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CYCLICAL OPERATION OF HORIZONTAL GROUND-SOURCE HEAT EXCHANGER IN A DUAL-SOURCE HEAT PUMP SYSTEM

Summary

In this paper, a novel small-scale ground-source heat exchanger is designed for usage in a dual-source heat pump system, opening the market of urban areas for horizontal ground-source collectors. The ground-source heat exchanger is used cyclically: Heat extraction, when operating as a heat source for the heat pump, alternates with heat injection, when the heat pump uses it as a secondary heat sink. A dedicated refrigerant cycle interconnection enables this operation mode. This cyclical operation impacts thermal behavior of the ground-source heat exchanger. Temperature changes of the small ground-source heat exchanger and ice layers impact the heat transfer rate in a short period; repeated ice layer formation and defrosting can impact the connectivity of the heat exchanger to the soil, thus impacting long-term thermal behavior. An experimental setup is introduced and investigated in this work, focusing on the cyclical behavior of a ground-source collector with very densely packed collectors as a high-power, low-energy ground source heat exchanger.

Keywords: dual-source heat pump, small-scale ground-source heat exchanger, cyclical operation, thermal response tests, experimental analysis

Field of application for the findings: decentral heat pumps in urban areas – optimizing the potential of ground-coupled systems

Addressed audience: researchers, planners

1. Introduction

Heat pumps are advancing as decentral and holistic heating – and cooling – systems in households. However, densely populated urban areas – like terraced buildings – still pose several difficulties with practical implementation: Air-source heat pumps have increased noise emissions often limited in urban areas; Ground-source heat pumps are often requiring specific geological conditions for their heat source, e.g. large space requirements for horizontal collectors.

One proposed solution are dual-source heat pumps (DSHPs; (Cao et al., 2023)). These can combine air-source heat exchangers (ASHXs) and ground-source heat exchangers (GSHXs), thus reducing the dimensions required for GSHX. For horizontal GSHXs, space required is crucial especially in densely built urban areas. Active regeneration, usually integrated when using GSHXs with solar thermal collectors, can further reduce the size of horizontal GSHXs. Refrigerant cycle-based active regeneration can increase flexibility, but requires a novel refrigerant cycle interconnection (Reum et al., 2026).

In this work, a novel operation concept for a small horizontal GSHX is introduced. This can introduce small GSHX in urban areas (e.g. terraced buildings) to improve space requirements while also increasing efficiency and reducing noise emissions compared to air-source heat pumps. This can open the market of densely populated urban areas to decentral heat pumps, currently still dominated by fossil fuel heat generation. The aim of the experimental investigation in this work is to use the benefits of DSHPs of serial heat extraction of a GSHX as well as introducing active heat pump-based regeneration to the GSHX even at relatively low ambient temperatures For this purpose, the GSHX is cyclically operated in heat extraction and heat rejection modes. As horizontal GSHXs can also experience freezing, ice formation and melting is a major impact factor on the performance, both short-term due to changing heat transfer coefficients as well as long-term due to changes in the soil connection of the GSHX surfaces.

For this purpose, a small-scale experimental setup is investigated under cyclical operation, thus evaluating the impact of ice-formation on its heat transfer, and deriving suggestions for filling materials around the GSHX and later control strategies of actual DSHP.

2. Methodology

2.1. System description

The operation strategy of the DSHP decides between heating operation with the ASHX, the GSHX or active regeneration, which is heating operation with ASHX and subcooling the refrigerant in the GSHX. This is made possible with a dedicated heat pump interconnection. It activates heating with the ASHX at relatively high ambient temperatures to GSHX temperature and relatively high GSHX temperatures (air-source operation: ASO), heating with the GSHX at relatively low ambient temperatures and high GSHX temperatures (ground-source operation: GSO), and active regeneration (AR) when ambient temperature is relatively high and a depleted GSHX. Concrete values for the control strategy as well as AR operation in the DSHP are yet to be determined in future studies. Fig. 1 shows an example strategy.

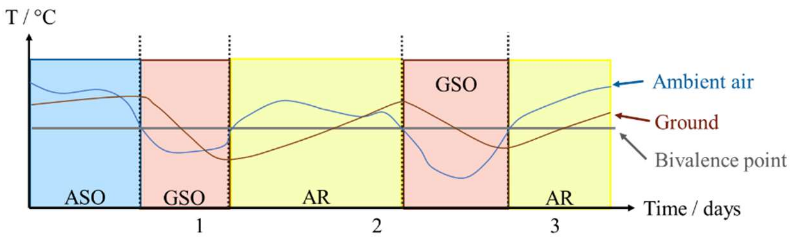

Fig. 1: Exemplary operation strategy of the DSHP. Changing ambient and ground temperatures are indicated, including a bivalence point for the change between ASHX, GSHX and AR operation.

This leads to cyclical operation of the GSHX, extracting heat during GSO and injecting heat during AR. This operation effectively reduces the net energy extracted during the heating period; On the other hand, the GSHX power needs to be high enough to cover GSO at high heating loads when ambient temperature is low. This means, a horizontal GSHX might be required to activate less ground volume but still need high surface area to the ground for high heating powers.

2.2. Collector measurement series

An experimental GSHX setup is constructed and tested in a laboratory environment. The testbench and the DSHP are described in (Reum et al., 2025). The testbench and DSHP setup can extract and inject heat serially to emulate GSO and AR. The laboratory GSHX setup needs to emulate the real thermal response of the novel GSHX, but at a smaller scale. Different volume flows and potentially fillings need to be appliable.

For the experimental investigation, the GSHX setup is cyclically operated: For some time, heat is extracted, followed by a heat injection period. Volume flows are controlled as well as temperature return flow to the heat pump. The heating power across the GSHX setup can be measured by the volume flow and temperature sensors at inlet and outlet, thus allowing measurement of thermal response tests in laboratory scale. Appropriate temperature levels and brine volume flows are emulated with the testbench and still need to be defined. The detailed measurement plan including temperature and volume flow profiles, durations, and which and how many collectors are used as well as the box filling (grout: sand, wet sand, etc.) is still under evaluation.

Additionally, repeated growth and shrinking of ice layers can impact the connectivity of the soil to the GSHX collector, thus impacting the long-term operation of the collector. For this, the same cycle of heat extraction and injection is repeated as the first test and the very last test and compared to each other.

3. Preliminary results

An experimental small-scale GSHX setup has been developed and constructed. Prefabricated, brine-filled PVC collectors are used, vertically placed in a box with dimensions of 1200 mm x 1000 mm x 800 mm (L x W x H). These are supposed to yield high power at small ground surface area due to increased surface area of the collectors. Four collectors are placed next to each other with distances of about 200 mm, but individual collectors can be closed to the brine flow. Fig. 2 shows a photograph of the experimental GSHX box in the laboratory. Box filling is not included yet.

Fig. 2: Photo of the experimental GSHX box in the laboratory environment.

The results revolve around investigating the heating power development over time in thermal response tests. Varying heating power over the cyclical heat extraction and injection periods shows changing heat transfer to the brine through the collectors. This is impacted by the box filling as well as the state of charge: ice formation of wet soil impacts the heat transfer coefficients. Additionally, the ice layer development during both heat extraction and injection is observed to allow conclusions about heat conductance in the different fillings, including longterm changes to the connectivity of the GSHX collectors to the filling.

4. Outlook

The measurement plan needs to be fixed to define the cyclical operation strategy. The test bench must be updated to enable appropriate temperature series, if necessary. Then, the respective measurement series is conducted as positive and negative thermal response tests and the evaluation for the results as described above is conducted.

The information on the heating power behavior in heat extraction and injection and the ice development will enable a more realistic design suggestion for the application of such a small GSHX collector for a DSHP. First, a simulation environment is investigated to develop an appropriate heat source management. Later, the whole system with the three individual components – GSHX collector, DSHP and heat source management – is installed in a real building. The work in this paper lays one foundation for the appropriate design of this system and therefore the research project.

References

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