Thermal Performance of an Adobe Structure Integrated with an Earth-Air Heat Exchanger: An Experimental Study

Ashish Shukla*, G.N. Tiwari and M.S.Sodha
*Centre for Energy Policy and Economics, Swiss Federal Institute of Technology, Zürichbergstr. 18, CH-8032, Zürich, Switzerland.
ashish.physik@gmail.com, ashukla@ethz.ch

ABSTRACT

In this paper an attempt has been made to study annual thermal performance of an adobe structure with an effective area of 53 m^2 located at solar energy park at Indian Institute of Technology Delhi, New Delhi ($28^0\ 35'\ N, 77^0\ 12'\ E$), India. Such houses are suitable for rural areas for various reasons e.g. storage of grains, low energy consumption, thermal comfort, made by local materials and environmental friendly. Experiments have been conducted during June 2004-May 2005 to measure hourly variation of room air temperature of room with an earth-air heat exchanger, untreated room and room with cross ventilation. Hourly variation of solar intensity, ambient temperature, inlet-outlet temperature of an earth-air heat exchanger has been measured. Analysis has been done by calculating average and maximum\minimum temperature of each room in each month. It has been found that room equipped with an earth-air heat exchanger gives best comfort among all other. It is seen that temperature of room with an earth-air heat exchanger is 6.5 ^oC more and 3.0 ^oC less than temperature of untreated room in December and May month. Experimental uncertainties for December and May for room with an earth-air heat exchanger have been found out 11.9 and 3.0 % respectively.

Keywords: Adobe structure, earth-air heat exchanger, India

1. INTRODUCTION

The adobe structure is constructed by using low energy intensive materials like adobe, soil and sand etc. Houses made from soil-based materials have been called by various names; adobe and cob are terms often used to describe sun dried clay materials (Bansal, 1994). Adobe is a Spanish word derived from the Arabic "atob", which literally means sun dried bricks. Adobe is one of man's first building materials. Tassinari et. al. (2007) has carried out detailed study on rural built environment. According to the United Nations an estimated 30 % of the world population still lives in houses constructed using unbaked bricks (Alva, 2001). The mass of adobe walls will absorb heat and radiates it back out into the house at night. In the summer the converse is true. Thus the swing in temperature inside the house is very mild. Adobe construction in combination with good passive solar design and techniques makes for an effective energy-saving solution in cold winter and hot summer areas. Luisa and Batty (2006) have carried out a detailed study which has shown effect of various factors on the thermal performance of adobe construction. The effect of wall thickness, thermal conductivity, and heat capacity has been studied by Givoni and Katz (1985).

In the last few decades the use of energy stored in the ground for heating/cooling of buildings and greenhouses has been received an increasing importance (Fahriye, 1976, Desmukh, 1991, Sodha et al., 1993, Jacovides et al., 1996, Swahney and Mahajan, 1996, Ghosal et. al., 2008). The use of energy stored in ground requires knowledge of the ground temperature profile (Khatry et al., 1978, Mihalakakou et al., 1997). An integrated method has been developed (Santamouris et al., 1995) to calculate the contribution of an earth-air heat exchanger to reduce the cooling load of the buildings. The soil can be used for heating/cooling of building in two ways; (i) direct method (by partial or total placing of building envelope in direct contact with the soil) and (ii) indirect method (by the use of buried pipe through which air from indoor or outdoor of building is circulated) (Thanu et al., 2001). The use of an earth-air heat exchanger in modern architecture for space heating/cooling has been reported frequently (Koronakis et al., 1989, Tombazis et al., 1990, Shukla et al., 2006). The conditioning of air as it flows through buried pipes has been studied by various researchers (Claeson and Dunanad, 1983, Bau, 1984, Arimilli et al., 1986, Sodha et al., 1994). The ground can be used as natural sink for round the year use. Thus the earth provides low cost alternative source of energy for heating and cooling purpose. In the present study the indirect method has been used for the use of energy stored in the ground. A detail analysis for the thermal performance of adobe structure has been divided in three sections:

(i) room with an earth-air heat exchanger,
(ii) untreated room and
(iii) room with cross ventilation, has been carried out.

No such work is reported so far which can give exact knowledge of thermal performance of adobe structure coupled with an earth-air heat exchanger and its comparison with untreated and cross-ventilated room. It has been found that use of an earth-air heat exchanger increases and decreases temperature of room significantly with comparison to untreated room during winter and summer vice versa. Thus integration of an earth-air heat exchanger is very useful for creating thermal comfort.

2. WORKING PRINCIPLE

The high thermal mass of adobe walls of house will absorb heat and radiates it back, out into the house at night. In the summer the converse is true. Thus the swing in temperature inside the house is very mild. One room of adobe structure is coupled with an earth-air heat exchanger. The energy stored in earth is used for either heating or cooling of living room by the use of an earth-air heat exchanger. Energy exchange between the earth around buried pipes and blowing air take place resulting in increased and decreased outlet temperature in winters and summers respectively. The velocity, density and specific heat of air have been considered as 13 m/s, 1.17 kg/m^3 and 1007 J/kg ^oC respectively.

3. EXPERIMENTAL SET-UP

The roofing system of the adobe house is spanned by nubian vaults. The adobe house consists of three-vault type structure. Figure 1a shows the photograph and schematic diagram of adobe house. The length, breadth and central height of vault structure are 6.0 m, 2.9 m and 3.65 m. In the first vault structure an earth-air heat exchanger is coupled, whereas, middle vault structure is with cross ventilation and third vault structure is untreated. Various design parameters have been given in Table 1.In north side of adobe house land area of $12m \times 7m$ is used for burying the PVC pipes at 1.5 m depth. Initially three lanes of $11m \times 0.6m$ have been digged up to 1.5 m. Distance between two consecutive lanes is $2.6m$ and distance between two pipes in a lane is $0.3m$. After this PVC pipe of length $78m$ and $0.06m$ diameter is buried in three lanes (Fig. 2a). Soil having density 2050 kg/m^3, specific heat 1840 J/kg ^{o}C, thermal conductivity 0.52 W/m ^{o}C is being filled up to surface of earth. Two ends of pipe are opened inside adobe house for suction and delivery of air (Fig. 2b). Proper insulation is made for pipe which is exposed in air to avoid heat transfer between flowing air in pipes and ambient. Experimental setup consists of blower, computer with data logger and thermocouples.

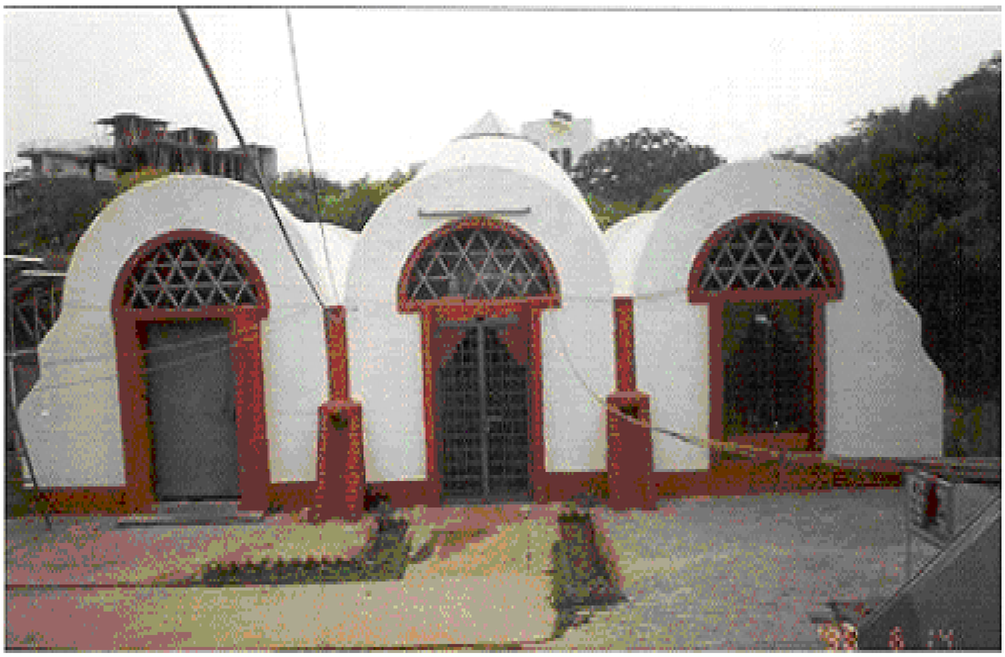

Figure 1a. Photograph of adobe house.

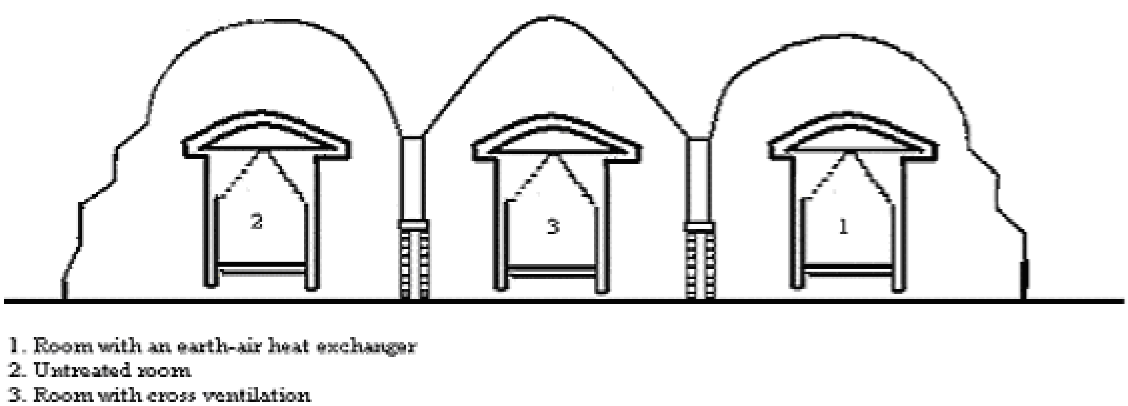

Figure 1b. Schematic diagram of adobe house.

Table 1. The following specifications have been used for various components of the building

Foundation:	Plain cement concrete (1:5:10) with brick bats as coarse aggregate
Plinth:	Burnt brick masonry with 1:4 cement mortar
Damp roof:	2.5 cm thick plain cement concrete with 0.25 cm dia coarse aggregate
Walls:	stabilized soil block (1 cement: 6 sand: 25 soil) masonry with soil cement mortar (1 cement: 6 sand: 20 soil)
Vault:	Abode (1 cement: 8 sand: 32 soil) masonry with mud mortar (1 cement: 8 sand: 30 soil)
Exterior finish:	mud-cow dung mortar (1 sand: 1 soil: 1 cow dung)
Interior finish:	white wash with slaked lime

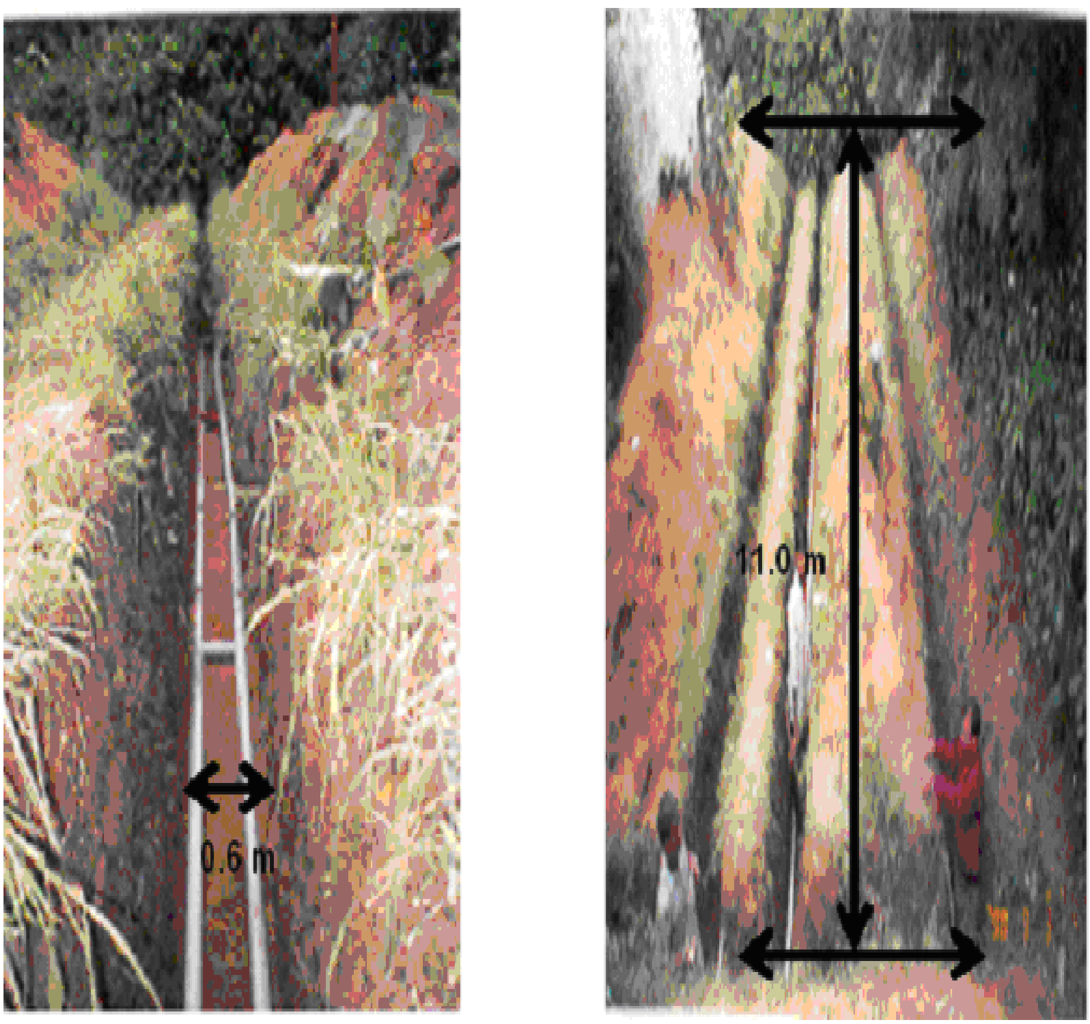

Figure 2a. Construction view of an earth-air heat exchanger

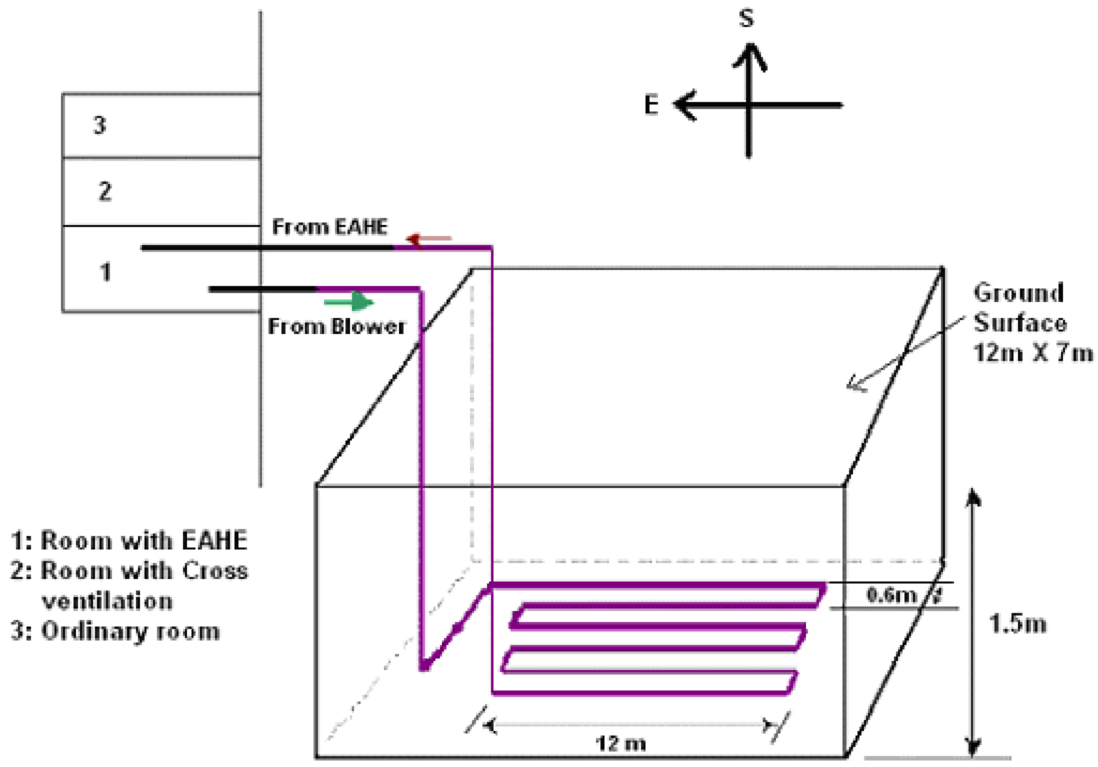

Figure 2b. Schematic diagram of adobe house integrated with an earth-air heat exchanger

4. EXPERIMENTAL PROCEDURE

4.1 The Measurements

Experimental work consists of the measurement of room air temperature and humidity of room with an earth-air heat exchanger, untreated room and room with cross ventilation and ambient temperature have also been measured. Monthly averages values of these measurements are given in Table 2 and 3.

4.2 Instrumentation

Measurement of temperature is done by T type of thermocouples (least count 0.1°C.). All thermocouples are calibrated by standard zeal thermometer. These thermocouples are attached to data logger and we get display in computer. A portable digital anemometer (least count 0.1 m /s.) has been used to measure the velocity.

Table 2. Hourly average values of ambient temperature during June 2004 –May 05

Time	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
01:00	12.0	17.0	21.0	26.0	28.0	32.0	29.5	30.5	28.3	29.1	16.9	11.0
02:00	11.2	16.0	20.5	26.0	27.0	31.0	29.4	30.0	28.0	29.3	16.0	10.0
03:00	11.2	15.5	20.0	25.0	27.0	30.0	29.3	29.5	28.0	29.1	15.7	10.0
04:00	11.0	15.0	20.0	25.0	26.0	30.0	29.3	29.2	28.0	28.8	15.5	10.0
05:00	11.0	15.0	19.5	24.5	26.0	29.5	28.8	29.2	28.0	28.7	15.4	09.0
06:00	10.5	14.5	19.5	24.0	26.0	29.3	28.6	29.2	28.0	28.6	14.5	09.0
07:00	10.7	14.0	19.2	24.0	26.0	29.5	28.4	29.9	28.4	28.6	15.0	10.0
08:00	10.0	15.5	21.0	27.0	30.0	28.0	27.5	29.5	28.6	26.6	15.0	12.0
09:00	12.0	16.0	21.0	30.0	31.0	28.5	28.9	29.8	29.0	27.3	17.5	16.0
10:00	13.0	16.5	22.5	30.0	31.5	29.1	29.1	30.0	29.5	29.2	19.5	18.0
11:00	13.5	17.5	24.0	31.0	33.0	34.0	28.9	31.3	30.8	29.5	20.0	19.0
12:00	14.5	18.5	25.0	33.0	34.0	35.0	32.0	31.6	31.5	30.0	20.5	20.0
13:00	14.5	19.0	26.0	33.0	35.0	36.0	34.0	32.0	32.0	30.5	21.0	20.0
14:00	15.5	19.5	26.5	33.0	35.0	36.0	34.0	32.0	32.8	30.5	21.7	20.0
15:00	15.5	20.0	26.0	35.0	35.0	37.0	34.0	32.5	34.0	30.0	21.9	19.0
16:00	15.5	20.0	26.5	35.0	35.0	37.0	34.0	32.2	33.6	29.7	21.5	19.0
17:00	14.8	19.5	25.5	34.0	34.5	37.0	33.0	31.6	33.6	29.5	20.2	15.0
18:00	14.0	18.5	25.0	32.0	34.0	37.0	32.0	31.3	32.0	29.1	19.0	14.0
19:00	14.0	18.0	24.5	30.0	32.0	35.0	30.0	31.1	32.0	28.5	19.0	14.0
20:00	13.5	18.0	23.5	29.0	31.0	35.0	29.6	31.0	29.3	28.4	18.3	14.0
21:00	13.0	17.5	22.5	29.0	30.0	34.0	29.5	31.0	29.0	29.1	18.1	13.5
22:00	13.0	17.5	22.5	28.0	29.0	34.0	29.7	31.0	28.6	29.2	17.5	13.0
23:00	12.2	17.5	22v	27.0	29.0	32.0	29.7	30.8	28.5	29.3	17.2	13.0
24:00	12.0	17.0	21.5	27.0	28.0	32.0	29.6	30.8	28.5	29.1	17.0	09.5

Table 3.1 Hourly variation of room air temperature of room with cross ventilation June 2004 – May 05

Time	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
01:00	09.1	14.0	17.6	22.0	28.0	27.9	28.5	27.1	27.9	20.5	12.4	11.2
02:00	08.6	13.0	16.9	21.5	27.8	27.7	28.0	27.0	27.3	20.5	12.3	10.1
03:00	08.5	12.9	16.7	21.0	27.2	27.4	28.0	26.5	26.9	20.5	12.0	10.1
04:00	08.5	12.5	16.5	20.0	26.7	27.4	27.0	26.3	26.2	20.0	12.0	09.1
05:00	07.5	12.2	16.2	20.0	26.6	27.2	27.0	26.1	26.1	19.5	11.9	08.2
06:00	07.5	11.2	16.0	21.0	27.9	27.5	27.2	26.1	25.7	20.0	12.0	08.6
07:00	07.5	10.5	16.5	21.0	27.7	27.8	27.5	26.5	25.6	21.0	12.5	10.4
08:00	07.2	12.5	19.2	26.0	29.0	29.1	29.0	26.3	24.5	23.7	13.5	11.5
09:00	08.5	13.0	21.0	31.0	30.6	30.9	30.0	27.6	25.8	25.7	16.5	15.3
10:00	11.5	15.5	23.0	34.0	30.7	32.0	31.0	28.0	27.1	27.6	18.8	17.9
11:00	12.0	18.4	24.5	35.0	33.1	34.8	32.5	29.0	29.0	29.0	21.0	19.8
12:00	15.5	19.3	26.8	36.0	35.3	38.2	34.2	29.6	30.3	29.9	24.0	21.5
13:00	16.2	19.7	27.5	37.0	38.0	40.3	36.0	30.3	32.3	31.0	23.6	23.4
14:00	17.2	20.3	27.7	38.0	40.3	41.5	35.7	31.3	34.9	31.3	24.0	23.1
15:00	17.1	21.0	29.0	37.5	41.5	41.5	35.0	31.9	33.1	30.2	23.3	23.0
16:00	15.9	21.0	29.0	37.0	40.4	40.6	35.0	31.5	32.6	29.7	22.5	22.6
17:00	14.6	20.0	29.5	35.0	39.7	40.0	33.9	30.6	31.7	28.0	20.8	19.6
18:00	13.5	18.5	25.5	35.0	37.8	37.2	33.0	29.5	31.9	26.1	17.9	16.2
19:00	12.4	17.5	23.7	34.0	35.2	34.7	32.2	28.9	31.6	25.0	15.6	14.2
20:00	12.0	16.3	21.0	32.0	33.5	32.2	30.5	28.1	30.4	23.5	14.6	14.1
21:00	11.5	15.6	20.0	29.0	32.7	30.5	29.5	28.0	29.9	22.4	13.8	13.2
22:00	10.7	15.7	19.0	26.0	30.4	29.3	29.2	28.0	29.9	21.8	13.3	13.2
23:00	10.5	14.7	19.2	25.0	29.9	28.7	29.0	27.4	29.0	21.5	12.9	12.7
24:00	09.8	14.5	18.5	23.0	29.2	28.1	28.5	27.6	28.3	20.7	12.7	12.5

Table 3.2 Hourly variation of room air temperature (^oC) of ordinary room June 2004 –May 05

Time	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
01:00	14.0	19.0	25.0	33.0	33.5	34.0	34.0	32.0	30.0	30.2	19.5	14.0
02:00	14.0	19.0	24.7	33.0	33.5	34.0	34.0	32.0	29.5	30.7	19.5	12.0
03:00	14.0	19.0	24.5	33.0	33.5	34.0	34.0	32.0	29.5	30.5	19.5	12.0
04:00	14.0	18.2	24.0	33.0	33.5	34.0	33.0	32.0	29.5	30.3	18.2	12.0
05:00	13.5	17.5	24.0	32.5	33.0	33.0	33.0	32.0	29.0	30.2	17.5	12.0
06:00	13.0	17.5	24.0	32.0	33.0	33.0	33.0	32.0	29.0	30.0	17.5	12.0
07:00	13.0	17.5	23.7	32.0	33.0	34.0	33.0	31.5	29.0	29.8	18.0	12.0
08:00	12.5	17.5	23.0	31.0	32.0	33.0	32.0	30.5	29.0	27.3	18.5	12.0
09:00	12.7	17.2	23.5	31.5	32.0	33.0	33.0	30.5	30.0	28.0	19.0	14.0
10:00	13.5	17.5	23.5	32.0	33.0	33.0	33.0	30.5	30.0	28.3	19.5	14.0
11:00	13.7	18.0	23.5	32.0	33.0	33.5	33.5	31.5	31.0	28.9	19.5	15.5
12:00	14.0	18.2	24.5	33.0	33.0	33.5	33.5	32.25	32.0	29.2	20.0	16.7
13:00	14.2	18.5	25.5	33.0	34.0	34.0	33.5	32.5	32.5	29.5	20.5	17.3
14:00	14.7	18.7	26.2	34.0	35.0	34.0	33.5	33.0	34.2	29.8	21.0	17.8
15:00	15.0	19.5	27.0	34.0	35.0	35.0	34.0	33.3	33.7	30.2	21.5	18.2
16:00	15.5	19.5	28.0	34.0	35.0	35.5	34.0	33.3	33.5	30.5	21.0	18.2
17:00	15.5	19.5	27.5	34.0	36.0	36.0	34.0	33.0	33.5	30.8	20.5	18.0
18:00	15.0	19.5	26.5	34.0	35.0	36.0	34.5	32.9	32.8	30.1	20.0	16.0
19:00	15.0	19.5	26.2	34.0	35.0	36.0	34.5	32.9	31.0	30.0	20.0	15.0
20:00	14.5	19.5	26.0	34.0	35.0	36.0	34.5	32.5	30.8	29.8	20.0	15.0
21:00	14.5	19.5	25.5	33.5	35.0	35.5	34.0	32.5	30.2	30.5	20.0	15.0
22:00	14.5	19.5	25.0	33.5	35.0	35.5	34.0	32.5	30.2	30.4	20.0	14.0
23:00	14.5	19.5	25.0	33.0	34.0	35.5	34.0	32.5	30.0	30.3	20.0	14.0
24:00	14.5	19.2	25.0	33.0	33.5	34.5	34.0	32.0	30.0	30.3	20.0	14.0

Table 3.3 Hourly variation of room air temperature (^oC) of room with an earth-air heat exchanger during June 2004 –May 05

Time	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
01:00	18.0	21.0	26.0	32.0	33.0	34.0	31.5	30.6	29.3	28.0	22.2	18.5
02:00	18.0	20.7	25.7	32.0	33.0	33.8	31.0	30.5	29.0	28.0	22.2	18.5
03:00	18.0	20.5	25.2	32.0	32.5	33.6	31.0	30.0	28.8	28.0	22.2	18.5
04:00	17.0	20.5	25.0	31.5	32.5	33.3	31.0	30.0	28.8	27.5	22.0	18.5
05:00	17.0	20.5	25.0	31.5	32.5	26.3	31.0	30.0	28.5	27.5	21.0	17.0
06:00	16.0	20.5	25.0	31.0	32.0	29.6	31.0	30.0	28.7	27.4	21.0	17.0
07:00	16.0	20.2	25.0	31.0	32.0	33.2	31.0	30.4	28.7	27.8	21.0	17.0
08:00	13.5	17.5	23.0	31.0	30.5	32.6	32.0	29.5	28.9	26.0	19.0	12.0
09:00	14.7	18.0	23.5	31.0	31.5	32.7	32.0	29.9	29.0	26.0	19.5	15.0
10:00	15.5	18.5	23.7	31.5	32.0	32.7	32.0	30.2	29.0	27.0	20.0	15.0
11:00	16.0	19.2	24.5	32.0	32.5	33.1	32.5	30.8	30.5	27.0	21.0	16.0
12:00	16.2	19.5	24.7	32.0	33.0	33.1	32.5	31.3	31.0	28.0	21.0	18.0
13:00	16.7	20.0	25.2	32.5	32.5	33.6	32.5	31.5	31.5	28.5	22.0	20.0
14:00	16.7	20.0	25.5	32.5	32.5	33.7	32.5	32.0	32.3	29v	22.0	21.0
15:00	17.0	20.2	26.0	32.5	32.0	34.0	33.0	32.2	33.0	29.0	22.0	21.0
16:00	17.8	20.7	26.7	32.5	34.0	34.1	33.0	31.5	33.0	29.5	23.0	21.0
17:00	18.0	20.7	27.0	32.2	34.0	34.4	32.5	31.5	33.0	29.8	22.9	21.0
18:00	18.0	21.0	26.5	32.5	35.0	34.8	32.5	31.5	30.0	29.6	22.3	20.0
19:00	17.8	20.7	26.5	32.5	34.0	34.6	32.0	31.5	29.9	29.4	22.2	19.0
20:00	17.7	21.0	26.2	32.0	34.0	34.4	32.0	31.6	29.6	29.0	22.5	19.0
21:00	17.7	21.0	26.2	32.0	34.0	34.3	32.0	31.5	29.6	29.0	22.5	19.0
22:00	17.7	21.0	26.0	32.0	33.5	34.3	32.0	31.4	29.4	29.0	22.5	19.0
23:00	18.0	21.0	26.0	32.0	33.5	34.3	32.0	31.3	29.4	29.0	22.2	18.0
24:00	18.0	21.0	26.0	32.0	33.0	34.3	31.5	30.7	29.3	28.4	22.2	18.5

5. MATHEMATICAL FORMULATION

5.1 Heating/Cooling Potential of an Earth-Air Heat Exchanger

A quasi steady state mathematical model (Shukla et al., 2006) has been used for prediction of outlet air temperature and heating/cooling potential of an earth-air heat exchanger.
The out let temperature at $x = l$; where l is the length of pipe of earth-air heat exchanger.

$$T_{fo} = T_o\left(1 - e^{-\frac{2\pi r h_c}{\dot{m}_a C_a} l}\right) + T_{fi}\, e^{-\frac{2\pi r h_c}{\dot{m}_a C_a} l} \qquad (1)$$

Heating/cooling potential for an earth-air heat exchanger is given by:

$$Q_{\frac{h}{c}} = \sum \dot{m}_a C_a \left(T_{fo} - T_{fi}\right)\Delta t \qquad (2)$$

5.2 Internal and External Uncertainty

The estimation of internal uncertainty (Nakra and Chaudhary , 1991) has been carried out for the experiment. Following expression has been used for estimation of internal uncertainty:

$$U_I = \frac{\sqrt{\sigma_1^{\,2} + \sigma_2^{\,2} + \cdots + \sigma_N^{\,2}}}{N} \qquad (3)$$

where σ is the standard deviation and is given as

$$\sigma = \sqrt{\frac{\sum \left(X - \overline{X}\right)^2}{N_0}}$$

where $X - \overline{X}$ is deviation of observation from the mean.
N & N_0 are number of sets and number of observations in each set.
The per cent uncertainty is given by the following expression:

$$\%\ \text{Uncertainty} = \frac{U_I}{Average\ of\ total\ number\ of\ observation} \times 100 \qquad (4)$$

External uncertainty has been evaluated by considering the chances of error that have been occurred in measurement of radiation, temperature and velocity of air .It is based on least count of the instruments used for measuring these parameters. Total percent experimental uncertainty is therefore sum of internal and external uncertainty.

5.3 The Confidence Level (CL)

CL=100× (1 - alpha)% (5)

or in other words, an alpha of 0.05 indicates a 95 percent confidence level. Where, the ‘alpha’ is the significance level (SL) used to compute the confidence level. The significance level has been considered to be the least count of instrument in the present work.

5.4 Confidence Interval (CI)

If we assume alpha equals 0.05, we need to calculate the area under the standard normal curve that equals (1 - alpha), or 95 percent. This value is ± 1.96. The confidence interval is therefore:

$$CI = \bar{x} \pm 1.96\left(\frac{\sigma}{\sqrt{n}}\right) \tag{6}$$

The confidence interval is a range on either side of a sample mean. Confidence interval is magnitude of the effect and interval within which the true values almost certainly lies.

5.5 Degrees of Freedom

The deviations of observations (n) from their sample average must sum to zero. This requirement, that $\sum(y-\bar{y})=0$, (here y is sample observation and $\bar{y}$ is sample average), constitutes a linear constraint on the deviations. It implies that any $n-1$ of them completely determine the other. The n residuals $y-\bar{y}$ (and hence their sum of squares $\sum(y-\bar{y})^2$ and the sample variance $\sum (y-\bar{y})^2 / (n-1)$) are said to have $n-1$ degrees of freedom. Thus degrees of freedom denote the extent of independence (freedom) enjoyed by a given set of observed frequencies. If we are given a set of n observed frequencies, which are subjected to k independent constraints, then n-k will be the degree of freedom for the given set of frequencies.

6. RESULTS AND DISCUSSION

The temperature of room with cross ventilation is directly influenced by ambient air temperature. Comparison of observations for room with an earth-air heat exchanger, untreated room and room with cross ventilation are shown in Figs. 3. In the summers the maximum value of temperature difference between room with an earth-air heat exchanger and untreated room occurs during day time whereas in winters maximum difference during night time. The temperature of room with an earth-air heat exchanger is 3.0 ^{o}C less during May month and 6.5 ^{o}C more than untreated room during December. The values of temperature reduction in March, April, May, June, July, August, September and October have been found by 1.3, 1.8, 2.5, 1.6, 1.5, 1.8, 1.9 and 1.9 ^{o}C. It is seen that maximum increase and decrease in temperature is due to use of earth-air heat exchanger occurs in December and May month (Figs. 3) due to high value of useful thermal energy from an earth-air heat exchanger. The maximum difference in temperature of room with an earth-air heat exchanger and cross ventilated room has been found in December (8.5 ^{o}C) and May (6.5 ^{o}C) month. It is quite interesting that temperature of room with cross ventilation is less in summers during night time and high during peak sunshine hours in winters in comparison with room with an earth- air heat exchanger and untreated room (Figs. 3). This is due to decrease in ambient temperature during night time in summers and increase in ambient temperature during peak sunshine hours in winters. Thus cross ventilation can also be a good option for heating in winters and cooling in summers.

Heating/cooling potential of an earth-air heat exchanger (Fig. 4) has been calculated by use of Equation 2. It is seen that heating potential is maximum (411 MJ) in December month where as cooling potential is maximum in May (391 MJ). Detailed statistical analysis has been carried out for the analysis of collected data (Table 4).

Table 4 Statistical analysis

Parameter	Value					
	December			May		
	With EAHE	Untreated	Cross vent.	With EAHE	Untreated	Cross vent.
Degrees of freedom	23					
Significance Level (SL)	0.05	0.05	0.05	0.05	0.05	0.05
Confidence Level (CL)	95 %	95 %	95 %	95 %	95 %	95 %
Confidence Interval (CI)	1.0	1.16	2.7	0.34	0.36	1.23
Experimental uncertainty	11.9 %	15.1 %	29.9 %	3.0 %	3.1%	10.8 %

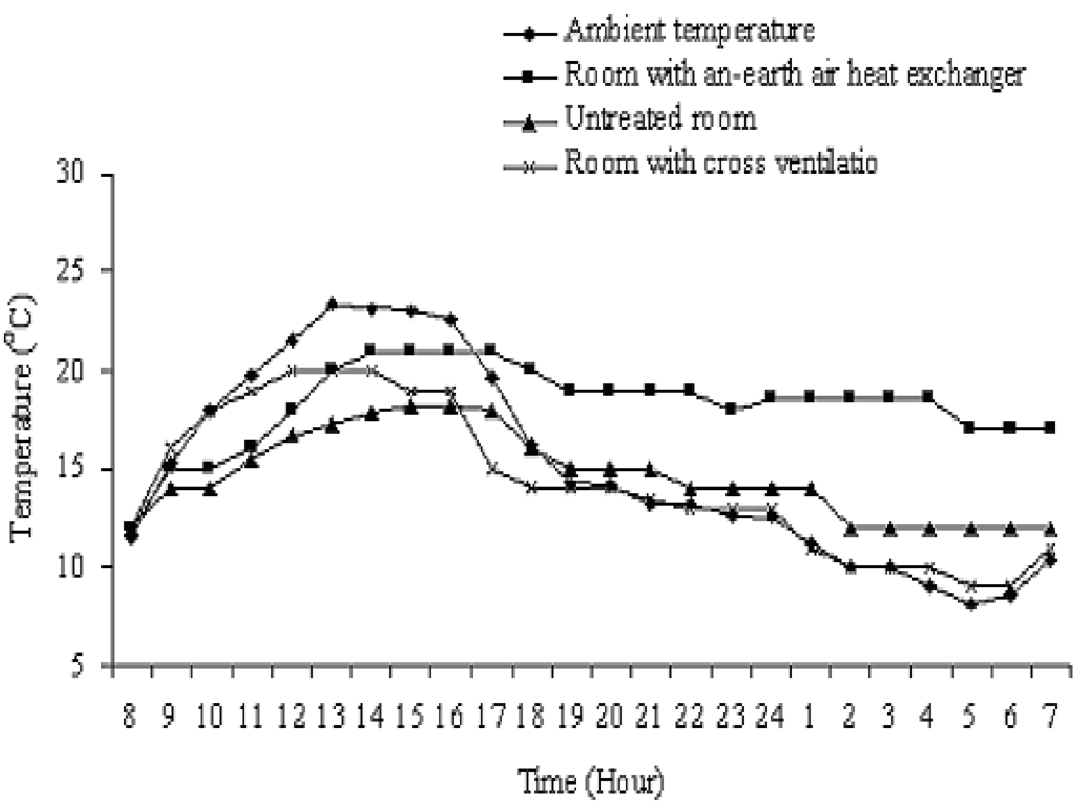

Figure 3a. Hourly variation of experimental temperature for, room with an earth-air heat exchanger, untreated room, room with cross ventilation and ambient temperature for December, 2004.

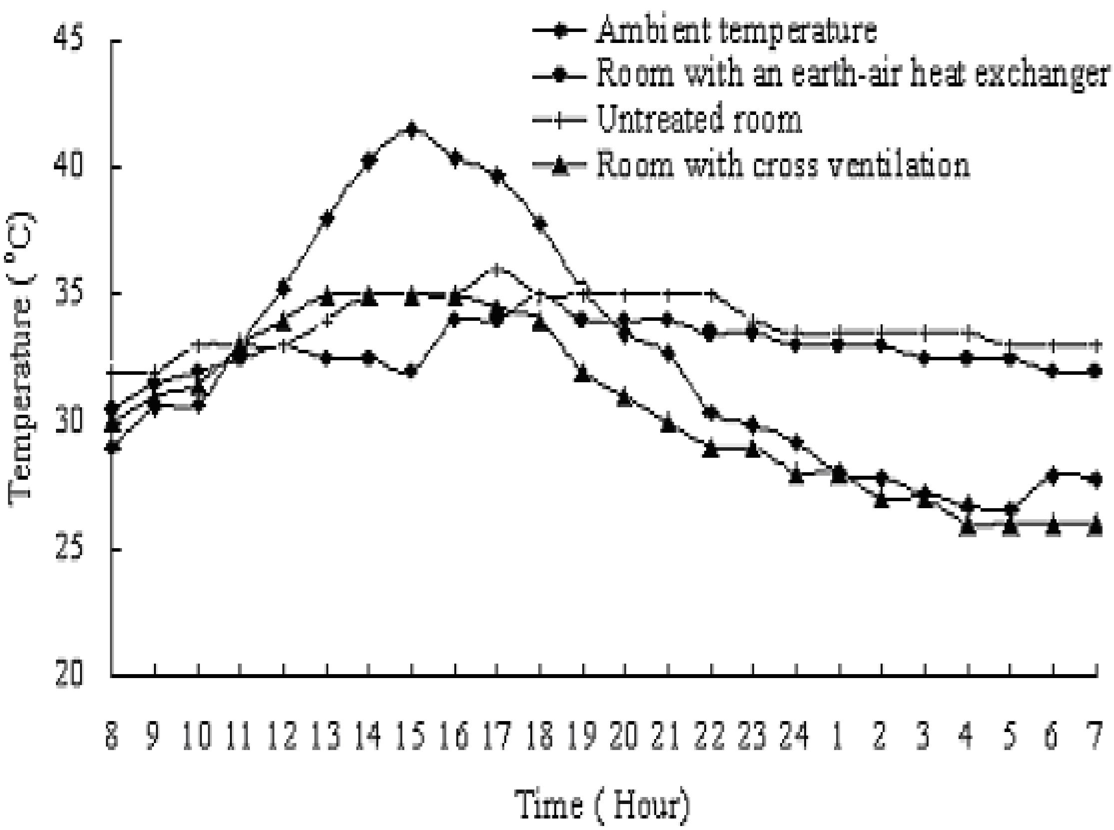

Figure 3b. Hourly variation of experimental temperature for, room with an earth-air heat exchanger, untreated room, room with cross ventilation and ambient temperature for May, 2005.

In the room with an earth-air heat exchanger, for significance level of 0.05 and confidence level of 95.0 %, the value of confidence interval for range of collected experimental data is 1.0 and 0.34 during May and December month respectively. The experimental uncertainty is also in the acceptable range, for room with an earth-air heat exchanger experimental uncertainty for December and May month is 11.9 % and 3.0 % respectively. In the Table 5 the average and maximum/minimum value of temperature for room with an earth-air heat exchanger, room with cross ventilation and untreated room has been given for the year 2004-05. For the room with an earth-air heat exchanger the average temperature during December month is 18.2 ^{o}C, which is 4.2 ^{o}C and 3.6 ^{o}C more than average temperature of room with cross ventilation and untreated room. The maximum value of temperature in room with earth-air heat exchanger is 21.0 ^{o}C. Where this value is 20.0 ^{o}C and 18.2 ^{o}C in room with cross ventilation and untreated room. Similarly during summer months the temperature of room with earth-air heat exchanger is less than temperature of room with cross ventilation and untreated room.

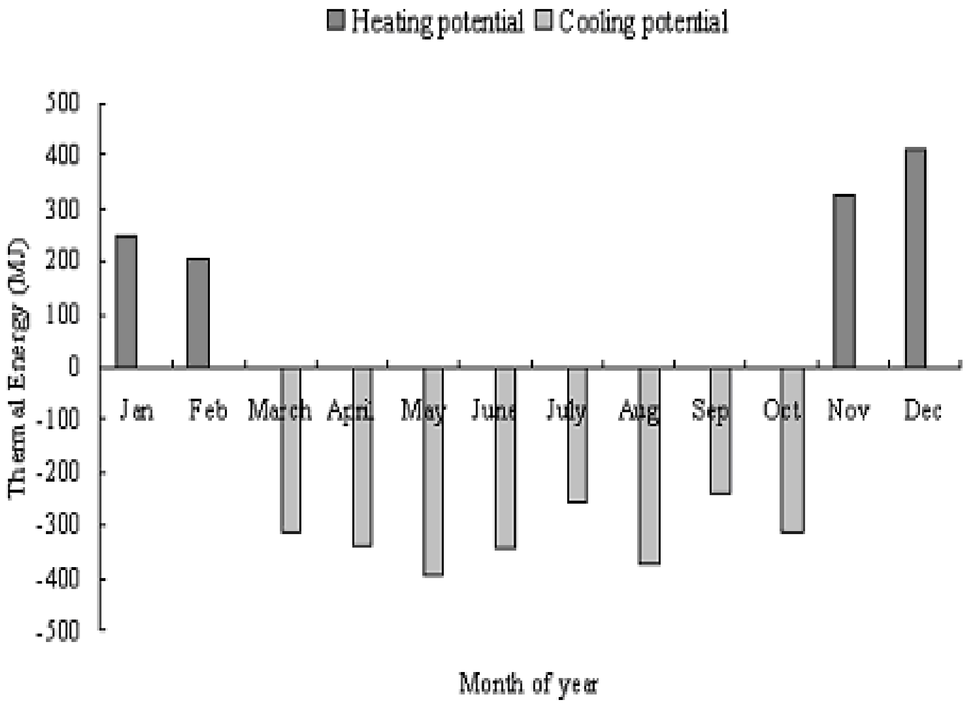

Figure 4. Monthly values of heating/cooling potential of an earth-air heat exchanger.

Table 5. Average, maximum and minimum temperature during June 2004 –May 2005

Month of the year	Room with an EAHE Temperature (^oC)			Room with ventilation Temperature (^oC)			Ordinary room Temperature (^oC)		
	Tav	Tmax	Tmin	Tav	Tmax	Tmin	Tav	Tmax	Tmin
January	16.9	18.0	13.5	12.8	15.5	10.0	14.1	15.5	12.5
February	20.2	20.7	17.5	17.2	20.0	14.0	18.6	19.5	17.2
March	25.4	27.0	23.0	22.7	26.5	19.2	25.0	28.0	23.0
April	31.9	32.5	31.0	29.0	35.0	24.0	33.0	34.0	31.0
May	32.8	35.0	30.5	30.5	35.0	26.0	33.9	36.0	32.0
June	33.2	34.8	26.3	32.8	37.0	28.0	34.3	36.0	33.0
July	31.9	33.0	31.0	30.3	34.0	27.5	33.6	34.5	32.0
August	30.8	32.2	29.5	30.7	32.5	29.2	32.1	33.3	30.5
September	30.0	33.0	28.5	30.0	33.6	28.0	30.8	34.2	29.0
October	28.2	29.8	26.0	29.0	30.5	27.3	29.8	30.8	27.3
November	21.6	23.0	19.0	18.0	21.9	14.5	19.6	21.5	17.5
December	18.2	21.0	12.0	14.0	20.0	09.0	14.6	18.2	12.0

7. CONCLUSIONS

On the basis of present study, following conclusions can be made:

(i) Use of an earth-air heat exchanger for heating and cooling of passive house is more effective in cold winter and hot summer conditions.

(ii) Temperature of room with an earth-air heat exchanger increases significantly (6.5 ^{o}C) in comparison with untreated room during December month.

(iii) During May the temperature of room with earth-air heat exchanger is 3.0 ^{o}C less than temperature of untreated room due to useful thermal energy input from an earth-air heat exchanger.

(iv) During off sunshine hours in summers and during peak sunshine hours in winters, temperature of room with cross ventilation is significantly low in comparison with other rooms, so cross ventilation might be good option for heating/cooling of room.

8. REFERENCES

Arimilli, R.V., M. Parang and P.R. Surapaneni. 1986. Heat transfer from circular tubes in a semi-infinite medium. *J.Heat Transfer* 108: 703-5.

Bansal N.K. 1994. A low cost low energy building, Low Cost Housing and Infrastructure. *Indian National Academy of Engineering*; 289-97.

Bau, H.H. 1984. Convective heat losses from a pipe buried in a semi-infinite porus medium. *Int. J. Heat Mass Transfer* 22: 2047-56.

Claeson, J. and A. Dunand. 1983. Heat exchange from ground by horizontal pipes. Swedish Council for Building Research. Document D1.

Deshmukh, M. 1991. Effects of Passive features on comfort conditions in buildings. Ph.D. Thesis, I.I.T.Delhi.

Fahriye, H.S. 1976. The use of earth covered buildings. In Proc. Conf. on Alternative in Energy Conservation: The use of Earth-Covered buildings, Fort Worth, Texas, Moreland F.(Ed.),: US GPO 038-000-00286-4, 21-26.

Ghosal, M.K., S. Nayak, G.N. Tiwari and N. Sahoo. 2008. Modeling and experimental study for winter performance of an earth to air heat exchanger: An alternative energy source for greenhouse. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript EE 07012, Vol X.

Givoni, B. and L. Katz 1985. Earth temperatures and underground buildings. *Energy and Buildings* 8(1): 15-25.

Jacovides, C.P., G Mihalakakou, M. Santamouris and J.O.Lewis. 1996. On the ground temperature profile for passive cooling applications in buildings. *Solar Energy* 57(3): 167-75.

Khatry, A.K., M.S. Sodha and M.A.S. Malik. 1978. Periodic variation of ground temperature with depth. *Solar Energy* 20: 425-27.

Koronakis, P., Y. Kalligeris and M. Santamouris. 1989. The contribution of appropriate energy design strategies and appraisal of a tourist residence complex in Crete. In Proc. Second European Conf. Architecture, Paris, France. EC Publication 365-72.

Luisa, P.M. and W. Batty. 2006. Thermal behaviour of adobe constructions. *Building and Environment* 41 (12): 1892-1904.

Mihalakakou, G., M. Santamouris, J.O. Lewis and D.N. Asimakopoulos. 1997. On the application of energy balance equation to predict ground temperature profiles. *Solar Energy* 60: 181-90.

Nakra, B.C. and K.K. Chaudhary. 1991. Instrumentation, Measurements and Analysis. Tata Mc-Graw Hill Pub. Co., New Delhi.

Santamouris, M., G. Mihalakakou, A. Argiriou and D.N. Asimakopoulos 1995. On the performance of building coupled with earth to air heat exchangers. *Solar Energy* 54 (6): 375-80.

Shukla A., G.N. Tiwari and M.S. Sodha.2006. Parametric and experimental study on thermal performance of an earth-air heat exchanger. *Int. J. of Energy Research* 46(2):135-146.

Sodha, M.S., D. Buddhi and R.L. Sawhney. 1993. Optimization of pipe parameters of an underground air-pipe cooling system. *Energy Convers. Mgmt*. 34(6): 465-70.

Sodha, M.S., U. Mahajan and R.L.Sawhney. 1994. Thermal performance of parallel earth air pipe system. *Int. J. of Energy Research* 18:437-47.

Swahney, R.L. and U. Mahajan. 1994. Heating and cooling potential of underground air-pipe system. *Int. J. of Energy Research* 18: 509-524.

Tassinari, P., D. Torreggiani, G. Paolinelli and S. Benni. 2007. Rural buildings and their integration on landscape management. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript LW 07020, Vol IX.

Thanu, N.M., R.L.Sawhney, R.N. Khare and D. Buddhi 2001. An experimental study of thermal performance of an earth air pipe system in single pass mode. *Solar Energy* 71 (6): 353-64.

Tombazis, A., A. Argiriou and M. Santamouris *1990*. Performance evaluation of passive and hybrid cooling components for a hotel complex. *Int. J. Sol. Energy* 9: 1-12.

9. NOMNENCLATURE

C	specific heat, J/kg ^{o}C
h	heat transfer coefficient, W/m^2 ^{o}C
l	length of pipe, m
$\dot{m}$	mass flow rate, kg /s
Q	heating or cooling potential, MJ
r	radius of pipe, m
T	temperature, ^{o}C
T_o	temperature above the pipe, ^{o}C
Δt	time period, hour
U	uncertainty, dimensionless

Subscripts

a	air
c	convective
f_o	outlet air
f_i	inlet air
h/c	heating or cooling