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# An overview of the problems and solutions of soil thermal imbalance of ground-coupled heat pumps in cold regions

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## HIGHLIGHTS

- Problems and solutions of thermal imbalance of GCHP in cold regions are reviewed.
- GHE-modified solutions are concluded to deal with slight imbalance.
- System-modified solutions are summarized to solve serious imbalance.
- Operation-modified solutions can further improve the energy saving rate.
- Conclusions/suggestions are provided for better GCHP applications in cold regions.

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## ABSTRACT

Ground-coupled heat pumps are widely applied in cold regions, but soil thermal imbalances in some projects greatly deteriorate the systems' practical performances and heavily inhibit the systems' reasonable applications. This paper presents a comprehensive overview of the main problems caused by soil thermal imbalance and the existing solutions targeting on them. The caused problems mainly present in the following aspects: soil temperature decrease, heating performance deterioration, heating reliability decline, and even system failure. Three kinds of existing solutions can be classified. Ground heat exchanger-modified solutions including increasing borehole space, increasing borehole length, modifying borehole layout, and improving thermal properties, can retard the thermal imbalance to some extent, suitable to projects with slight imbalance. System-modified solutions integrating auxiliary energy sources like fossil fuel, solar energy, ambient air and waste heat with ground-coupled heat pumps or using ground-coupled absorption heat pumps, can eliminate serious thermal imbalance essentially by increasing soil thermal injection and decreasing the extraction. Thus, they are dominant in the applications and attract more attention along with the utilization of renewable energies. Apart from the modifications of system design, operation-modified solutions, like seasonal and intermittent operations, are also helpful to maintain better soil thermal balance. Based on the overview, the current application situations and economic performance of different solutions are discussed. Finally, some suggestions for the applications of ground source heat pumps in cold regions are proposed to make the overview helpful for the system research and applications.



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**Nomenclature**

| | |
|---|---|
| AHC | air-source heat compensator |
| AHC-dc | AHC for direct heat compensation |
| AHC–GCHP | hybrid GCHP system integrated with AHC |
| ASHP | air-source heat pump |
| COP | coefficient of performance |
| DHW | domestic hot water |
| GCAHP | ground-coupled absorption heat pump |
| GCAHP–GCEHP | hybrid system combining GCAHP with GCEHP |
| GCEHP | ground-coupled electrical heat pump |
| GCHP | ground-coupled heat pump |
| GHE | ground heat exchanger |
| GSHP | ground-source heat pump including ground-coupled heat pump, surface-water heat pump, ground-water heat pump |
| HCUT | heat compensation unit with thermosyphon |
| HCUT–GCHP | hybrid GCHP system integrated with HCUT |
| PEE | primary energy efficiency |
| Rc_AHP | ratio of cooling load supplied by GCAHP |
| Rh_AHP | ratio of heating load supplied by GCAHP |
| SGCHPS | hybrid GCHP system integrated with solar collector |
| TIR | thermal imbalance ratio |



## 1. Introduction

With the improvement of people's living standards, global energy consumption is increasing rapidly, among which the proportion of building energy consumption is also growing apace [1]. Taking China as an example, the building energy consumption accounts for 19% of the total social energy consumption [2]. Traditional heating systems mainly based on fossil fuel burning cause a waste of high-grade energy, consume a large amount of energy and emit massive amounts of pollutants [3,4].

Since the energy crisis of the twentieth century, heat pump technology has become more and more popular all over the world [5–11]. The use of air-source heat pump [12–14], water-source heat pump [15–17] and ground-source heat pump (GSHP) [18–21] is increasing very quickly. Among these technologies, owing to the steady temperature of soil during a whole year, the GSHP yields high heating and cooling coefficients of performance (COPs) [22–28] compared with air-source and surface water-source heat pumps. The capacity and number of GSHPs used in leading countries are shown in Table 1 [29]. GSHP was first introduced into China in the 1980s. Since then, the total application area of GSHP has increased year by year as shown in Fig. 1(a) [30–32], and with a growth rate over 30% since 2004. The regions of GCHP applied in China are presented in Fig. 1(b) [30,31], among which the cold regions (North China, Northeast China and Northwest China) account for 42%. Here, the cold regions are where most buildings are heating dominant.

**Table 1**
GSHP application in some leading countries [29].

| Country | MWt | GW h/year | Number installed |
|---|---|---|---|
| USA | 6300 | 6300 | 600,000 |
| Sweden | 2300 | 9200 | 230,000 |
| Germany | 640 | 930 | 46,400 |
| Switzerland | 525 | 780 | 30,000 |
| Canada | 435 | 600 | 36,000 |

The ground-coupled heat pump (GCHP), a kind of GSHP, exchanges heat with the soil through pipes inside the borehole and has the best applicability among different GSHPs. It is widely applied in the USA, central Europe and northern Europe for space heating [33,34]. Recently, the application of GCHP has also increased in China, especially in large commercial buildings and residential areas. However, in cold regions, the practical heating effects of GCHPs in some projects are not satisfactory [35]. It has been found that the heating COP of GCHP decreases, indoor air temperature drops below the setting value and the system cannot run normally after a few years of operation. The main reason is the soil thermal imbalance.

Because of the low thermal conductivity of soil, the natural heat dissipation at the boundary of the soil heat retainer around the