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Utilization of Ground Water Directly for Space Heating Application Using Heat Pump: Demonstration and Case Study from Dehradun, India

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ABSTRACT

A case study is presented regarding utilization of ground water directly for space heating using a heat pump. A ground source heat pump was installed in Dehradun, Northern region of India to demonstrate the technical and economic feasibility of the method of utilizing direct water for space heating. The setup utilizes heat potential of the ground water obtained from a wellbore to deliver design heat output of 12 kW to the room. The exit water from the heat pump system is delivered back for normal utilization purposes. Performance analysis of the installed heating system was done in the present work. Result shows technical and economic feasibility of the method to be replicable on a larger scale in areas with existing tube wells which are used for extracting ground water for various other applications.

1. INTRODUCTION

With growing worldwide energy consumption, application of fossil fuel for fulfilling the energy demand is posing a threat to the environment due to increased CO_2 emission. A major contribution to the energy consumption in the developed nations is that of heating and cooling. More than 40% of the energy delivered to the residential buildings is used for space heating and cooling in Western countries (Sivasakthivel et al., 2012). The energy demand in developing countries like India is also growing at a faster rate. The total installed capacity in India for electric power generation is 186.65 GW with 65% of contribution from fossil fuel, mainly coal. The energy consumption of the country for space heating and cooling is one third of the total energy consumption. The energy demand for space heating and cooling is increasing every year with increased population and more access to the electricity. Studies have shown energy saving as the most cost effective method to reduce greenhouse gas emission (Bayer et al., 2012). Application of efficient methods for heating and cooling, which contributes to a major portion of energy consumption, can therefore help reduce CO_2 emission. Studies have been done by various authors with regard to application of direct heating technologies for space heating and the amount of CO_2 savings. Blaga et al. (2010) studied the environmental and economic benefits of shallow district geothermal heating system. Jenkins et al. (2009) examined the potential CO_2 savings of closed horizontal-loop ground source heat pump systems in the UK. Results shows application of ground source heating system as an effective method of reducing CO_2 emissions.

For a country like India with a very large area, the energy requirement for heating or cooling vary with the geography of the region. Figure 1 show the climate zones in the different regions of India (Sanaye and Niroomand, 2011). As shown in the figure, majority of the region experiences hot dry or humid climate with some areas in the north and eastern region of the country experiencing a cold climate. In cities with cold and moderate climate, the space heating is done using electric energy. The contribution to CO_2 emission is less if the source of energy is renewable, such as hydro energy. The majority of electric energy production in the country is however, done using coal, which adds to greenhouse gas emission. Moreover, utilization of direct electric energy for space heating is an inefficient way of energy consumption (Oktay and Dincer, 2009). The space heating application involves conversion of a high grade form of energy (electric energy) into a low grade form of energy (thermal energy). Though the conversion process is almost 100% efficient, a reverse process, which is usually required for generating electricity from a heat source such as fossil fuel is very less efficient as governed by the second law of thermodynamics.

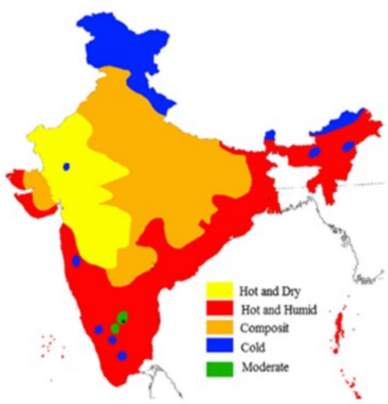

Figure 1: Climate zones of India (Sanaye and Niroomand, 2011).

An efficient way of space heating can be achieved using the application of heat pump. The system works on the principle of heat engine, such that the total amount of heat delivered by the system is equal to the sum of heat extracted from the surroundings and the work input to run the system. Based on the type of the surrounding from which the heat is extracted, heat pumps are classified into two types: Air Source Heat Pump (ASHP) and Ground Source Heat Pump (GSHP). A review on the technologies regarding heat pump can be found in the literature (Sarbu and Sebarchievici, 2014). For ASHP, the air above the ground acts as a heat source. The temperature above the ground is affected by weather conditions and therefore the surrounding air acts as a poor source of heat energy. For GSHP, the ground acts as a heat source. The ground temperature below certain depth remains almost constant throughout the year which is usually higher than that of the ambient air temperature during winter. The ground surface can therefore be assumed as an infinite source of thermal energy. The GSHPs are further classified into three categories (ASHRAE, 1995) based on the type of heat source available from the ground: (1) ground-coupled heat pump: using borehole with an indirect circulating fluid loop for heat extraction from the ground (2) ground-water heat pump: using direct water from the ground for heat energy (3) surface-water heat pump: using water from a lake or a pond.

Though the application of GSHP technology is common in developed nations, the technology is not popular in developing countries such as India. This is due to high initial cost required for the installation. It is however noted that, a major cost involved in GSHP installation is that of the boring and excavation required for ground heat exchanger loop. This involves drilling a wellbore or excavating for a long pipe loop horizontally or vertically. An effective solution to overcome this cost can be obtained by using water from the existing wellbores used for other household applications. Since the extracted water from the ground has a sufficient degree of heat due to its contact with the ground, the water can be used as a heat source before it is utilized for other purposes. In many regions of India where the water table is found at a shallow depth, it is common to install a wellbore with a submersible pump for fulfilling the water demand. An economical way of space heating can thus be achieved by allowing ground water from the wellbore to pass though the heat pump before utilizing it for other purposes. The method can reduce the price of ground source heat pump installation by almost 50%. Application of the suggested method shall involve controlled flow rate of water from the wellbore which can be achieved using an overhead tank for storage which is usually constructed for a constant head supply to household. To demonstrate this cost effective and energy efficient technique, an installation of a ground water heat pump was done in Dehradun, India as a part of Indo-Norwegian Geothermal (INDNOR) project between the Ministry of Science and Technology of India and the Norwegian Geotechnical Institute in Oslo. The present work discusses the design and performance analysis of the ground water heat pump installation.

2. DESIGN OF SPACE HEATING SYSTEM

The design of heating system involves calculation of the heat load, selection of the equipment's available in the market and the system layout design, which are discussed as follows:

2.1 Heating Load Calculations

The most important parameter in designing an energy efficient space heating system is the heat load estimation. The cost of installation and the energy consumption is proportional to the heat load requirement. The buildings in the cities with moderate cold climate are generally constructed, taking into consideration the climate during summer and locally available material. The buildings therefore usually have high heat losses. For minimizing the heat pump running and installation cost, it is therefore important to estimate the heat load requirement accurately. For the present case, the total heat load (Q_T) is given as:

$$Q_T = Q_{tr} + Q_{ac} + Q_m \tag{1}$$

where Q_{tr}, Q_{ac} and Q_m are the loads due to transmission, air changes and miscellaneous factors given as follows:

- Transmission heat load:

$$Q_{tr} = UA\left(T_{design} - T_{amb}\right) \tag{2}$$

where A is the area of surface, T_{design} is the design room temperature, T_{amb} is the ambient temperature and U is the overall heat transfer coefficient given as:

$$\frac{1}{U} = \frac{1}{h_{int}} + \frac{x}{\lambda_{surf}} + \frac{1}{h_{ext}} \tag{3}$$

where λ_{surf} is the thermal conductivity of the surface, x is the wall thickness, h_{int} is the heat transfer coefficient inside wall, assumed constant equal to 3 W/m^{2}K and h_{ext} is the convective heat coefficient outside the wall calculated as:

windward side:

$$h_{ext} = 8.07 \times V_w^{0.605} \tag{4}$$

leeward side:

$$h_{ext} = 18.64 \times (0.3+0.05V_w)^{0.605} \tag{5}$$

where V_w is the wind velocity

- Air Changes:

The heat gain from air change (Q_{ac}) is calculated as:

$$Q_{ac} = \frac{AC \times volume \times \rho \times c_p \times (T_{design} - T_{amb})}{24 \times 3600} \tag{6}$$

where AC is the air changes per hour, ρ and c_p are the density and specific heat capacity of air respectively

- Miscellaneous heat load:

The miscellaneous heat gain (Q_m) occurs due to the occupants inside the building and electric instruments as is given as:

$$Q_m = heat\ emitted\ by\ each\ element\ \times number\ of\ elements \tag{7}$$

The heat load does not take into account the effect of solar radiation considering the location of the space to be heated on the ground floor and window sides facing the north direction. For heat load calculation, the inside design temperature is assumed 23 ℃ and the minimum outside temperature is assumed 1 ℃ based on the past 5 years temperature data (Singh et al., 2013).

2.2 Equipment selection and layout

The selection of the heat pump unit is made based on the peak load requirement calculated at the design condition. The heat pump selected is having a heating capacity of 12 kW with refrigerant R407C. Figure 2 shows the performance characteristics of the installed heat pump in terms of Coefficient of Performance (COP) for different values of condenser and evaporator temperature. The installations allows fixing the condenser temperature based upon the climate conditions. The value is to be kept high for low outdoor temperature. The evaporator temperature depends on the temperature of the ground water which is used as a heat source.

Due to the chances of scaling occurring because of the presence of minerals in the water, it is evident to use an additional fluid flow loop using a heat exchanger so as to prevent direct contact of the ground water with the heat pump. A braze plate type heat exchanger is therefore selected for the purpose. The size of the heat exchanger and ground water flow rate requirement is calculated based on the heat load requirement, standard Coefficient of Performance (COP) of the heat pump unit and the pinch point temperature to be achieved in the heat exchanger.

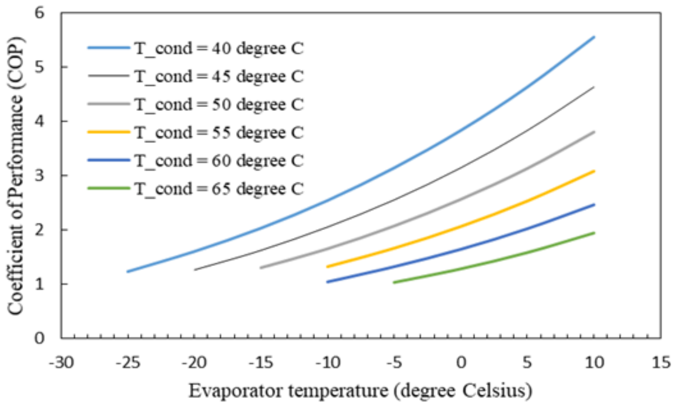

Figure 2: Coefficient of performance of the selected heat pump for different evaporator and condenser temperature.

Figure 3 shows the layout of the ground water heating system. Ground water from the wellbore is made to pass through the heat exchanger to deliver its heat energy to the brine loop. The ground water from the heat exchanger is then lifted to the overhead tank for its household application. The heat energy from the brine loop is delivered to the heat pump unit. Heat transfer from the heat pump to the room is done using a secondary brine loop and convective blowers. Heat flow control from the convective blowers to the room is done using a thermostat controlled fans. The heat pump operation is controlled using a thermostat for the compressor guiding the condenser temperature. An accumulator is installed in the secondary brine loop for thermal energy storage, thus acting as a buffer for the compressor operation and heat load.

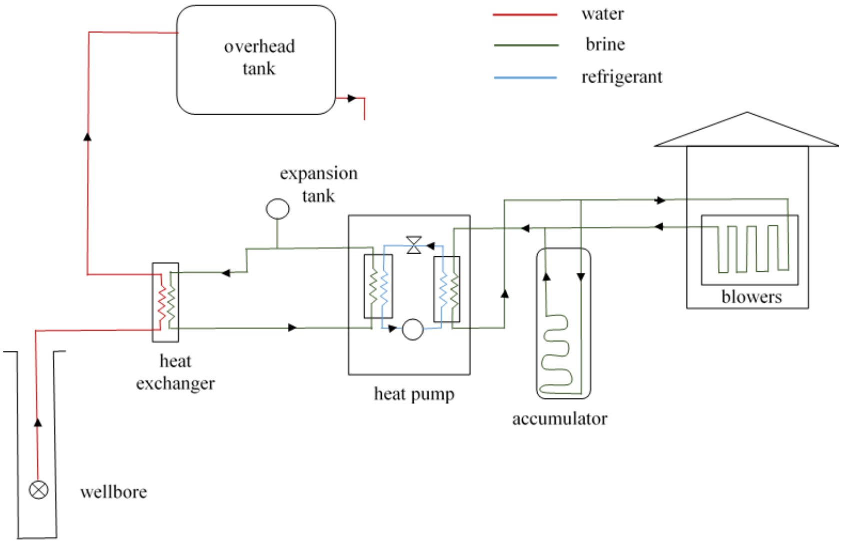

Figure 3: Layout of the ground water heat pump system.

2.3 Performance estimation

In order to estimate the annual heat load requirement and the cost involved, simple methods which can give accurate results are required. One such method is the heating degree day method (HDD). The method is based on the average day temperature. The HDD is calculated based on the difference in the average outdoor temperature (T_{av}) for the day and the base temperature (T_b). The base temperature is the outdoor temperature below which heating is required and is assumed to be 18℃ in the present study. The number of heating degree days (*HDD*) for one year is calculated as:

$$HDD = \sum_{year}(T_b - T_{av})^+ \quad (8)$$

where only positive value are considered.

The total annual heat load (Q_{year}) in kWh is then given as:

$$Q_{year} = 24 \times K_l \times HDD \quad (9)$$

where K_l is the heat loss characteristic of the building given as:

$$K_l = \frac{Q_T}{T_{design} - T_{amb}} \quad (10)$$

The electric energy required annualy to run the heat pump is calculated based on the COP of the heat pump, using the following relation:

$$COP = \frac{Q_{year}}{E_{year}} \quad (11)$$

where E_{year} is the annual electric energy in kWh required to run the compressor of the heat pump.

The total saving on replacing the electric heating system by the ground water heat pump is given as:

$$energy\ saving = Q_{year} - E_{year} \quad (12)$$

$$cost\ saving = 5 \times (Q_{year} - E_{year}) \quad (13)$$

3. RESULTS

Heat load calculations for the design conditions were done as shown in Table 1. The space heating facility is provided for two separate rooms: living room and the dining hall. The indoor design temperature was assumed to be 23°C and the minimum outdoor ambient temperature was assumed 1°C.

Table 1: Heat load for the selected space.

Room	transmission (kW)	air change (kW)	miscellaneous (kW)	total load (kW)
living room	5.8	0.1	-1.0	4.9
dining hall	9.1	0.2	-2.0	7.3
heat load	15.0	0.3	-3.0	12.3

Figure 4 shows the annual outdoor air temperature and the heating degree days for Dehradun region. The reference temperature for heating degree days was assumed to be 18 ℃. The chart for the heating degree days shows space heating as a necessary requirement for at least four months in a year. The total number of heating degree days in a year for Dehradun region is 699.

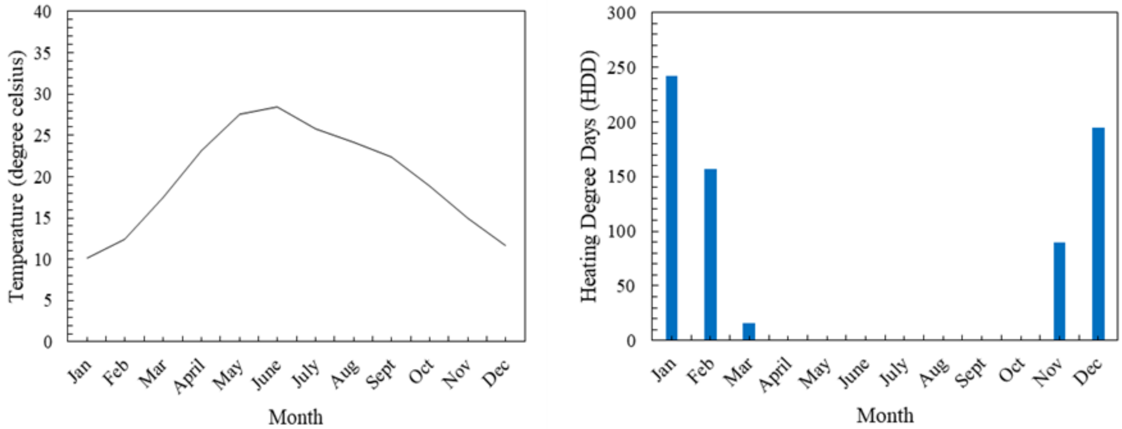

Figure 4: Annual outdoor air temperature and the heating degree days for Dehradun region.

For estimating the total savings made using the application of ground water source heat pump, calculations were made for the amount of energy and cost savings in comparison to what used for heating directly using electric heating system. Ground water heat pump machinery requires setting a value for the condenser temperature. For a moderate cold climate in Dehradun, a nominal value of 45 ℃ is selected. Based on the set value of condenser temperature, value of COP of machinery can be obtained from the heat pump characteristics shown in Figure 3 for different values of evaporator temperature. The evaporator temperature depends upon the ground water temperature. The evaporator temperature can therefore be estimated from the ground water inlet temperature by assuming a temperature difference of 7 ℃ occurring due to pinch point difference of 5 ℃ in the evaporator heat exchanger of the heat pump with two phase flow and 2 ℃ pinch point difference in the plate heat exchanger of the brine loop with a single phase flow. Study shows a minimum ground water temperature of 14 ℃ in the Dehradun urban region (Yasir and Srivastava, 2016). The savings are calculated for three different nearby values of the ground water temperature. Table 2 shows the electricity and cost saving achieved for different values of ground water inlet temperature. Increase in electricity and cost savings is obtained with increase in ground water inlet temperature. The total annual cost for heating completely using electric heating system is 47205 Indian Rupees (INR). The savings are calculated based on the electric heating cost as a reference value.

Table 2: Electricity and cost savings for different heat source temperature.

source temperature (degree C)	COP	electricity load (kWh)	energy saving (kWh)	cost saving (INR)
12	3.84	2450	6960	34801
14	4.15	2267	7143	35716
17	4.68	2028	7382	36913

4. CONCLUSION

Performance analysis of the ground water heat pump installation in Dehradun, India has been carried out in this paper. Results for the heat load calculation and the heating degree days shows heating as a necessary requirement for at least 4 months in a year. The installation is found to have high efficiency due to reasonably high degree of ground water inlet temperature. A reasonable value of saving in terms of energy and cost is obtained utilizing the ground water heat pump. Though the initial cost of installation of the heat pump is high, utilizing ground water from the existing wellbores minimizes the initial cost of installation. The amount of cost benefit due to energy saving using the application of heat pump shows a reasonable payback over a relatively a long time scale. The heat pump installation under study was mainly focused on demonstration of ground water for heating application in the region and was performed on a household scale. Application of the proposed method for large scale heating by utilizing total water pumped for everyday use from a single wellbore can proportionally increase the payback without any additional cost for drilling.

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REFERENCES

ASHRAE.: Commercial/institutional ground-source geat pump engineering manual, American society of heating, Refrigeration and Air-conditioning Engineers, Atlanta, (1995).

Bayer, P., Saner, D., Bolay, S., Rybach, L., and Blum., P.: Greenhouse gas emission savings of ground source heat pump systems in Europe: A review, Renewable and Sustainable Energy Reviews, 16, (2012), 1256-1267.

Blaga, A.C., Rosca, M., and Karytsas, K.: Heat from very low enthalpy geothermal source versus solid fuels in the Felix-Sanmartin area, Romania, In Proc: World Geothermal Congress, Bali, Indonesia, (2010).

Jenkins, D.P., Tucker, R., and Rawlings, R.: Modeling the carbon-saving performance domestic ground source heat pumps, Energy and Buildings, 41, (2009), 587-596.

Oktay, Z. and Dincer, I.: Exergoeconomic analysis of the Gonen geothermal district heating system for buildings, Energy and Buildings, 41, (2009), 154–163.

Sanaye, S., and Niroomand, B.: Vertical ground coupled steam ejector heat pump,: thermal-economic modeling and optimization, International Journal of Refrigeration, 34, (2011), 1562-1576.

Sarbu, I., and Sebarchievici, C.: General review of ground-source heat pump systems for heating and cooling of buildings, Energy and Buildings 70, (2014), 441-454.

Singh, O., Arya, P., and Chaudhary, B.S.: On rising temperature trends at Dehradun in Doon valley of Uttarakhand, India. Journal of Earth System Science, 122, (2013), 613-622.

Sivasakthivel, T., Murugesan, and Sahoo, P.K.: Potential reduction in Co2 emission and saving in electricity by ground source heat pump system for space heating applications- A study on northern part of India, Proceedia engineering, 38, (2012), 970-979.

Yasir, and Srivastava, S.: Monitoring of ground water quality in the province of district Dehradun, Uttarakhand, India. Archives of Agriculture and Environmental Science, 1(1), (2016), 43-48.