

A design methodology and analysis of combining multiple buildings onto a single district hybrid ground source heat pump system



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ABSTRACT

In this study, the appropriateness of combining multiple buildings onto a single district hybrid GSHP system is assessed. For this purpose, a new methodology is introduced enhancing and utilizing a methodology previously introduced by the same authors for designing hybrid GSHP systems [Alavy et al., Renewable Energy 57 (2013) 404–412]. The new methodology is applied to a utility model of heating and cooling for 100 different commercial buildings, in which a utility or private company installs a larger hybrid GSHP system and then distributes heating or cooling to buildings via a common water loop. The methodology proposed in the present study automatically computes the savings potential associated with thousands of possible building combinations to perform a statistical analysis on the value and potential of the utility model for heating and cooling. It is shown that the methodology can result in reducing the net present value (NPV) of total costs (up to 50%), increasing the potential savings, and still meeting a significant amount of the buildings' heating and cooling demands. This study also shows that for a desired value of NPV savings, increasing the number of buildings combined is only valuable until a certain threshold (which depends on location, weather, building type and building size), after which adding additional buildings to the combinations is not worthwhile. It is also shown that some buildings, for which installing a GSHP system was totally uneconomical, lend themselves particularly well to the utility model and in return, can benefit from a more environmentally friendly geothermal source of heating and cooling.

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1. Introduction

Global warming has been recognized as a major threat to the future, the main cause being the dependency on fossil fuels in the transportation, power generation, and space conditioning sectors [1]. Alternative energy technologies offer potential solutions to counteract or reduce the effects of climate change, particularly with regard to reducing or eliminating sources of CO₂ emissions. Wind, biomass, solar, hydro, and geothermal energy sources are common examples of sustainable energy technologies that produce little to no greenhouse gas (GHG) emissions [2].

A sustainable approach for space conditioning of many building types is using ground source heat pump (GSHP) systems. When coupled to a common water loop through a heat exchanger, these systems can be particularly suited to provide some of all of the heating and cooling requirements of large, multi-zone commercial buildings or of multiple neighbouring buildings. To better understand the working principle of such a system, a schematic

representation of a hybrid GSHP system coupled to a common water loop through a heat exchanger is shown in Fig. 1.

As can be seen in Fig. 1, the common water loop, which is a two-pipe (supply and return) system, supplies water (which is kept between approximately 15 °C and 30 °C by the hybrid GSHP system) to multi-zone buildings or multiple buildings serving as a heat source or a heat sink for a main heat pump in each building. In turn, the main heat pump will serve a common water loop in the building which supplies water to heat pumps in all zones for providing simultaneous heating and cooling. The heat pumps in each zone are controlled by a thermostat and are in either heating or cooling mode depending on the zone temperature. If some zones require cooling, such as in the case of computer network server rooms, which typically require year-round cooling, the heat pumps for those zones will dump heat to the water loop. At the same time, if other zones require heating, the heat pumps for those zones will extract heat from the water loop. This way, heat that is removed from one zone can be indirectly added to another zone which will consequently result in reduced net energy consumption.

In some hours during the year, the heating and cooling demands of the building will balance each other and the water loop

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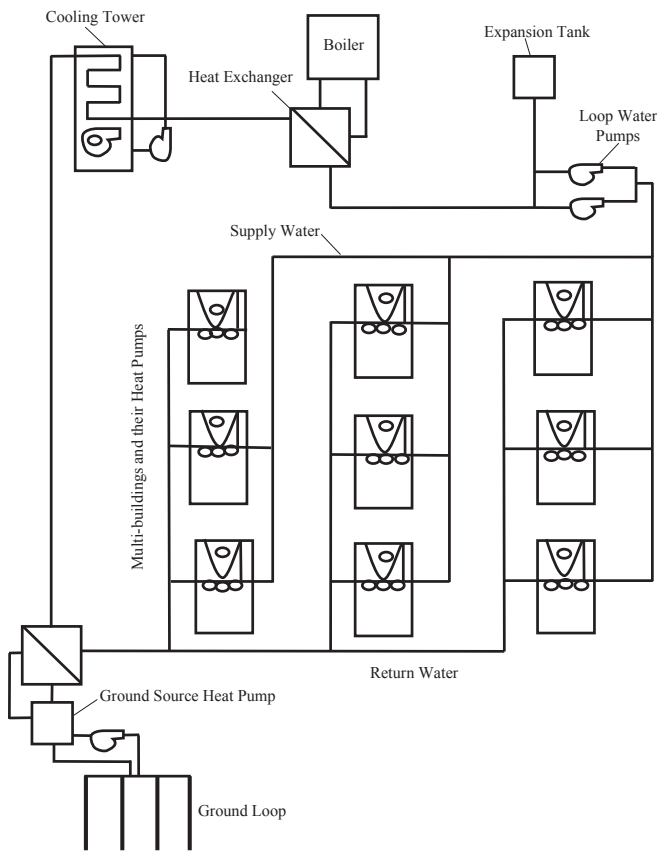


Fig. 1. A schematic representation of a hybrid GSHP system coupled to a common water loop.

temperature does not change. However, in most hours of the year, the cooling and heating demands of the building will not balance. This load imbalance will cause the water loop temperature to fluctuate. When this temperature fluctuation of the water loop occurs, either the boiler or the cooling tower (or a GSHP if present) will be kicked in to maintain the water loop temperature within certain limits.

Despite these potential benefits, longer payback periods, lesser return on investment, and higher upfront costs often make GSHP systems unappealing compared to their conventional alternatives. In a recent work, the authors of the present study addressed some proposed solutions to remove the economic obstacles associated with installing GSHP systems in large commercial and industrial buildings; in particular, the potential of employing hybrid GSHP systems was assessed [3]. In hybrid GSHP systems, the GSHP meets base load demands while conventional systems are used to supplement supply on the hottest and coldest days of the year. Therefore, peak demand is met by a combination of systems, and GSHP installation cost is reduced while the GSHP still meets most of the total annual heating and cooling demands. As a result, hybrid systems offer a potential solution to decrease the payback periods and the risk of the investment.

There have been few studies on the design strategies of hybrid GSHP systems in the literature. Those design strategies are summarized and reviewed in Alavy et al. [3]. For example, ASHRAE [4] and Kavanaugh and Rafferty [5] presented design approaches that are only valid for cooling-dominant buildings (those that would require a longer ground loop to meet the total cooling demand than to meet the total heating demand) and lack the prediction of a

precise value for the capacity of the GSHP systems. These methods are only tested in hot or moderately warm climates, so they have a limited scope of applicability. Another design strategy is to use a rule of thumb such as that presented by the Canadian Standard Association [6], which suggests that for a residential building, hybrid systems should be designed in such a way that the GSHP meets 70% of the building's peak heating or cooling demand, whichever is greater, and leaves 30% of the building's peak demand to be met by auxiliary systems. A recent study by Ni et al. [7] presented a brute force approach to find the optimal design ratio for a GSHP with a gas boiler as the auxiliary heat source for a heating-dominant building. For detailed information on the available design strategies in the literature, the reader is referred to [3].

Recently, in Alavy et al. [3] the authors introduced a rigorous mathematical, computational approach to size hybrid GSHP systems. In that study, it was assumed that in cases where a building required simultaneous heating and cooling, the GSHP would only meet the net demand. In Alavy et al. [3] a rigorous computer program was presented that determined the optimum extent to which a GSHP as part of a hybrid system should be sized to meet building loads. The methodology presented in Alavy et al. [3] has significant advantages over previous works in this field. One of the main advantages is that this methodology can be applied to either heating dominant (those that would require a longer ground loop to meet the total heating demand than to meet the total cooling demand) or cooling dominant buildings whereas previous works were only applicable to cooling dominant buildings. The other advantage of the methodology is that it provides a method for designing hybrid GSHP systems for commercial and industrial buildings for which there was no rule of thumb or rigorous methodology on which to base designs. The methodology in Ref. [3] was tested for ten buildings from residential to commercial and industrial buildings with the target of minimizing the NPV of total costs, including installation and operating costs of both the GSHP and the conventional system. The ten datasets were for actual installations performed in Canada between 2005 and 2012. The data included the actual building heating and cooling demands that were used to size the GSHPs. For each building, the methodology determined an optimal GSHP capacity, as a portion of peak demand, defined as α for cooling dominant buildings and β for heating dominant buildings. Note that, by "cooling dominant", it is meant that the ground loop length that is required to meet the cooling loads of the building is longer than that required to meet the heating building loads and *vice versa*. The algorithm predictions were compared to the non-hybridized cases, which were actually installed. Among the ten buildings studied, the optimum α or β varied between 0.25 and 0.66. The results indicated that the rule of thumb presented by Canadian Standard Association [6] of 0.7 for residential buildings may be far from optimum, and showed that for commercial and industrial buildings, hybrid system optimization should be performed as well. Average savings associated with using that rigorous methodology were significant, varying between \$2 per m² and \$78 per m².

The present study represents a major advancement upon the previous work by Alavy et al. [3], in which the potential and viability of combining multiple buildings onto a common water loop, connected to a hybrid GSHP system is explored. In addition, a much larger statistical sample of 100 possible commercial or industrial buildings is considered in the present study, of which two or more buildings can be combined for the purposes of feasibility analysis.

One potential application of GSHP systems is to use a common water loop among multiple buildings with numerous heat pumps in the so-called "utility model", in which a utility may install a large hybrid GSHP system and then sell energy or lease facilities to

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