

Performance Analysis of a Proposed ‘Water Tube Heat Exchanger’ Space Cooling System in Kerala



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Increasing energy demand for domestic space cooling in Kerala, India, necessitates innovations in the passive systems. Earth tube heat exchangers (ETHE) are gaining popularity in the architectural practice of the region. Owing to the higher specific heat of water and the other underlying principles of the ETHE, there is a possibility of developing a similar system by replacing earth with water as the heat exchange medium. A conceptual water tube heat exchanger (WTHE) system was designed, which consists of a 45 m long PVC pipe staggered in an underground reinforced concrete rain water harvesting tank connected to a house. Performance of the system was assessed using the ‘Psychrometric Chart+Duct Calculator V4.3 simulation tool. Later, this system was developed on site and its performance was analysed. The simulation predicted a maximum difference of 4.7°C between the inlet and outlet air temperatures. However, a difference of 8.4°C was achieved by the proposed WTHE system built.

Keywords: sustainable energy systems, passive cooling, water tube heat exchanger

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ABSTRACT: Increasing energy demand for domestic space cooling in Kerala, India, necessitates innovations in the passive systems. Earth tube heat exchangers (ETHE) are gaining popularity in the architectural practice of the region. Owing to the higher specific heat of water and the other underlying principles of the ETHE, there is a possibility of developing a similar system by replacing earth with water as the heat exchange medium. A conceptual water tube heat exchanger (WTHE) system was designed, which consists of a 45 m long PVC pipe staggered in an underground reinforced concrete rain water harvesting tank connected to a house. Performance of the system was assessed using the 'Psychrometric Chart+Duct Calculator V4.3 simulation tool. Later, this system was developed on site and its performance was analysed. The simulation predicted a maximum difference of 4.7°C between the inlet and outlet air temperatures. However, a difference of 8.4°C was achieved by the proposed WTHE system built.

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INTRODUCTION

Increasing energy demand and rising energy prices have enabled a vast amount of research in areas related to energy. Earth tube heat exchanger (ETHE) is one of the significant realms where active studies are happening. The principle of the ETHE system lies on certain characteristics of soil. Soil has a high heat storage capacity and it transports heat slowly. These properties enable soil to carry over some heat from summer to winter, which can be extracted by means of ETHE [1]. Temperature of soil below three metres normally remains nearly constant throughout the year, compared to the corresponding surface temperature [2]. This property of soil, coupled with its high specific heat enables it to be a good medium for ETHE.

Both analytical as well as practical studies have been conducted to study and establish relations between the various factors affecting the process. Practical experiments have shown that the length and radius of the pipe, mass flow rate and the depth at which the pipe is buried are the major players in deciding the effectiveness of the ETHE system [3]. It has been proved that the material of pipe has the least effect on the performance [4]. The results of the simulation studies in EnergyPlus software are also in tune with the results of the site experiments [5].

A major drawback of ETHE earlier in being implemented in hot humid climates was the chances of condensation and mould-growth inside the pipes. However, this issue has been addressed and solved successfully by aligning the pipes in a gentle slope and providing weep-holes [3]. Another argument against the use of this system in hot humid climates is that the

subsurface temperature in these regions shows significant variations with seasons.

All the studies and discussions in this field yet are limited to soil as the exchange medium. It is true that soil has high specific heat. Also, the heat transfer capability of the soil is directly dependent on the presence of moisture [6]. It proves that water is highly responsible for the heat transfer in ETHE. This opens up a possibility of using water itself as a transfer medium instead of soil in this technology. The relatively low temperature of water in underground tanks has a hidden potential to be tapped. If given adequate grass cover or shade on the surface, water inside them might be able to resist any significant temperature change. In regions of hot humid summer, e.g. Kerala, India, where there are abundant water resources, there is an immense scope of incorporating heat exchangers with the existing rain water harvesting tanks, ponds or wetlands. One major advantage of this system is that it requires much less investment when compared to the conventional ETHE systems. The heat exchanger pipes can be immersed in an existing water body, which eliminates the need of trenching. Ease of locating leakage and maintenance is some of the many potential leverages of this method.

There has been a gradual increase in the summer temperature in this region from last 3 decades [7]. It could be read in relation with the increase in sales of air-conditioners in the whole of India from 2006, as mentioned in the World Bank report on residential power consumption in India [8]. The report projects power consumption by heating and cooling systems to nearly 50% of the total consumption in 2030 from the current 35%. This paper looks at the possibility of using a water tube heat exchanger as an alternative to the

conventional air-conditioning system in a residential building in Kerala, India. This study carried out the design of a water tube heat exchanger (WTHE) system proposed in relation to the local context and case. The potential cooling capacity was assessed initially by making use of the software called ‘Psychrometric Chart + Duct Calculator V 4.3’ and later, practically onsite. It is also aimed at finding out any other possible factors that would affect the performance of such a system.

GEOGRAPHICAL CONTEXT

The residence under this study is located in Central Kerala. This area receives an annual average rainfall of about 3,000 to 4,000 mm per annum, majority of which is obtained during the two rainy seasons spanning from June to November (Fig.1). According to the local climate data collected from the weather station at Centre for Water Resource Development and Management (CWRDM) campus at Calicut, the minimum average temperature in the coldest months (i.e. December and January) reaches approximately 21°C (Fig.2) [9]. The maximum temperature in the hottest months (i.e. March to May) goes around 37°C. These figures give a picture of the type of air conditioning required in the area. Winter heating is not at all a concern, while summer cooling is highly desirable.

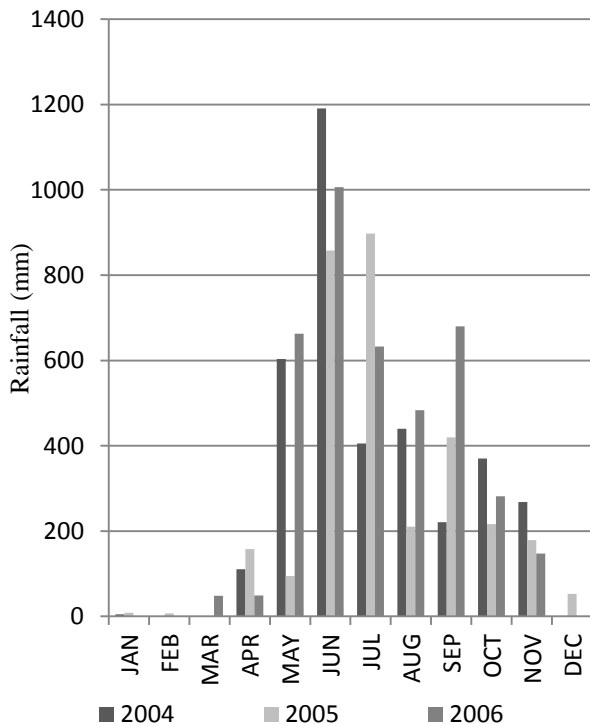


Figure 1: Monthly average rainfall data of Kerala for three consecutive years [9].

The western boundary of the state is Arabian Sea with around 575 km long coastal stretch and there are 44 rivers flowing within its geographical boundaries.

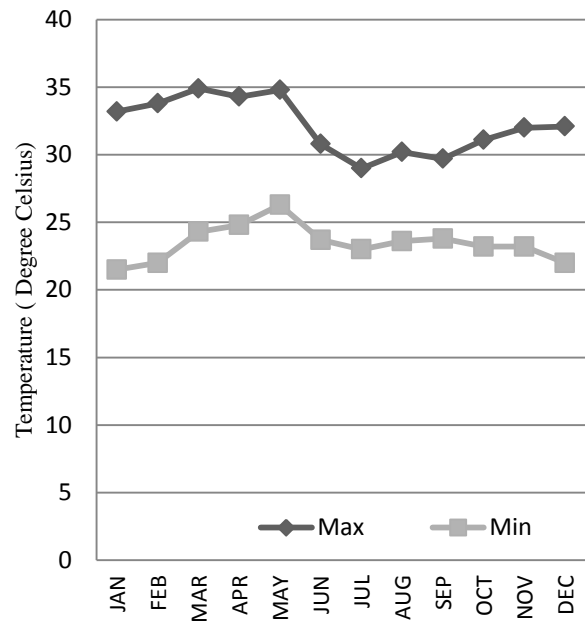


Figure 2: Monthly average maximum and minimum temperature of Kerala in 2005 [9].

Apart from them, the state is well known for its backwaters, canals and lakes. Many of the traditional houses have a pond and well associated to them. Monthly average relative humidity is between 65 and 85%. However, there are regions which are not typical to this, where there is shortage of water in summer. As a serious attempt to recharge the ground water resources, the state government has mandated the construction of a rain water harvesting tank system with every newly built residential building exceeding 100m² floor area (of capacity 25 litre per m² floor area).

PROFILE OF A SELECTED RAIN WATER TANK

A house in Central Kerala (i.e. Malappuram) was selected for the purpose of this study. An underground reinforced concrete rain water harvesting tank was constructed with this house during this summer. The topography of the site is generally hard with the typical red laterite common to this region. Dimensions of the water tank are 11m in length, 2.4m in width and 4.2m in depth. The tank can accommodate around 110,000 litres of water. The aim of the study is to design and develop an air-conditioning system for one room in the house. A 3.1m wide, 3.6m long and 3.3m high study room was chosen for investigation of the cooling performance of the proposed WTHE system.

Considering three air changes per hour, as per the Indian Standard Code for Ventilation in Buildings (IS: 3362-1996), the room of 36.83 m³ needs 110.48 m³ of fresh air per hour.

WTHE SCENARIO SETTING AND SIMULATION

Practical experiments conducted in Ahmedabad in 2004 [10] provides a detailed report on hourly variation of heating and cooling of their model of earth tube heat exchanger. The findings of their study are used as a starting point for developing a water tube heat exchanger in this paper. Their model performed well by cooling the space in the hot summer days of May. An output temperature of 27.2°C was achieved against an inlet temperature of 40.8°C and soil temperature of 26.6°C with the Co-efficient of Performance of 4.4 at the hottest time of the day.

A conceptual model for the selected room was developed, based on the Ahmedabad model, with some changes in material and configuration. A PVC pipe of 50mm in diameter and 2mm in thickness formed the 45m long heat exchanger, which will be immersed to the bottom of the rain water harvesting tank. In order to check the accuracy of the simulation, data from the Ahmedabad experiment report is fed in the Psychrometric Chart + Duct calculator V4.3. The result indicates an accuracy of 97%. Then, this software was used to predict the performance of the conceptual WTHE model proposed at an air velocity of 5 m/s. The simulation results show a temperature difference of 2.2 to 4.7 °C between the inlet and outlet air (Table.1).

Table 1: *T_i* – Inlet air temperature (monthly average high temperature) *T_w* – expected water temperature inside the tank, *T_o* – Outlet air temperature.

| Month | T _i | T _w | T _o | (T _i - T _o) |
|-------|----------------|----------------|----------------|------------------------------------|
| JAN | 32.9 | 27 | 29.4 | 3.5 |
| FEB | 33.9 | 27 | 29.8 | 4.1 |
| MAR | 35 | 27 | 30.3 | 4.7 |
| APR | 34.8 | 27 | 30.2 | 4.6 |
| MAY | 30.7 | 27 | 28.5 | 2.2 |

WTHE SYSTEM SITE ASSEMBLY

In view of the conceptual model studied, the WTHE system was actually built on site (Figs.3&4). The built system consists of nine 50 mm diameter PVC pipes with 2mm thickness. Each of the 5m long pipes was arranged parallel to one another, connected at its ends by means of standard elbow joints that make a duct of 45m in

length. This assembly was immersed in the bottom of the tank. In total, there are 10 elbow joints (Figs 5&6).



Figure 3: 3D model of the residence with the location of rainwater harvesting tank marked in a rectangle.



Figure 4: The tank as constructed on site.

During the time of the experiment, the tank had water only up to a height of 75cm from the bottom. One end of the pipe rose up through the slab 45 cm above the ground level to form the inlet. The other end was kept at a height just above the water level for the measurement purpose. A 500W household blower was used to blow air through the inlet. The air velocity was controlled by connecting a regulator to the blower. A laboratory thermometer was used to measure the temperatures. Inlet air temperature, water temperature inside the tank, and the outlet temperature were measured. A digital anemometer was used to measure the air velocity at the outlet.

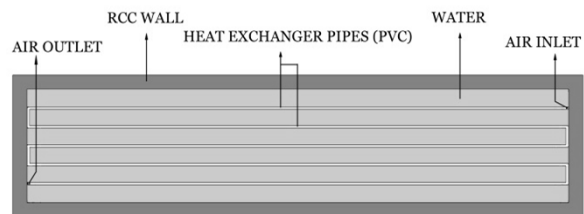


Figure 5: Plan of the tank and layout of pipes.

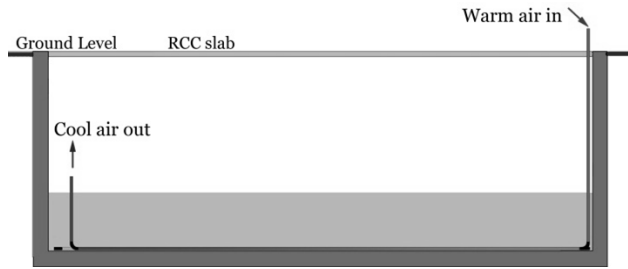


Figure 6: Section of the tank and layout of the pipes.

PERFORMANCE MEASUREMENT

Measurements at site were carried out 4 times a day, on 4 consecutive days in hot summer days in April. As tried in the simulation, air was blown at a velocity of 5 m/s in the duct, measured at the outlet. The temperature of air achieved at the outlet was almost the same as the temperature of the water (Table 2). There is a considerable disparity between the results of the simulation and site measurement.

Table 2: Temperatures measured at site for an air velocity of 5 m/s. T_i – Inlet air temperature (atmospheric temperature) T_w – water temperature inside the tank, T_o – Outlet air temperature

| Day | Time | Temperature | | | |
|-------|------|-------------|-------|-------|-----------------|
| | | T_i | T_w | T_o | ($T_i - T_o$) |
| Day 1 | 6am | 28.5 | 27.1 | 27.2 | 1.3 |
| | 2pm | 35.2 | 27.5 | 27.8 | 7.4 |
| | 6pm | 31.5 | 27.3 | 27.6 | 3.9 |
| | 10pm | 28.5 | 27 | 27.1 | 1.4 |
| Day 2 | 6am | 29.3 | 27.3 | 27.7 | 1.6 |
| | 2pm | 36 | 27.5 | 27.6 | 8.4 |
| | 6pm | 30.1 | 27.2 | 27.5 | 2.6 |
| | 10pm | 28 | 27 | 27 | 1 |
| Day 3 | 6am | 28 | 27 | 27 | 1 |
| | 2pm | 35.5 | 27.7 | 27.5 | 8 |
| | 6pm | 30.5 | 27.2 | 27.4 | 3.1 |
| | 10pm | 28.3 | 27.1 | 27.3 | 1 |
| Day 4 | 6am | 28.5 | 27 | 27.2 | 1.3 |
| | 2pm | 36 | 28 | 28.2 | 7.8 |
| | 6pm | 31 | 28 | 28.2 | 2.8 |
| | 10pm | 28.2 | 27.2 | 27.3 | 0.9 |

Air velocity was varied with the aim to analyse the corresponding temperature variation (Fig.7). In this study, the effect of noise was less of a consideration.

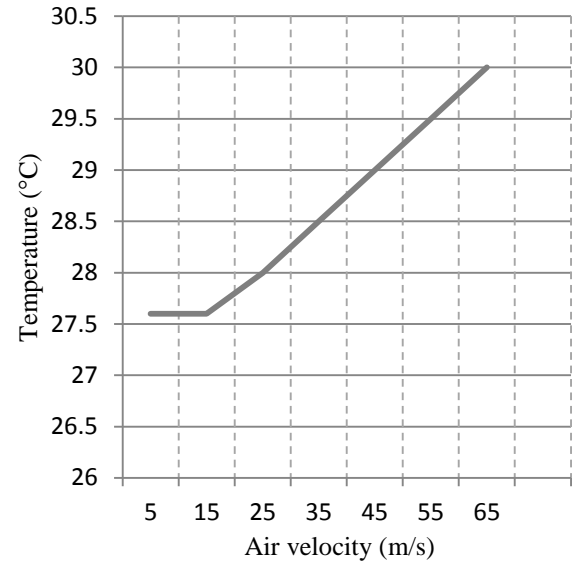


Figure 7: Graph showing the trend of temperature increase with increase in air velocity

CONCLUSION

The performance of the actual WTHE built model was far better than that of the simulation conducted earlier. The simulation predicted a maximum difference of 4.7°C between the inlet and outlet air temperatures. However, the actual difference in temperature achieved at site was as high as 8.4°C at the hottest time of the day. Moreover, no change in the outlet air temperature was observed throughout the system's continuous operation for 30 minutes. Also, in the built system measured, the outlet air temperature was close to the water one with the range of 0.1 to 0.4°C. This was not the case in the simulation.

In this study, the correlation between the system's duct air velocity and the associated noise was not measured. Also, the effect of the rain water tank concrete slab exposed to direct sunlight on the water temperature was less of a consideration. Furthermore, there was no thorough investigation on the chance of condensation inside the duct, which may lead to possible indoor air quality (IAQ) problems. One of the potential solutions for this IAQ issue could be dehumidification of the inlet air before it enters the duct. However, the in depth research on these problems needs to be carried out for advancement of this proposed WTHE system.

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