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Designing Geothermal Air Conditioning System for a Commercial Application

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Abstract: The main objective is to design an energy efficient or energy conservative air conditioning system for a commercial application, by enabling the use of renewable energy that exists in nature in abundance. Hence, an air conditioning system that partially runs on the principle of geothermal heat exchange i.e. geothermal energy is designed for a commercial building meant to be used for a shopping mall. A hybrid geothermal air conditioning system that mainly uses an array of ground heat exchanging loops and an auxiliary air cooled chiller system along with the necessary pumping and air distribution system is selected for fulfilling the requirements. This type of air conditioning system has a wider scope over a variety of air conditioning applications due to the numerous advantages such as high energy efficiency, low operating costs compared to conventional system, high flexibility, environmental friendly, etc.
Keywords: Geothermal, Ground Loop, Air conditioning, Heat exchange, Heat pump

I. INTRODUCTION

The geothermal air conditioning is mainly based on the uniform temperature that exists under the earth's surface throughout which can be used for heating or cooling the air to be supplied to the space being conditioned. The rate of heat transfer generally depends on the temperature difference between that of the ambient air and the ground or earth's temperature. Generally, the value of this temperature difference varies in the range of 10and 25 degrees in case of summer season. A geothermal system is also referred as an earth-coupled or ground source system as it works on the principle of using earth's surface or ground as a heat sink for heat rejection during cooling process and a heat source for deriving thermal energy during heating process. However, a geothermal air conditioning system also includes the usual components of standard indoor climatic control system meant for humidity control, zoning, air quality control, maintaining desired air changes, etc.

II. GEOTHERMAL SYSTEM

A Geothermal air-conditioning system comprises of three main components or elements. They are the earth-coupled section that comprises of the circulation loops, the load section to which conditioned air is to be supplied (the space or building where heating or cooling is to be done) and an auxiliary system that provides the additional energy required for obtaining desired level of heating or cooling, such as a heat pump or any other conventional air conditioning system.

The earth-coupled section is basically a portion of earth's surface within which a series of pipes in the form of a loop is installed for circulating the heat exchanging medium through the ground. The heat exchanging medium such as water is pumped through this loop where it conducts the heat from or to the ground while flowing through this loop. The pipe loop is generally made up of metal or plastic material. This underground loop is connected to auxiliary system or air handling unit.

The load section is the significant portion for any air conditioning system. It represents the heating or cooling load requirements needed to be fulfilled by the air conditioning system.

A. Closed Loop Geothermal System

The closed loop geothermal system is one which uses a closed continuous underground loop installed in series or parallel arrangement. It is widely applicable in areas where large amount of underground water is not available, however, this system can also be integrated with the nearby natural water bodies such as lakes or ponds for more effective heat transfer. There are two configurations available for this type of system i.e. a horizontal closed loop system and a vertical closed loop system.

A vertical closed loop system is suitable where less ground area is available and it comprises of a loop that is installed vertically within a drilled deep vertical borehole. And in each borehole different types of loops can be installed i.e. single-U pipe, double-U pipe, simple coaxial type and complex coaxial type loop.

An important consideration in designing a vertical closed loop is the spacing between two vertical boreholes and generally based on thumb rule a distance of about 15 feet to 20 feet is maintained between two boreholes in order to prevent ineffective thermal conductance of two loops.

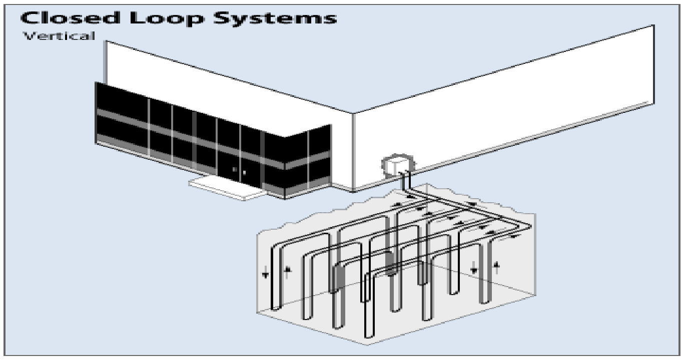

Fig. 1 Closed Loop Vertical System

B. Hybrid Closed Loop System

A hybrid geothermal system is basically an extension of the closed loop system consisting of all the elements of a closed loop system and an additional auxiliary system employed for increasing the efficiency of a system or to fulfil the load requirements partially. That is this system is either employed to enhance the efficiency of system to a desired level or when energy obtained from the ground is insufficient to produce required cooling or heating. Hence, a part of load requirement is fulfilled by ground loop and the remaining part of load requirement is achieved by using an auxiliary air conditioning system such as chiller plant or any other conventional system.

III.BUILDING DETAILS

The building chosen is intended to be used as a shopping mall. The building is proposed to be located in Hyderabad, India. It is provided with a complete glass section on the north and south sides. The building comprises of two floors i.e. a ground floor and the first floor and these two floors are similar to each other, thus, they are referred as typical floors. The total area of the building is about 9300 square feet and it comprises of different sections including the areas with and without air condition system. There are different kinds of spaces in this building as it is a commercial building such as lobby, lift section, corridor, spaces for shops or outlets, air handling unit room where the indoor unit of the air conditioning system is located, toilet section and many other spaces. Hence, a total area of about 7900 square feet out of the overall building area is supplied with the conditioned air and about 51 spaces are considered while designing an air conditioning system.The maximum occupancy of this building ranges up to about 284 persons per each floor and the number of occupants that can be accommodated within each floor is estimated from the ASHRAE standard that specifies about 30 square feet per person. An important consideration in this aspect is, the number of occupants is selected based on the area to be air conditioned and not the total building area.

Fig. 2 Building Plan

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IV. CALCULATIONS

A. *Heat Load Calculation*

The heat load calculation is done using hourly analysis program (HAP) software. The net heat load estimated for the specified building is 87.2 T.R and for each floor the heat load is 43.6 T.R. The maximum air flow rate obtained in terms of cubic feet per minute for each floor is 21406 CFM.

B. *Pipe Sizing*

The cooling water pipe sizing is done using the software named pipe sizer developed by Mc Quay. The main consideration or the input parameter in the design of cooling water pipe size is the water consumption rating. The water consumption rating for geothermal system ranges between 2 gpm and 3 gpm per TR based on the load of the building.

1) Water consumption rating – 2.4 gpm per TR for closed cycle
2) Total gpm required = 87.2 × 2.4 = 209.28 gpm
3) Gpm for each floor = 43.6 × 2.4 = 104.64 gpm
4) Pipe size obtained from calculation = Ø 4”

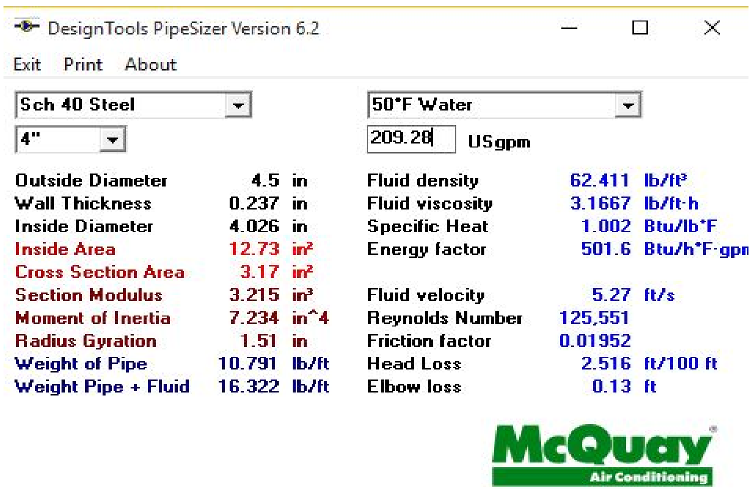

Fig. 3 Pipe Sizer

C. *Ground Loop Length Calculation*

The length of the underground loop that is required corresponding to the load of the building is determined manually by using the formula specified by the International Ground Source Heat Pump Association (IGSHPA) which is given below.

Expression for loop length,

$$L = \frac{572 \times \left(\frac{COP-1}{COP}\right)(R_P + R_S F_C)}{(T_2 - T_1)} \times C_C$$

Where,

R_P – Pipe resistance
R_S – Soil resistance
T_2 – Maximum fluid temperature attainable
T_1 – Minimum ground temperature
C_C – Cooling capacity
F_C – Cooling factor = 0.6
COP – 2 to 4 for cooling application

$$L = \frac{572 \times \left(\frac{3-1}{3}\right)\left((7.791 \times 10^{-5}) + (0.829 \times 0.6)\right)}{(27 - 21)} \times 87.2 \times 3.156$$

Minimum ground temperature for this region is around 21°C.
Due to pipe's thermal conductivity, maximum fluid temperature attainable is 27°C
C.O.P is taken as an average value of2 to 4 i.e., '3'.

$\therefore L$ = 9693.769 feets

When single – U bend pipe is taken and loop depth is considered as 100 feets, as per the thumb rule, then,

∴Total number of U – loops,

$$= \frac{9693.769}{2 \times 100} = 48.468$$

$$\therefore N \cong 49$$

Hence, an array of 7 × 7 parallel loops is employed.

Distance between two loops is taken as 15'

The material used for underground loop is galvanised iron (G.I). It is selected such that it is available at a very lower price compared to copper and it possess adequate thermal conductivity as well as longer service life.

D. Hybrid System Selection

The need of a hybrid system arises when the load requirements of the building to be conditioned cannot be fulfilled only by using complete ground source energy. Therefore, in order to meet the part load requirements an auxiliary system is employed and integrated with the geothermal air conditioning system. When water is circulated through the ground loop the maximum range of temperature attainable with respect to the building specified is 27° C. But, the desired temperature to be maintained within the building during peak conditions is 16° C. Hence, it can be noted that with only application of geothermal system, 60 % of the desired cooling can be obtained.

1) 16 ÷27 = 0.592 i.e. 0.6 or 60 %

Thus, the remaining 40 % of the cooling according to the desired temperature is achieved by employing an air cooled chiller system in integration with the geothermal cycle. An air cooled chiller is selected as an auxiliary system as the net heat load is below the range of 100 T.R and within which air cooled chiller system is highly suitable. And, the capacity of air cooled chiller is selected with respect to the 40 % of the net building heat load.

E. Comparison of Costs

TABLE I: COST COMPARISON WITH RESPECT TO A CONVENTIONAL SYSTEM

S.No	Type of Cost	Air Cooled Chiller System	Hybrid Geothermal System
1	Initial Cost	₹2230000/-	₹3899700/-
2	Operating costs per month	₹718050/-	₹388224/-

The cost data for the purpose of comparison of costs with respect to conventional systems are obtained from the realistic market analysis.

V. CONCLUSIONS

Initial cost of the hybrid geothermal system is 75 % higher compared to that of a conventional system. About 45 % savings are obtained in case of operating costs per month when geothermal system is used over a conventional system. The designed geothermal system is highly efficient especially in winter season, as there will be no need of any auxiliary system because the comfort temperature to be maintained within the space can be readily obtained through the direct heat transfer from the ground.

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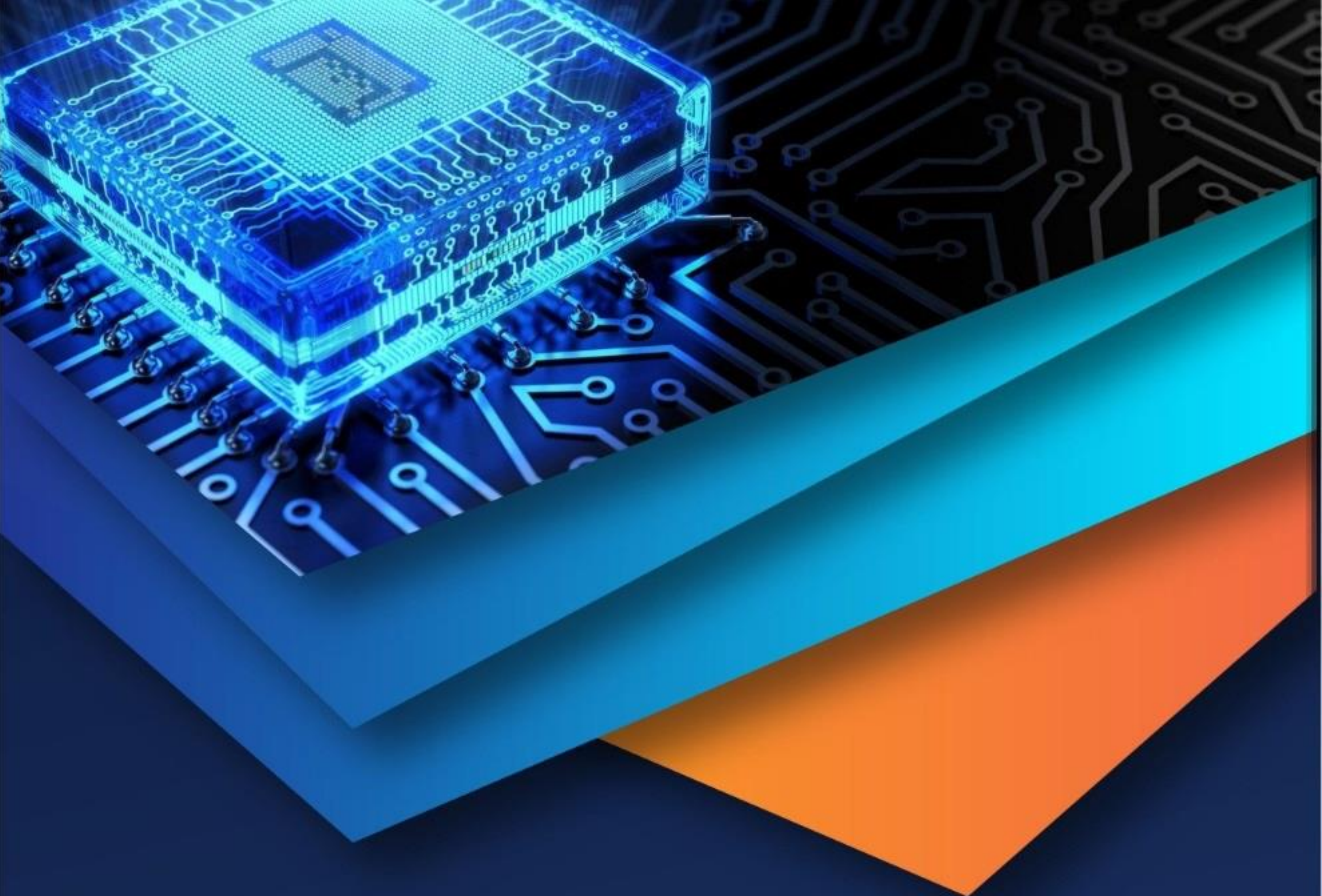

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