New Ways to Combine Solar Thermal with Geothermal

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Abstract

A more efficient and less costly method for heating and cooling of buildings is possible using any of several types of solar thermal collectors along with a geothermal or ground source heat pump (GSHP). This paper considers only shallow earth geothermal, as opposed to deep earth geothermal typically used for electricity generation. Although a variety of solar assisted ground source heat pump (SAGSHP) systems have been described in the literature in past years, none of these have become commercially viable products. It is possible that with a more optimum design, this general approach could become more cost-effective than conventional ground source heat pump systems and thereby become commercially viable. The general consideration is that there is a trade-off between the size and cost of a solar thermal collector array and the ground loop for the geothermal portion of the system. For parts of the world where the cost of drilling and installing ground loops is high, it is likely that the added cost of a solar thermal array (or possibly an air to liquid heat exchanger) will be lower than the cost of the portion of the ground loop which is eliminated. This could lead to commercial viability for a system such as described herein.

Keywords: Solar Thermal Collector, Ground Source Heat Pump, Geothermal

1. Introduction

The U.S. consumes approximately 19% of the total energy of the world, in which buildings account for 41% of the U.S. energy consumption. However, only 9% of the U.S. building energy is renewable. Within the 41%, Heating, Ventilating, and Air Conditioning (HVAC) accounts for about 60% of U.S. building site energy consumption (Buildings Energy Data Book). A heat pump system is a type of HVAC system for buildings which provides heating and cooling using a conventional refrigeration cycle and is known to have higher system efficiency (especially for heating) compared to many other HVAC systems, such as systems with gas-fired furnaces or boilers.

Although a GSHP system has the potential for achieving a high system efficiency, the high initial cost is a major barrier for the broad application of GSHP systems in the market. Additional source(s) can be used within a heat pump system along with the ground, such as solar thermal, ambient air, water (lake, river, etc.). A heat pump system with more than one source is known as a multi-source heat pump system. Recent studies (Allaerts et al., 2015; Emmi et al., 2015; Corberán et al., 2018) indicate that the size of the underground loop of a conventional GSHP system can be reduced by about half without a reduction of system efficiency if an additional source is used along with the ground, such as a solar thermal collector or an air to liquid heat exchanger. Although all types of solar thermal collectors are capable of collecting thermal energy from the sun, certain types of collectors are suitable for collection of both heat and cold. Two of these types are unglazed plastic collectors (often used for swimming pool heating) (Anderson et al., 2011, 2013; Man et al., 2011) and photovoltaic/thermal (PV/T) collectors (Eicker and Dalibard, 2011; Pean et al., 2015). These collectors dissipate heat through both convection and radiation and thus would be suitable for use in any climate. The unglazed and PV/T types are functionally similar to air to liquid heat exchangers, also known as dry coolers. The word "cooler" is somewhat of a misnomer because these devices can collect heat just as well as dissipate heat.

The use of inexpensive solar thermal collectors or dry fluid coolers instead of more expensive ground loops contributes to the reduction of the overall system cost, thus providing a cost-effective way to overcome this barrier of GSHP systems. This paper introduces an innovative multi-source heat pump system design that is lower cost to build (much smaller ground loop) and use (higher average annual efficiency) compared to standard, conventional GSHP systems. All new concepts presented herein are currently either patented or patent pending.

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2. System Design and Discussion

This paper builds upon three papers published in Europe recently and also one commercial heat pump product currently available in much of Europe. A group based in Spain (Corberán et al., 2018) describes a dual source heat pump system wth two separate source fluid heat exchangers in the refrigerant loop, thus providing both an air source and a ground source mode (Figure 1). The mode selection is based on whichever source temperature is best at any given time. A conclusion of this paper is that the system has an efficiency similar to a conventional GSHP system but requires a one half size ground loop (about 50% lower ground loop cost). However, a limitation of this design is that since the air source heat exchanger uses refrigerant rather than water, it cannot provide preconditioning of the ground loop (i.e., to connect the air source heat exchanger and the ground loop directly to collect heat/cold from the aimbient air and then transfer it to the ground to allow a certain level of underground thermal energy storage). This is a significant disadvantage, as will be discussed below.

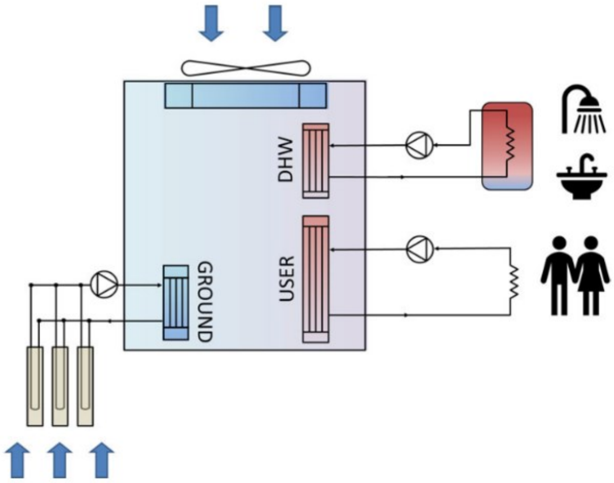

Fig. 1: Dual source heat pump system design (Corberán et al., 2018)

A multi-source system functionally similar to the system from Spain is now in production by a German company, Thermselect (THERMSELECT). This product differs from the Spanish design in that it has physically separate modules for the water and air source heat exchangers (one inside the building and one outside). The Thermselect system also has an option for use of solar thermal collectors. This product is designed for European electrical power standards, and thus is not available in North America. In common with the Spanish system, the Thermselect product cannot provide ground loop preconditioning since the air source heat exchanger uses refrigerant rather than water, and it is claimed that the ground loop needs to be only one half the size of a conventional GSHP loop (SmartHeat). For cold climate regions, a paper by Italian authors (Emmi et al., 2015) shows a simple SAGSHP system which also functions well with a much smaller ground loop. In contrast to the systems described above from Spain and Germany, this Italian design does provide for preconditioning of the ground loop, since the solar collectors and the ground loop both use water rather than refrigerant (Figure 2). This paper from Italy shows simulation results for six different cold climate cities. The worst case example (coldest) location was a city in northern Poland (Bialystok). Even with this coldest location, the summer preconditioning using solar thermal collectors gives a higher efficiency than a conventional GSHP system after seven years of operation, and this is with a 70 percent ground loop size reduction.

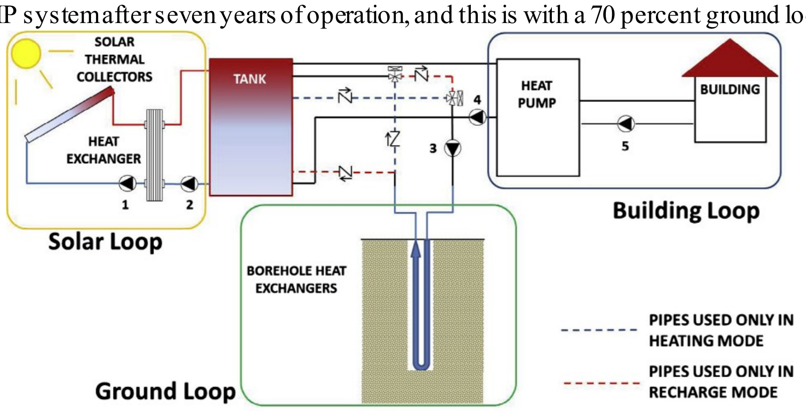

Fig. 2: SAGSHP system design (Emmi et al., 2015)

A much different type of multi-source system is described by the authors in Belgium (Allaerts et al., 2015). This system (Figure 3) uses a dry cooler with a water source heat pump, but it does not have or use an air source mode as do the systems from Spain and Germany. Instead of this it uses only preconditioning into two separate ground loops, one for hot storage and one for cold storage. This system has a somewhat complex valve design and it needs two separate water pumps for the source fluid. The system reverses the flow patterns for summer and winter seasons (Figure 3). On hot summer afternoons, the preconditioning pump supplies hot water into the warm ground loop while at the same time the other water pump sends cold water from the other ground loop to the heat pump. On the coldest winter nights this is reversed, with preconditioning of very cold water (or antifreeze solution) into the cold ground loop while much warmer water is used by the heat pump. This selection of modes provides a significant benefit for both efficiency and total ground loop size. Even though this Belgian design has two separate ground loops, the summation of size for both loops together is approximately half the size of a conventional single loop GSHP design. It should be noted that the dry cooler as proposed by the Belgian authors could instead be an unglazed solar or PV/T array. The relative cost-effectiveness of solar collector use versus dry cooler use will require further study.

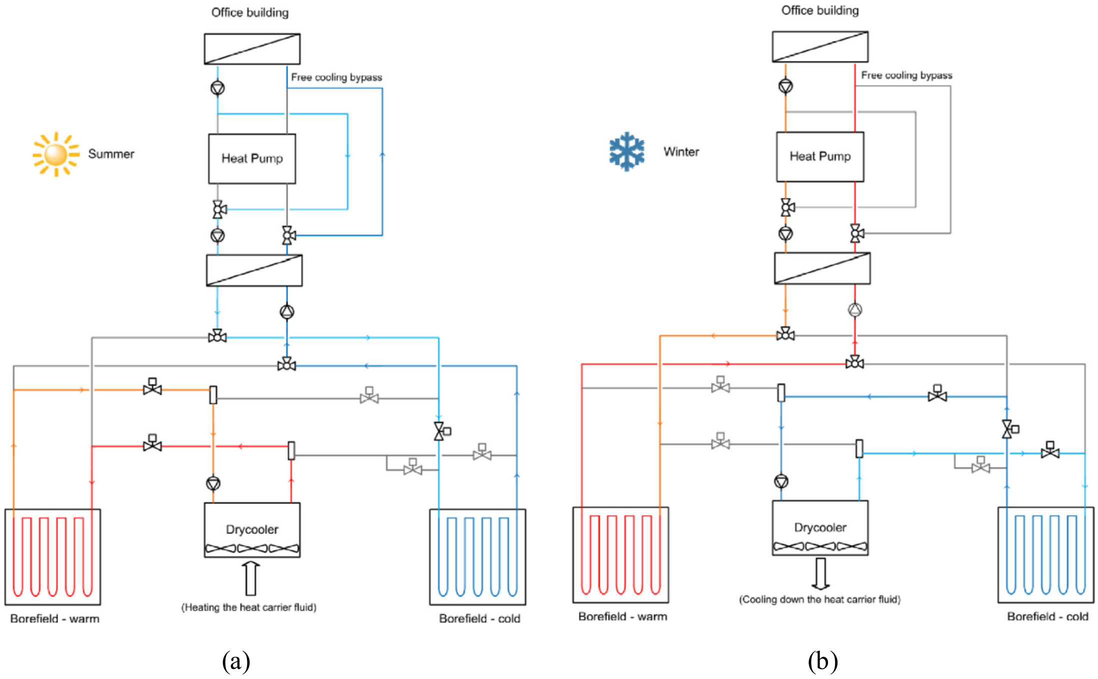

Fig. 3: Multi-source system design: (a) cooling mode (b) heating mode (Allaerts et al., 2015)

Figure 4 shows a simplified diagram of the Spanish/German system approach on the left versus the Belgian approach on the right. The Spanish/German approach simply allows a choice between an air source mode or a ground source mode (no preconditioning of the ground loop). The Belgian approach does not have an air source mode into the heat pump, but it does have preconditioning into two separate ground loop regions. Since both of these approaches have been shown to give about a 50 percent ground loop size reduction (with equal or better system efficiency), the use of both concepts in a single system should give something better than 50 percent. This combination in a single system could reasonably have a 60 percent ground loop size reduction.

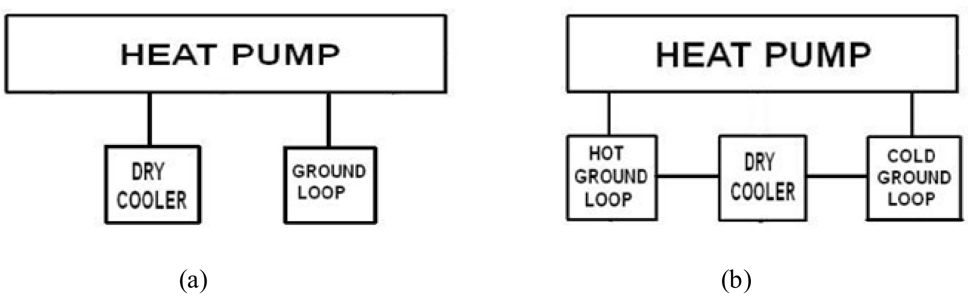

Fig. 4: Dual source system design options: (a) Spanish/German system approach (b) Belgian approach

Figure 5 shows a possible design that includes all of the concepts discussed above. The top water pump in Figure 5 is used for supplying source water to the heat pump. The bottom water pump is used for preconditioning into either or both of the ground loops. Both water pumps are in use when the air source mode is selected. The three ball valves in Figure 5 give at least twelve different modes of operation. These modes are delineated in a recent patent application for this system. A very similar design, also using three valves, is described in US 10724769.

The three valves in Figure 5 are all identical types, and use what is known as an internal T-port configuration (ValveMan). The valves and pumps are assumed to be electrically actuated and computer controlled. The T-port ball valves have four different settings with 90-degree angular increments of the internal ball. If the valve is oriented such that the connections are in an east-west-south arrangement, the four settings are as follows:

1. Flow is allowed in or out of all three connections.
2. Flow is allowed only between east and west connections.
3. Flow is allowed only between west and south connections.
4. Flow is allowed only between east and south connections.

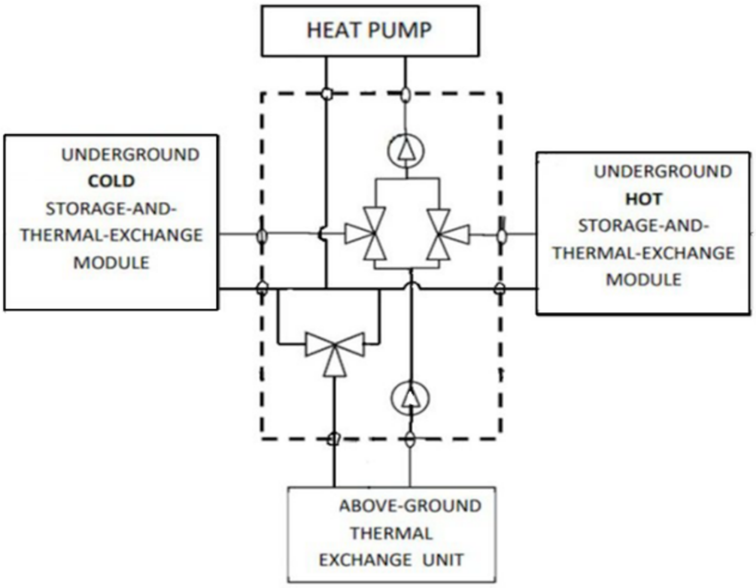

Fig. 5: Revised multi-source system design

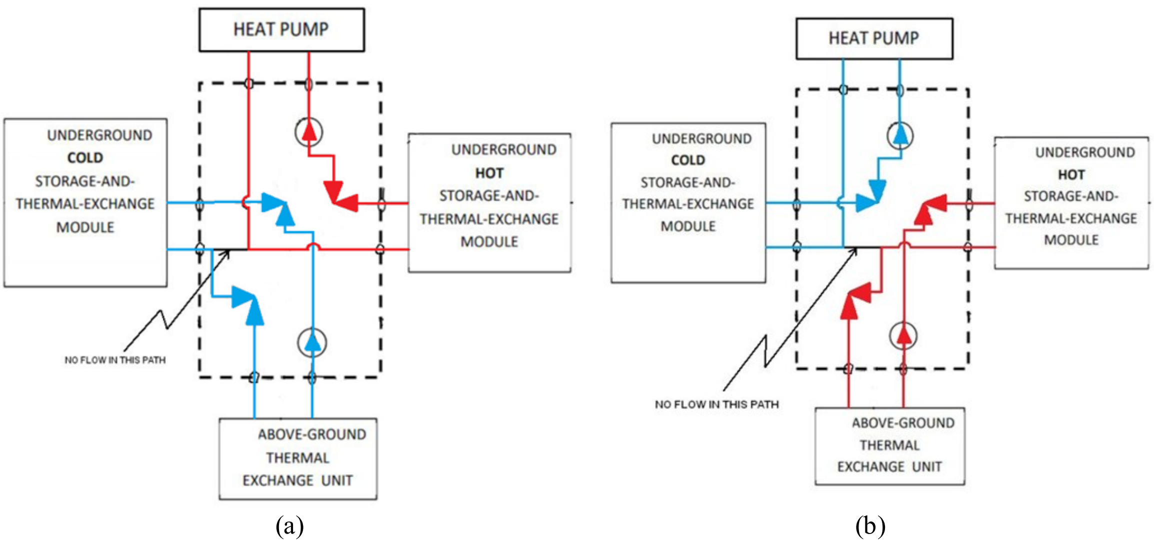

Fig. 6: Flow paths during (a) the coldest winter night and (b) the hottest summer day

It is expected that both water pumps in this design are variable speed types, although most of the functionality is possible with single speed pumps. It is also expected that there will be a control computer and at least two temperature sensors. Both outdoor ambient and source input temperatures would be recorded in the computer at regular intervals, and these two temperature histories would determine the best settings for valves and pump speeds. It is assumed that when the heat pump is in a heating mode, a maximum source input fluid temperature is desired and vice versa for the cooling mode.

Figure 6 shows the valve settings that will accomplish what the paper from Allaerts et al. (2015) describes. The blue color is intended to show cold fluid and the red color much warmer fluid. These would be the modes most appropriate for the most extreme ambient temperature conditions. Consider now the situation where the outdoor ambient temperature is beginning to rise above an extreme cold condition. There will likely be an ambient temperature at which the above ground thermal exchange unit (dry cooler or solar thermal element) will give a higher source input temperature than that from the ground loop. A simple approach would be to switch from ground source mode to above ground mode at this point. Although simple, this approach is not optimum. A better strategy is to use a parallel mode at and near this temperature crossover point. The parallel mode is indicated in Figures 7 and 8. If it is desired to have equal flow rates from the above ground unit and from the ground loop, the top water pump would be adjusted to have a flow rate which is double the flow rate of the bottom pump. As shown in Figure 8, the parallel mode red and green curves give a significantly higher temperature than the simpler case where the parallel mode is not used. The graph of Figure 8 is for the case of the heat pump being in a heating mode. A similar graph would exist for the case where the ambient temperature is coming down from an extreme hot condition.

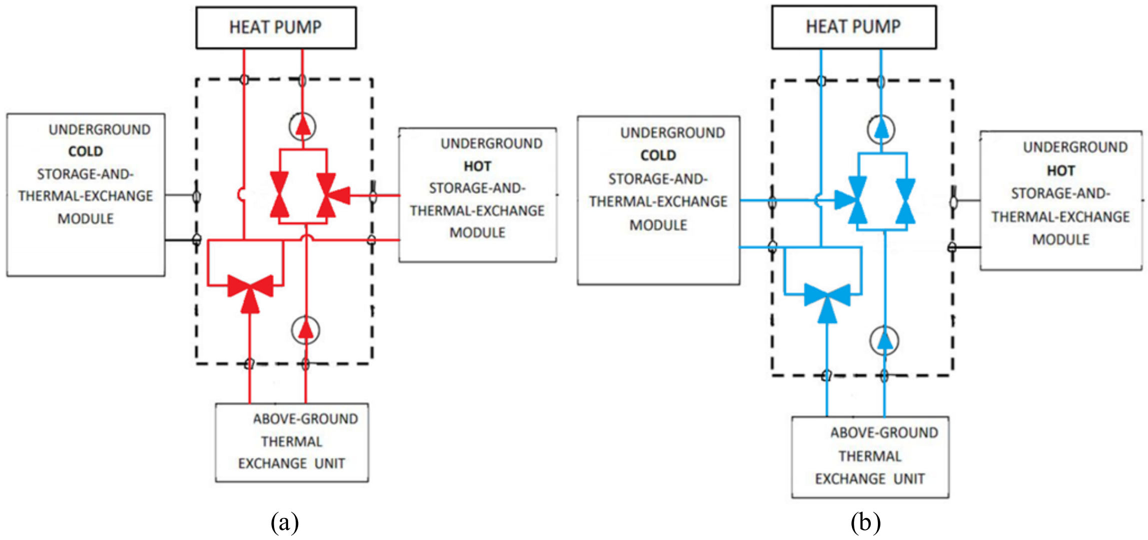

Fig. 7: Parallel modes using (a) hot module and (b) cold module

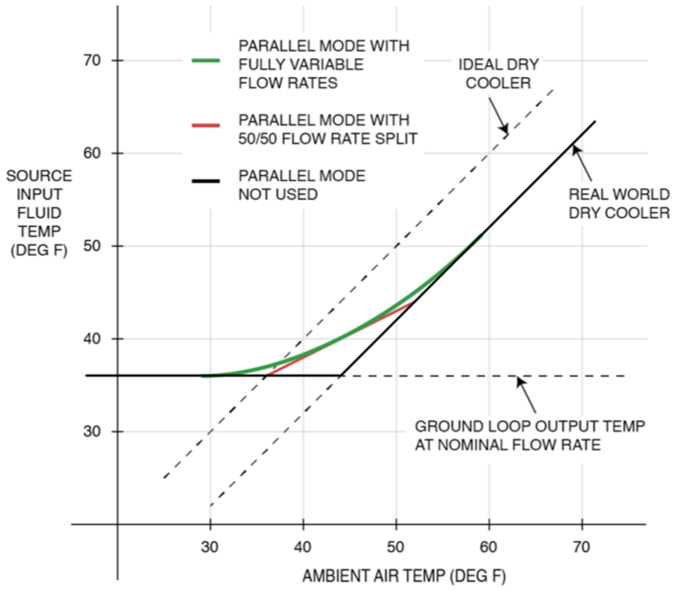

Fig. 8: Temperature curve

Valve settings for the air source mode are shown in Figure 9. Both water pumps are used, and there will be no flow through either of the ground loops. In case where there is just one ground loop, two of the valves are not needed. In this case, the configuration could be as shown in Figure 10. Even with this simpler configuration, there are still four modes possible: ground source, air source, parallel, and preconditioning.

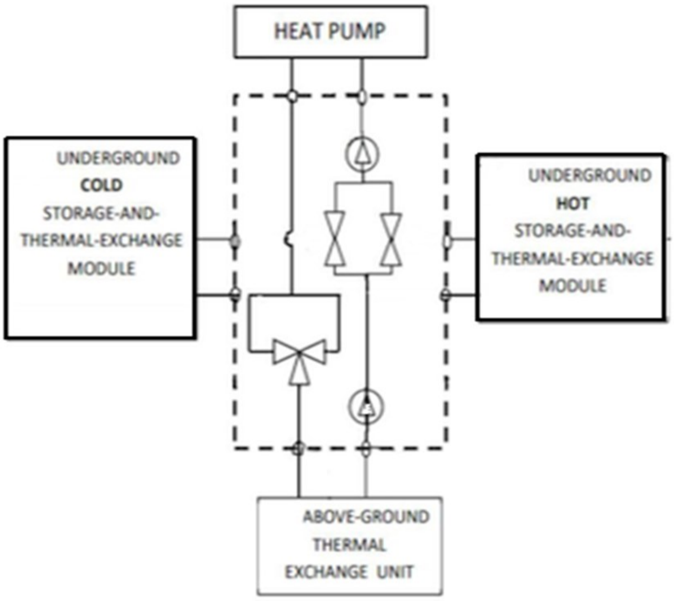

Fig. 9: Air source mode flow paths

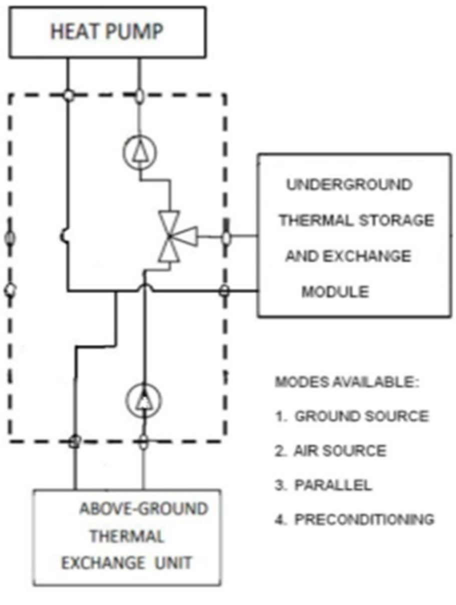

Fig. 10: Modification for a single ground loop

As shown in the paper by Allaerts, et al. (2015), ground loop preconditioning might lead to ground loop temperatures such that the heat pump and compressor are not needed for space conditioning. This is very likely the case at the start of the cooling season, after a winter of cold loop preconditioning. In this case the heat pump can be bypassed, resulting in very cost-effective cooling. This might best be done using a water source heat pump which has an internal design with a water side economizer capability.

Regarding the physical implementation of the system described above, there are four possible configurations:

1. Place the three valves and two water pumps in a separate box, allowing interface to many different heat pumps and many different above ground units.

2. Place the valves and pumps in the same box as the above ground unit, allowing interface to many different water source heat pumps.
3. Place the valves and pumps in the same box as a water source heat pump, allowing interface to many different above ground units.
4. Place all components of all elements of the system in a single box, most likely to be located outdoors.

Although all of the figures above show a connection to a single heat pump, this can be changed such that multiple heat pumps are supplied with a flow of water around a closed loop. This could be a two-pipe loop or a one-pipe loop. A one pipe loop is shown in Figure 7 of the patent referenced above (US 10724769). This figure shows the use of a reversing valve at the primary loop pump, to make sure that all heat pumps in the loop have the same long-term average efficiency. To make this idea practical, reversible flow fixtures are used in place of closely spaced tees for all interfaces to the loop. This means that the heat pump in all the figures above would be replaced with a reversible flow fixture which interfaces with the primary loop. As long as temperature in this primary loop can be kept between 40 and 80 degrees F, all heat pumps will have good efficiency for both heating and cooling. Reversible flow fixtures can be constructed in many ways, but a specific type is commercially available from Taco Comfort Solutions (Taco LoadMatch). This product is available in a wide size range and has the brand name Twin-Tee.

3. Conclusion

This paper describes a possible design that can be used to advance the development of a high-efficiency, multi-source heat pump system. This system consists of a heat pump(s) with two underground regions (one for heat and one for cold) and above-ground thermal exchange unit(s), such as solar thermal collector(s), dry cooler(s), etc. A variety of control strategies have been discussed in the paper with the goal of not only providing enough heating and cooling to buildings but also maximizing system efficiency. This type of system design has the potential for reducing the overall system cost without sacrificing system efficiency compared to a conventional GSHP system, thanks to the significant reduction of the borehole size (more than 50%) realized by using inexpensive above-ground thermal exchange unit(s) as well as optimized control strategies. This study provides a cost-effective way to design and use a multi-source heat pump system. It has the potential for a wide application when used in dense urban areas due to its requirement of smaller ground loop areas. More simulation and experimental work will be performed in the future to further verify the design and optimize the size of system components.

4. Acknowledgments

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