INTEGRATED GEOTHERMAL ICE-STORAGE SYSTEM

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ABSTRACT

Large buildings often have peak cooling loads greater than their peak heating loads. Internal and solar gains often drive equipment selection in large buildings, even in cold northern climates. The cost of the equipment and earth loop needed to meet the peak cooling loads can increase the initial cost of a GeoExchange™ system to the extent that a less costly conventional system is often chosen.

Thermal ice storage systems have been used for many years to reduce installed chiller capacity and shift peak electrical demand. Traditionally such systems have been installed with a conventional heating plant to heat the building while the chiller builds ice at night for the following day's cooling demands.

A distribution system designed to take advantage of the heat removed from the ice, and use an earth loop as an alternate heat source and heat sink provides benefits, including:
- Elimination of separate equipment to provide space and water heating
- Reduction of equipment capacity needed for space cooling
- Reduction of the size and cost of the earth loop needed
- Doubling the efficiency of a geothermal HVAC system
- Reduction in greenhouse gas emissions

Key Words: ***system integration, thermal ice storage, energy storage, water-to-water heat pumps***

1 INTRODUCTION

Many large buildings, such as office buildings, schools, churches, factories etc. have a unique energy balance. Office buildings and schools, for example, have large, scheduled heat gains when the building is occupied five days a week. Heat rejected by occupants and the equipment activated during occupancy often provides enough heat to activate the cooling system, even in cold northern climates with outdoor ambient temperatures as low as -20 to -30° C (-4° to -22° F). In fact, many buildings require cooling while occupied even when winter design temperatures are reached. Churches and conference centers have a similar energy balance profile, but are typically occupied for only a few hours, and have a greater interval between cooling events. Figure 1 illustrates the energy balance of a typical office building in summer, winter and shoulder season conditions.

This article is based on the use of water-to-water heat pumps used with a four-pipe hot and chilled water system to distribute heating and cooling. Water-to-air heat pumps are not considered in this article.

Ice storage systems have been used effectively for many years to reduce the capacity of the chiller required to provide cooling for peak cooling events, and to shift peak electrical demand to off-peak periods. When combined with a GeoExchange™ system thermal energy storage systems can provide additional benefits, including:
- Reducing the size and cost of the earth loop associated with the geothermal system
- Eliminating the need for a heating plant typically used in conjunction with the chiller
- Significantly enhance the efficiency of the geothermal system

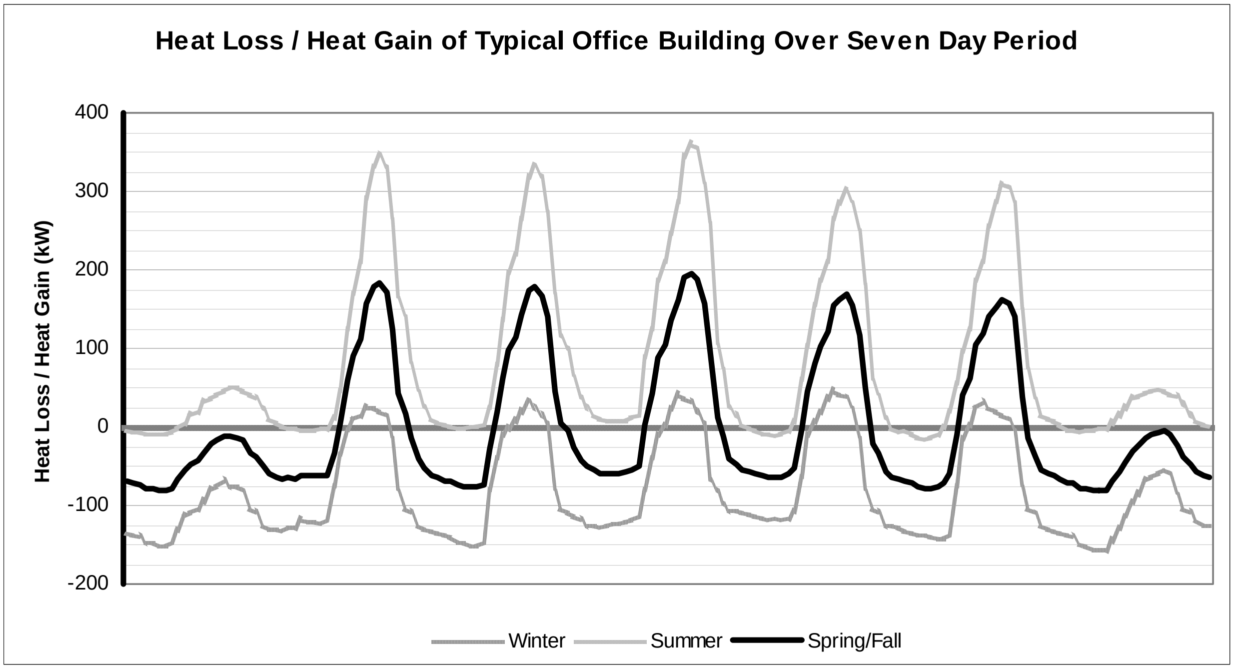

Fig. 1. This chart illustrates the daily energy balance of a typical office building or school occupied five days per week in a moderate to cold climate. Note that when the building is unoccupied on Days 1 and 7, the peak cooling load is lower because there are very few internal gains (occupants, lighting, electrical) The peak cooling loads in summer are often much greater than the typical peak heating loads during winter design temperatures. In the shoulder seasons, there are often both significant heating and cooling loads in a 24 hour period. The peak heating load in winter is approximately 158 kW, while the peak cooling load in summer is approximately 360 kW.

2 SIMULTANEOUS HEATING AND COOLING

By their nature, water-to-water heat pumps produce both hot and cold fluid whenever the compressor is in operation. A heat pump that uses the earth as a heat source is efficient because the heat source is free and is infinitely renewable. A heat pump produces warm fluid while it cools the earth, or produces cold fluid while it heats the earth.

When the heating load in one area of a building matches the cooling loads of another part of the building, an earth loop is not needed as a heat source for the heat pump. The part of the building that requires the cooling is the heat source for the heat pump, while the part of the building that requires heat is the heat sink for the heat pump. This has a significant effect on system efficiency.

2.1 System Efficiency versus Heat Pump Efficiency

Having the capacity to simultaneously make use of both the warm and cold fluid streams of the heat pump greatly enhances the efficiency of the system. The coefficient of performance (COP) of a heat pump has been defined as the heating or cooling output divided by the power input.

The heating COP (COP_h) of a GeoExchange™ system is calculated by dividing the heat output by the energy input. If the output of the heat pump is 14.0 kW, and the power input is 4.0 kW, the COP_h is 14.0 / 4.0 = 3.5. The cooling COP (COP_c) is calculated by dividing the cooling output by the power input. If the output is 18 kW, and the power input is 4.0 kW, the COP_c is 18.0 / 4.0 = 4.5.

When both the hot and cold fluid can be used, the efficiency can be considered as the total output of the system divided by the power input. The following table illustrates the system efficiency in a variety of different operating conditions.

Table 1. This table shows the heating and cooling capacity and COP under various operating conditions, and the System COP. If both the warm fluid and chilled fluid of the heat pump system can be used, the System COP is considered the sum of the COP_h and COP_c

	Heating Output (kW)	COP_h	Cooling Output (kW)	COP_c	System COP
ISO13256-2 (heating)[1]	94.4	3.78	---	---	3.78
ISO13256-2 (cooling)[2]	---	---	132.6	5.62	5.62
Simultaneous Heating & Cooling[3]	129.2	4.52	100.6	3.52	**8.04**
Building Ice & Heating[4]	80.1	3.44	56.8	2.44	**5.88**
Building Ice[5]	---	---	75.1	3.58	3.58

[1] EWT Condenser: 40°C, EWT Evaporator: 0°C
[2] EWT Condenser: 25°C, EWT Evaporator: 12°C
[3] EWT Condenser: 40°C, LWT Evaporator: 7°C
[4] EWT Condenser: 40°C, LWT Evaporator: -6°C
[5] EWT Condenser: 25°C, EWT Evaporator: -6°C

2.2 Earth Loop as Alternate Heat Source / Heat Sink

Making use of both the hot and cold fluid produced by a heat pump greatly enhances the efficiency of a GeoExchange™ system. This can be difficult to achieve because the need for both heating and cooling simultaneously is limited or non-existent in most buildings.

Thermal energy storage systems provide the opportunity to produce heat or cold today for use the next day or in the near future. Ice storage systems absorb or give up large amounts of energy because of the phase change of the water to ice.

Even when energy storage is incorporated into a system, there are times when there is not enough capacity to always produce useable hot and cold fluid simultaneously. An alternate heat source and/or heat sink is needed. A properly designed earth loop will absorb or supply large quantities of heat very efficiently when the controlled storage in the system can't absorb or supply more. It operates like a sponge, absorbing excess heat when it can't be used in the building and allowing us to "squeeze" heat from it when it is needed and the building or thermal cold storage is satisfied. In this manner, the earth acts as an additional, long-term thermal energy storage medium. As illustrated in Fig. 5 (section 3.1, page 8), the heating capacity and efficiency of a heat pump is significantly greater when the source temperature is nearer the heat sink temperature. The heat pump operates more efficiently and produces more heat as the earth loop becomes warmer.

2.3 Thermal Energy Storage

People have taken advantage of the benefits of thermal energy storage for several hundred years, when they began harvesting ice from lakes to provide refrigeration or air conditioning the following summer. In the mid-twentieth century, several manufacturers began building tanks that could be used with chillers to create ice during off-peak hours for the following day's air conditioning loads.

Thermal energy storage is effective in any application with large, intermittent peak heating or cooling loads. A church or a community hall with a large occupant load a few times per week is a good example. An office building or a school with a large influx of people and a large increase in lighting and electrical loads that typically coincide with large solar loads is another good example where effective use can be made of thermal ice storage. Similarly, warm storage can be used effectively to reduce the peak heating capacity of a heating plant. Examples of warm storage include hot water storage for process applications requiring large intermittent supplies of hot water or high thermal mass buildings that can absorb heat into their structures to reduce peak heat loads.

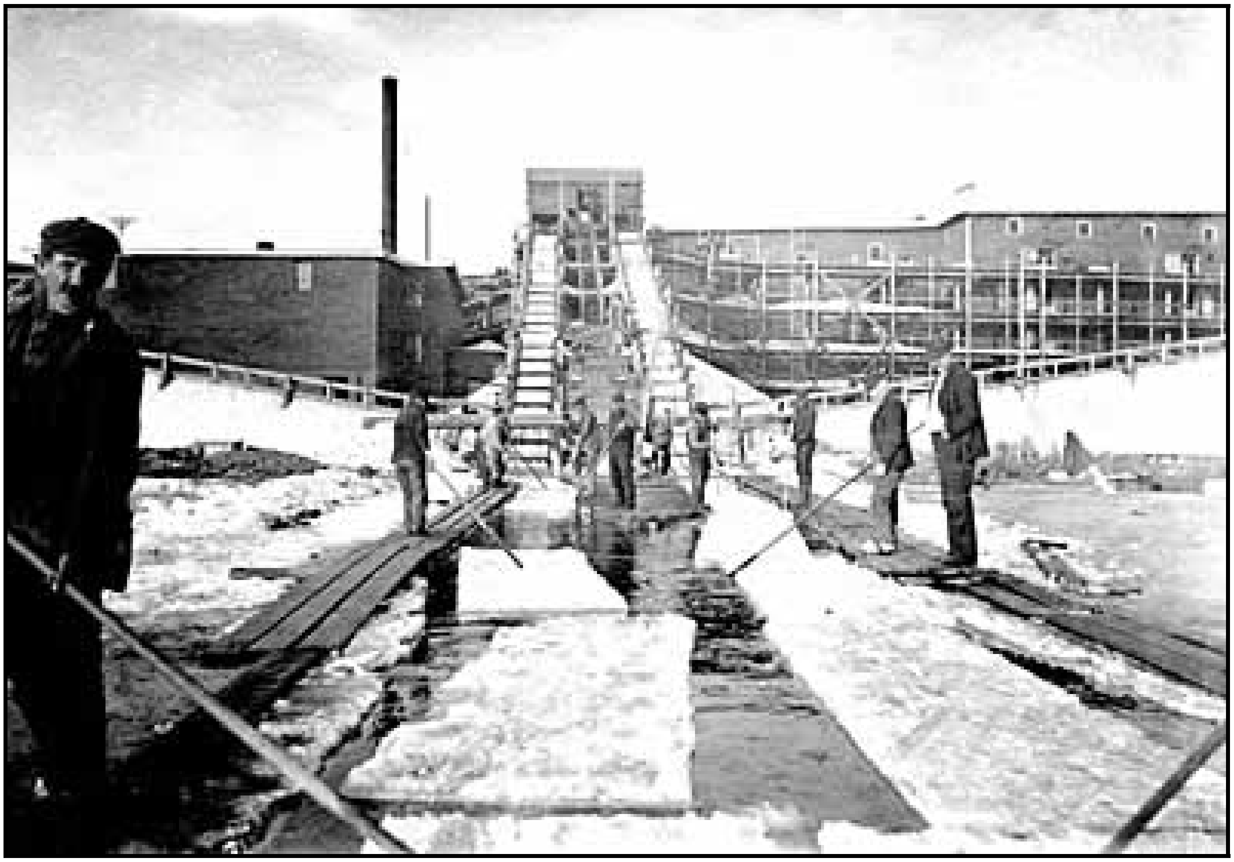

Fig. 2. Ice is being harvested from the frozen lake surface and stored to provide refrigeration and air conditioning the following summer. Photo from www.fauerbachbrewery.com/ iceharvesting.htm.

2.3.1 Benefits of ice storage

The change of phase between water and ice, as with any phase change, releases or absorbs a large amount of energy. The energy exchanged during a phase change is 144 times greater than the sensible change seen with chilled water storage, reducing the volume needed to absorb or discharge significant amounts of thermal energy.

The temperature of the phase change (0° C) coincides well with the temperatures needed for a chilled water air conditioning system.

2.3.2 Energy storage as backup heating and cooling

In the event of a power outage, stored energy is available to provide warm or chilled fluid to a building by simply distributing it as needed using a minimal power source. When ice storage is available circulation pumps can discharge the ice while providing emergency cooling to operating rooms, computer server rooms and other mission-critical air-conditioned rooms. Much smaller generators can be used to provide backup cooling than are needed if chiller operation was required.

2.4 Integration of Heating, Ventilating, Air Conditioning and Refrigeration (HVAC/R) with Earth Loops and Thermal Energy Storage

Heating, ventilating and air conditioning (HVAC) systems are traditionally thought of as a number of separate systems. A boiler system provides heat for the building. A chiller provides chilled water for air conditioning. A ventilation system provides fresh air. Geothermal heat pump systems combine heating and cooling in one system and use the earth as an efficient heat source or sink.

Physics dictates that water-to-water heat pumps produce warm and cold fluid simultaneously. To produce chilled fluid something else must absorb the heat taken from the fluid as well as the energy put into the heat pump to transfer the energy. Stable ground temperatures help ground source heat pumps operate very efficiently.

In an integrated system, the heat pumps are used to provide heating and cooling simultaneously. If the building requires heat, the energy can be taken from the ice storage tanks and, when the ice is built, the earth loop becomes the heat source. If the building requires cooling the heat pumps or the stored ice is used to chill the fluid circulated through the fan coil units. It is possible to use only the heat pumps, or only the stored ice, or both together to chill the fluid.

It is important to note that the cooling capacity is contained in the ice storage tanks and can be delivered at the appropriate temperature, without use of a compressor. This is more efficient than in a conventional geothermal system since the heat pump compressor in an integrated system is used once while making the ice (and heating the building) and is not used again while discharging the ice (cooling the building).

In a conventional geothermal system, compressor operation is needed to heat the building and again to cool the building, meaning the system COP is limited to approximately one-half of the integrated system COP because the compressor is operated twice. In a heating-dominated application a large percentage of the heat is provided by the compressors, increasing energy consumption. In a cooling dominated application, all the energy used to operate the compressor is rejected to the earth loop, increasing the amount of earth loop needed and/or increasing the loop temperature and reducing heat pump efficiency. Basically, the integrated system contains the cooling effect obtained from heating, allowing both heating and cooling to be delivered from a single compressor operation.

Ensuring that the fluid is brought to temperatures needed to distribute heating or cooling adequately in the building is important. The temperature difference between the heat source and the heat sink has a large effect on the efficiency of a heat pump (as shown in Fig. 5), and is a primary consideration in designing the distribution system to accommodate lower temperatures in heating mode and higher temperatures in cooling mode.

Understanding the heating and cooling loads on the building is important. Taking into account the heat gains from the sun, the lighting and electrical loads, and the occupants throughout the year has an impact on the sizing of both the heating and cooling plant. Balancing seasonal loads (rejecting and extracting equal amounts of energy to/from the earth loop on a seasonal basis) reduces the amount of earth loop required. This concept is elaborated on in Section 3.1.

Changing technology will have significant impacts on the loads on the building. Liquid crystal display computer screens use approximately 80100 watts less energy than a similar size cathode ray tube computer screen. In a typical office building with 300 employees and a corresponding number of computers, the reduction in cooling load is approximately 24 kW. There is also a 24 kW less heat gain that helps heat the building during cold weather. This does not take into effect the use of monitors that shut themselves off when not in use.

As lighting strategies change, the cooling and heating loads change. More efficient lighting reduces the heat put into the space. Light emitting diode (LED) lighting reduces the internal lighting gains by 50-60% compared to fluorescent lighting, and over 90% compared to incandescent lighting. In a 5,000 square meter office building this can reduce the internal lighting gains by as much as 50 kW. Natural daylighting will also reduce internal heat gains in many situations, and may increase heat losses.

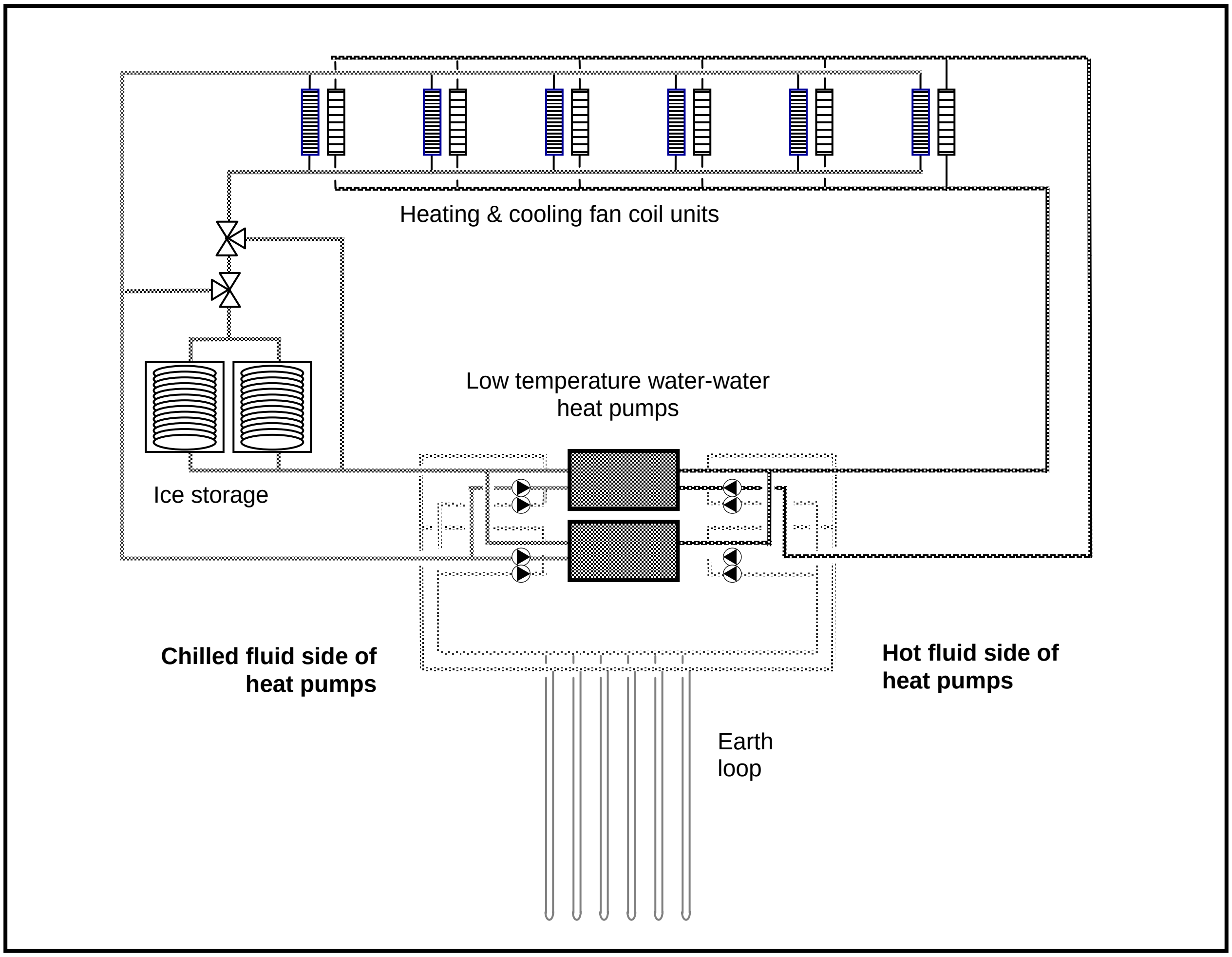

Fig. 3. Mechanical schematic shows integrated system incorporating thermal ice storage tanks, an earth loop, water-to-water heat pumps capable of operating at low temperatures, and a four-pipe fan coil distribution system. Heat pumps provide chilled fluid directly to fan coil units. When motorized three-way valve positions are changed the heat pumps chill the ice storage tanks and build ice. The valves can be modulated to make use of heat pumps and ice storage to provide chilled fluid to the fan coil units. When cooling is not required and ice building is not required, heat can be drawn from the earth loop. Heat is rejected either to the fan coil units if space heating is required or to the earth loop if not.

Integrated systems have been used in various types of buildings. A church built near Winnipeg, Manitoba uses two water to water heat pumps with a total cooling capacity of approximately 42 kW (12 tons) in conjunction with an ice storage tank containing approximately 3,100 litres of water. When converted to ice, the tank can discharge between 45 and 52 kW (12 to 15 tons) of cooling capacity. When the church sanctuary is fully occupied the heat pumps and storage tank together deliver up to 94 kW (26 tons) of cooling capacity to the building. This capacity can be delivered continuously for up to six and one half hours, until the ice storage tank is completely discharged. During the following week the ice is built again. The heat is used either to heat the building, or is stored in the earth loop.

Ice rinks are another very viable application of thermal energy storage. The ice surface must be maintained at approximately -6 to -8° C. During heavy use, when the ice is resurfaced at regular intervals and lights and activity on the ice are adding heat to the ice surface, heat must be withdrawn continuously.

If heat is needed in the rest of the building or to produce hot water, the warm water produced by the heat pumps while making ice is circulated directly through radiant floor heat pipe or a heat exchanger to produce hot water. When the ice is not in use and there is less heat load on the ice, heat can be withdrawn from a thermal storage buffer built into the ice floor (Canadian patent #2,273,760 and United States patent #6,170,278). Chilling the thermal storage buffer several degrees colder than the ice surface provides a significant amount of chilling capacity for the ice surface during peak use times the following day, while providing a heat source for the building when the ice is not heavily used. The earth loop is used as a heat source when the ice temperature is satisfied and the thermal storage buffer is adequately chilled. Heat that can't be used in the building while the ice surface or buffer is being chilled is stored in the earth loop.

This concept has been implemented successfully in over fifty hockey and curling arenas across Canada and the United States. Energy consumption is typically reduced by 35-65% when compared to a conventional refrigeration plant and conventional HVAC system in similar buildings.

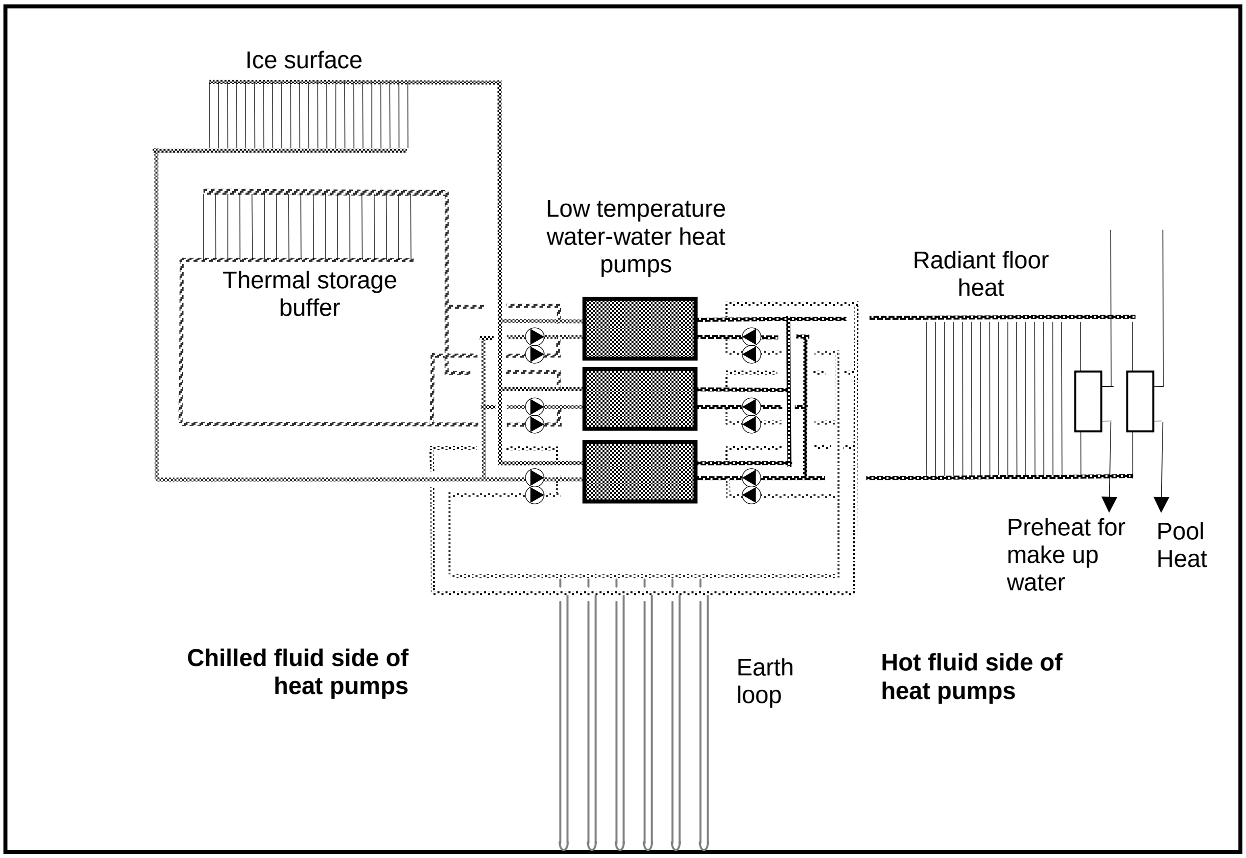

Fig. 4. Mechanical schematic using low-temperature heat pumps in an integrated geothermal ice rink system. Heat pumps extract heat from the rink surface, the patented thermal storage buffer below the ice surface, or the earth loop. Heat is rejected directly to the building radiant floor heat system or to the earth loop if not required.

3 SYSTEM DESIGN CONSIDERATIONS

3.1 Effect of Distribution System on System Efficiency

The efficiency of a heat pump is directly related to the ΔT (temperature difference) between the heat source and heat sink. As the ΔT increases, the efficiency and capacity of the heat pump decreases.

If a continuous supply of hot water is available from a hot spring at 40°C that is flowing with enough pressure that a circulation pump is not needed, a system can be designed that will require no energy input whatsoever. The COP can be considered infinite. However, if the distribution system is designed in such a manner that a circulation pump is needed to provide additional pressure to circulate the water through the system, or that 41°C water is needed, an energy input is needed, and the COP becomes measurable. If a larger pump is needed because the pressure drop through the system is greater, or if 45° water is needed because of poor equipment selection, a greater energy input is needed, and the COP drops.

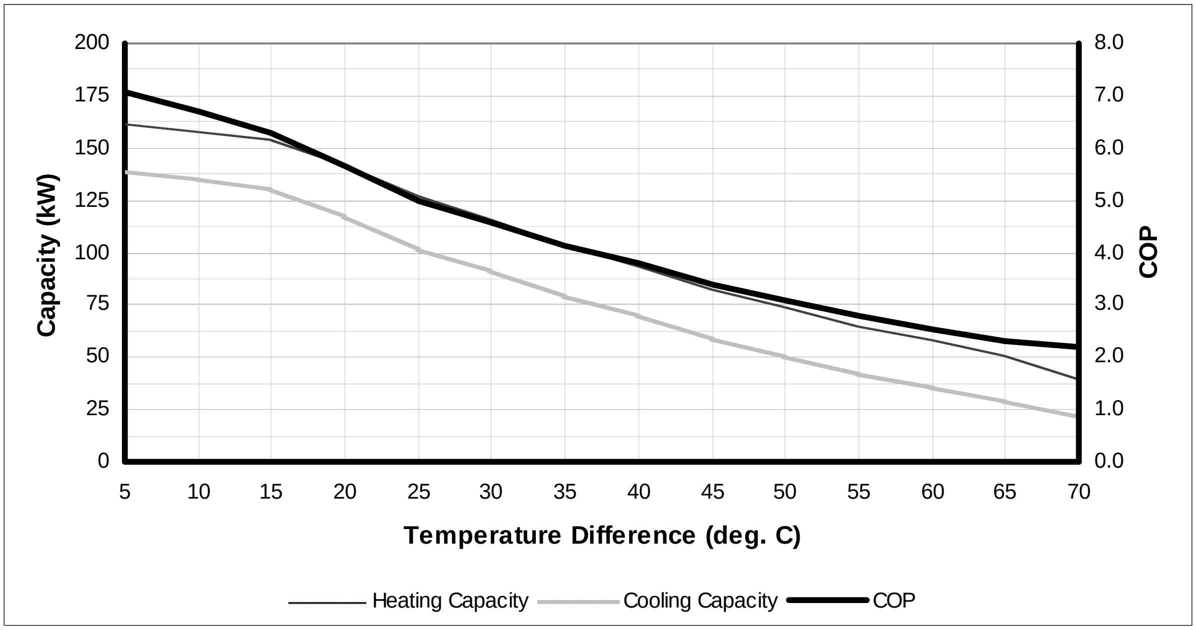

Fig. 5. This chart illustrates the effect of the ΔT (temperature difference) between the heat source and the heat sink on capacity and efficiency of a heat pump.

When designing a GeoExchange™ system, the distribution system must be carefully considered. If a four-pipe fan coil system is planned, the water temperature needed by the fan coil unit in heating mode must be as low as possible, and in the cooling mode as high as possible. Spacing of the piping in a radiant floor heat system, building insulation values, internal building loads, etc. all have an impact on the efficiency of a geothermal system.

3.2 Earth Loop Sizing

In an appropriate application an HVAC/R system integrated with an earth loop and thermal energy storage will have a total heat pump capacity smaller than a system with a conventional geothermal system. Using thermal energy storage reduces the amount of equipment needed to meet the peak cooling capacity by 40-50%. This has an impact on the amount of earth loop needed.

An office building for example, typically requires cooling only during the day when the building is occupied, the lights and computers are activated and the solar gain is the greatest. The peak begins when people arrive at work and builds till early afternoon, and then is reduced when occupants vacate the building in the late afternoon. The earth loop must be designed to accommodate the peak cooling loads for seven to eight hours to prevent the temperature from climbing too high.

If the system is designed to provide the same total amount of cooling, but spread out over a twenty-four hour period, the loop temperature does not climb as high. If you were to ride a bicycle up and down steep slopes for eight hours, you would probably require legs like Lance Armstrong's. But if the ride could be spread over 24 hours, and the incline were not as steep, more riders would be able to reach the same altitude as a professional rider. Thermal storage allows you to ride the long gradual slope up the hill, spreading out the energy requirements over a longer period. But beyond that, all the heat from the rider's muscles is captured by a water cooling system to provide a warm shower at the end of the day. Thermal energy storage integrated with a geothermal system, climbs the long gradual slope and provides the warm shower at the end of the day. Table 2 shows the impact of ice storage on the loads on earth loop, while Table 3 shows the impact on the length of earth loop needed.

Table 2. Typical cooling and heating for an office building with high internal gains from occupants, lights and computers. These loads are used to calculate the loop lengths required for two scenarios. Scenario 1 is a geothermal system with heat pumps sized to meet the peak heating and cooling loads. Scenario 2 is the same building with heat pumps sized for to meet the peak heating load and the average cooling load during the peak design cooling day.

	Peak Building Loads		**(1) Without Ice Storage**		**(2) With Ice Storage**	
Time Slot	**Cooling kWh**	**Heating kWh**	**Heat Gain (kW)**	**Heat Loss (kW)**	**Heat Gain (kW)**	**Heat Loss (kW)**
8 am – Noon	1,360	60	340	15	165	15
Noon – 4:00	1,520	0	380	0	165	0
4 pm – 8 pm	360	120	90	30	165	30
8 pm – 8 am	720	1,800	60	150	165	150
	Equivalent Full Load Hours		1,400	1,200	3,800	1,000
Daily Loads	3,960	1,980				
Annual Loads	5,544,000	2,376,000				

GHPC Calc Loop Sizing software was used to determine the amount of vertical borehole required for this building with a geothermal system sized to meet the peak heating and cooling loads and a geothermal system designed to meet the peak heating loads and the average cooling loads over a 24 hour period on the design cooling day integrating a thermal ice storage system.

Table 3. Parameters used in calculating loop length required using GHPC-Calc Loop Sizing Software. The loop length required in this building is 30% shorter when ice storage is integrated into the system design when compared to a system designed to meet peak heating and cooling loads.

Heat pump flow rate (per ton):	0.189 l/s (3 USgpm)
Minimum entering water temperature:	-4° C (24.8° F)
Maximum entering water temperature:	30° C (86° F)
Undisturbed deep ground temperature:	10° C (50° F)
Thermal conductivity of formation:	2.25 w/m/°C (1.3 BTUH/ft/°F)
Diffusivity of formation:	0.07 m^2/day (0.75 ft^2/day)
Grout conductivity:	0.76 w/m/°C (0.44 BTUH/ft/°F)
Pipe:	25 mm SDR11 (1" SDR11)
Borehole diameter:	100 mm (4")
Borehole configuration:	10 x 10 x 6 m spacing (20')

Borehole length based on heat pumps sized for peak loads without ice storage
82 meters

Heat pumps sized for peak heating load and average cooling load over 24 hours during design cooling day
57 meters

4 IMPACT OF SYSTEM INTEGRATION

Complete integration of the HVAC/R system with earth energy and thermal energy storage has a significant impact on the environment, energy consumption, energy cost, capital cost and the life cycle cost of the building.

4.1 The Environment

Complete integration of the Refrigeration with the HVAC System in a building with Thermal Energy Storage and an earth loop has a significant impact on the energy performance of a building.

- Peak electrical load for air conditioning, when compared to either a conventional chiller, a central water to water heat pump system or to a terminal heat pump system is reduced by 40-50%.
- The requirement to provide a separate system, typically a fossil fuel boiler, is eliminated

- The efficiency of the low-temperature water to water heat pump system is significantly increased when both heating and cooling can be done simultaneously. The opportunities to do this are increased with thermal energy storage and using the ground for energy storage.

4.1.1 Greenhouse gas emissions

Greenhouse gas emissions from a building are significantly reduced with an integrated system that incorporates ice storage and earth energy. More opportunities for simultaneous heating and cooling are created. Less energy is used by the system because of simultaneous heating and cooling. When fewer kilowatt-hours are used, less greenhouse gases are emitted at the generating stations.

Table 4. Kilograms of CO_2 emissions per kWh in various electrical generation scenarios*

	Hydro-electric or Nuclear	Mix of Generation	Heavily Coal & Oil Generation
Kilograms CO2 / kWh	0.01 – 0.03	0.25 – 0.50	0.75 – 1.00

* *Direct CO_2 emissions only. Hidden resource extraction and life cycle emissions are often not taken into account in these estimates.*

In addition to the direct kilowatt-hour reduction, most utilities tend to use their cleanest generating plants to provide for their base load. As electrical peaks build during heavy use, the plants that are the costliest to operate and use the dirtiest forms of energy are ramped up. A kilowatt-hour used during peak system demand usually emits more CO_2 into the atmosphere. Thermal storage used for cooling, that is ice built up at night, uses off-peak power. The kilowatt hours used to build the ice are, with many utilities, cleaner energy than that produced during peak use. If a cooling tower is used to supplement the earth loop (a scenario applicable to highly cooling-dominated applications), operation of the cooling tower during the night increases the system efficiency by allowing the heat to be rejected to the cool nighttime air.

The large scale use of off-peak electrical power has significant impact on the electrical distribution infrastructure the utilities have built. Fewer generating stations are required. Smaller electrical distribution lines are required. Smaller electrical sub-stations and transformers are needed. With some utilities it can mean that electricity does not have to be transported as great a distance, with fewer resulting line losses.

4.1.2 Equipment Maintenance

A system design that requires less equipment, whether it is a boiler, additional circulating pumps, more complex controls, additional heat pumps, or chillers, requires less maintenance. If there is no boiler, there is no boiler to service, and no boiler to replace in the future. If a pump can be eliminated, there are fewer seals to replace and motors to rewind. Fewer heat pumps have fewer compressors to fail. Less equipment requires less maintenance. With less equipment to service, there should be fewer service calls, fewer vehicle trips by the service technicians, fewer replacement components to manufacture, and consequently, less impact on the environment.

A system that uses the same equipment to provide heating, cooling, and in some cases domestic hot water, requires less equipment. The mechanical room(s) can be smaller leaving more usable rentable space for the owner. The ice storage tanks require space, but the location is usually more flexible than space needed for mechanical equipment. Some tanks are designed for on-grade installation outside the building or can be buried beneath or outside the building.

4.2 Impact on Energy Costs

Electricity costs are typically charged to the consumer in consumption (kilowatt hours) or in peak demand (kilowatts) Making simultaneous use of both sides of the heat pump whenever possible has a dramatic effect on both consumption and demand. The time of use of electricity is also impacted, and can have a dramatic effect on the cost of energy for a building.

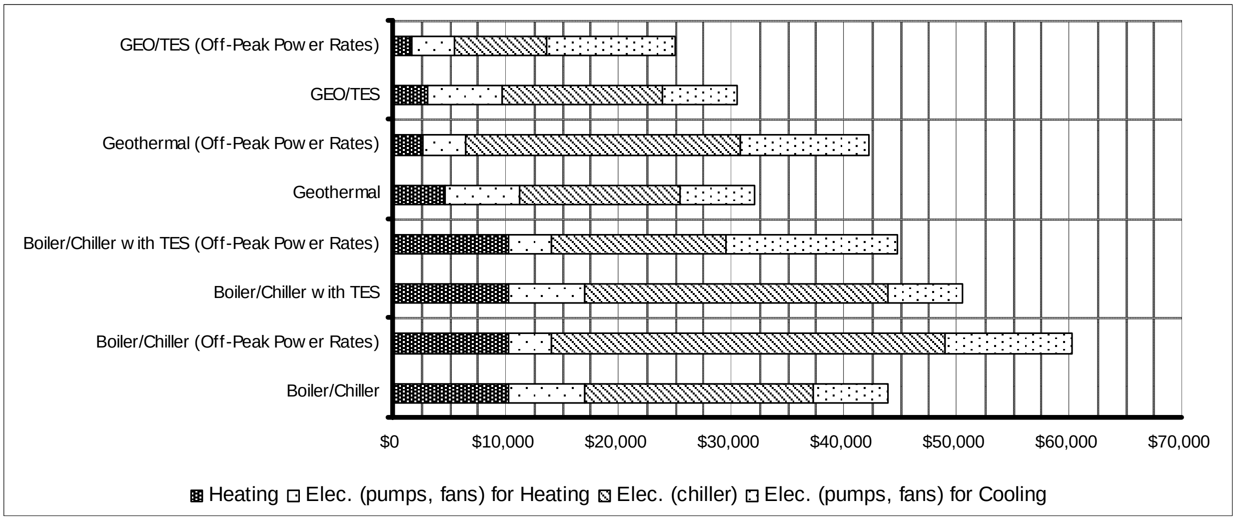

Fig. 6. This graph illustrates the effect of "off-peak" electrical rates compared to standard electrical rates on conventional boiler/chiller system with and without TES and geothermal system with and without TES in typical 5,000 square meter office building. (Cost of electricity – standard rates: $0.06/kWh, Off-peak rates: $0.04/kWh, Peak-rates: $0.10/kWh)

4.2.1 Off-Peak electrical rates

Many utilities offer lower rates when electricity is used during off-peak hours. Many utilities charge more per kWh for electricity during peak times when everyone's air conditioning is in operation than at night when there is little load on the system. There can be as much as a 300–500% increase in cost per kilowatt hour during peak hours. Ice is built in the storage tanks during off-peak hours and is used to cool the building during peak times the following day. During peak cooling periods, only a circulation pump is needed to provide chilled water to fan coil units to cool the building. This can significantly reduce the cost of energy used to cool the building. The use of the chiller does not coincide with the use of lighting and other electrical use when the building is occupied. Figure 6 illustrates the reduction in peak demand.

4.2.2 Reduced electrical consumption

When a heat pump is producing warm and chilled fluids simultaneously, the COP of the system increases, and fewer kilowatt hours are needed to provide space conditioning and hot water. Building ice in ice storage tanks and using the heat taken from the ice to provide heat to the building or hot water for showers uses increases the system COP, and reduces electrical costs. As utilities change their rate structures to encourage customers to reduce energy consumption, energy costs will be reduced even further. Figure 6 graphically illustrates the reduction in electrical consumption as

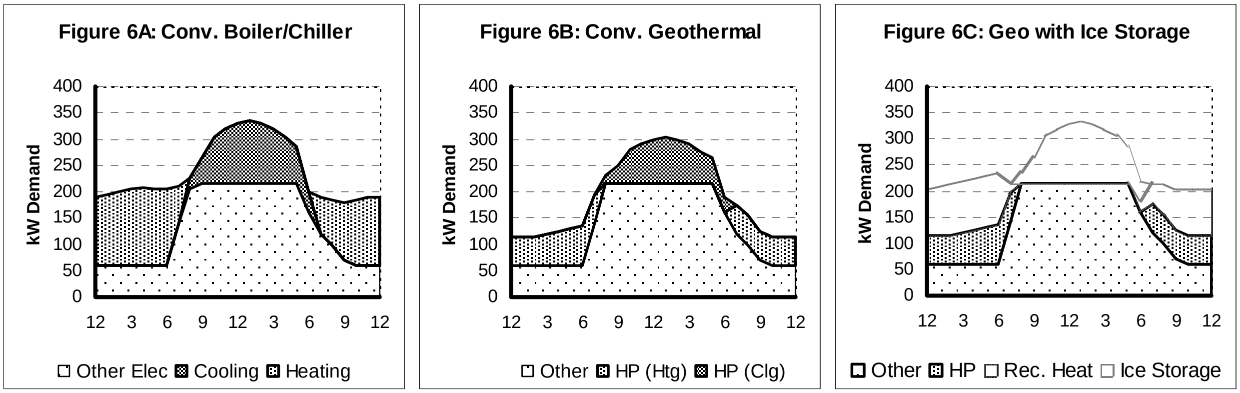

Fig. 7. These graphs compare the peak energy load profile of a building with a gas boiler and chiller (gas boiler, electric chiller), a conventional geothermal system designed to meet peak heating and cooling loads, and a geothermal system integrated with an ice storage system. The peak electrical load is reduced significantly during the day peak use period, and night time heating is similar to a conventional geothermal system, but is significantly lower than a fossil fuel heating system. These charts graphically illustrate both the reduction in peak electrical demand (kW) during daily peak cooling periods & electrical consumption (kWh).

4.2.3 Elimination of Fossil Fuels

Using "waste" heat taken from the building or from the ice storage tanks, or from the earth loop, provides enough heat for the building. This eliminates the need for fossil fuel to provide space heating or hot water.

4.3 Impact on Capital Cost

A significant barrier to the adoption of geothermal systems has been the higher up-front cost of installing the system. The cost of the earth loop is a significant part of the additional capital cost. The use of thermal energy storage reduces the heat pump capacity needed in the building by as much as 40-60%. With less mechanical equipment, less space is needed for the mechanical room.

Preliminary calculations show that in the appropriate building, the size and cost of the earth loop can be reduced by one quarter to one third compared to a geothermal system that is designed to meet the peak heating or cooling loads. This typically reduces the cost of the earth loop accordingly. For some projects reducing the length of the earth loop by this amount can be the factor that determines whether the project can even be done as an earth source system. Space requirements and geological conditions can eliminate the option for an earth loop in some projects.

The capacity of the equipment needed to distribute the heating and air conditioning for the building is unaffected, since the same amount of space conditioning is still needed in the individual building zones.

There is an additional capital cost for the installation of the thermal energy storage tanks in the system. The overall capital cost of a system that integrates thermal energy storage and an earth loop with the HVAC/R system is typically lower than the cost of a conventional geothermal system, and often competes well with the cost of a conventional boiler/chiller system.

5 CONCLUSIONS

Many buildings have unique heating and cooling load profiles where cooling is still required during the coldest design day due to internal heat gains. Ice storage systems reduce peak chiller capacity and, particularly when combined with a geothermal heat pump system, increase the efficiency of the system.

Ice storage tanks can be used in combination with high thermal mass buildings to create cold and warm storage opportunities, enabling simultaneous heating and cooling and increasing the system efficiency.

Ice storage tanks and high-thermal mass buildings are combined to build efficiencies into daily heating/cooling cycles, while the earth loop is incorporated into the system to take advantage of seasonal thermal energy storage.

Integrated geothermal / thermal energy storage systems reduce the capital cost, energy costs, operating and maintenance costs, and environmental impacts of a building.