronically to perform various tasks (*also see* Thermostat).

Property set-backs: areas, usually along a property line, set aside by municipal, provincial or territorial legislation for common services, such as sidewalks, etc.

Pump test: in an *open-loop* system, a verification that primary and *return wells* can provide the volume of water necessary to operate an *EES* efficiently.

Radiant floor heating system: *see* Floor-heating system.

Refrigerant: a fluid used in a *heat pump* designed to condense and vaporize at specific temperatures and pressures to enable the transfer of heat energy between two *heat exchangers* (*also see* CFC).

Reset control, outdoor: a control used primarily with *radiant floor heating systems* that is designed to raise and lower the temperature of the water being circulated through the system according to the outdoor temperature. During colder weather, hotter water is circulated through the floor to convey more heat to the space. As the outdoor temperature increases, less heat is needed and the temperature of the water circulated through the floor can be decreased. This strategy permits continuous operation of the heating system and increases the levels of comfort in the space and the efficiency of the heating system.

Return well: a water well in an *open-loop* system designed to return water to an *aquifer*.

Reversing valve: a device used to reverse the flow of *refrigerant* in a *heat pump* to enable it to heat as well as air-condition a space.

Right-of-way: *see* Easement.

Set-back period (on a thermostat): a *programmable thermostat* allows the user to set a specific temperature for a home during part of the day and a different temperature during another period. This type of thermostat is used to turn down, or set back, the temperature of a home during the night to conserve energy. The set-back period is the time when the thermostat is turned down. This type of thermostat can also be used to set a higher temperature during warm weather to conserve energy while air-conditioning a home.

Set-backs, property: *see* Property set-backs.

Short-cycling (of a well pump): a well pump with too large a pumping capacity for an *EES* will turn on and off continuously when the *heat pump* is in operation, or short-cycle. Short-cycling can damage the motor of a pump over the long term by causing premature wear of some components, and can use significantly more energy than a properly sized pump.

Simple payback: a rough method of determining the economics of installing one *EES* as opposed to another that can be installed at a lower first cost. The simple payback of an EES is calculated by dividing the difference in cost between two systems by the estimated savings in energy costs. This calculation ignores the cost of maintaining the systems and replacing them as they deteriorate over a longer term. A more accurate method is the *cash-flow analysis*, which includes the cost of purchasing the system and the energy cost, or the *life-cycle cost analysis*, which adds the cost of replacing the equipment over the longer term.

Size, sizing: calculating the capacity of the heating and cooling system required based on an accurate heat loss and heat gain analysis of the home (*also see* Oversizing).

Slab-on-grade floor: a common term for a concrete floor for a building that is poured at ground level, or "at grade."

Thermostat: a switch that turns a *heating and air-conditioning system* on or off according to the temperature of the space in which it is located (*also see* Programmable thermostat).

Tracing wire, tracing tape: metal wire or foil-backed tape placed in a trench above the buried pipe of an *EES loop* to make it easier to find the loop in the future and to avoid damage during future excavation.

Tremie line: used in the installation of a *vertical loop*; a pipe inserted to the bottom of the borehole through which grout is piped down and retracted as the hole fills (CSA requirement). It is designed to eliminate air pockets and ensure good contact with the soil (*also see* Grout, grouting).

Water coil: *see* Coil (air, water).

Water heating/air-conditioning system, Conventional: *see* Conventional heating/air-conditioning system.

Water-water heat pump: a heat pump designed to produce hot water or chilled water. Heated or chilled water is used to convey energy using water as a transfer medium. Hot water is often used in a *radiant floor heating system*, and chilled water is used in conjunction with a *fan coil unit*; the pump can also be used to heat water for domestic use.

Well-water system: an *open-loop EES*; typically consists of two drilled wells: the primary well and the *return well*.

Appendix D: Conversion Factors

Table 15. Conversion Factors

To Convert From	To	Multiply By
Btu/h	watts	0.293
Btu/h	kilowatts	0.000293
watts	Btu/h	3.413
kilowatts	Btu/h	3413
m^2	square feet	10.76
square feet	m^2	0.093
metres	feet	3.281
feet	metres	0.305
litres	U.S. gallons	0.264
U.S. gallons	litres	3.785
imperial gallons	litres	4.546
°C	°F	1.8 and add 32
°F	°C	subtract 32 and multiply by 0.555

Reader Survey

Thank you for your interest in Natural Resources Canada's (NRCan's) *Commercial Earth Energy Systems: A Buyer's Guide*. To help us serve you better and to improve future editions of this guide, please take a few moments to answer the following questions:

How did you find out about this *Buyer's Guide*?

O Introductory brochure (NRCan) O Dealer O Retail store
O Earth Energy Society of Canada O Trade show O Other
O Other renewable energy association

Did you find this publication informative?

O Yes O No

How much did you know about earth energy systems before reading this *Buyer's Guide*?

O Everything O Quite a bit O Some
O A little O Nothing

Please rate the publication on the following characteristics:

	Excellent	Good	Average	Satisfactory	Poor
Ease of understanding	O	O	O	O	O
Length	O	O	O	O	O
Clarity	O	O	O	O	O
Completeness	O	O	O	O	O
Photographs	O	O	O	O	O
Graphics	O	O	O	O	O
Format/organization	O	O	O	O	O

Please feel free to add any comments or suggestions.

____
____
____
____
____
____

If I purchase a system, it would be for

O Commercial application O Industrial application
O Other (please specify): ____________

I would like to receive a list of dealers, installers or contractors in my area.

O Yes

Please print
Name ______________________________________
Address ____________________________________
City _______________________________________
Province/Territory ______________ Postal code ______________
Telephone ______________ E-mail ______________

After you have filled out this survey, please send it to
Renewable and Electrical Energy Division
Natural Resources Canada
580 Booth Street, 17th Floor
Ottawa ON K1A 0E4
Fax: (613) 995-0087

Thank you for participating in this survey!

RENEWABLE
ENERGY