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Comparison of earth pipe cooling performance between two different piping systems

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Abstract

Rational use of energy and power is a key to the economic development of human society and to achieve sustainable environment. Power and energy have been the major contributors to the global warming and researchers around the world have put a lot of effort to find new ways to save and control energy through energy efficient measures. Earth pipe cooling technology is considered as one of the viable options to save energy for a hot and humid subtropical climate. This paper presents the comparison of earth pipe cooling performance between two different piping systems for a hot and humid subtropical climatic zone in Queensland, Australia. Two different piping systems of vertical and horizontal were laid in the ground in order to compare the cooling performance. A thermal model is developed for the earth pipe cooling system using ANSYS Fluent. Data were collected from two modelled rooms connected with the two different piping layouts and systems. Impact of air temperature and velocity on room cooling performance is also assessed. A temperature reduction is observed for both the piping systems. The results indicate that the vertical piping system shows better performance in comparison with the horizontal piping system.

Keywords: Passive air cooling; Earth pipe cooling; Cooling performance; Subtropical Climate; Horizontal and vertical piping system.

1. Introduction

Sustainable development has become one of the significant considerations in the design and execution of development policies in the world. Energy crisis is one of the major obstacles for the sustainable development. Energy consumption in different forms is steadily rising around the world. Population and income growth are the key drivers behind this rise in energy demand. By 2030 world population is projected to reach 8.3 billion, which indicates an additional 1.3 billion people will need energy and world income in 2030 is expected to be roughly double the 2011 level [1]. The buildings in the major sectors of industry, agriculture, commercial and residential are responsible for more than 40% of global energy use.

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where Australian buildings use up to one-third of their electricity on air conditioning. Australia’s net energy consumption was increased at an average annual rate of 1.8% over the 10 years from 1999-2000 to 2009-2010, compared with 2.3% over the previous 10 years [2]. The energy consumption for the Australian residential sector in 1990 was about 299 petajoules (PJ) and that by 2008 had grown to about 402 PJ and is projected to increase to 467 PJ by 2020 under the current trends [3]. This represents a 56% increase in energy consumption in residential sector over the period 1990 to 2020. Energy consumption in a building can be reduced in several ways. Passive air cooling of earth pipe cooling (EPC) system is a viable option to reduce the energy consumption in the buildings for most of the warm climatic zones including subtropical climate. The technology works with a long buried pipe with one end for the ambient air intake and the other end for providing air cooled by soil to the house. It is the least expensive means of cooling a building with the lowest environmental impact. Applications of this technique were described by Saini [4], and Fanciotti and Scudo [5]. In case of earth pipe cooling performance, many researchers found that the resulting temperature at the buried pipe outlet decreases with increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air in the pipe and increasing depths up to 4m [5, 6]. Cooling performance of horizontal earth pipe system was investigated in an agricultural greenhouse in the tropical climate of Thailand [7] and in a subtropical climatic zone in Queensland, Australia [8]. The EPC technology became increasingly popular in Europe and America after the oil crisis in 1973 [9]. The concept of underground pipes can be traced back several centuries. Most of these studies concentrated mainly on modelling and analysis of EPC system with some limited experimental studies for some selected climatic conditions. Since this passive cooling technology has not been adopted in Australia, this study will contribute immensely to reduce the impact on climate and environment through the use of efficient energy. This paper presents the comparative performance study of vertical earth pipe cooling (VEPC) system and horizontal earth pipe cooling (HEPC) system.

2. Experimental Design and Measurement

Two shipping containers were fitted and installed as modelled rooms in the Sustainable Precinct at Central Queensland University, Rockhampton, Australia. One was connected to VEPC system and other to HEPC system. A blower was set inside the pipe to suck intake air from pipe inlet and to pass the air through a series of buried pipes into the room. An air conditioner was installed to cool both the rooms using lower energy in combination with EPC system. Both vertical and horizontal piping system shown in Figure 1 and Figure 2 consist of two simple Polyvinyl Chloride (PVC) pipes (known as manifold) with outside diameter 125 mm.

![Figure 1 Vertical piping of EPC system](Image)

![Figure 2 Horizontal piping of EPC system](Image)

Intake air comes through one of the manifolds and passes through a series of buried pipes and moves into the room through another manifold. The manifolds were connected with 20 corrugated PVC pipes each of length 8 m, diameter 21 mm and thickness 1 mm. The 20 corrugated PVC pipes were pressed
(friction fitting) into the manifold in 5 rows vertically in VEPC system and in one row horizontally in HEPC system. Each corrugated PVC pipe in each row was separated from its neighbour by 20 mm for both piping system. For measuring the performance of VEPC system, average air temperature and velocity were collected from both the rooms by turning off the HEPC system. Likewise, data were also collected from both the rooms by turning off the VEPC system for measuring the performance of HEPC system. Data were collected from April to June, 2013 and July to September, 2013 to measure the performance of VEPC and HEPC system respectively.

3. Modelling Approaches

Re-Normalisation Group (RNG) turbulence model was used to develop the thermal model of this study. The modelling equations are described in the ANSYS Fluent theory guide [10]. A 2D geometry was created for this model and a typical mesh was generated using DesignModeler in ANSYS 13.0. A 2D pressure-based-segregated solver was used for the modelling. The pressure implicit with splitting operators (PISO) pressure-velocity coupling scheme was adopted for numerical calculations. The PISO scheme allows for a rapid rate convergence without a significant loss of solution stability and accuracy [11]. Pressure was discretised with a PRESTO scheme because of its strong convergence capability [12]. Spatial discretization of second-order upwind scheme was used for momentum, turbulent kinetic energy and turbulent dissipation rate as the second-order discretization of the viscous terms is always accurate in Fluent.

4. Results and Discussion

Experimental results were obtained for air velocity and air temperature at the pipe inlet and different points of the modelled rooms. An average air velocity of 3.40 m/s and air temperature of 294.16K (21.01°C) were measured at the pipe inlet of the VEPC system. The room temperatures of 297.76K (24.61°C) and 298.02K (24.87°C) were also measured near to the walls of the modelled rooms connected to the VEPC system and the standard container (not connected to any EPC system) respectively. The inlet velocity and temperature were set in the boundary conditions of the model. The room temperature of 298.02K (24.87°C) was also imposed as the indoor room temperature (near to the wall). For HEPC system, average air velocity of 1.1 m/s and air temperature of 293.2K (20.05°C) were found at the pipe inlet. The room temperatures of 297.73K (24.58°C) and 298.05K (24.90°C) were measured near to the wall of the modelled rooms connected to the HEPC system and the standard container respectively. The standard room air temperature of 298.05K (24.90°C) was also set as the indoor room temperature in the boundary conditions. Measured room temperature of both VEPC and HEPC system was compared with the standard room temperature which are shown in Figure 3(a) and 3(b).

![Figure 3(a) Temperature profile for vertical earth pipe cooling system and non-earth pipe cooling system](image1)

![Figure 3(b) Temperature profile for horizontal earth pipe cooling system and non-earth pipe cooling system](image2)
Figure 3(a) shows that the room temperatures for the months of July, August and September are increasing gradually for both the rooms (standard and vertical earth pipe cooling). In Australia, the winter ranges from June to August and spring starts from September, and the day time temperature in spring is always greater than that of winter are the main reasons behind this. Moreover, temperature fell on 15 and 16 August, 2013 due to the rainfall. The indoor temperatures shown in Figure 3(b) are decreasing for both the rooms (standard and horizontal earth pipe cooling) at the end of June as winter starts from June. To compare the performance between the two systems, temperature and velocity profiles were calculated numerically at the iteration of 30,000 which are shown in Figure 4 and Figure 5 respectively.

The predicted maximum room temperatures of 296.2K (23.05°C) and 297K (23.85°C) were found for VEPC and HEPC system respectively as shown in Figure 4. The predicted temperature for VEPC system shown in Figure 4(a) is 1.82°C less than the measured maximum room temperature of 298.02K (24.87°C). On the other hand, the predicted temperature for HEPC system shown in Figure 4(b) is 1.05 oC less than the measured temperature of 298.05K (24.90°C). It was also seen from Figures 4(a) and 4(b) that the maximum temperature reductions of 3.5°C and 3°C are observed for VEPC and HEPC system respectively. Thus, the results indicate that the VEPC system performs better than the HEPC system.

A study was carried out to check the effect of the grid variation and to establish the optimum mesh size which ensures the consistent results for every mesh size. The results obtained in this study were also validated at the pipe inlet and inside the room by comparing the numerical result with the experimental result. The comparison between experimental and numerical results is summarized in Table 1. The overall numerical simulation results for air velocity and temperature showed some deviations from the experimental data because of the air pressure drop inside the pipe. However, the overall simulated results are in very good agreement with the corresponding experiments and lie within 0.76%-6.34% limits.
Table 1. Comparison between experimental and numerical results

<table>
<thead>
<tr>
<th>Data</th>
<th>Experimental</th>
<th>Numerical</th>
<th>Average differences (%)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>VEPC HEPC</td>
<td>VEPC HEPC</td>
<td>VEPC HEPC</td>
</tr>
<tr>
<td>Average air velocity at pipe inlet (m/s)</td>
<td>3.40 1.1</td>
<td>3.53 1.5</td>
<td>3.82 4.55</td>
</tr>
<tr>
<td>Average air temperature at pipe inlet (°C)</td>
<td>21.01 20.05</td>
<td>20.85 20.85</td>
<td>0.76 3.99</td>
</tr>
<tr>
<td>Average room air temperature (°C)</td>
<td>24.61 24.58</td>
<td>23.05 23.85</td>
<td>6.34 2.97</td>
</tr>
</tbody>
</table>

5. Conclusion
Comparison of thermal performance between vertical and horizontal earth pipe cooling system was assessed in this study by developing a thermal model for a subtropical climate in Queensland, Australia. The thermal performance of the systems was measured by calculating the impact of air temperature and air velocity on the room cooling performance using simulation. The inlet air velocity and air temperature was set at the pipe inlet to predict their effect on the room temperature. The simulation result shows the minimum temperature reductions of approximately 1.82°C and 1.02°C in the modelled room of vertical and horizontal earth pipe cooling system respectively. The result shows that the vertical earth pipe cooling system performs better than the horizontal earth pipe cooling system although there was no significant temperature reduction found for both the systems. The developed model was validated at the pipe inlet and different points of the room with the measured data. Further investigation is being undertaken in this study.

References

S.F. Ahmed is doing a PhD research on Passive Air Cooling in the school of Engineering and Technology at Central Queensland University, Australia. He is a Senior Lecturer at Prime University, Bangladesh. He received his M.Phil degree from the University of Rajshahi, Bangladesh in 2011. His research interests are in the area of Applied Mathematics, Fluid Mechanics and Sustainable Energy Technologies. He has published over 10 research papers including a book.