Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 25 No. 2-2020
ISSN:1813-1786 (Print) 2313-7770 (Online)

Earth-Tube System to Control Indoor Thermal Environment in Residential Buildings

T.A. Khan[1], K.Shabbir,[2] M. M. Khan[3], F.A, Siddiqui[4], M. Y. R. Taseer[5], S. Imtiaz[6]

[1,2,3,4,5,6] *Bahauddin Zikria University, Multan, Pakistan*

[4] Farrukh.siddiqui@bzu.edu.pk

Abstract- Earth-Tube systems are used in residential buildings as a passive heating & cooling technique to reduce the over-all active energy utilization in buildings. The Earth-Tube systems tend to warm up the residential buildings during winter & cool them down in summer, using the temperature difference phenomenon between the atmosphere and beneath the earth surface. Seasonal variations in temperature drop off with depth and disappear below 4 to 5 m due to thermal inertia. This research through experimental study, explored the use of earth–air heat exchanger (EAHE) system in an economic way to control indoor air temperature by using local materials. An EAHE was built near the meeting room of Department of Architectural Engineering and Design, University of Engineering & Technology, Lahore, Pakistan. Outdoor and indoor day-time temperature was recorded for seven days in the month of May and June. On average, system was able bring the indoor temperature to 30°C as compared 40°C outdoor. Efficiency of EAHE system was determined as 88% which can be considered as more than acceptable. Payback period analysis was conducted on the data based on cooling the room with air-conditioning alone and with air-conditioning and EAHE system together. It was found that the EAHE system will payback its installation amount in less than six years through electricity saving. The research is highly significant keeping in view Pakistan's severe energy crises and environmental issues arising from fossil fuels to produce electricity. The research finding will be helpful to introduce a cost effective environmentally friendly non-hazardous tubing system and will provide necessary guideline for Architect and Engineers to implement this passive thermal controlling technique in residential entities.

Keywords- Earth-Tube, Thermal, Heating, Cooling, Building.

I. INTRODUCTION

The status of energy for the survival of our society is well known. Thus, it is vital and urgent to find substitute sources to replace conventional fuel or at least reduce its consumption to decrease its detrimental impact on environment. This kind of energy is infinite and can be found and exploited likewise well [1, 2]. Currently, air conditioning is not only widely used for industrial productions but also for the ease of inhabitants too. It can be attained proficiently by vapor compression machines. Though, the reduction of the ozone layer and global warming caused by chlorofluorocarbons (CFCs) and the necessity to lessen the high grade energy consumption have all resulted in several alternative practices[3, 4]. One such method is earth–air heat exchanger (EAHE) system, which can be employed to decrease the cooling load of buildings in summer. These heat exchangers comprise single or multiple tubes in parallel, through which air or fluid is passed following an inlet to outlet channel. The tubes are placed approximately 3 m to 5 m deep inside earth surface that tends to heat down the flowing air or fluid in winter and cools it down in summer. Cooling the outdoor air through buried pipes by means of an EAHE has the potential to provide comfort to building's inhabitants [5, 6]. The significant feature of EAHE is to classifying the sites in terms of accessible geology. This classification not only involves the soil type but also its physical and thermal properties (i.e. diffusivity, density, thermal conductivity etc.), ground water's depth and also the depth of bedrock.

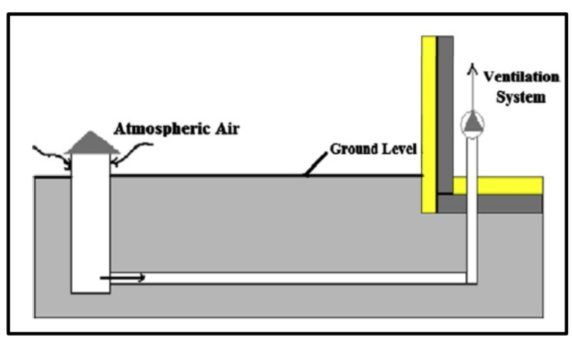


Figure 1: Earth–air heat exchanger (open loop system)

This information is helpful for the designer for selecting the type of EAHE system for its employment and in system's design [7-13]. There are two major types: i.e. 'open-loop' (i.e., sucking outside air by the pipes to ventilate the building) as shown in Figure 1 or 'closed-loop' (Figure 2) (i.e. re-circulating air through earth tubes from building)[1].

A case study conducted to inspect the gradient of ground temperature along with performance of EAHE in Burkina Faso. Experiments were performed at burial depth of 0.5, 1.0 and 1.5 m respectively. It was observed that about 7.6°C decrease in outdoor temperature could be achieved for 25 m long EAHE buried at depth of 1.5 m through a ventilator of 95 m^3/h capacity. The lowest underground temperature was recorded at the day time when the outdoor temperature was highest [14]. In another study, the examination of thermal performance of ground heat exchanger in summer conditions of Tehran, Iran was conducted. It was noted that system was capable to efficiently replace the conventional system of air-conditioning [15]. Analysis of an EAHE on experimental and numerical grounds revealed that it could reduce the usage of conventional energy through the use of soil's thermal energy for heating and cooling of built environments [16]. Energy efficient cooling of domestic building by utilizing the combined geothermal tube process and the chimney operated by solar means was studied. It was observed that extended geothermal tube process with a length greater than the 20m necessarily be employed to supply suitable thermal conditions [17]. Use of appropriate pipe layout can significantly reduce the initial capital cost and land area requirement for the EAHE. It can be settled that if EAHE system is fitted with proper design strategies, can result in a clean and cost-effective method for building cooling/heating with substantial power savings[18].

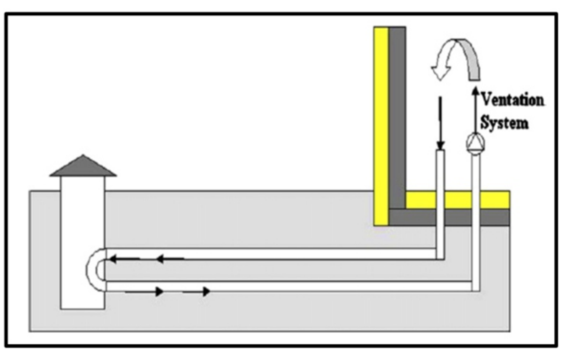


Figure 2: Earth–air heat exchanger (closed loop system)

In developing countries, the principal operators that guided to the high growth rate in the renewable energy market over the past twenty years comprise not only the exorbitant increase in the price of crude oil, dwindling fossil reserves, widening energy deficit, but also the lavish lifestyle of consumers of energy. Almost one-third of total primary energy is used for space cooling and heating. Renewable and passive systems can reduce the building cooling and heating energy demand. [19, 20]. Lahore is a city in Punjab province of Pakistan and is the country's second-most populous city after Karachi with a population of 6,310,888. It is located 31.55 latitude and 74.34 longitudes, and it is situated at elevation 224 meters above sea level (Figure 3). Average monthly temperature and precipitation are shown in Figure 4. May and June are the hottest months, where average monthly temperature in daytime rises up to 40°C. In these months maximum day time temperature reaching 46°C is very common which requires air-conditioning for long hours to achieve comfort level for the inhabitants. Unfortunately, electricity shortage in Pakistan is increasing every year (Figure 5). Furthermore, as mentioned earlier use of conventional fuels is very harmful to the environment. This situation demands to explore environmental friendly solutions to bridge the gap between the supply and demand. One solution is to use earth–air heat exchanger (EAHE) system in residential buildings as a passive heating and cooling technique to reduce the over-all active energy utilization in buildings. In this regard, this is the first study of its kind in Pakistan to check suitability and efficiency of EAHE system for the city of Lahore. For this purpose, an EAHA closed loop system was built for the meeting room of Department of Architectural Engineering and Design, University of Engineering & Technology Lahore, Pakistan. After the system was built the temperatures were recorded in the month of May, which is one of the two hottest months in Lahore.

Figure 3: Location of Lahore

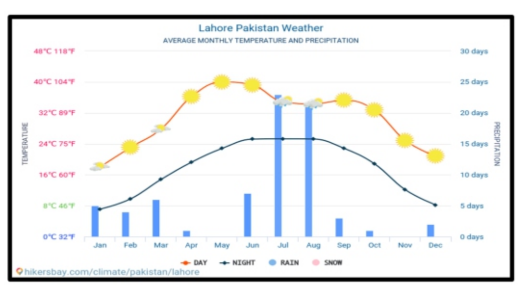


Figure 4: Lahore monthly temperatures 2015 – 2019
Ref.: http://hikersbay.com/climate/pakistan/lahore?lang=en

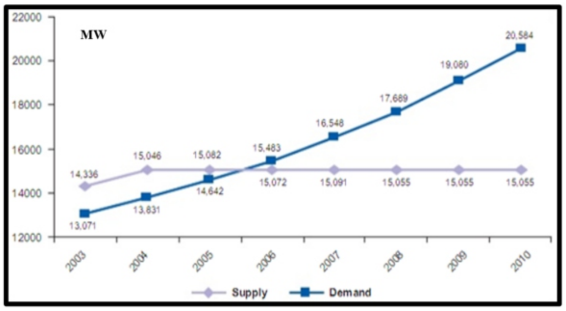


Figure 5: Energy crisis in Pakistan
Ref.:https://noorpower.pk/News/Energy-Crisis-In-Pakistan.aspx

II. Materials and Method

Selection of materials is the foremost functions of productive engineering design because this decides the success of the plan in terms of commercial and cost-effective aspects. In material selection, orderly approach is important to choose the suitable materials for specific application. First this is necessary to carefully brief the utilization demands in the terms of environmental, mechanical, thermal and chemical characteristics. Then choices are reduced by process of the elimination. Progression methods also have huge importance in the choosing of the suitable material. The real efficiency of the specific material under several circumstances may change from what was expected. Following are factors to be considered in proper selection of materials:

(a) Competitive advantage and cost
(b) Design flexibility
(c) Environmental impact
(d) Durability
(e) Corrosion
(f) Functional properties
(g) Manufacturing properties

The detail of components (materials) of EAHE system is as under:

A. Air Tubes / Pipes

The nearby air is extracted through the tubes laid at a specific depth; gets warmed in the cold and vice versa in the summer. In this process, heating and the cooling rate of any building can be minimized passively. The outside air is thrown by using the length of underground air tubes heat interchangers, where the heat gain or the heat loss happens via convection and then to some amount; conduction between earth and air. As the result, the going air gets either chilled or warmed relying on the temperature of soil. As a result, the air in outlet can straight be used for the heating or the cooling with enough air velocity to give end user the thermal comfort.

The material of a pipe can be anything from thin wall 'sewer' plastic, metal or concrete. The reliability of an underground pipe is linked to following parameters:

(a) Soil thermal diffusivity
(b) Air temperature of Inlet
(c) Velocity of the Air
(d) Thermal Conductivity
(e) Price
(f) Corrosion
(g) Thermal conductivity of pipes
(h) Durability
(I) Pipe length, width
(j) Ease of Installation
(k) Temp. of earth at the depth of installed exchanger

Available options for earth air tubes are:

(a) Copper Pipes
(b) Stainless Steel Pipes (SS-Pipes)

Table 1: Properties of different pipes-materials (by suppliers)

Property	Copper Pipes	SS-Pipes	GI-Pipes	RPSR-Pipes	RPPR-Pipes	PVC-Pipes
Thermal Conductivity (W/m K)	386	45	31	0.50	0.33	0.19
Cost (Rs/ ft.)	560	440	215	60	60	35
Susceptible to Corrosion	No	No	Yes	No	No	No
Durability under earth	Yes	Yes	No	No	No	Yes
Ease of Installation	Yes	Yes	Yes	No	No	Yes

(c) Galvanized Iron Pipes (GI-Pipes)
(d) Rubber Polymer Steel Ringed Pipes (RPSR-Pipes)
(e) Rubber Polymer Plastic Ringed Pipes (RPPR-Pipes)
(f) Polyvinyl Chloride Pipes (PVC-Pipes)

The comparison among properties of the above pipe-materials is given in Table 1.

Copper pipes (Figure 6) were chosen though the most expensive due to its highest thermal conductivity which is the most important requirement. Higher thermal conductivity of pipes allows the air to become cooler when it passes through the pipes buried in the ground, as the transfer of heat between air and soil is fast and increases its resistance against corrosion.

Figure 6: Copper pipes

B. Insulation Sheets & Pipes

Insulation is basically done over pipes to protect them and to prevent them from losses like heat gain and condensation or frost formation on water. Rubber insulation was done on exposed pipes. While poly vinyl chloride (PVC) pipe insulation is done over rubber insulation because it is light weight, cost effective, chemical resistant and low maintenance is required (Figure 7).

Figure 7: PVC Pipe Insulation over Rubber Insulation

C. Fan Canopy

In EAHE; stainless steel fan canopy was used with inner dimensions of 12” x 12” for installation of fan unit. Dimension remains consistent till 6” and then tapers down (tapering length is 12”) to 2” for installation of copper pipe with it. So, in this way canopy reaches overall length of 18”.

D. Blower & Fan Unit

Fan and blower system used in EAHE system were procured locally. Blower had silicon steel motor, with 100% pure copper winding and designed for both high and low speed.

E. Site layout, excavation and installation

Before an installation of an Earth Tube System, layout of a site (outside the sub entrance which lies adjacent to meeting room of Department of Architectural Engineering & Design, Design, University of Engineering & Tech. Lahore)

Figure 8: Pipes laid in the pit

was done to mark the location of a proposed Earth tube system planned to install in a building.

A pit was excavated outside the sub entrance (which lies adjacent to Faculty room) of Department of Architectural Engineering and Design. Pit was 12 feet long, 12 feet wide while its depth was 15 feet.

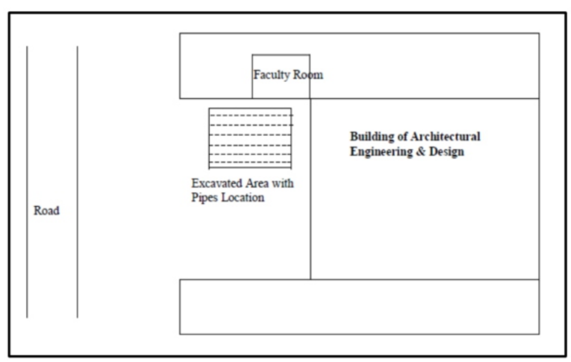


Figure 9: Site with excavated area

First, six copper pipes were cut to ten feet, and then they were all joined in a U-shaped pattern (placing parallel) by using pre-fabricated copper joints, also a one feet long copper pipe was attached on either side of ten feet

ISSN:1813-1786 (Print) 2313-7770 (Online)

long copper pipe with pre-fabricated copper joints (Figure 8). Silicon was used over connecting point on every copper pipe for preventing air infiltration. Further tape sealing was done. Two pipes were vertically placed; one as inlet while other as outlet.

Blower was installed at the outlet at 9 feet ceiling level while fan at the inlet at 1 foot from finish floor level so basically total difference of level was 8 feet. Specifically, air is sucked by means of a fan or a passive system providing adequate pressure difference from the ambient which enters the building through the buried pipes. Due to ground properties the air temperature at the pipe outlet maintains moderate values all around the year. Temperature fluctuates with a time lag (from some days to a couple of months) mainly relative to the depth considered.

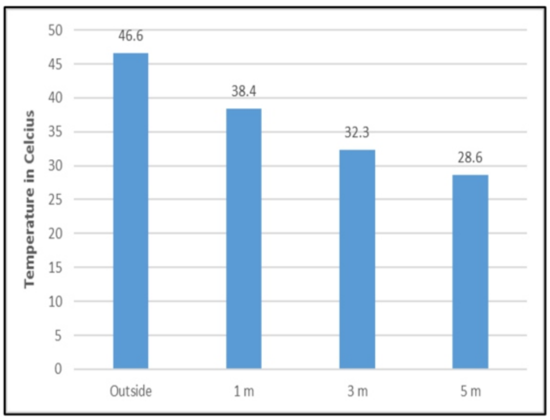


Figure 10: Temperature variation with depth below NSL

Copper pipes laid in ground (Figure 9) uses the heat storing capacity of earth so when air is blown into outlet, warm air will be taken at approximately 40° C then it will go to earth tubes and temperature will be lowered to approximately 26° C, then it would be sucked by fan installed at inlet to enter the air into the room.

III. Results and Discussion

Before backfilling after installation of earth tube system, temperature was recorded at different depths on May 28, 2017 using atmospheric thermometer. The temperature record is given in Figure 10. Indoor and outdoor temperature was recorded for six days i.e. 30 and 31 May, 1, 23, 25 and 26 June 2017. The variation of indoor and outdoor temperature with time for these days is given in Figure 12. Figure 12 provides time variation of the six-day average temperatures.

From Figure 10 (a) the first reading of temperature was recorded at 10:30 AM. At that time the difference in outdoor and indoor temperature was 3.4°C. As the day progressed, the outdoor temperature was increased and reached to 43.2°C at 3:30 PM (probably the hottest time of the day). But as the EAHE system started working the indoor temperature started to decrease and reached to 29.6°C at 3:30 PM. The increase in the outdoor temperature and decrease in indoor temperature resulted in continuous increase in temperature differential. The maximum temperature difference was observed at 3:30 PM i.e. 13.6°C. It is worth mentioning here that indoor temperature of 29.6°C at 3:30 PM can be considered as very comfortable compared to 43.2°C outdoor. Similar trend can be seen from the graphs drawn for the recorded temperature for 31 May, 1 June and 23 June. The next two days (25 and 26 June) the weather was rainy; thus, the outdoor temperature was reduced. Consequently, the temperature difference between outdoor and indoor was decreased. For these two days the maximum differential is around 6°C.

Figure 11 shows the average temperature for recorded six days. The average maximum temperature differential was determined as 11.1°C at 3:30 PM. The EAHE system was switched on 10:30 AM, had this been working earlier than this the maximum temperature differential would have been attained before 3:30 PM. Thus, if EAHE systems runs for longer hours a temperature of 30°C and less can be maintained inside the room.

Results exhibited that the EAHE could deliver a reduction of 1700W in the peak cooling load, with an indoor temperature decrease of 2.8°C during middle of July. The EAHE has the potential for reducing cooling energy demand in a typical house by 30% over the peak summer season –[5]. Experimental results showed that the room air temperature during winter was found 5–15°C higher as compared to ambient air temperature while lower during summer months[21].

A. Efficiency of EAHE System

After collection of data it is very important to calculate the efficiency of an earth tube system. After recording indoor and outdoor temperature for six different days with different time intervals, their average was calculated to find efficiency of the proposed system as explained below. The efficiency of EAHE system can be worked out by using the expression as under:

$$\eta = \frac{T_o - T_o(\mathrm{L})}{T_o - T_s}$$

$$= \frac{(35.667\ - 29.45)\mathrm{x}100}{(35.667\ - 28.6)}$$

$$= 87.9\%$$

where:

T_o	=	Average Outlet Air temperature
$T_o(L)$	=	Average Inlet Air temperature
T_s	=	Undisturbed Soil temperature

A total length of nearly 130 ft of pipe is a good compromise and by using tube length more than 200 ft, the cooling energy reduction becomes negligible. Air flow rate of 200 m^3/h is recommended when the efficiency of the system is 85%[22].

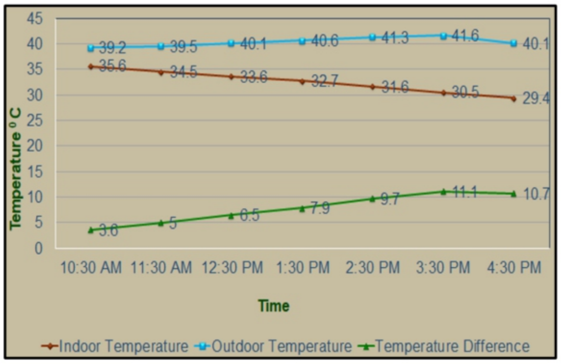
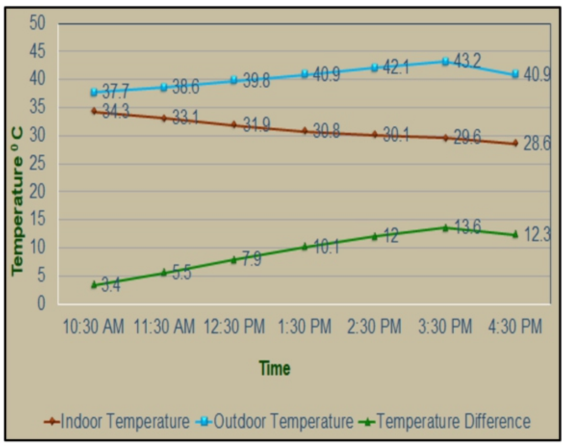
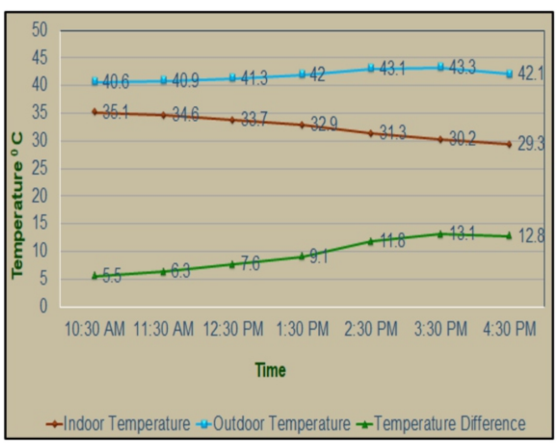


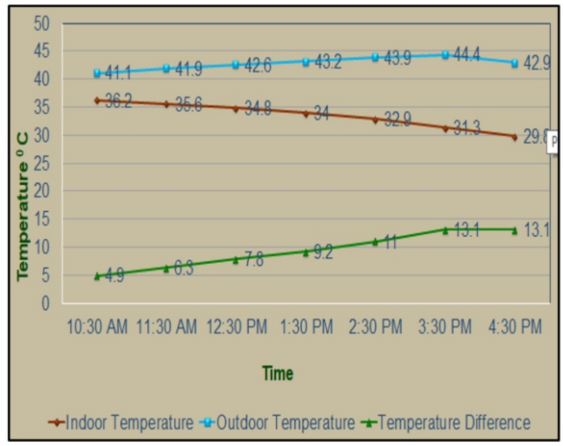
Figure 11: Variation of indoor and outdoor average temperature



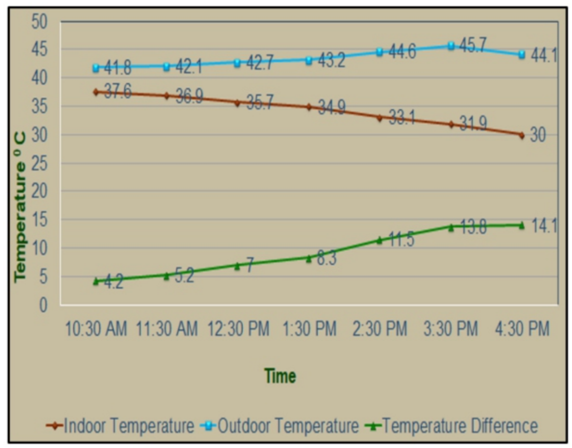
(a)



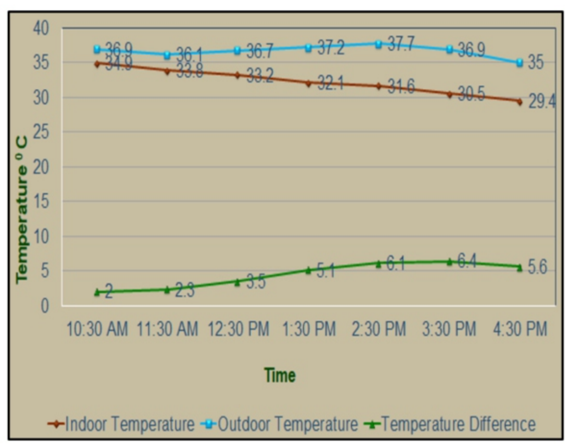
(b)



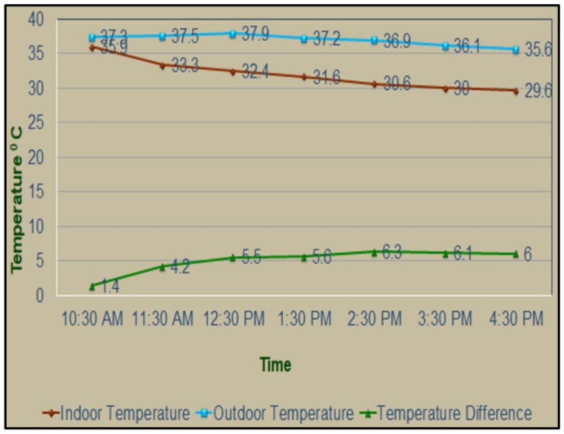
(c)



(d)



(e)



(f)

Figure 12: Variation of indoor and outdoor temperature with time: (a) 30 May; (b) 31 May; (c) 1 June; (d) 23 June; (e) 25 June; (f) 26 June

Table 2: Electricity consumption calculation

Appliance	Quantity	Wattage (Watts)	Hours	Energy Consumed (Quantity x wattage x hours) / 1000 kWH	Rate / kWH	Energy Consumed/day x Rate / kWH)
AC	01	7032	1.3	9.1416	15	Rs. 137.124
Blower / Fan	01	110	2.0	0.22	15	Rs. -3.3

B. Payback Period of EAHE System

The payback period is an evaluation method employed to assess the amount of time required for a project to pay back the initial investment in the project. For this purpose, on 30 July and 31 July the room was cooled with air-conditioning alone and air-conditioning plus EAHE system (hybrid) respectively. In both cases the indoor temperature was brought to 25°C. The summary of the data and calculations (Table 2) are as under:

Case-I:
Using Air-Conditioner (AC) only:
Time taken by AC to achieve 25 °C = 2 hr. 31 mins.

Case-II:
Using both EAHE & AC:
Time taken by AC to achieve 25 °C = 1 hr. & 13 mins.
Time taken by EAHE to achieve 25°C = 2 hrs.
Difference in time to achieve 25°C=1 hr. & 18 mins. =1.3 hr.
Total Cost Incurred on the Project = Rs. 139,000/=
Payback time in Days = 139,000/133.824
= 1038.678 days
Payback time for 6 Months of
AC utilization = 34.622 Months
Payback time in Years = 5.770 years (say 6 years)

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on study conducted the following conclusions can be drawn:

i. The efficiency of the installed EAHE system, with Copper tubes 2" diameter, gauge-18 & tube length 120 ft (tube surface area 62.8 ft^2) is 88%, which is fairly acceptable being a passive cooling technique.
ii. The installed system efficiency proves that 29.5 ° C of indoor temperature can be achieved within 4 to 6 hr., which can act as base temperature for working of air-conditioner, making it a hybrid system.
iii. The analysis of payback period of EAHE system reviled that the initial cost can be recovered in about six years' time.

Finally, some recommendations are made as follows:

i. It is recommended that Building Controlling Authorities in various cities of Pakistan may formulate their Byelaws for introducing ETS for energy savings in residential buildings.
ii. Engineers & Architects may carry out study on effect of soil type on performance of earth tube system.
iii. It is recommended to study the EAHE System's efficiency for winter season.

REFERENCES

[1] Bisoniya, T.S., A. Kumar, and P. Baredar, *Experimental and analytical studies of earth–air heat exchanger (EAHE) systems in India: a review.* Renewable and Sustainable Energy Reviews, 2013. 19: p. 238-246.

[2] Jakhar, S., et al., *Thermal performance investigation of earth air tunnel heat exchanger coupled with a solar air heating duct for northwestern India.* Energy and Buildings, 2015. 87: p. 360-369.

[3] Bansal, V., et al., *Performance analysis of earth–pipe–air heat exchanger for winter heating.* Energy and Buildings, 2009. 41(11): p. 1151-1154.

[4] Bansal, V., et al., *Performance analysis of earth–pipe–air heat exchanger for summer cooling.* Energy and Buildings, 2010. 42(5): p. 645-648.

[5] Al-Ajmi, F., D. Loveday, and V.I. Hanby, *The cooling potential of earth–air heat exchangers for domestic buildings in a desert climate.* Building and Environment, 2006. 41(3): p. 235-244.

[6] Kumar, R., S. Ramesh, and S. Kaushik, *Performance evaluation and energy conservation potential of earth–air–tunnel*

system coupled with non-air-conditioned building. Building and environment, 2003. 38(6): p. 807-813.

[7] Milun, S., T. Kilic, and O. Bego, *Measurement of soil thermal properties by spherical probe.* IEEE transactions on instrumentation and measurement, 2005. 54(3): p. 1219-1226.

[8] Kersten, M.S., *Laboratory Research for the Determination of the Thermal Properties of Soils*. 1949, Minnesota univ Minneapolis engineering experiment station.

[9] De Vries, D., *Thermal properties of soils. In van Wijk, WR (ed.) Physics of Plant Environment*. 1963, North-Holland Publishing Co., Amsterdam.

[10] DeVries, D.A. and N.H. Afgan, *Heat and mass transfer in the biosphere*. 1975: Scripta book company.

[11] Becker, B.R., A. Misra, and B.A. Fricke, *Development of correlations for soil thermal conductivity.* International Communications in Heat and Mass Transfer, 1992. 19(1): p. 59-68.

[12] Chen, Y., M. Shi, and X. Li, *Experimental investigation on heat, moisture and salt transfer in soil.* International communications in heat and mass transfer, 2006. 33(9): p. 1122-1129.

[13] Yu, M., et al., *A simplified model for measuring thermal properties of deep ground soil.* Experimental Heat Transfer, 2004. 17(2): p. 119-130.

[14] Woodson, T., Y. Coulibaly, and E.S. Traoré, *Earth-air heat exchangers for passive air conditioning: Case study Burkina Faso.* Journal of Construction in Developing Countries, 2012. 17(1): p. 21-32.

[15] Khalajzadeh, V., M. Farmahini-Farahani, and G. Heidarinejad, *A novel integrated system of ground heat exchanger and indirect evaporative cooler.* Energy and Buildings, 2012. 49: p. 604-610.

[16] Vaz, J., et al., *Experimental and numerical analysis of an earth–air heat exchanger.* Energy and Buildings, 2011. 43(9): p. 2476-2482.

[17] Maerefat, M. and A. Haghighi, *Passive cooling of buildings by using integrated earth to air heat exchanger and solar chimney.* Renewable Energy, 2010. 35(10): p. 2316-2324.

[18] Agrawal, K.K., et al., Effect of different design aspects of pipe for earth air tunnel heat exchanger system: A state of art. International Journal of Green Energy, 2019. 16(8): p. 598-614.

[19] Agrawal, K.K., et al., A review on effect of geometrical, flow and soil properties on the performance of earth air tunnel heat exchanger. Energy and Buildings, 2018. 176: p. 120-138.

[20] Singh, R., et al., Recent advancements in earth air tunnel heat exchanger (EATHE) system for indoor thermal comfort application: A review. Renewable and Sustainable Energy Reviews, 2018. 82: p. 2162-2185.

[21] Chel, A. and G. Tiwari, Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate. Energy and Buildings, 2009. 41(1): p. 56-66.

[22] Oudjehani, N., et al. Evaluation of earth-air heat exchangers efficiency in hot and dry climates. in Advanced Materials Research. 2013. Trans Tech Publ.