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

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Abstract

This study presents the construction of underground assisted air heating and cooling system using four distinguish materials to investigate the comparative air cooling and heating effect for human comfort to discourage the use of traditional air conditioner in the living room. The system is installed 8ft depth from the ground surface and their length was 30 ft. The performances were investigated and recommend the better materials for the system. The results showed that the system is able to deliver cold air during summer season (mid of March) and hot air during winter season (mid of December) in line with the human comfort condition. PVC pipe perform better cooling effect compared to other pipe. The COP of PVC pipe found to 3.65 is quite attractive to use for the air conditioning purpose. The COP is lower for the other system. The system is simple, cost effective, environment friendly and easy to install can be used instead of air conditioner.

Keywords: Conditioning of air, Underground system, Performance comparison.

1. Introduction

The demand of conditioned air for human comfort is growing worldwide. Air conditioning system is the most widely used system for conditioning indoor air to bring it under comfort level. The main component of this system is compressor consumes significant amount of electricity. Till now share of primary energy is dominating in the electricity generation sector in spite of alarming news regarding global primary energy crisis. So, researchers are suggesting the alternative way to meet the energy demand. 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 in spite of facing a trouble of energy distribution due to the lack of availability. Researchers are working hard to find an alternative way to make the room air under comfort level. Underground assisted system so called earth tube is one of the methods to make the air for the expectation of human comfort. A new module was developed for and implemented in the Energy Plus program in USA for the simulation of earth tubes [1]. The model was validated and showed good agreement with both theoretical and experimental data. Using the new module, a parametric analysis was carried out to investigate the effect of pipe radius, pipe length, air flow rate and pipe depth on the overall performance of the earth tube under various conditions during cooling season. Pipe length and depth turned out to affect the overall cooling rate of the earth tube, while pipe radius and air flow rate mainly affect the cooling rate. The cooling and heating potential of earth tubes in four different locations were also investigated. This system showed more than 50% of cooling load could be possible to save. A study on earth tube was undertaken by Thevenard reported that earth tubes can provide between 30% and 100% of cooling needs, and only a small fraction of heating needs [2]. Zukowski et al. reported the computer simulation result and experimental investigation of thermal performance of earth tube heat exchanger. The study showed that the system can decrease the heating load and significantly reduce the room air during summer season [3] Darkwa et al reported that earth tube system made of PVC is able to contribute 62% and 86% of the peak heating and cooling loads respectively and corresponding COPs of 3.2 and 3.53. The average relative humidity level reduces to 10% in the heating period [4]. Hollmuller and Lachal studied the buried pipe system made of PVC for heating and cooling the air under central European climate. The study compared the cooling vs heating potential by the system [5]. Sharan and Jadhav reported the performance of single pass earth tube heat exchanger made of mild steel (MS) for heating and cooling the air [6]. The system was able to reduce the temperature of hot ambient air by as much as 14℃ in May and warm up the cold ambient air by a similar amount in the nights of January. The coefficient of performance (COP) was found to 3.5. Deglin et al reported the earth tube performance made of non perforated PVC pipe [7]. Study showed that soil saturated in water, greater depth, smaller pipes and lower fan speeds are preferable to get better performance.

The review of existing literatures shows that the study was conducted using single type of material. The comparative performance study of different types of materials is unusual in the available literatures. The comparative experimental performance is important to select the suitable materials for this system. Addressing this research gap an experimental comparative study was undertaken in this paper to recommend the better material for the underground assisted heating and cooling system. The objectives of this study are to construct the system using different materials and performance evaluation among the materials and recommend the better materials for the system.

2. Construction

Four types of materials are available in Bangladesh namely, MS, PVC, PVC perforated available in the local market and bamboo were selected to construct the system. Ref. [2] reported that, length of the pipe is increase causes decrease the outlet air temperature and length can typically from 30 to 300 ft. In this system the length of the pipe is 30 ft used considering the cost and convenience for installation. The outlet air temperature increase with increasing the pipe diameter but thermal point of view smaller diameters are preferred. So, it needs a balance between them. In this study 1.5 inch diameter pipes were selected based on the cost and standard available in the market. Deeper positioning of the tubes ensures better performance. Typical depths are 4.5 to 9 ft used because at this depth the underground temperature remains constant in both summer and winter season. This study used 8 ft depth of the pipe was positioned under the ground. Lower flow rates are beneficial to achieve better performance. Typical flow rate is 3-5 m/s and the maximum flow rate was used in this study is 4.5 m/s. The circulation of the air is done using fan of 1.92 watt capacity and velocity measured by digital air flow meter. Digital hygrometer was used to measure the temperature and humidity. The sectional view of the setup is shown in Figure 1.

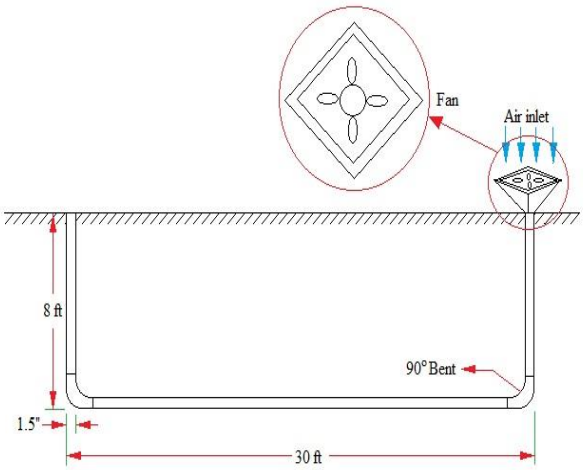

Fig. 1. Sectional view of the underground assisted air heating and cooling system

3. Results and discussion

The performance of the system was recorded at day time and night time of the winter season for the setup of four materials. Temperature, relative humidity and coefficient of performance (COP) were examined as these parameters are main responsible for human comfort and system performance respectively. The results of the experiment are described in the following sub sections.

3.1 Characteristics of temperature and relative humidity in the winter season

Figure 2 shows the behavior of temperature and relative humidity for the day time and night time of the winter season (mid December). It is seen that the temperature is increasing with time from the beginning of the day and maximum temperature is 27^0C at 12.10 pm and then decrease with increasing time. The temperature is decreasing with increasing time at night time and minimum temperature is 17^0C at 3.0 am. Relative humidity is maximum of 48% at morning and minimum of 36% at noon. This is due to the water droplet contents in the air is higher at morning and lower at noon. Similarly, relative humidity is increasing with increasing time at night time due to increase the water droplets in to the air and appear to constant humidity from mid night. The

maximum and minimum relative humidity at night time is 64% and 81% respectively. Hence, most of the people feel comfort under combination of 21^0C dry bulb temperature and 40% relative humidity in winter season and 26^0C dry bulb temperature and 40% relative humidity in summer season [8]. It needs effort to bring the temperature and humidity under comfort level.

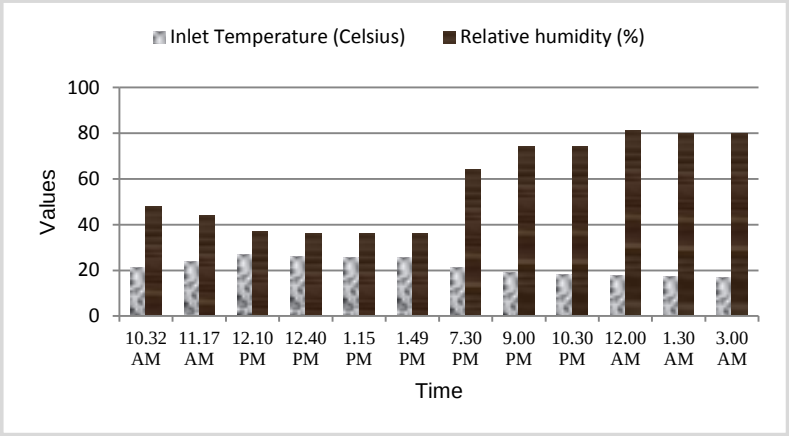

Fig. 2. Behavior of temperature and relative humidity in mid December

3.2 Effect of system materials on exit air temperature

Figure 3 shows the outlet air temperature for four types of setup over day time. It is seen that the system with bamboo material is better to cool down the exit air temperature under same condition compared to other materials. The minimum temperature is 19^0C provided by the system of bamboo. This may be due to the wood itself has moisture content that help to reduce the air temperature. The minimum temperature for the PVC, PVC perforated and MS materials are 23.2^0C, 23.5^0C, and 23^0C respectively. Though bamboo materials shows better cooling effect but the other materials have shown the values are suit with close to comfort level also. The cooling performance of PVC and MS have shown similar trend over the day. It needs justification the relative humidity to recommend the better one for the human comfort. The observation at night time shows that bamboo materials show the minimum temperature is 19.2^0C and minimum temperature for the PVC, PVC perforated and MS materials are 23.3^0C, 24.2^0C, and 23.2^0C respectively. Hence, PVC and MS materials show very similar performance both in day and night time.

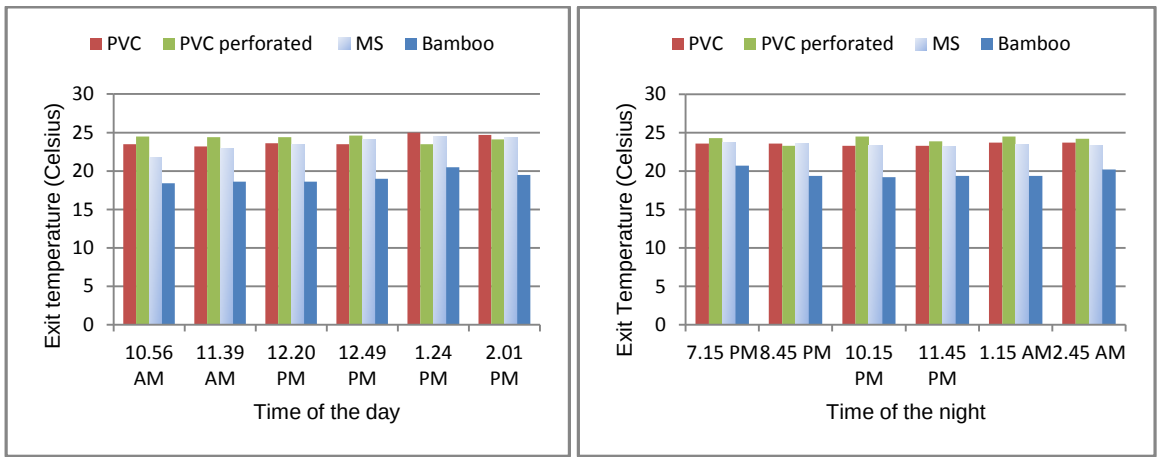

Fig. 3. Effect of system materials on outlet air temperature

3.3 Effect of system materials on exit relative humidity

Figure 4 shows the effect of system materials on exit relative humidity of the air with time. It is seen that the relative humidity is extremely higher and its values are more than 75% for the PVC perforated and bamboo materials which is not suitable for human comfort condition with comfort air temperature. This is may be due to

the moisture added from the underground soil for the perforated PVC pipe and moisture contents itself of bamboo materials. Relative humidity for the PVC and MS materials has shown better for the comfort condition values of 40-50%.Minimum relative humidity of PVC and MS materials are 39% and 41% respectively. Observation at night time shows that relative humidity for the PVC and MS materials are 47% and 48% respectively. Hence, PVC material is better to deliver comfort air for the occupancy. Its optimum combination for the day time is found to 23.2^{0}C and 39% relative humidity and in night time is 23.3^{0}C and 47% relative humidity is suitable for the conditioning of air.

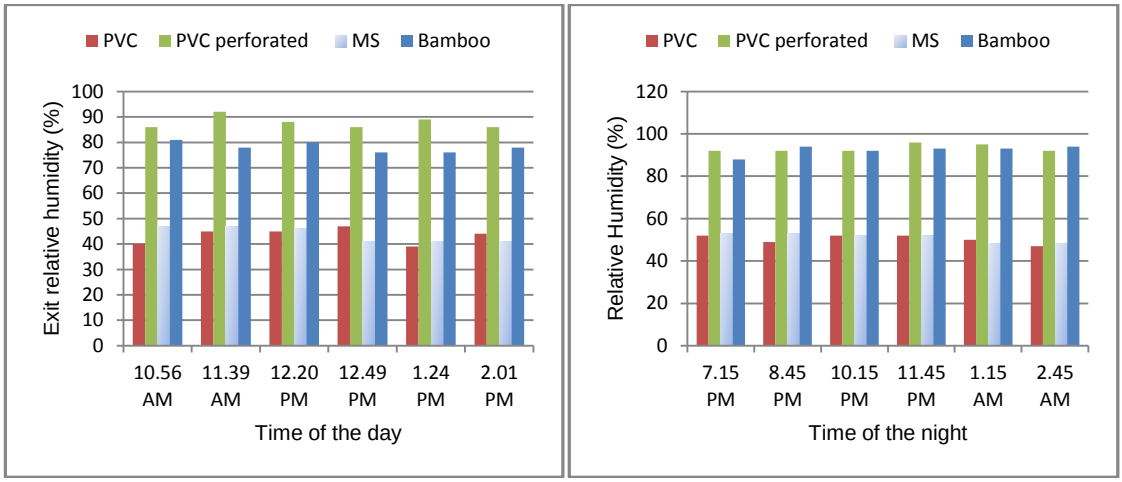

Fig. 4. Effect of system materials on outlet relative humidity of air

3.4 Effect of system materials on COP

Coefficient of performance is the ratio of the cooling effect to the energy input [2]. It is denoted by COP. The mathematical expression of the equation is

$$\text{COP} = \frac{Q_{out}}{W_{in}} \qquad (1)$$

Where,
Q_{out}= $m_a C_p$ (To-T_i)
C_p= Specific heat of air (J/ kg ℃)
Q_{out}= Cooling effect
W_{in} = Energy input into the system by fan
m_a= Mass flow rate of air (kg / s)
T_i = Temperature of air entering the pipe (℃)
T_o = Temperature of air at the outlet (℃)

Mass flow rate, $m_a = \rho \times A \times V$
ρ = Air density (kg/m^3) = 1.29 (For atmospheric condition)
A= Cross sectional area of pipe (m^2)
V = Velocity of air at exit (m/s)

Figure 5 shows the effect of system materials on COP of the system. It is seen that at day time maximum COP for the PVC, PVC perforated and MS found to 2.91, 0.97 and 2.28 and at night time its values are 4.72, 3.98 and 3.45 respectively. The COP calculation for the bamboo materials was not possible due to extremely friction loss inside the passage made the outlet air velocity negligible and was not able to measure the velocity using air flow meter. The observation shows that the COP for the PVC material is found to better compare to other materials both in day time and night time. The maximum values of COP using PVC materials in day time and night time are 2.91 and 4.72 respectively. Hence, PVC materials can be used to bring the room air for human comfort with combination of 23.2^{0}C air temperature and 39% relative humidity at day time and 23.3^{0}C and 47% relative humidity in night time with COP of 3.84 averages in the winter season of Bangladesh.

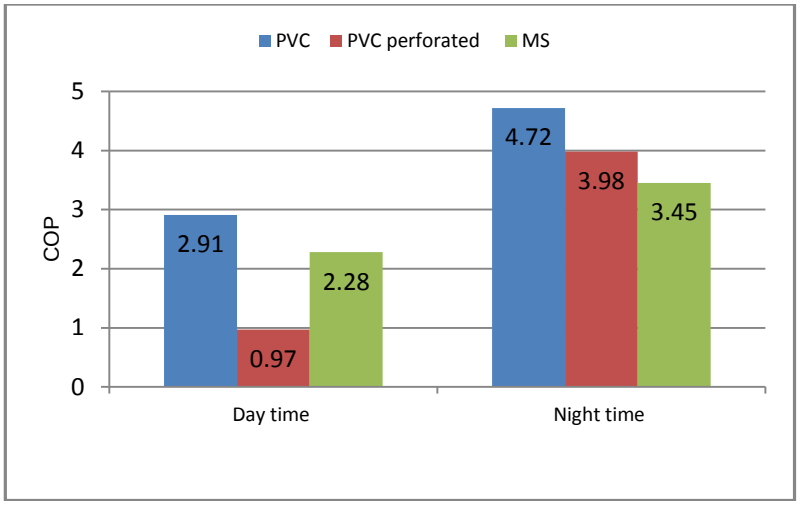

Fig. 5. Effect of system materials on maximum COP

3.5 Performance in summer season using PVC materials

Figure 6 shows the effect of PVC materials on outlet temperature and relative humidity in summer season. The performance was conducted in day time. The results showed that the inlet temperature of the system was above 30^{o}C and the outlet temperature is almost close to 25^{o}C over the day. It implies that the system is able to make down the high temperature air to low temperature as well as comfort condition. The inlet relative humidity of the system is almost lower than 15% and the system is able to deliver with the relative humidity of 20 to 30% which help to build comfort combination of the temperature and humidity.

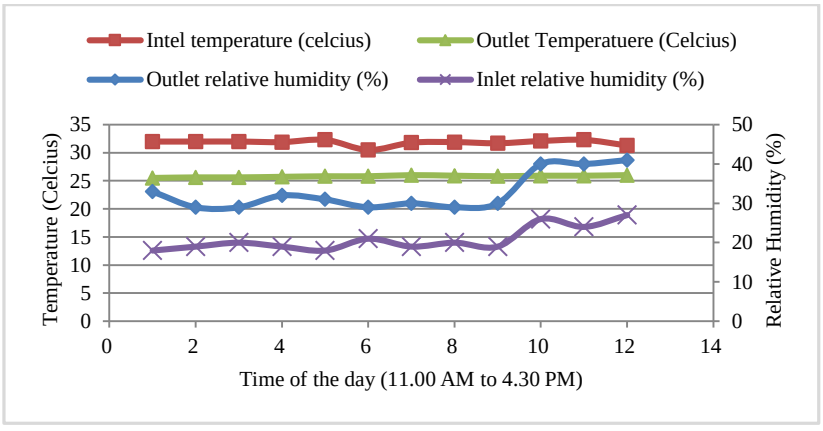

Fig. 6. Effect of PVC materials on temperature and humidity in summer season

4. Conclusions

An experimental study was undertaken in this study to make the room air under comfort condition using underground assisted heating and cooling system. PVC, PVC perforated MS and bamboo materials were used for the system and their performance compared. The result showed that PVC pipe is better compared to other materials to achieve the room air under comfort level. This study was investigated in winter season and the optimum comfort combination of outlet air temperature and relative humidity are 23.2^{0}C and 39% in day time and 23.3^{0}C and 47% relative humidity in night time respectively. The average coefficient of performance is found to 3.84 which is better for the application instead of air conditioner in the occupied room and will be able to make the room air under comfort level. The value of COP in this study is also higher than that of the

literatures presented in this paper of 3.5. The system could be used widely in the residential and industrial sector to minimize the fossil energy use in the context of energy crisis in Bangladesh and overseas.

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