Construction and Performance Study of an Underground Air Heating and Cooling System

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Abstract: This is the time of searching alternative energy sources because of increasing demand of energy day by day against our limited resources. Now-a-days finding and developing alternative energy sources is the important responsibility and duty for human being and it is also demand of time. However, it is not easy to find an efficient alternative energy source. Thus, we can concentrate in finding a solution which can ensure a reduced load on the conventional energy sources. This project is about an underground room heating and cooling system which takes a very little energy to run itself. The system is totally environment friendly, does not produce any harmful exhaust or gases which could pollute the atmosphere. Moreover, it can be highly economical so that everyone can install this at their houses and also in educational organizations and offices. Four types of pipes of different materials were installed underground to cause heat transfer between ambient air passed through the pipes and the soil in contact with the pipe. Heating and cooling action in winter and summer respectively can be achieved by this system. The length of the pipes used is 30 feet and dug 8 feet deep. An inlet air flow at 4.5 m/s was provided. The air flow rate was found to be reduced at the exit and a change in temperature was also found. The cooling rates varied depending upon the temperature of the inlet air.


1. Introduction

In tropical country like Bangladesh, cooling of indoor air is growing due to increasing comfort expectations. Air conditioning is the most widely used cooling system for indoor air in Bangladesh.

The main component used in an air conditioner is compressor mainly driven by electricity. Electricity generation processes are fossil based and responsible for nitrogen dioxide, carbon, Sulphur and other GHG emission.

Refrigerants that are used in air conditioning have also negative impact on the environment. Freon like CFC and HCFC refrigerants are harmful to Ozone layer and are out of used now-a-days. CFC, HCFC and HFC (which used as replacement of CFC and HCFC) are all greenhouse gas.

Global warming in the impact of GHG gases responsible for average temperature rise worldwide. "The increase in temperature in the 20th century is likely to have been the largest in any century during the past 1000 years. 1990s were the warmest decade and 1998 was the warmest year. Global average land and sea surface temperature in May 2003 were the second highest since records began in 1880-WMO [1] in a press release 2 July 2003. All these happened due to consumption of fossil energy.

Bangladesh currently facing a trouble of energy distribution due to the lack of availability. Still now only 62% populations [8] under electrification as per govt. data. The demand supply gap of electricity is almost more than 500 MW based on the connected load. Considering the energy shortage attention has gone to the energy intensive domestic appliance (air conditioning) currently using in Bangladesh to comfort of indoor air. The underground assisted system to heat and cool the indoor air whenever needed to replace the use of a conventional air conditioning system & contributes in the global GHG mitigation.

The overall objective is to construct the underground assisted air heating and cooling system and its performance study. The specific objectives are -To construct the system, performance evaluation for winter season and to estimate the cost.
The regular air conditioners or room heating and cooling devices cost a fortune. The effect of the elements used in those are not also environment friendly. Thus a solar powered room heating and cooling device can offer in a lower cost as well as can be excellent environment friendly as it does not contain any harmful chemicals. The people all over the world can be benefitted from this device. Specially, in the developing countries, it could be a better choice.

2. Methodology

![Figure 1. Methodology.](image)

Figure 1 shows the methodology of the study. The objectives are in two dimensional named design, construction and performance study. The design of underground air passage includes depth, length, diameter, materials etc. The design of the sample house to be considered for heating and cooling includes volume of house, materials and set up arrangement etc. Then construction has been done assembling the entire materials. Finally the performance evaluation has been carried out using few performance indicators.

3. Construction

3.1. Technical Terms

Various technical terms are used to refer to earth tubes:
- Earth tubes
- Buried pipes
- Earth channels
- Air-to-soil heat exchanger
- Underground air pipe
- Earth-to-air heat exchanger (EAHX)
- Subsoil heat exchanger
- Earth-air tunnel system
- Ground tube heat exchanger
- Ground coupled heat exchanger

These terms all refer to the same kind of device: a pipe or series of pipes buried underground, and through which ventilation air is circulated. ‘Earth-to-air heat exchanger’ is probably the most technically accurate terminology, although ‘earth tubes’ also enjoys wide use. The systems can either be ‘closed-loop’ (i.e. recirculating the air from the building through the earth tubes), or ‘open-loop’ (i.e. drawing outside air through the pipes to ventilate the house). The system we have used in our set-up is an open loop system.

When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. The energy is transferred by conduction and that the heat transfer rate per unit area is proportional to the normal temperature gradient. [7]

\[
q = kA \frac{dT}{dx}
\]  

(1)
3.2. Pipe Length Selection

As the pipe length increases, the inlet air temperature decreases due to the fact that the longer pipe provides a longer path over which heat transfer between the pipe and the surrounding soil can take place given the same overall heat transfer coefficient of earth tube. Length can typically range from 10 to 100 m. Longer tubes correspond to more effective systems, but the required fan power and the cost also increase. [5]. For cost considerations, we have taken 30 feet for each of the four pipes.

3.3. Pipe Diameter Selection

As the pipe diameter increases, the earth tube outlet air temperature also increases due to the fact that higher pipe diameter results in a lower convective heat transfer coefficient on the pipe inner surface and a lower overall heat transfer coefficient of earth tube system. Smaller diameters are preferred from a thermal point of view, but they also correspond (at equal flow rate) to higher friction losses, so it becomes a balance between increasing heat transfer and lowering fan power. [5]. The pipes we have used has 1.5 inch diameter. For budget considerations, we only used similar diameter pipes for all the materials.

3.4. Pipe Depth Selection

As the pipe depth increases, the inlet air temperature decreases, indicating that the earth tube should be placed as deeply as possible. However, the trenching cost and other economic factors should be considered when installing earth tubes. Deeper positioning of the tubes ensures better performance. Typical depths are 1.5 to 3 m. The tubes can be positioned under the building or in the ground outside the building foundation. [5]

The depth of the pipes we used was 8 feet. The depth of the pipe required to heat or cool the air generally varies depending upon the geography of the set-up.

3.5. Material Selection

Four types of materials were used in our underground cooling and heating system.

1. Mild Steel pipe
2. PVC pipe
3. PVC filtered pipe
4. Bamboo

We used different types of materials to measure if there is any change in the cooling effect with respect to the change in materials. All materials mentioned above are available in local market and cost effective at the same time. The use of these materials with the above mentioned specifications would allow all class of people to install the system as household room heating and cooling device.

3.6. Flow Rate Selection

Lower flow rates are beneficial to achieve higher or lower temperatures, and also because they correspond to lower fan power. However, a compromise has to be made between pipe diameter, desired thermal performance, and flow rate. From literature review, we were suggested that the flow rate is preferable from 3-5 m/s. [5]. The flow rate we used was 4.5 m/s.

3.7. Fan

The circulating constant speed fan used at the inlet of the pipes to ensure the uniform air introduction into the system was a 1.92 watt fan. The power required to drive the fan or the input work is measured by the equation

\[ P = VI \]

Where,

- \( P \) = Power (watt)
- \( V \) = Voltage (volt)
- \( I \) = Current (ampere)

The current was measured by connecting an ammeter to the multimeter circuit with the circulating fan.

\[ P = 12 \times 0.16 = 1.92 \text{ watt} \]

3.8. Battery Capacity

The battery used to run the fan was a 12 Volt battery. Solar panel could also be used to run the fan.
3.9. Digital Hygro-Thermometer

A digital Hygro-thermometer is a versatile instrument which is used to measure the temperature and moisture content of air. This instrument was used to measure the inlet and exit temperature and humidity [9].

![Digital Hygro-Thermometer](image)

Figure 3. Digital Hygro-Thermometer.

3.10. Anemometer

An anemometer or wind meter is a device used for measuring wind speed, and is a common weather station instrument. Anemometers can be divided into two classes: those that measure the wind's speed, and those that measure the wind's pressure; but as there is a close connection between the pressure and the speed, an anemometer designed for one will give information about both [10].

![Anemometer](image)

Figure 4. Anemometer.

3.11. Construction

The above figure shows our basic design for the heating and cooling system for each pipes. The pipe depth is 8 feet, whereas the pipe length is 30 feet. The diameter of the pipes selected is 1.5 inch each.

![Underground Air Heating and Cooling System](image)

Figure 5. Underground Air Heating and Cooling System.

4. Result and Discussions

4.1. Description

The data required from the underground air conditioning system is categorized below as per their respective material. The data was recorded from 6.00 PM, 16th December, 2014 to 3.30 AM, 17th December, 2014 for the night time condition. And from 10.00 AM- 2.00 PM December 21st, 2014.

![Underground Air Heating and Cooling System behind Boiler Lab](image)

Figure 6. The setup of underground air heating and cooling system behind Boiler Lab.

![The inlet port of the pipes with battery and fan](image)

Figure 7. The inlet port of the pipes with battery and fan.
4.2. Variation of Inlet Temperature with Time (Night & Day)

As the time passed, the temperature reduced. This is caused by the change in atmospheric condition. The lowest temperature recorded was 15.1 degree Celsius. The data was taken by digital hygro-thermometer.

Figure 8. Variation of inlet temperature with time (night).

Figure 9. Variation of inlet temperature with time (day).
During the day time, the change in temperature was not gradual. Rather it was random. However, as there were cloud in the sky, the hygro thermometer had problem sensing the temperature. The highest temperature found was 27.4°C.

4.3. Variation of Inlet Humidity with Time (Night & Day)

As the night grew older, there was a considerable increase in the moisture content of the air. The highest humidity was found 84%.
The humidity level at the day time was found to be considerably less than the humidity during the night. As time passed, it gradually decreased. The highest humidity was found 48%.

4.4. Variation of Temp. and RH for PVC with Time Under Inlet and Exit Condition (Night & Day)

This curve gives a qualitative comparison of the inlet and exit air and helps us judging the air properties. The outlet temperature for all the observations were around 23.5°C. We get a considerable amount of air heating by this set of observations.

The variation of temperature and RH was found to be different than night in the day time. Sometimes it has shown cooling character and sometimes it has shown heating character. The lowest outlet temperature found was 23.2°C.
4.5. Variation of Temp. and RH for MS with Time Under Inlet and Exit Condition (Night & Day)

Mild Steel pipe has had a very stable heating property. The outlet temperatures for all the observations were around 23.5°C. We get a considerable amount of air heating by this set of observations.

However, during the day time, MS pipe has shown scattered readings. Sometimes it has cooled the air and sometimes it has heated the air. It has been found that the humidity remains in the region of 40%.
4.6. Variation of Temp. and RH for PVC Filtered Pipe with Time Under Inlet and Exit Condition (Night & Day)

PVC filtered pipe has shown the best heating properties of all the pipes during the night. But, it has increased the humidity of the air to a very high level. The highest outlet temperature recorded was 24.5°C.

PVC filtered pipe has shown more or less similar characters during the day and night time. It has increased the temperature and humidity of the air. The lowest outlet temperature recorded was 23.5°C.
4.7. Variation of Temp. and RH for Bamboo with Time Under Inlet and Exit Condition (Night & Day)

Bamboo has increased the temperature of the air during night. It has also resulted in a high humidity. The highest outlet temperature recorded was 20.7°C.

Figure 18. Variation of temp. and RH for Bamboo with time under inlet and exit condition (night).

Figure 19 shows the variation of temperature and relative humidity for bamboo with respect to time. The data was taken by digital hygro-thermometer. The bamboo has shown great cooling performance in the day time. It had the highest cooling rate among all the pipes despite giving the lowest performance during the night time. The lowest outlet temperature recorded was 18.4°C.

Figure 19. Variation of temp. and RH for bamboo with time under inlet and exit condition (day).
4.8. Variation of COP with Time (Night & Day)

As the time passed, the performance of all the pipes grew higher. The lowest COP was 1.4 found for MS pipe and the highest COP was 4.7 found for PVC pipe.

Figure 20. Variation of COP with time (night).

Figure 21 shows the variation of the co-efficient of performance of various pipes with time during the day time. During day time, the COP has varied very randomly with time. The lowest COP was 0.05 found for PVC filtered pipe and the highest COP was 2.91 found for PVC pipe.

4.9. Maximum COP of Various Pipes During Day and Night

Figure 22. Maximum COP of various pipes during day and night.

Figure 22 shows the maximum COP of various pipes at day and night time. The highest COP was found for PVC pipe at night and it was 4.72.
4.10. Cost Estimation

The overall cost of the system was 6540 taka (approximately $82). The most cost effective system can be designed by PVC pipe. The labor cost or excavation cost can be reduced by proper planning. However while installing the system in household purpose, we would use only one pipe. So, the overall cost would not contain the cost of other pipes.

Table 1. Cost estimation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Amount (Taka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC Pipe</td>
<td>1.5 inch diameter, 50 ft. long</td>
<td>750</td>
</tr>
<tr>
<td>MS Pipe</td>
<td>1.5 inch diameter, 50 ft. long</td>
<td>1250</td>
</tr>
<tr>
<td>PVC Filtered Pipe</td>
<td>1.5 inch diameter, 50 ft. long</td>
<td>1000</td>
</tr>
<tr>
<td>Bamboo</td>
<td>1.5 inch diameter, 50 ft. long</td>
<td>1100</td>
</tr>
<tr>
<td>Elbow</td>
<td>4 PVC, 2 MS Pipe</td>
<td>140</td>
</tr>
<tr>
<td>Excavation Cost</td>
<td>Labor cost for excavation</td>
<td>2300</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>= 6540</td>
</tr>
</tbody>
</table>

4.11. Quantity of Materials

Table 2. Quantity of materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC Pipe</td>
<td>6</td>
</tr>
<tr>
<td>PVC Filtered Pipe</td>
<td>6.75</td>
</tr>
<tr>
<td>MS Pipe</td>
<td>9.1</td>
</tr>
<tr>
<td>Bamboo</td>
<td>54</td>
</tr>
</tbody>
</table>

PVC pipe is also the lightest material. The weight of the PVC pipe for the whole system was 6 kg. While the heaviest pipe was bamboo.

5. Conclusion

The design and construction of the system was a simple one. Though it takes huge space, there are very little moving parts. So the system has a very simplified design. The performance study was a lengthy one. To obtain precise characteristics of underground heating and cooling system for various materials, thorough observation and accurate data collection at regular interval was ensured. Our objective was to provide simultaneously heating action in the winter season and cooling action in the summer. A considerable amount of heating action was obtained from PVC, MS and PVC filtered pipe. Bamboo provided a reduced heating performance. Thus, with the use of PVC/ MS/ PVC filtered pipe, an economical and energy saving heating action can be obtained. On the other hand, with bamboo a considerable amount of cooling action can be achieved. Whereas the other pipes had less cooling properties than bamboo.

- The average COP of PVC pipe at night is 3.65, during day time it is 0.99.
- The average COP of MS pipe at night is 2.76, during day time it is 1.003.
- The average COP of PVC filtered pipe at night is 3.39, during day time it is 0.518.
- The COP of bamboo could not be measured as the exit velocity was very little.

The set-up of PVC and MS pipe was very much secure and sealed. It was ensured there was a minimum of leakage. So, the exit condition of these two pipes has shown a constant and stable nature. In the case of PVC filtered pipe, due to the perforations in the pipe, the air passing through the pipe came in direct contact with the moisture content of the soil. That is why the humidity content was found to be very high. In case of bamboo, to ensure continuous flow of air, the bamboo was slit longitudinally into two parts. Then the joints were separated and the two split parts were joined again in order to give it a pipe shape. The whole process kept a huge amount of leakage due to unavoidable misalignment. This allowed the air to come in ample contact of soil and take moisture content of soil with it.

Recommendation

At first, we considered Bamboo as our prime target for cost efficient material. But, practically it was found that bamboo is neither cheap nor its set up and processing is simple. It takes a lot of work to split the bamboo into half, remove the joint and rejoin the two parts without any leakage with proper alignment. Thus the performance obtained from Bamboo was not satisfactory for the night time. But it gave a very good cooling performance during day time.

On the other hand, PVC filtered pipe gave a very good heating property during night. But it did not give any mentionable cooling property. So, for the cold weathers, use of PVC filter pipe would give very good performance.

Night Condition

In the case of PVC and MS pipe, it was found that the temperature increases and the humidity decreases. In the case of PVC filtered pipe, the humidity increases to a very high level. However, the humidity level of the air obtained from PVC and MS pipe was significantly low. Hence, in both cases, the air may be uncomfortable for the user. This is a huge limitation of the system. A device can be used to control or regulate the moisture content of the air.

Day Condition

In the case of PVC and MS pipe, it was found that the temperature and the humidity remains more or less identical. As the day passes from morning to noon, a considerable amount of heat transfer occurs and cooling action is obtained. In the case of PVC filtered pipe, the humidity increases to a very high level. However, the humidity level of the air obtained from PVC and MS pipe was significantly low. Hence, in both cases, the air may be uncomfortable for the user for day time too.

We had to keep the pipe length to 30 feet for scarcity of available space and cost considerations for the material and digging. The system is likely to give better performance if the length of the pipe is increased. The longer the air remains in contact with the soil, the more is the rate of heat transfer.

A reduced pipe diameter gives better cooling and heating
performance. But it also gives a very low exit velocity due to high frictional loss. Again, a pipe of larger diameter would take a fan of higher power which would increase the energy requirement of the system. Hence, a pipe of moderate diameter is suggested.

Data collection over a vast period of time is suggested. It would be more convenient if data is taken at different regions depending upon geographical and climatic conditions. The soil composition of different places may vary resulting a different heat transfer rate.

References


Biography

Amit Shor has received his B.Sc. degree in Mechanical Engineering from Rajshahi University of Engineering & Technology in 2014. He is an associate member of Institute of Engineers, Bangladesh. His membership ID is A-16635. His field of research in the area of Renewable energy, Heat transfer, Combustion, Heat recovery system.

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