A Guide for Best Practices for Ground-Source (Geothermal) Heat Pumps

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Scope

The purpose of this Guide is to describe the practices and approaches for successful and efficient procurement, design, construction, and operation of ground-source heat pump systems, also frequently called geothermal heat pumps (GHP). This Guide will not present background information on the technology, for that the reader is referred to Efficiency Vermont (2009) for an overview or Phetteplace (2007) for more detail. This Guide will also not present detailed design guidance, the reader is referred to Kavanaugh and Rafferty (1997) for such guidance. While approaches and systems will normally be different for residential versus commercial scale applications, the discussion here will cover those applications together with specific issues of each outlined where appropriate.

This guide covers the most common types of systems suitable for use in Vermont. These are broken into two basic groups for the purposes of the discussion here. **Ground-coupled** systems refers to systems that exchange heat with the ground by circulating water or a water based antifreeze solution in a closed piping network buried in the ground. Ground coupled systems are also called "closed-loop" systems. For ground-coupled systems the piping can be placed either horizontally or vertically as explained in more detail in Phetteplace (2007). **Ground water** systems use the ground water as a means of coupling with the earth. The water may be used directly in the heat pumps where quality is adequate (more common in residential systems) or isolated from the heat pumps by a heat exchanger (common in commercial applications). Ground water based systems are also called "open-loop" systems.

The intended audience for this Guide is the consumer of the technology or those acting as their advocates. Some engineering concepts are used but the intent is that non-HVAC engineers will be able to follow the discussion and those with no engineering background should be able to follow much of the discussion. While this Guide may be of some use to designers and installers, they will require much more in depth training as well as experience, the need for which we hope will be made apparent here.

While GHP systems are not complicated, they are not common place either, especially in the Northeastern United States, hence the need for this document. Certain aspects of their design and installation are foreign to designers and installers of "conventional" HVAC systems. ***Experience has shown that when approached like a conventional system by designers and installers the result usually suffers both with respect to functionality and efficiency and in addition will likely be more costly than necessary. This aspect of the application of GHP cannot be overemphasized.*** While this guide will lay out many of the pitfalls that await those who are inexperienced in the technology, it is not intended to leave the reader as an expert who may successfully procure, design, install, and/or operate a GHP system under each and every circumstance. When in doubt, the reader is always advised to seek the council of an expert with demonstrated and well documented field experience. This is critical for all applications but especially so for unique or specialized facilities/applications.

Why GHP are different

Rather than simply extracting heat from the ground or rejecting heat to the ground, closed-loop GHP also use the ground as a heat storage device. Understanding the process of heat exchange with the ground requires not only knowing the current heat transfer conditions, but also the heat extraction or rejection to the ground that has occurred in the past. For heating and cooling loads the normal time of interest is the annual cycle of heat extraction and rejection to the ground. Understanding this annual cycle requires in turn that much more detail be known about the "loads" that will be imposed on the ground by the GHP system and their timing. For most other types of HVAC systems this level of detail is not needed. Thus, alternative sizing methods must be used for GHP systems or there may be negative consequences as discussed below.

While the heat transfer process with the ground is not as complicated for open loop GHP systems, it is still necessary to properly size the components of the GHP system as over-sizing will result in higher initial costs and likely lower operating efficiencies. Additional discussion is presented later in this Guide on loads and sizing.

What are good applications for GHP (and what are not)

GHP are a capital intensive HVAC technology and costs are typically a linear function of size within any given type of system, that is the cost of each unit of capacity is about the same as the initial increment of capacity; bigger is not necessarily much, if at all, less expensive. This is obviously much different than fossil fuel fired heating equipment where additional capacity comes at much lower cost that the initial increment. For this reason the best applications of GHP technology tend to be tight buildings with lower heating and cooling loads per square foot. This tends to favor newer construction as opposed to retrofit. This should not be construed to mean that retrofits are categorically not economical viable; in some market segments such as schools many successful and cost effective retrofits have been constructed.

Also favoring new construction over retrofit, GHP typically deliver heat by heated air, as opposed to the more popular hydronic heating systems common in many existing Vermont buildings. (An exception to this is hydronic systems that use radiant floor or other low temperature delivery techniques where GHP are well suited.) The inability to easily retrofit GHP into hydronic systems that use baseboard or cabinet convectors or radiators is a major drawback for retrofit of GHP technology in Vermont; the reason why this is true is discussed later.

Applications that have low capacity utilization such as churches and other facilities where the heating/cooling may be "set back" or off for the majority of the time are poor applications of GHP. In such applications the energy savings that will be achieved will be smaller since the system simply will not be operating as much thus not allowing for recovery of the higher first cost. It is possible to reduce the initial costs of such application somewhat as the amount of ground coupling can be reduced due to the lower load duration. However, this must be done with caution; if the usage of the facility increases the ground coupling will be undersized.

In general, commercial scale applications are likely to have better comparative economics than residential scale systems. This is true in part because air-conditioning is normally provided in new commercial construction in Vermont, which tends to be tight and have high internal heat gains necessitating air-conditioning.

Buildings such as schools that often have spread out floor plans, often only single story, are good applications for GHP's as this technology with its distributed heating/cooling equipment is well adapted to such buildings.

In addition to these general guidelines on buildings and types of applications, below there is additional information on system types and practices that are not recommended.

Site conditions for GHP in Vermont

Vermont has highly varied topography and geology. Both of these aspects will have an impact on the selection of type of ground-coupling to be used. In some areas of Vermont it will be possible to predict with some degree of certainty the availability of water supply for open loop systems; however in areas where wells are to be drilled in fractured rock, there is always a very high uncertainty on the outcome. When groundwater is available in adequate quantities and of acceptable quality open loop systems will normally be the best option, especially for commercial scale applications. This results from the fact that water supply development costs tend to scale at a rate significantly lower than linear, which is not the case for ground-coupled systems where each increment of ground coupling capacity will cost essentially the same as the last. For example, a ground-coupled application with twice the load will essentially require twice as much ground coupling which will cost essentially twice as much. For an open loop system, developing a well that produces say 40 gpm will normally not cost twice what it would to develop a 20 gpm well, given that the geology will support the larger well. However, the negative aspect of open loop systems is that since the initial increment of water supply cost may be high, for residential systems unless the well used for domestic water supply is also used as supply for the GHP system, open loop system will not always offer the most favorable economics.

While some types of systems may have seen wider application in Vermont than others, nothing should be construed from this as to applicability. Much of what is seen in the current mix of system types in Vermont is the result of the influence of particular designers, equipment dealers, and installers who often tend to favor one approach over another regardless of what the site might indicate as being reasonable. With the very limited design and installation infrastructure currently in Vermont the influence of any one designer, equipment dealer, or installer can be significant. Although aggravated by the meager market penetration of GHP in Vermont, this situation is not unique to Vermont as pointed out by Hughes (2008). The consumer of GHP will need to be vigilant to ensure that the best system type for his/her site and application is selected.

Selecting a designer

For both the design and installation of GHP the infrastructure is lacking in Vermont and the Northeast in general when compared to other parts of the country. For this reason it is a more challenging task to achieve a cost competitive and efficient design and installation of a GHP system in Vermont. Little is known about the impact of this lack of infrastructure on efficiency of installed systems; perhaps data gathering studies recently requested by DOE will provide information on this issue. With respect to construction costs, according to Hughes (2008) the installation cost of ground heat exchangers can be 100-400% higher in areas where infrastructure is undeveloped/underdeveloped. These factors must be recognized when procuring design and installation services in Vermont.

Design of residential systems is fairly straightforward and is often accomplished by the HVAC contractor. One should look for a contractor that is experienced in the design and installation of GHP systems, recognizing that at the current time those are quite rare in Vermont. The normal practice of seeking multiple bids should be followed. Due to the general lack of installers in Vermont, competition is not well established and large variations in costs can be expected. As always, the consumer should ask for references and follow up with them; the more successful installations they have made, the better. When speaking with owners about their experience with a HVAC contractor, ask not only about how well the system works, but also what sort of energy consumption or electric power bills they are experiencing: poorly designed or installed systems may provide acceptable levels of heating and cooling but use much more energy than necessary in the process; additional details on this aspect of GHP may be found in Phetteplace (in prep).

The cost effectiveness of a GHP is a very strong function of choosing the best option for the site and application, and thus it may be necessary for the consumer to ensure that all systems types are investigated in order to achieve an acceptable and near optimal design. While a HVAC contractor may be familiar with and able to install a system of a particular type (i.e. closed loop) they may have little or no experience in other methods (i.e. open loop). For this reason it is unlikely that all the options will be properly evaluated when a HVAC contractor does the design; an aspect that is unfortunately even more true when less experienced engineers are responsible for the design. Please refer to the section presented later entitled “What to look for in an installation” for additional information on installer selection criteria.

The design of commercial scale systems is much less straightforward than residential. There are many pitfalls that the designer inexperienced in GHP systems can fall into. Even a designer who is entirely successful at HVAC design for commercial systems in applications other than GHP systems may well produce a GHP design that fails or is far from optimal in terms of overall system efficiency. As noted above, experience has shown that when approached like a conventional system by designers and installers of conventional systems the result usually suffers both with respect to functionality and efficiency and will often be more costly than required as well. Very often even an experienced HVAC designer will make this mistake. Thus, as with residential scale systems it is important to fully vet the designer with respect to his prior GHP projects, even if the designer is known to have produced other fully acceptable non-GHP designs. For commercial scale designs the customer should insist that in addition to having demonstrated success in GHP design, that the designer be a Registered Professional Engineer (PE) in Vermont. Registration as a PE demonstrates the designer’s commitment to the profession as well as putting his/her registration, which is often required by many customers, at risk with each design tendered. As with residential systems, for commercial scale systems one should shop for a designer as discussed above and also expect to repeat the process when it comes time to seek construction bids. Because the performance of a poorly designed or poorly installed GHP can be far from optimal, procuring a GHP system by the Design-Build process is especially risky. The designer/installer has no incentive to provide a system that achieves low operating and maintenance costs. It is recommended that if the design build process is used that an experienced GHP consultant be retained and that the RFP require that this individual/organization review and approve the design, which should be in compliance with the accepted guidance of Kavanaugh and Rafferty (1997). Below we'll discuss some of the things to look for in a design.

What to look for in a design

As noted above, it is beyond the scope for us to provide detailed design guidance here; the interested reader is referred to Kavanaugh and Rafferty (1997). Rather our intent is to provide a few highlights of system design. If the selected system design/contractor is proposing a design that strays from the guidance below it should be a cause for concern and questions.

- *Loads and sizing.* As noted earlier, rather than simply extracting heat from the ground or rejecting heat to the ground, GHP also use the ground as a heat storage device. Understanding the process of heat exchange with the ground requires not only knowing the current heat transfer conditions, but also details about heat that has been extracted or rejected to the ground up to the present. This in turn requires that much more detail be known about the "loads" that will be imposed on the ground by the GHP system and their timing than is the case for most other types of HVAC systems. In commercial scale applications, equipment sizing methods for the typical fuel-fired heating equipment or air-source heating/cooling equipment are normally not recommended for sizing a geothermal heating and cooling system. In addition, due to the fact that there is little cost penalty for doing so, conventional HVAC equipment is typically significantly oversized (Kavanaugh and Rafferty, 1997). In the case of a geothermal based system, significant cost penalties will result from system over-sizing and these will in turn adversely affect economics; this is especially true for ground-coupled systems. While the heat transfer process with the ground is not as complicated for open loop GHP systems, it is still necessary to properly size the components of the GHP system as over-sizing will result in higher initial costs and likely lower operating efficiencies resulting in higher operating costs.

  For residential scale systems GHP sizing is simpler as detailed modeling of the ground is normally not needed; the exception being high end residential installations with features such as indoor pools, theaters, commercial kitchens, etc., that resemble more closely commercial applications. However, it is necessary to properly size the heat pumps themselves for the actual load in the residence since over-sizing, as is typically done with fuel fired heating equipment, will result in significantly higher costs, lower operating efficiency, and under some conditions potential problems with humidity control in the cooling mode. It is also required that accepted sizing criteria be followed, such as is available from http://www.geokiss.com/res-design/GSHPDesignRec2.pdf.

  Specifically what is needed for the design of commercial scale geothermal heat pump systems are the "block loads" on the peak design heating and peak design cooling days. Block loads differ from installed equipment capacity and even the actual peak load. Without delving into a level of detail beyond the scope here, suffice it to say that the block loads are average loads within specific blocks of time during the 24 hour design day and they are aggregated for the entire building, or that portion connected to a given section for ground-coupling, taking into account the diversity of demand across all zones. These block loads are then used by design tools that account for the heat pump performance, and in the case of a closed-loop geothermal heat pump system, model the response of the ground to the net heat extraction/rejection loads placed on it (i.e., the degree to which the ground temperature increases or decreases over time as a result of heat rejection or extraction). The interested reader is referred to Kavanaugh and Rafferty (1997) for further discussion. For ground-coupled systems thermal properties of the ground must also be known as well as the total amount of heat rejected to and extracted from the ground annually; this is normally expressed in terms of equivalent full load hours for heating and cooling. For open-loop geothermal heat pump systems the design the process is a bit simpler as the ground's response need not be modeled, however the flow rates of water required are still based on the aggregated block loads and the performance of the heat pumps.

- *In-building equipment configuration.* A number of different types of water-source heat pumps are available for use in GHP systems. Both upflow and downflow units are available as well as horizontal and console units. Water-to-water units are available for radiant floor heating applications, hot water heating, or ventilation air preconditioning. Typical commercial-scale applications use units mounted in the ceiling space or small utility closets. These units are quiet enough that noise is not generally a problem, however it is a good practice to gather the noise data from the equipment manufacturer and discuss that with the owner and make certain that the noise levels will be acceptable. Ideally, it would be best for the prospective owner to visit a similar facility with the proposed equipment installed as planned and witness the noise levels first hand before agreement.

  One of the principal advantages of a GHP system, or for that matter the more conventional water-loop heat pump system using a boiler and cooling tower, is the flexibility of zoning. In general, it is best to treat each zone with its own individual heat pump; or in the case of larger zones multiple heat pumps. There is little, if any, advantage to using a larger unit to serve several areas, even if they are reasonably served as a single zone. There are two reasons why the "bigger is better" mentality may not be best with GSHP systems:

  - In general, the smaller heat pump units themselves have higher efficiencies than larger units.
  - The cost advantage of a single larger unit over multiple smaller units is modest and will be easily offset by the cost of the additional ducting the larger unit will require.

- *Ground loop configuration.* In concert with the decision on how to serve the zones with heat pumps, the best way to configure the ground-coupling loops that will serve the heat pumps must be chosen. The principal options are:

- Connect all heat pumps to a common circulating loop and a common set of ground-coupling wells. This works best for compact floor plans and allows the maximum benefit to be derived from diversity of the zone loads.
- Provide a separate ground-coupling loop field for each heat pump unit. This may work well where the floor plan is spread out, like school buildings, and in retrofit situations where it would be difficult to run piping for the central circulating loop. Separate ground-coupling fields thwart any attempt to take advantage of diversity, but provide redundancy so that any system failures will only affect single zones.
- Some combination of the two solutions above. This option offers exceptional flexibility for buildings or applications that don't fall clearly into one of the categories above. Often the specifics of the application and site plan will also have an impact on selecting the best configuration of the ground loops.

- *Central systems.* One of the major advantages of a GHP system, or a water loop heat pump system for that matter, is derived from the fact that the heating and cooling equipment is out in the individual building zones. This allows the heating or cooling demand in a given zone to be met exactly without regard to what is happening in other building zones. This provides ideal zone control while eliminating the energy wasted by systems that use reheat to achieve zone control. It also means that the air that needs to be moved to provide the heating and cooling effect travels a much shorter distance to arrive at the zone to be conditioned. This saves significant amounts of fan power: moving air as a means to provide heating and cooling effect is a very inefficient process. In addition to these advantages inherent to a system with the heat pumps dedicated to individual zones, the arrangement of multiple heat pumps on a single piping loop allows for the reject heat from a heat pump unit in the cooling mode to be recovered by a heat pump unit that is in the heating mode. This reduces the net heat that must be supplied from or rejected to the ground. One of the most common errors made by the designer of conventional systems who is tasked with designing a geothermal system is to use central equipment, i.e. a chiller cooled by a geothermal closed-loop ground-coupling arrangement and an otherwise conventional HVAC systems such as a variable air volume (VAV) system. In doing so all of the advantages of having the heat pumps out in the zones that are discussed above are lost, not to mention the fact that the controls will be much more difficult and expensive.

- *Supplemental heating.* For residential scale system supplemental heat may be cost effective if properly sized. For residential scale systems this would normally take the form of electric resistance heating, often called "strip heaters" installed in the outlet duct of the heat pump (water-to-air). When considering supplemental heating on a residential system be certain to look at the economics closely. As the addition of additional supplemental heat will lower the size of the GHP and its associated ground-coupling it will reduce first cost. However, the first cost reduction will come at the expense of higher operating costs; heating supplied by the strip heat will cost about 3-4 times more than that provided by the GHP. The balance is achieved when the present value of the additional cost to operate the strip heat is equal to the cost difference between the system with strip heat and a system that could supply all the heat with the GHP. The user is cautioned that in the quest for low installed cost to not settle for a system that has such a high fraction of strip heat that it really becomes a GHP in name only. It is also important to point out that while the control of strip heat is normally integrated into the GHP unit and is thus fairly straightforward, there is the potential for abuse and if the user regulates the heat by "bang-bang" control with the thermostat. In this event, the strip heat may be activated much more frequently than expected resulting in higher than expected operating costs. Note that for commercial applications in Vermont electric strip/resistance heating is not permitted by the state energy code.

On commercial scale systems in heating dominated climates like Vermont, inexperienced geothermal designers will frequently add a "peaking" or "supplemental" boiler fired by propane or oil in an effort to reduce the amount of ground-coupling required and thus installed cost. While this would seem like a reasonable approach, experience has shown that geothermal does not mix well with "peaking boilers". The issue is control of the systems which would seem like a simple matter, yet in reality problems usually result and the efficiency of the system suffers dramatically. Even systems that initially function well may degrade over time. Installations have been observed where after a year or two adjustments were made to the control set points and the boilers were heating up the ground as well as the building at great expense. Also it should be noted that if open loop geothermal is an option there would likely be less, if any, initial cost advantage to using "peaking boilers" and operating costs would be higher if they were used. In new installations the advantage of being able to avoid the use of all fuel burning equipment in the structure should be considered. This translates to not only the deletion of boilers, but also fuel storage and handling. This could reduce insurance costs as well as environmental liabilities. The in-building as well as exterior footprint will likely also be increased if peaking boilers are added. Thus when looking at the perceived saving from reducing the geothermal portion of the system by adding peaking boilers all these factors must be considered.

- *Cooling towers.* It is becoming more common practice on commercial scale ground-coupled applications in warmer climates and applications with significant cooling needs to consider integrating a cooling tower into the system. Such systems are normally called hybrid GHP. The cooling tower is used to reject a portion of the heat such that the net of heat rejected to the ground loop and heat extracted from it are closer to being in balance, thus reducing the amount of ground coupling needed and its cost. The cooling towers are most frequently closed circuit fluid cooler type, which isolate the tower water from the water circulating to the heat pumps and the ground coupling. In Vermont hybrid systems will probably only make sense in applications with very high cooling loads, for example data centers.

- *Heat delivery systems.* Delivery of heat into the space in both residential and commercial scale GHP systems is normally by air or radiant systems. Gone from the available options is the popular baseboard convector or other types of convectors/radiators. This is a major disadvantage in retrofit of buildings in Vermont where hydronic systems with baseboard convectors are so popular. The problem is that these distribution systems require much higher water temperatures that can be generated with a GHP. Water-to-water GHP can provide output temperatures as high as 130 °F, although their efficiency suffers at these higher temperatures. They are much more efficient supplying water temperatures around 100 °F as would be required for a radiant floor heating system. Radiant heating is a good application for GHP. While baseboard convectors will have some output at lower temperatures the reduction is often not appreciated. For example when finned tube or cabinet heaters are de-rated from the more typical 180 °F hydronic supply temperature down to 100 °F supply temperature it reduces their capacity to merely 18.5% for 70 °F room air. (ASHRAE, 2008).

While using radiant panels and floors as a heat delivery means is a good option for GHP systems, the majority of GHP systems deliver both heating and cooling to the space by air. This is best done by using water-to-air heat pumps positioned out in the zones as discussed elsewhere.

- *Sewage and other novel heat sources/sinks.* When considering a GHP system one should also look for other available sources of low grade heat besides the earth below. Sewage, for example, is an excellent source of heat and it should be considered for applications such as heating a sewage treatment plant or buildings nearby. Special precautions are necessary in transferring heat with the sewage. It must be pointed out, however, that for most applications the sewage generated within an individual building will not be adequate in quantity for heating and/or purposes for that building. The best applications will be sewage treatment facilities or other locations within the sewage collection system where access to large quantities of sewage would be possible. Aside from sewage other novel sources of heat include commercial/industrial processes, ground water from pump and treat operations, or ground coupling in building piles.

- *New and improved.* Ground source heat humps, or GHP have several well-proven embodiments. In arriving at the tried and true solutions, many other approaches were investigated. Those who are unfamiliar with GHP technology, often well intended enough, frequently want to improve on the existing approaches and often the solutions suggested are approaches that were tried and failed earlier on. One such approach is vertical concentric borehole heat exchangers. Early on concentric tube heat exchangers were tried and ultimately their failure led to the u-tube type systems we see now as this was a means to salvage the failed and leaking concentric tube units.

  One claim that is often made by alternatives to the typical vertical u-tube ground-coupling arrangement, concentric tube heat exchangers being one such alternative, is improved heat transfer with the ground. While it may be possible to decrease the resistance within the borehole with these schemes, the fact remains that most of the resistance to heat transfer is within the surrounding soil. Thus any benefit from such approaches will be minor and will be over stated by sort term test data. Proper consideration to the grouting of the borehole (discussed later) and its impacts will help reduce the deficiencies of the vertical u-tube arrangement in thermally coupling with the ground.

Direct expansion GHP circulate refrigerant directly to the ground rather than using a water or a water based solution. Such systems are neither new nor novel. They are often marketed based on their ability to better transfer heat with the ground via the copper tubes they normally use. The expected benefit of direct expansion using copper tubes for better heat transfer is a complete fallacy. The fact of the matter is that the limiting heat transfer effect is the heat transfer in the surrounding ground, not the connection to the ground; copper pipe has negligible impact. The other stated benefits (no water-to-refrigerant heat exchanger, no water pumping) are very minor and in reality they are normally more than offset by the reduced ground coupling volume that is usually installed due to the high cost of copper pipe when compared to HDPE. Add that to the cost and liabilities of having such a large refrigerant charge, oil return, etc and it's easy to see why these systems have never gained much market share.

- *Combining geothermal with solar.* Another alternative often proposed is the marriage of a GHP with solar. In the case of solar thermal the idea is often sold as a way to augment the GHP ground coupling when it is needed the most. Unfortunately, the ground source could use augmentation largely coincident with the time when solar is least able to provide augmentation. Often the argument is also advanced that the solar can be used to "charge" up the ground with heat for that time when the ground coupling will be stressed. Unfortunately this does not work very well either as the best time to charge the system from the perspective of the solar available is during the cooling season when dumping additional heat to the ground will reduce cooling performance. And then there is the issue of economics. Both solar and GHP are capital intensive technologies where additional capacity comes at expense not much different that the initial increments of capacity. Thus, to not be able to fully utilize either of the systems when they are able to perform at the greatest efficiency will make cost recovery more difficult for technologies that are already handicapped in that regard. Solar electric is not much different than solar thermal with one exception: where net metering is available it's at least possible to make the most use of the solar during the cooling season. However, with the high cost of solar PV systems, adding such a system to a GHP installation is not likely to improve the economics over the GHP system economics alone. Even solar domestic hot water systems are not an ideal marriage for GHP when air-conditioning is being provided because a desuperheater equipped GHP (residential) or a dedicated water-to-water heat pump (commercial) would provide domestic hot water at low cost as it is essentially waste heat from the air-conditioning process.

- *Noise control.* A frequently cited issue with any system using heat pumps placed out in the zone to be conditioned will be noise. These units do have compressors and fans in them and thus there is noise generated. The problem is far from insurmountable, however, and even for environments like schools where low noise is crucial, it's a simple matter to achieve acceptable levels of noise. Proper vibration isolation for heat pump units mounted above the ceiling is necessary. By using lower fan speeds, for example, noise (and the effects of drafts) can be reduced to acceptable levels. Certainly a number of installations have been made where unitary heat pumps are actually placed in the conditioned space of a classroom and noise has not been an issue. To do so however, requires that care be exercised in the design and the expectations of the user must be fully recognized, appreciated, and addressed.

- *The multiple unit maintenance issue.* A frequently cited criticism of using one or more unitary GHP in each zone is that the many heat pump units represent a maintenance liability. While clearly a system with distributed unitary heat pumps does include more pieces of equipment to maintain when compared to a central system, the maintenance is simple and the maintenance is very easy to perform if consideration is given to this in design. The heat pumps themselves are highly reliable as is evidenced from ASHRAE (2007) that estimates the *MEDIAN* service life of water-to-air heat pumps is greater than 24 years based on the most recent survey cited. Thus maintenance will mainly be filter changes. This requires very low skill levels and also lends itself to contracting out for those who prefer that option.

- *Ventilation air.* Providing adequate ventilation air is a necessary component of commercial scale HVAC system design. The need to condition that ventilating air can be a significant heating or cooling load. Energy recovery is normally employed in current practice and for buildings located in heating dominated climates such as Vermont heat recovery is the primary consideration. Essentially what is done is that the heat is recovered from the air being exhausted from the building and that heat is used to preheat the incoming ventilation air. GHP systems are well suited to energy recovery. Energy recovery is available built in to some heat pump units and it is also possible to provide a dedicated outdoor air system (DOAS) for the ventilation requirements. With DOAS heat pumps in the zones would handle all of the non-ventilation loads. The DOAS system could include heat recovery if desired. Ventilation air can be preconditioned with coils supplied by water-to-water heat pumps.

- *Borehole grouting.* For vertical ground coupling boreholes it will normally be required that the borehole be grouted with a low permeability material once the heat exchanger u-tube has been installed. The purpose of the grout is to prevent contamination of ground water with surface water and/or any potential for cross contamination between separate ground water aquifers. Unfortunately, the thermal conductivity of materials normally used for grouting is very low when compared with the thermal conductivity of most native soil formations. Thus, grouting tends to act as insulation and hinders heat transfer to the ground. Standard bentonite based grouts, the most popular grouting materials, typically have thermal conductivity values of 0.73 W/m-°C (0.42 Btu/hr-ft-°F) according to Kavanaugh and Rafferty (1997). With few exceptions, the thermal conductivity of the native rock and soil formations are much higher than standard bentonite grout thermal conductivity (Kavanaugh and Rafferty, 1997). Thus, grouting around the vertical u-tube heat exchanger with standard bentonite based grouts is equivalent to insulating the heat exchanger from its heat source/sink. To solve this problem, grouts with enhanced thermal conductivity have been developed. The two principal thermally enhanced grouts are cementitious mixtures (Allan and Kavanaugh, 1999) and bentonite/quartzite sand mixtures (Remund, 1997). Experimental work (Spilker 1998) has confirmed the negative impact of grout on borehole heat transfer. Under heat rejection loading, average water temperature was nearly 6ºC (11ºF) higher for a 16.5-cm (6.5-in.) diameter borehole backfilled with standard bentonite grout when compared to a 12.1-cm (4.75-in.) diameter borehole backfilled with thermally enhanced bentonite grout. Using fine sand as backfill in a 16.5-cm (6.5-in.) diameter borehole lowered the average water temperature over 8ºC (14ºF) when compared with the same-diameter bore backfilled with standard bentonite grout. For a typical system (Spilker, 1998) with a 16.5-cm (6.5-in.) diameter borehole, the use of standard bentonite grout would increase the required bore length by 49% over fine sand backfill in the same borehole. By using thermally enhanced grout in a smaller 12.1-cm (4.75-in.) borehole, the bore length is increased by only 10% over fine sand backfill in the larger 16.5-cm (6.5-in.-) diameter borehole. Thus, the results of this study (Spilker, 1998) suggest three steps that may be taken to reduce the impact of grout on system performance.

  - First, reduce the amount of grout used to the bare minimum. Sand or cuttings may be used where allowed, but take care to ensure that the entire interstitial space between the piping and the borehole diameter is filled.
  - Second, when grout must be used, employ thermally enhanced grout.
  - Finally, reduce the borehole diameter as much as possible to mitigate the effects of whatever grout or backfill is used.

- *Thermal properties testing*. Due to the large uncertainty in soil thermal properties even when the soils themselves are well known, which is seldom the case for vertical ground-coupled systems, in-situ thermal properties testing has become common on larger GHP projects using vertical ground coupling. Essentially the test is conducted by installing a single vertical u-tube heat exchanger in a manner as near as possible to the planned final installation and then placing a heat load on the u-tube and monitoring the ground's temperature response. In general, on vertical ground-coupled systems over 25 tons it is recommended that such thermal properties testing be performed before the design is finalized. In Vermont for cases where systems may be expected to be primarily in bedrock, such tests may not be necessary as the rock thermal properties are more uniform and the type of rock is often well known. Where tests are necessary the procedure outlined in ASHRAE (2007) should be used.

- *Antifreeze*. For closed loop systems in heating-dominated climates like Vermont a mixture of antifreeze and water must often be used in the ground coupling loops if loop temperatures are expected to fall below about 5ºC (41ºF). An ASHRAE research project (Heinonen et al., 1997) establishes the important considerations for antifreeze solutions for GHP systems and provides guidance on selection. In general most applications will probably use propylene glycol which is a very good all around choice and one that is readily available.

Pumping. Pumping energy consumption in GHP systems can be excessive if proper care is not taken in the design. Excess pumping is a very typical mistake that an inexperienced designer makes on commercial scale systems with central pumping schemes. The following guidelines will help achieve acceptable pumping energy consumption:

- Size piping and headers properly based on the recommendations of accepted design guidance (Kavanaugh and Rafferty, 1997).
- Avoid the use of antifreeze, but if it is necessary, keep concentrations to a minimum.
- Use variable-speed pumping and two-way valves at the heat pumps for centrally pumped systems. Alternately, simply the system by using a single pipe and staged pumping as demonstrated by Mescher (2009).
- Use pumps with high-efficiency motors, and design them to operate near their point of maximum efficiency.
- Select heat pumps and control valves with low pressure drops. Total system head should be less than 60 feet.
- Do not pump more fluid to the heat pumps than necessary. High-efficiency heat pump units will operate with little performance degradation at lower flow rates.

Kavanaugh and Rafferty (1997) suggest the following benchmarks for pumping energy consumption for centrally pumped systems:

Pump Input Power/Cooling Capacity		
(W/ton)	(HP/100 tons)	Relative ranking
≤50	≤5	Excellent
50-75	5-7½	Good
75-100	7½-10	Mediocre
100-150	10-15	Poor
>150	>15	Bad

- *Controls.* Control of GHP systems that use distributed unitary heat pumps is inherently simple. Simple room thermostats will provide very good control for space comfort and do so at minimal costs and very high reliability. For ventilation air, control by CO_2 sensors will provide adequate ventilation while conserving energy. The temptation to use elaborate DDC control with GHP’s should be avoided. Often such control systems can contribute significantly to the costs while adding no value and potentially becoming an expensive O&M cost; especially where controls are proprietary.

- *Domestic hot water heating.* It is possible for heat pumps to supply domestic hot water, although it is not always advantageous to do so. For residential scale systems this is normally done by a device called a "desuperheater". The desuperheater, simply put, recovers heat at the highest possible temperature in the heat pump refrigeration cycle. In the heating mode this is heat that would have been available for space heating and thus the heating capacity is reduced somewhat when a desuperheater is used. In the cooling mode the recovered heat is reject heat that would have gone to the ground and thus it's in essence free (there is a small bit of pumping needed to recover it). For residential applications in Vermont there will be little or no air conditioning and thus this advantage will not be great. In the cooling mode the desuperheater reduces the heat rejected to the ground; this can be a significant advantage in air-conditioning dominated climates, however for residential applications in heating dominated climates like Vermont it is of little or negative consequence as over the annual cycle far more heat will be extracted from the ground than rejected. Thus the result is a heat "deficit" annually which is only worsened by the desuperheater. The end result will be slightly lower seasonal performance in the heating mode unless additional ground loop is installed to offset the impacts of the desuperheater.

  For commercial scale applications where domestic hot water is needed a dedicated water-to-water heat pump is normally provided. These units can generate hot water up to approximately 130 °F, which will be adequate for most applications. For kitchens and laundry facilities where high temperatures may be required it is still possible to use heat pumps to heat the hot water to approximately 130 °F and then provide point-of-use heaters for the kitchen and/or laundry where temperatures need to be boosted to perhaps 140 °F. This will not increase the amount of hot water that needs to be stored; it will however reduce the heat loss from hot water in storage by about 15% and save the expense of generating 140 °F hot water for other uses only to have it mixed down to the lower temperatures for use. The hot water heating supplied by the heat pumps, which would be the majority (approximately 90%), would be much more economical than either oil or propane.

  For commercial scale applications where domestic hot water is re-circulated a similar approach might be used: the water-to-water heat pump would be used to heat the incoming makeup water to the system which would keep the heat pump in a temperature range where its performance would be favorable. To maintain the re-circulated water at temperature electric or oil/propane heaters could be used.

What to look for in an installation

A properly designed GHP system will not present any challenges for the experienced installer. The best designs will be simple and will make the installation easy. In Vermont experienced installers of the ground-coupling portion of the system will be much more difficult to secure than those who can install the interior portions of the system. The installation of the heat pumps and any distribution systems in both residential and commercial scale systems should be easily accomplished by HVAC contractors experienced in those business sectors. The difficulty comes in that those who are most experienced in the ground-coupling are often well drillers and those experienced with the in-building systems are HVAC contractors. Thus finding a contractor who is willing to act as the single point of responsibility for both aspects of the installation may be difficult, especially for residential systems. Below are a list of a few things to look for in installers and their installations.

- *Experience and References.* Look for installers who have installed the type of system you are planning (e.g. closed-loop vertical ground-coupled) and ask how many installations they have done and for a list of references you could call. Ask if the candidate installer has any projects currently under construction that could be visited. When asking about prior installations try to get the dates of those and check references for some of the old installations. For residential projects where the design will likely be done by the installer, ask the installer if he/she has installed other types of systems besides the one they would recommend. You should also inquire as to why they are recommending that particular type of system.

- *Certification and equipment.* All installers should have IGSHPA (International Ground Source Heat Pump Association) installer certification. Pertinent further questions of an installer are: When did you receive certification and do you have multiple staff members trained and certified? Do you own the fusion tools for HDPE (high density polyethylene) piping? Do you have a high capacity pump for flushing the installed ground loops? Do you have a grout pump for grouting the boreholes? Have you worked with thermal grout before?

- *Sub-contractor issues*. For residential projects where ideally the consumer would like to deal with just one contractor for the reasons discussed earlier, check to see if the contractor is willing/able to take on responsibility for the entire system including the HVAC "indoor portion" and the ground-coupling portion.

- *System sizing.* For commercial scale systems this would be done by the designer as discussed above, but for residential systems this will normally be done by the contractor so the consumer must determine what method will be used. The most common is the ACCA Manual J method (ACCA, 2006). For retrofit installations the contractor should not be permitted to size the system based on the sizing of the existing fossil fuel fired equipment; this will result in unnecessary and costly over-sizing. It's also important to ask the contractor how the ground-coupling will be sized once the heating and cooling loads are known. This is commonly done with rules of thumb for residential systems; ASHRAE (2007) contains some guidance that should be consulted.

Commissioning

Commissioning is in essence the process of startup of the building HVAC systems and determination that all equipment functions and that the design intent has been achieved. This includes making certain that all control points and sequences meet the design intent. For more information on the commissioning process refer to ASHRAE (2007).

If the guidance detailed above and that of the accepted design references such as Kavanaugh and Rafferty (1997) are heeded, commissioning of a GHP systems should be straightforward. During the commissioning some of the features unique to GHP that should be checked will be the temperature drop/increase (heating/cooling modes, respectively) in the water side at the each heat pump unit. The pressure drop across this heat exchanger should also be checked. Both of these measurements can be made using the P&T ports (sometimes called Pete's Plugs) that should be a feature of any quality installation either commercial or residential. The manufacturer of the heat pump units will have data available on both the temperature drop/increase to expect as well as the pressure drop. The temperature drop/increase will verify that the unit is operating properly in terms of supplying heating and cooling and the pressure drop will help establish that the flow across the unit is adequate and within the specifications. The flow measurement should be made not only at each heat pump with just that heat pump running, but also under the operating condition where all heat pumps are running.

Closing thoughts

These pages of cautions and advice are not intended to scare the reader away from GHP. Our only intent is to inform so that the best possible system can be obtained. Aside from the energy savings, which are difficult to generalize, there are significant carbon footprint savings that can be realized from GHP when displacing fossil fuels for heating, especially in states like Vermont where the majority of the electric supply comes from sources that emit little or no carbon in generating electricity. The table below provides some rough estimates of carbon emissions reductions possible with GHP as percentages. The carbon loadings were sourced from http://www.puc.nh.gov/Sustainable%20Energy/RFPs/GHGER%20FUND%20022309%20RFP.pdf with the exception of electricity for which the carbon loading was assumed to be 1030 lbs/MWh which is the average avoided rate for New England per Hornby et al. (2009).

Heating Method	CO2 Emissions Raw Energy (lbs/MMBtu)	Approximate Conversion Efficiency	CO2 Emissions Delivered Heating (lbs/MMBtu)	Reduction by use of GHP @ COP_h=4	Reduction by use of GHP @ COP_h=3.5
Electricity Resistance	301.8	100%	301.8	75%	71%
Natural Gas	117.1	90%	130.1	42%	34%
Distillate Fuel Oil (#1, 2 & 4)	161.4	90%	179.3	58%	52%
Residual Fuel Oil (#5 & 6)	173.0	90%	192.2	61%	55%
Kerosene	159.5	90%	177.2	57%	51%
Propane	139.2	90%	154.7	51%	44%
GHP @ Heating COP of 4	------------	------------	75.4	0%	-14%
GHP @ Heating COP of 3.5	------------	------------	86.2	13%	0%

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References

Allan, M. L. and Kavanaugh, S. P. 1999. “Thermal conductivities of cementitious grouts and impact on heat exchanger length design for ground source heat pumps.” HVAC&R Research, 5(2), 85–96.

ACCA. 2006. Manual J Residential Load Calculations, 8th ed., v. 2, Air-Conditioning Contractors of America, Arlington, VA.

ASHRAE. 2007. ASHRAE Handbook, HVAC Applications Volume, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.

ASHRAE. 2008. ASHRAE Handbook, HVAC Systems and Equipment Volume, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.

Efficiency Vermont. 2009. Ground Source Heat Pumps, The right choice for you?, available at: http://www.efficiencyvermont.com/pages/Residential/Home_Heating/heating_systems/GSHP/

Heinonen, E.W., Tapscott, R.E., Wildin, M.W., and Beall, A.N. (February 1997). “Assessment of Antifreeze Solutions for Ground-Source Heat Pump Systems,” Report 908RP, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, Ga.

Hornby, R., P. Chernick, C. Swanson, D. White, I. Goodman, B. Grace, B. Biewald, C. James, B. Warfield, J. Gifford, and M. Chang. 2009. Avoided Energy Supply Costs in New England: 2009 Report, Synapse Energy Economics, Inc., Cambridge MA. Report available at http://psb.vermont.gov/sites/psb/files/projects/EEU/2009avoidedcosts/2009_AESC_Report_20090821[1].pdf.

Hughes, P. 2008. Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers tpo Adoption, and Actions to Overcome Barriers, Oak Ridge National Laboratory, ORNL/TM-2008/232.

Kavanaugh, S. and K. Rafferty. 1997. Ground source heat pumps—design of geothermal systems for commercial and institutional buildings. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.

Mescher, K. 2009. Simplified GCHP System: One-Pipe Geothermal Design, ASHRAE Journal, vol. 51, no. 10, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA.

Phetteplace, G. 2007. Geothermal Heat Pump Technology, Journal of Energy Engineering, Vol. 133, No. 1, pgs. 32-38, American Society of Civil Engineers.

Phetteplace, G. in prep. Key Design Decisions and System Components and their Impacts on Geothermal Heat Pump System Efficiency, document in preparation by GWA Research LLC for Efficiency Vermont.

Remund, C. P. 1997. Grouting for vertical geothermal heat pump systems: Engineering design and field procedures manual. EPRI Final Report TR-109169, Electric Power Research Institute.

Spilker, E. H. 1998. Ground-Coupled Heat Pump Loop Design Using Thermal Conductivity Testing and the Effect of Different Backfill Materials on Vertical Bore Length, Proceedings of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), January 1998 meeting, San Francisco, Calif., paper SF98-1-3.