

Design, Construction and Performance Evaluation of Earth -to -Air Heat Exchanger for Room Cooling in Sokoto, Nigeria

*Sani Aliyu , *Muazu Musa and **Yahuza Abdullahi

*Department of Physics

Usmanu Danfodiyo University Sokoto

**Ahmadu Bello Academy

Sokoto

Nigeria

ABSTRACT

Tropical climate is characterised by high ambient temperatures and solar radiation, a combination of these factors causes thermal discomfort in buildings. With the rapid increase in population and economic growth of countries in the tropical regions, it is becoming inevitable that passive and low energy strategies must be used as suitable alternatives. Earth air heat exchanger (EAHX) is a subterranean ventilation system that explores soil temperature below the surface to pre-cool or pre-heat ventilation air. Performance of the earth air heat exchanger varies with climatic and soil condition of the area. In this research paper, an Earth air heat exchanger (EAHX) was designed, constructed and installed at Sokoto energy research centre, Usmanu Danfodiyo University, Sokoto, Nigeria, Its actual field performance was evaluated. The results suggested that the earth air heat exchanger alone is not sufficient to create thermal comfort, but can provide significant portion of cooling load. The average coefficient of performance (COP) in the hot season was obtained at 3.45 .The earth air heat exchanger was able to cool the hot ambient air by 4.5^oC during hot season.

Keywords: Heat exchanger, Coefficient of performance, Thermal comfort, Ventilation, Temperature.

1.0 INTRODUCTION

Air conditioning is the most widely used cooling system for indoor air in Nigeria. 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 greenhouse gas (GHG) emission.

Building cooling demand in Nigeria increased living standards in the developing world using non-climatically responsive architectural standards have made air conditioning quite popular. Importantly, this has increased energy consumption in the building sector. Actually there are more than 240 million air conditioning units and 110 heat pumps installed worldwide according to the International Institute of Refrigeration (IIR) (IIR, 2002). IIR's study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide (IIR, 2002).

However, Nigeria need to start considering alternative low energy (passive) cooling strategies and technologies that have potential to reduce energy consumption and cost associated with the use of air conditioning. Passive system have potential to reduce operational energy consumption for cooling buildings in the tropical climate help reduce rising energy demands and the associated greenhouse gas emission that is detrimental to the planet [1]

Earth to air heat exchanger (EAHX) is a device that enables transfer of heat from ambient air to deeper layers of soil and vice versa. Since the early exploration of its use in cooling commercial livestock buildings [2] there has been considerable increase in its application. Earth is used to condition the air in livestock buildings (Spengler and Stombaugh, 1983). It is use in North

America and Europe to cool and heat greenhouses [3]. This earth pipe cooling technology has been explored by many researchers and used by building designers as cooling means for various building types in temperate countries as well as hot and arid countries, where the results have been significant and positive Fabrizio *et al.*, (2011) Min, Z. (2004).

Bansal *et al.*, investigated the performance analysis of Earth to Air Heat Exchanger (EAHX) for summer cooling in Jaipur, India using 23.42 meter long and 2 to 5 m/s flow rate for steel and PVC pipes achieve cooling in the range of 8.0 to 12.7 °C, they showed performance of system is not significantly affected by the materials buried pipe instead it is greatly affected velocity of air fluid. They observed COP variation 1.9 to 2.9 for increasing 2 to 5 m/s [4].

Sanusi *et al.*, (2013) reported a field investigation of earth pipe cooling technology, conducted in international Islamic university Malaysia (IIUM), Gombak campus, kuala lumpur. It was found at 1m underground, the result is most significant, where the soil temperature is 6 °C and 90 °C lower than the maximum ambient temperature during wet and hot and dry season, respectively. It was also found energy plus simulation results correlate well with the field work [5].

Misra *et al.*, (2013) conducted an exhaustive parametric analysis on the performance of earth air heat exchanger (EAHX) also analyzed how in continuous operation performance degrades and devised a term “derating factor” to relate this degradation. Their results show a variation of 0 % to 64 % in derating factor which is caused by choosing different parameters like air velocity, pipes dimensions, depth, soils thermal conductivity [6].

This study is therefore aimed at designing, constructing and evaluating the performance of earth-air heat exchanger for room cooling in Sokoto and its environment using cooling test,

2.0 MATERIALS AND EXPERIMENTAL PROCEDURES

2.1 Materials

The earth-air heat exchanger was designed and constructed using: Galvanised steel pipes, T type thermocouples, 8- channel data logger, digital vane type anemometer, Blower Thermometers, Thermistor, Temperature auto scanner, Instruments used during the test measurements are digital vane type anemometer, T type thermocouples, thermistor with temperature auto scanner sensor.

1. Anemometer: Vane type anemometer was used for measuring the velocity of the air. A vane anemometer which uses a small fan is turned by air flowing over the vanes. The speed of the fan was measured by a revolution counter and converted to a wind speed by an electronic chip. Hence, volumetric flow rate may be calculated if the cross-sectional area is known.
2. Thermistor: it was used for measuring the temperature of the air. It has 1.5g mass and operating temperature range – 25 to 100⁰ C.
3. Temperature Auto Scanner: It displays the temperature encountered by the thermistor attached with the instrument.

2.2 Experimental Procedures

2.2.1 Pipe Depth Selection

The ground temperature is defined by the external climate and by the soil composition, its thermal properties and water content. The ground temperature fluctuates in time, but the amplitude of the fluctuation diminishes with increasing depth of the tube, and deeper in the ground the temperature converges to a practically constant value throughout the year. On the basis of temperature distribution, ground has been distinguished into three zones [7].

- Surface zone: This zone is extended up to 1m in which ground is very sensitive to external temperature.
- Shallow zone: This zone is extended up to 1-8 m depth and temperature is almost constant and remains close to the average annual air temperature.
- Deep zone: This zone is extended up to 20 m and ground temperature is practically constant.

As the pipe depth increases, the inlet air temperature decreases, indicating that the earth air heat pipe should be placed as deeply as possible, however, the trenching cost and other economic factors should be considered when installing earth air heat pipes. Deeper positioning of the pipes ensures better performance. Typical depths were 1 m to 1.5 m. The pipes were positioned under the building or in the ground outside the building foundation [8].

The depth of the buried pipes used was 1 m. The depth of the pipe required to cool the air generally varies depending upon on the geography of the experimental set – up.

2.2.2 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 Length can typically range from 10 m to 100 m longer pipes correspond to more effectiveness systems, but the required fan power and the cost also increase [8]. In this research 200 cm was taken for the inlet and 350 cm for the outlet pipe considering cost implications..

2.2.3 Tube Materials Selection

The main considerations in selection tube material are cost, strength, corrosion, resistances, and durability. Tubes made of concrete, metal, plastic, and other materials have been used. Simulations indicate tube materials have little influence on performance. Increasing the conductivity of the tube to a value corresponding to that of aluminium increased total heat transfer by less than 10%.

2.2.4. Pipe Diameter Selection

As the pipe diameter increases, the earth air heat exchanger 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 air heat exchanger pipe 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 [8].

2.2.5 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. Therefore flow rate of 11 m/s was used in these experiments.

Table 1.1 Parameters Used In The Construction And Their Specifications

Parameters	Specifications
Specific heat capacity of air	1007Jkg ⁻¹ k ⁻¹
Thermal conductivity of soil	0.540Wm ⁻¹ k ⁻¹
Mass flow rate of air	0.0975kg/s
Velocity of air	11m/s
Volumetric flow rate of air	0.0863m ³ /s
Thickness of pipe	5mm
Length of inlet pipe	200cm
Depth of buried pipes	1m
Diameter of pipe	3cm
Number of pipes buried in parallel connections	22
Energy input into the heat exchanger	300W
Length of outlet pipe	350cm
Space between the pipes buried in parallel connections	5cm

2.3 Theoretical Considerations

The thermal performance of the EAHX system can be estimated in terms of the coefficient of performance COP. Coefficient of performance (COP) is one of the measures of heat exchanger efficiency. It is defined as a ratio between the cooling capacity of EAHX, Q_s, and the power consumption of the blower/fan, that is,

$$COP = \frac{Q_s}{P_f} \dots\dots\dots 1$$

According to (ASHRAE, 1985) the thermal performance of the earth to air heat exchanger can be evaluated as

$$COP = \frac{Q_{out}}{W_{in}} \dots\dots\dots 2$$

$$Q_{out} = MaCp(T_i - T_o) \dots\dots\dots 3$$

Where; Q_s = Total cooling of Earth to air heat exchanger (W), P_f = Power Consumption of the blower/fan (W), Q_{out} = Total Cooling (W), W_{in} = Energy use by blower

Ma = Mass flow rate of air through the pipe (kg/s) , Cp = Specific heat capacity of air (J/kg.k), T_i = inlet temperature of air ($^{\circ}C$) , T_o = outlet temperature of air ($^{\circ}C$)

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

$$q = KA \frac{dT}{dx} \dots\dots\dots 4$$

Where:

q = The rate of heat transfer. k = Thermal conductivity of the material, A = Cross section of the pipe, dT = The change in temperature, dx = Thickness of the pipe

$\frac{dT}{dx}$ = Temperature gradient

3.0 RESULTS AND DISCUSSION

3.1 Cooling Test

The earth to air heat exchanger system was operated for seven hours a day for three consecutive days. The tube air temperatures at the inlet, outlet and soil temperature at 1m depth were noted at the interval of one hour. System was turned on at 10:00 am and shut down at 5 pm. Tests were carried out in the three days. The ambient temperature on these three days was very similar. The results of the three days were therefore average as indicated. The ambient temperature started with $31.3^{\circ}C$ at 10.00 am and rose to a maximum of $40.8^{\circ}C$ at 2pm. The temperature of air at outlet was $26.8^{\circ}C$; as the system started and rose only slightly to $27.2^{\circ}C$ at which it stayed through the 7 hour of test run. The outlet temperature was just above the basic temperature $26.6^{\circ}C$ at 1m depth, suggesting that the tube was exchanging heat quite effectively.

Energy input into the heat exchanger is the energy used by the blower (300W). In the first hour of operation the ambient air temperature rose from $31.3^{\circ}C$ to $33.7^{\circ}C$. The mean of this work out $32.5^{\circ}C$. we shall assume this to be, T_i , during this first hour. The coefficient of performance (COP) for cooling test was calculated by the equation:

$$COP = \frac{M Cp (T_i - T_o)}{Power\ input} \dots\dots\dots 5$$

$$= 0.0975 \times 1007 \times (32.5 - 26.8) / 300$$

$$= 1.9$$

Hourly, value of the coefficient of performance (COP) was 1.9 at the start, rising to a maximum of 4.5 at 2 pm when the ambient temperature was at peak. Mean value of COP over the test run 7 hour is 3.45.

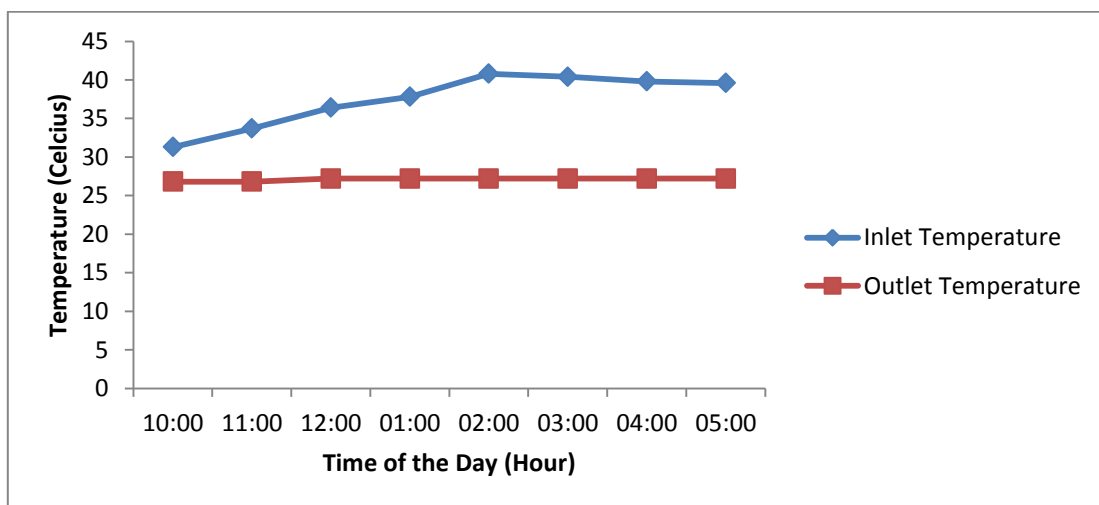


Figure 1.1: Variation of inlet and outlet temperatures with time for the cooling test

Figure 1.1: presents a comparison between the inlet and outlet temperatures during the cooling mode test in the summer day time. What is apparent from the figure 1.1 is that peak cooling exists when temperature is at its highest value. The inlet temperature started at 31.3°C at 10:00 am then increased to a maximum of 40.8°C then declined to become 39.6°C at 5:00pm .The outlet temperature was 26.8°C to 27.2°C with an average temperature of 30.9°C and a peak 27.2°C. The maximum different between the inlet and outlet temperatures was 13.6°C and the minimum was 4.5°C.

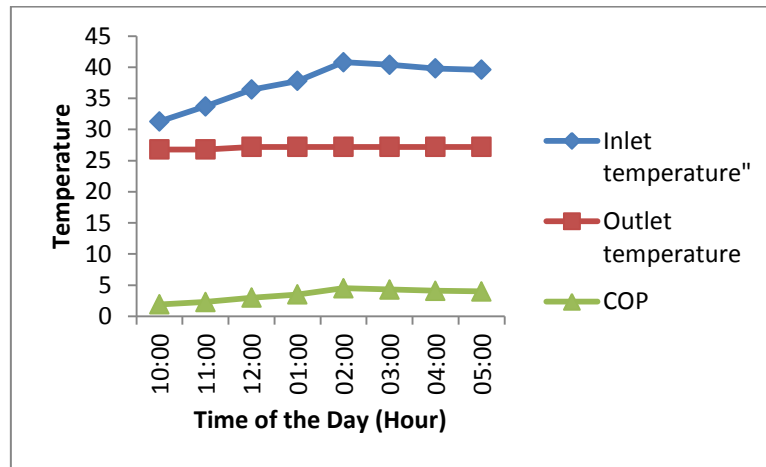


Figure.2.2 Comparison of inlet, outlet temperatures and coefficient of performance during cooling test;

Figure.2.2. shows comparison of inlet, outlet temperatures and coefficient of performance during cooling test; results from figure 4.2 shows a 23°C difference between outlet temperature and coefficient of performance and difference of 8°C between inlet and outlet temperatures.

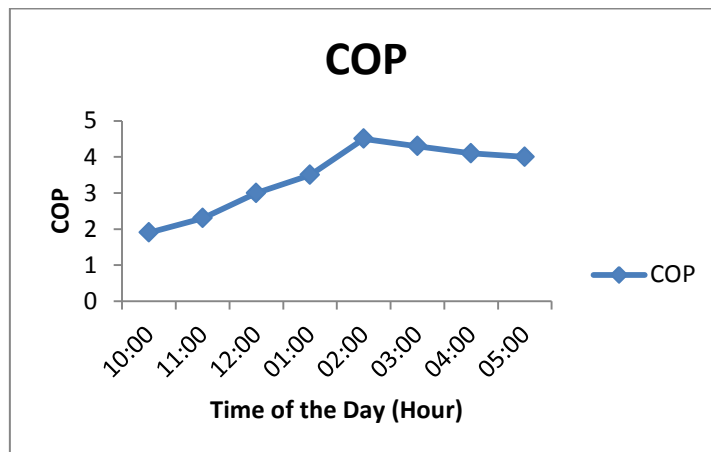


Fig.3.3: variation of coefficient of performance with time for cooling during hot summer days

The final cooling coefficient of performance during high ambient temperatures, where cooling is greatly needed is shown in figure 3.3. During these periods the value of coefficient of performance attained by the system for the cooling tests at high temperature was 4.5.

4. CONCLUSION

Based on the obtained results, it can be stated that the earth air heat exchanger (EAHX) design, constructed and tested in this work holds considerable promise as means to cool ambient air for variety of applications such as in office buildings. It can also concluded that though the system alone is not sufficient to cool or heat as conventional air condition , but can provide significant portion of heating/cooling load to provide thermal comfort.

The earth to air heat exchanger system designed was able to create cooling by temperature drop up 1.9 - 4.5°C in hot season. It was observed that the maximum cooling was obtained when the ambient air temperature was maximum. That is when the ambient air was 40.8°C; the room air temperature was recorded to be 27.2°C.

It was also observed that the coefficient of performance of the earth air heat exchanger system increased with time during cooling test and the system coefficient of performance depends greatly on the increased of ambient air temperature on hot season.

The design of an earth air heat exchanger mainly depends on the cooling load requirement of a building to be conditioned.

Various factors such as tube length, tube diameter, airflow rate, tube material, tube depth, tube arrangement affect the performance of earth to air heat exchanger which needs to be optimized to maximize the system performance effectiveness.

It is also environmentally friendly as it uses natural air and has no emission or release of hydro- chlorofluorocarbon (HCFC) and chlorofluorocarbon (CFC) which are detrimental to the environment.

4.2 RECOMMENDATIONS

- Though the results of the cooling performance were found to be encouraging it is recommended to have a more control strategy in the operation of the system.
- To couple the system with conventional air conditioning system for good thermal comfort of the building's interior, as a supplementary cooling method.
- The earth air heat exchanger is not in wide use in tropical regions, as a passive cooling/heating system; hence it is here by recommended for more applications in the field

REFERENCES

1. Ahmed, A., Gidado, K. (2008). The Use of Earth-to Air Heat Exchanger for Improving Building Comfort Conditions in the Tropical Climate.pg 1-7.
2. Scott,,N.R., Persons, R.A., and Kohler, T.A. (1965). Analysis and Performance of an Earth Tube Heat Exchanger. *ASAE Paper* No.65 – 840.
3. Santamouris, M., Mihalakakou, G., Balaras, G., Argirious, A., Asimakopoulos, D.,Vallindras,M. (1996). Use of Buried Pipes for Energy Conservation in Cooling of Agriculture Greenhouses. *Solar Energy*, (2), 111 – 24.
4. Bansal, V., Misra, G., Agrawal, G., and Muthur, J. (2010). Performance Analysis of Earth to Pipe Heat Exchanger for Summer Cooling. *Energy and Building*, 42, 645 – 648.
5. Sanusi, A., Shao, L., and Ibrahim, N., (2013). Passive Ground Cooling System for Low Energy Buildings in Malaysia (Hot and Humid Climates), *Renewable Energy*, 49, 193 –196.
6. Misra, R., Bansal, V., Agrawal, G., Mathura, J., and Aseric, T. (2013). Transient Analysis Based Determination of Derating Factor for Earth Air Tunnel Heat Exchanger In Summer. *Energy and Buildings*, 58, pg 103 – 110.
7. Popie, C., Wojtkowiak, J., and Biernaka, B. (2001). Measurement of Temperature Distribution In Ground. *Experimental Thermal Fluid Science*, 25, 301 – 309.
8. Thevenard, D. (2007). Bibliographic Research on the Potential of Earth Tube: Numerical Logic Inc. Waterloo, Canada.
9. International Institute of Refrigeration (2002). Industry as a Partner for Sustainable Development Refrigeration, Report Published by Paris, France.