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Study of technical, economical and environmental viability of ground source heat pump system for Himalayan cities of India

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ABSTRACT

In recent years applications of ground source heat pump (GSHP) systems are well utilized for space heating and cooling applications in many countries and India also can benefit from the same. This study estimates the possible energy saving and reduction in CO_2 emission by the use of GSHP technology for space heating and cooling applications in cities located in and around the Himalayan region. For the purpose of analysis a building with 120 m^2 with a medium level of insulation has been considered. Currently, the buildings located in these cities meet their heating and cooling demands by conventional techniques. A detailed study has been carried out to estimate the investment cost, payback period, technical feasibility, greenhouse saving and risk associated with the implementation of GSHP technology using RETScreen tool. The analysis shows that if GSHPs were used in the above cities, they can be ordered based on lower to higher payback period as Darjeeling, Tawang, Shimla, Dehradun, Srinagar, Nangal, Shillong, Chandigarh, Saharanpur and Delhi. The minimum length of ground heat exchanger to supply the required heating and cooling is found to be 140 m for heavy rock ground formation and it is affected by different types of ground formations. In any place if the ground formation is a heavy rock, then the length required to meet the building demand is drastically reduced. If the ground formation is a light soil with no moisture, then the length of the heat exchanger is increased multifold. Whenever the knowledge of ground formation is not known thermal response test has to be performed. Countries like India can offer incentives and tax benefits to promote GSHP technologies in order to achieve significant saving in electricity and reduction in CO_2 emission.

Contents

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Nomenclature

GSHP	ground source heat pump
GHX	ground heat exchanger
DHW	domestic hot water
ASHP	air source heat pump
HDD	heating degree days
CDD	cooling degree days
BHX	borehole heat exchanger
COP	coefficient of performance
T&D	transmission and distribution
UTES	underground thermal energy storage
CFD	computational fluid dynamics
kw	kilo Watt
kwh	kilo Watt hour
EER	energy efficient ratio
gw	giga Watt
mwh	mega Watt hour
INR	Indian rupee
PV	photovoltaics
GHG	greenhouse gas
mw	mega Watt
TRT	thermal response test
AC	air conditioner

1. Introduction

In the present energy scenario, one third of India's energy consumption is being used for space heating and cooling applications [1]. At present this demand is fulfilled by fossil fuels and contributions from renewable energies are limited, but the future is dependent on sustainable energy technologies. Much of commercial and individual buildings use electricity to produce heating and cooling, which is an inefficient process from thermodynamic point of view. Instead, this heating and cooling can be supplied more efficiently by some other methods, which will consume less electricity and thereby contribute to reduction in CO_2 emission as well. In this direction, one of the promising technologies that can be used for space heating and cooling processes is ground source heat pump (GSHP) technology. The basic principle of GSHP technology is to make use of the temperature of the earth at a relatively lower depth, which is almost constant and lower than the ambient temperature during the summer and higher than the atmospheric temperature during winter. A GSHP system will extract/discharge thermal energy at this constant earth temperature for all of its applications [2–14]. Fig. 1 shows the schematic diagram of the GSHP system for space heating and cooling. A GSHP system for space heating and cooling consists of three subsystems: ground loop system, heat pump system, and heat distribution system [15]. The ground loop used for GSHP applications can be either open loop or closed loop. In an open loop system generally water bodies are used as a source for heating. In a closed loop system a ground heat exchanger (GHX) is used as a linking medium between the ground and heat pump. A GHX can be either a horizontal or a vertical loop system. A refrigerant loop in the heat pump system absorbs thermal energy from the ground loop converts the liquid refrigerant to vapor using the ground heat. Finally, the heat absorbed from the ground is transferred to room by means of a refrigerant-to-air heat exchanger. This technology is well developed in European countries, USA and Canada for space heating applications. As per a recent study [16], 15.4 GW of GSHP systems has been installed all around the world. The majority of these systems are installed in North America (USA, Canada) and in Europe [17]. In Asia [18–20], China is the leading country in implementing the GSHP technology with the capacity to meet 20 million square meters of building area [21–26]. However in India GSHP technology is in its preliminary stage and researchers are started examining GSHP on pilot basis [27–29] and in this paper an attempt is made to give some overview about how this GSHP technology can be adopted to Indian climatic conditions and what are all benefits this can offer to Indian cities are discussed.

1.1. Applications of GSHP in India's context

Climatic conditions of India vary from region to region. Some parts of the country only require cooling and some parts require only heating and most of the regions require both heating and cooling; in order to understand the suitability of GSHP to different climatic conditions of India some of the applications of GSHP are reviewed. Applications of GSHP can vary from space heating to hot water supply and it has been evaluated by different researchers in different countries [30–45] from different aspects. Ozyurt and Ekinci [46] studied the performance of a GSHP system for space heating application in Turkey. During the experimental trial runs GSHP was able to fulfill the required heating demand and they suggested that for GSHP system floor heating is better than radiant heating. Yu et al. [47] conducted year round experimental study on GSHP system in China to evaluate the performance of GSHP system for both heating and cooling applications and their results show that the GSHP system was able to meet the required building archives design code of China and in China itself another researcher [48] attempted to study the performance of GSHP system in only cooling mode operation and they found that after one year of operation soil temperature increased by 0.5 °C and they recommended to use multiple BHX with minimum distance between the heat exchangers as 4–5 in order to avoid heat accumulation in the ground. In Korea, Kim et al. [49] studied the heating performance of a GSHP system installed in a school building. It was found that in partial load operation the COP of heat pump in heating mode varied from 4.3 to 8.3 and Aikins et al. [50] suggested some methods to improve the use of GSHP system in Korean market. Naili et al. [51] studied the possible uses of GSHP system for Tunisian climatic conditions and their results show that the heat exchange rate increases with increase in GHX length. In Poland, Maryanczyk et al. [52] used GSHP system for space heating a building. The GSHP system was able to meet on an average of 15% of building heating load. Esen et al. [53] carried out experimental study on a GSHP system coupled with horizontal GHX for space heating applications in Turkey and also they created a numerical model to