Performance of Single Pass earth-Tube Heat Exchanger: An Experimental Study

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Abstract

A single pass earth-tube heat exchanger (ETHE) was installed to study its performance in cooling and heating mode. ETHE is made of 50 m long ms pipe of 10 cm nominal diameter and 3 mm wall thickness. ETHE is buried 3 m deep below surface. Ambient air is pumped through it by a 400 w blower. Air velocity in the pipe is 11 m/s. Air temperature is measured at the inlet of the pipe, in the middle (25 m), and at the outlet (50 m), by thermisters placed inside the pipe. Cooling tests were carried out three consecutive days in each month. On each day system was operated for 7 hours during the day and shut down for the night. Heating tests were carried out at night in January. Test results are presented in summary form for each month. Detailed analysis is presented for two months only -- May for cooling and January for heating.

ETHE cools the ambient air in May by as much as 14^{o}C. It heats the ambient air in January nights also by similar amount.

Key Words : **Earth Tube Heat Exchanger, air tunnel**

Introduction

We have been developing earth-tube heat exchanger (ETHE) for use in greenhouse in arid areas like Kutch. As a first step, deep soil temperature regime was studied in Ahmedabad, Sharan and Jhadav (2002). After year-long measurements they reported that the soil strata between 2m to 3m depth had stable temperature regime suitable for installation of ETHE. Temperature in this stratum displays no diurnal fluctuation. It does display annual fluctuation, but the amplitude is small. Average temperature in this stratum is $27^{o}C$ As a second step one single pass ETHE was built to investigate the actual cooling and heating performance. This ETHE is made of 50m long ms pipe of 10 cm nominal diameter. It is buried 3m deep below surface. We report here the results of investigation carried out on this facility. Specific aim of those investigations is:

(a) to determine the operating characteristics of ETHE in cooling and heating mode

(b) to develop data base of its performance in each of the twelve months

In this paper, details of the experimental facility are described. Performance data has been collected for all the twelve months, but for reasons of space only May and January results are presented and discussed in detail. May month is the hottest part of summer, January the coolest part of winter in Ahmedabad region. Basic results of tests in the remaining months of the year are however given in summary form.

Review of Literature

Earth-Tube Heat Exchanger (ETHE) 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 (Scott *et al* 1965) there has been considerable increase in its application. ETHE is used to condition the air in livestock buildings (Spengler and Stombaugh 1983). It is used in North America and Europe to cool and heat greenhouses (Santa Mouris *et al* 1995). There have also been works aiming at gaining better understanding of its working in cooling and heating mode (Baxter 1992, 1994). Mathematical models of ETHE have also been developed (Puri 1985; Goswami and Dhaliwal 1985). There has also been some work in India. Sawhney *et al* (1998) installed a ETHE based system to cool part of a guesthouse. Sharan *et al* (2001) installed a ETHE based cooling system for tiger dwelling at Ahmedabad Zoological Garden. Authors have visited Tata Energy Research Institute, where a system is installed to cool rooms in its training center near Delhi.

The experimental system we have built is similar to Baxter's, though smaller and less elaborately instrumented. Baxter's facility at Knoxville, Tennessee (USA) is a single pass earth-tube heat exchanger 64-m long, 15-cm diameter, made of 18- gauge spirally corrugated galvanized metal. The tube is buried at 1.8-m depth, and is elaborately instrumented with temperature sensors inside the tube and in soil around it. Air is pumped by a high pressure industrial blower of about 572 w power. Instrumentation permits measurement of air temperature along the tube and in soil around the tube.

Experimental Set-up

Site

The installation is on an open field at village, Thor, some 40 km from IIM, Ahmedabad campus. Soil at the site was tested at Soil Mechanics Laboratory of L.D. Engineering College, Ahmedabad and found to be sandy-silt (sand 48%, silt 41%, clay 11%). Moisture content at the time of excavation was 12.61% (d b). Experimental set-up consists of an ETHE, fan house, temperature sensors and back-up risers. A schematic diagram of the set-up is shown in **figure-1**.

Earth-Tube Heat Exchanger

ETHE consists of a 50 m long 10 cm diameter ms pipe with wall thickness of 3 mm. Especially made fins have been installed on the outer surface of the pipe, all along the 50 m length. Fins are made of thin GI strip spirally wound over the pipe and then spot-welded at several points. There are 40 fins per meter length. Strip that makes the fins is 2 cm wide, 2 mm thick. A 1 m wide, 3 m deep and 50 m long trench was first excavated by a bucket excavator. Trench floor was properly leveled and a 15 cm thick bed of sand placed on it. ETHE was then placed on it and covered with sand up to about 15 cm above it. After that trench was back-filled with the original soil. The inlet and outlet of the ETHE rise 0.5 m above ground. Inlet is connected to the delivery end of blower and outlet is open to atmosphere. A 90 elbow at the end makes the outlet horizontal to the entry of rain water.

Instrumentation

It was desired to obtain air temperature in the ETHE at three location -- at the entrance, at the middle (25 m) and at the end (50 m). One thermister was installed at each of these three locations inside the tube at the center. **Figure-2** shows the thermister assembly configuration. A 15 cm long 10 cm dia coupler was used to build the thermister assembly. A acrylic strip, 10 cm long (to fit snug across the inner dia of the coupler) 2 cm wide and 2 mm thick and was placed horizontally at the center in the coupler as shown. Its ends were bonded to the pipe wall with adhesive. Thermister (AD 590) was placed at the center and bonded to upper surface of the strip using a very thin layer of adhesive. Leads were taken out of the coupler via a 2 mm hole drilled on the side. Hole was then sealed to make it air tight. A 25 mm threaded hole was made on the top side of the coupler. A PVC pipe of 25 mm dia was connected to the coupler as shown. The PVC pipe was 3.5 m long. It is placed vertically and rises above the ground about 0.5 m. Upper end of the riser is normally closed with a cap. Risers were provided to act as a back-up for obtaining tube air temperature, if built in sensors failed. The leads also are taped to the outside of PVC pipe and brought above ground and connected to a digital indicator. Indicators were housed in a wooden box to protect these from weather. Three such assemblies were made. One is installed at the entrance of the ETHE, one in the middle, and one at the end. Air velocity in the pipe is not high and therefore the convective cooling of thermisters due to their being immersed in air stream will be negligible.

Basic soil temperature at 3 m depth was measured using a separate vertical probe, of the type described in detail by Sharan and Jadhav (2003). The Probe was in place just one meter away from the pipe entrance.

Fan House

Blower, motor and controls are placed inside a over-ground fan house. Fan is direct drive industrial type 0.5 hp blower with radial blades. It is custom built to provide air flow rate of 5.6 m^3/min at 25 mm static water pressure. Fan housing is insulated to prevent motor heat from entering. Motor rating is 400 watts. Actual energy used during operations was measured independently, using an energy meter.

Cooling Mode Tests

The air velocity was 11 m/s. Velocity was measured by a portable, digital vane type anemometer (Thermo-Anemometer, PROVA Instruments). The vane size is 66 x 132 x 29.2 mm and velocity range 0.3 to 45 m/s. The anemometer measures mean air velocity. The volume flow rate of air was 0.0863 m^3/s and mass flow rate 0.0975 kg/s. The ETHE system was operated for seven hours a day for three consecutive days of each month. The tube air temperature at the inlet, middle and outlet, and soil temperature at 3-meter depth were noted at the interval of one hour. System was turned on at 10.00 AM and shut down at 5 PM. Tests in May were carried out on 28th, 29th, and 30th (2000).

The ambient temperature on these three days was very similar. The results of the three days were therefore averaged. **Table-1** shows the data, which is mean of the three days. **Figure-3** shows the data graphically.

The ambient temperature started with 31.3°C at 10.00 AM and rose to a maximum of 40.8°C at 2 PM. The temperature of air at outlet was 26.8°C ;as the system started and rose only slightly to 27.2°C at which it stayed through the 7 hour of test run. The outlet temperature was just above the basic soil temperature (26.6°C) at 3 m depth, suggesting that the tube was exchanging heat quite effectively. As can be seen from the table most of the cooling occurred in the first half of the tube (25 m). At 2 PM, air temperature reduced from 40.8°C to 29.7°C by the middle (25 m), i.e. by 11.1°C. In the next 25 the further reduction was only 2.5°C. This is expected, because as the difference between air temperature and that of the soil reduces, heat transfer rates are reduced.

Coefficient of Performance (COP)

Coefficient of performance is one of the measures of heat exchanger efficiency. It is defined as (ASHRAE 1985)

$$COP = \frac{\dot{Q}_{out}}{\dot{W}_{in}}$$

$$\dot{Q}_{out} = \dot{m}_a \; C_p \; (T_i - T_o)$$

c_p Specific heat of air (J / kg °C)

Q_{out} Rate at which heat is exchanged between hot air and cooler soil

$\dot{W}_{in}$ Rate of energy input into the heat exchanger (energy used by blower)

$\dot{m}_a$ Mass flow rate of air (kg / s)

T_i Temperature of air entering the tube (^oC)

T_o Temprature of air at the outlet (^oC)

T_i and T_o are both treated as bulk temperatures, independent of radial variation. This is realistic, pipe diameter being only 10 cm.

Energy input into the heat exchanger is just the energy used by the blower (300 w). In the first hour of operation (10.00 - 11.00 AM) the ambient air temperature rose from 31.3^{o}C to 33.7^{o}C. The mean of this works out to 32.5^{o}C. We shall assume this to be, Ti, during this first hour. Properties of air used in computation relate to temperature of 35^{o}C.

$$COP = \frac{0.0975 \text{ x } 1007 \text{ x } (32.5 - 26.8)}{300}$$

$$= 1.73$$

Hourly, values of COP are shown in **Table-1**. COP value was 1.73 at the start, rising to a maximum of 4.4 at 2 PM, when the ambient temperature was at peak. Mean value of COP over the test run of 7 hours is 3.3.

Baxter presented detailed analysis of ETHE performance during three weekly periods -- first week of June, third week of July and last week of August. These represent periods where high ambient temperatures prevail and cooling is greatly needed. During these periods the value of COP in the hours of high energy exchange (day time when ambient temperatures were high) ranged from 4.37 to 6.31. The mean hourly values for the entire period of test ranged from 1.4 to 2.69. During these periods basic soil temperature varied from 14.8°C to 18.2°C. The maximum ambient temperature varied from 33.9°C to 35.6 °C. The cooling effected in the three weekly periods was 8.3 °C, 8.9°C and 5°C.

Heating Mode Tests

Heating mode tests were carried out for three nights of January 2000 (28^{th}, 29^{th}, & 30^{th}). The system was turned on at 6 PM and operated for 12 hours continuously, till 6 AM next day. Temperature readings were noted at hourly interval. Here also the conditions on the three consecutive nights were similar and therefore the results combined. Table 2 shows the data, which is the mean of three test runs. Fig. 4 shows the same data graphically.

The ambient temperature started at 23.6°C (5 PM), falling to the lowest value 8.3°C at 2 AM. Thereafter it began to rise again and was 9.8°C at 6 AM when the test was closed. Basic soil temperature at 3 m depth was constant at 24.2°C. Temperature of the air at the outlet stayed virtually constant at 23°C; varying from 22.8°C to 23.3°C. ETHE was able to raise the ambient air temperature at 2 AM from 8.3°C to 23°C or by 14.7°C. The table also shows the COP values. The mean hourly COP is 3.8. The greatest hourly values of COP in heating mode reported by Baxter ranged from 3.2 to 10.3. Mean hourly value over the entire period of test ranged from 1.6 to 4.2.

As stated earlier, the tests were conducted for three days of each month. For reasons of space, all results are not presented in detail. But a summary is given in **Table-3** showing basic results of each month.

Summary and Conclusion

A single pass earth-tube heat exchanger (ETHE) was installed to study its performance in cooling and heating mode. ETHE is made of 50 m long ms pipe of 10 cm nominal diameter and 3 mm wall thickness. ETHE is buried 3 m deep below surface. A 400 w blower pumps ambient air through it. Air velocity in the pipe is 11 m/s.

ETHE was able to reduce the temperature of hot ambient air by as much as 14^{o}C in May. The basic soil temperature in May was 26.6^{o}C. It was able to warm up the cold ambient air by a similar amount in the nights of January. The basic soil temperature in January was 24.2^{o}C.

The coefficient of performance (COP) in cooling mode averaged to 3.3. Cooling tests were of 7 hour continuous duration during the day. In heating mode it averaged to 3.8. Heating tests were of 14 hour continuous duration through the night.

Based on the results it can be stated that ETHE holds considerable promise as a means to cool or heat ambient air for a variety of applications such as the livestock buildings and greenhouses.

Acknowledgement

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Table 1: Air Temperature inside ETHE and Soil Temperature (MAY)

Time	T_a	T_s	T_{md}	T_o	COP
10:00	31.3	26.6	29.1	26.8	1.73
11:00	33.7	26.6	29.2	26.8	2.6
12:00	36.4	26.6	29.5	27.2	3.2
13:00	37.8	26.6	29.5	27.2	3.9
14:00	40.8	26.6	29.7	27.2	4.4
15:00	40.4	26.6	29.7	27.2	4.2
16:00	39.8	26.6	29.8	27.2	4.1
17.00	39.6	26.5	30	27.2	4.0

Values are mean of three consecutive days of tests (28,29,30 May)

Table 2 : Air Temperature inside ETHE and Soil Temperature (JANUARY)					
Time	T_a	T_s	T_{md}	T_o	COP
18:00	19.8	24.2	22.3	23.4	1.5
19:00	17.6	24.2	22.2	23.4	2.6
20:00	13.3	24.2	22.1	23.3	3.5
21:00	11.9	24.2	21.9	23.3	3.4
22:00	10.4	24.2	21.8	23.3	4.3
23:00	9.6	24.2	21.7	23.3	4.5
0:00	9.1	24.2	21.6	23.2	4.6
1:00	8.7	24.2	21.5	23.2	4.7
2:00	8.3	24.2	21.5	23.0	5.0
3:00	8.7	24.2	21.4	23.0	4.5
4:00	9.1	24.2	21.3	22.9	4.4
5:00	9.6	24.2	21.2	22.9	4.3
6:00	9.8	24.2	21.2	22.8	4.2
Values are mean of three consecutive nights of tests (28,29,30 Jan.)					

Table 3 : Summary of Cooling Test Results			
Month	Ambient Temperature At 14 hours (^{o}C)	Basic Soil Temperature T_s (^{o}C)	Outlet Temperature At 14 hours (^{o}C)
January	Heating test		
February	37.9	25.2	26.4
March	39.4	25.8	26.4
April	41.4	26.6	28.0
May	40.8	26.6	27.2
June	37.5	29.8	31.9
July	No test due to rain	-	-
August	No test due to rain	-	-
September	39.1	28.9	30.0
October	34.8	25.6	26.2
November	30.6	24.2	24.2
December	30.7	24.4	24.4

Values are mean of three consecutive days of test in each month.

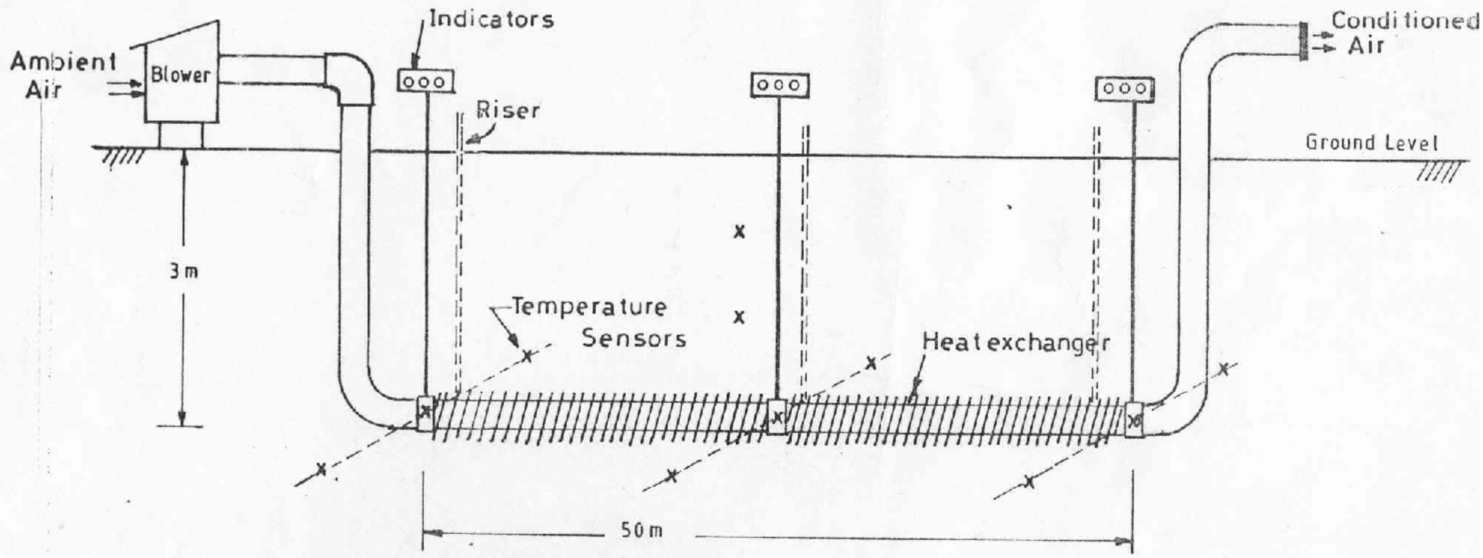

Figure-1 : Earth Tube Heat Exchanger (ETHE)

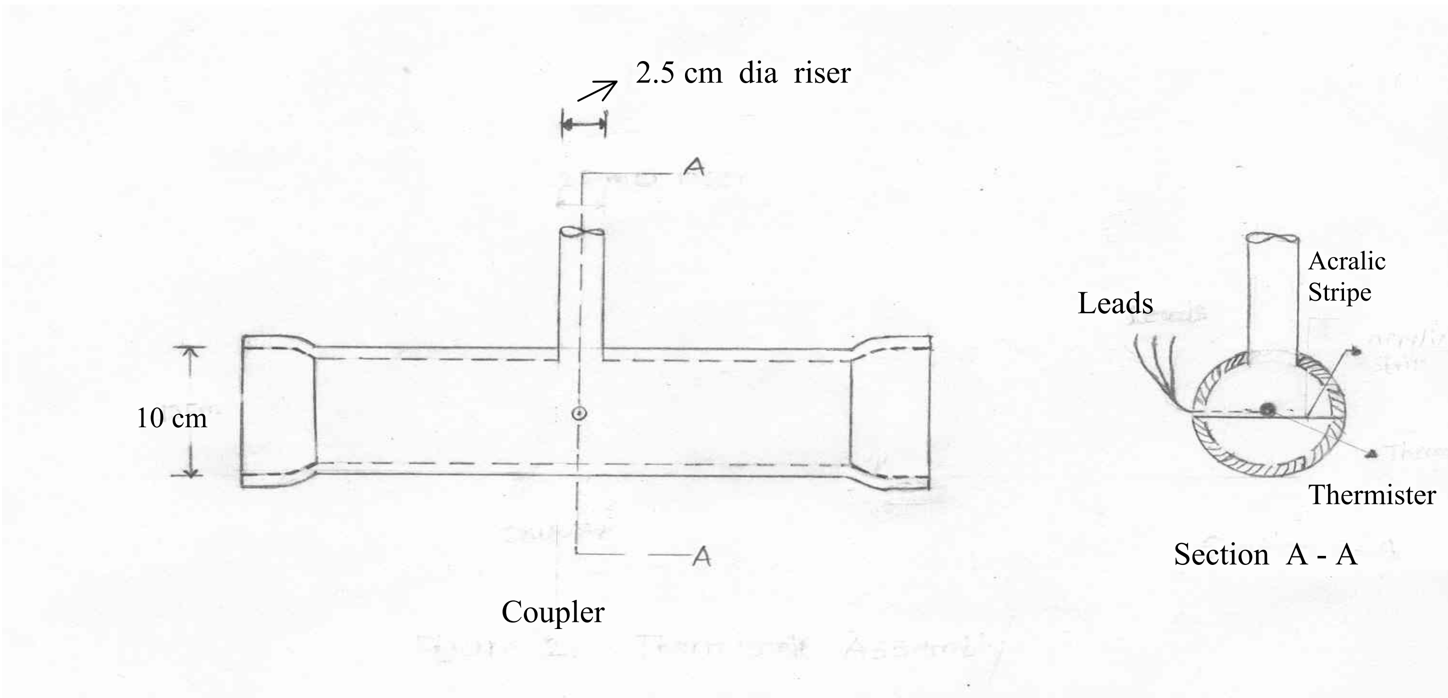

Figure-2 : Thermister Assembly

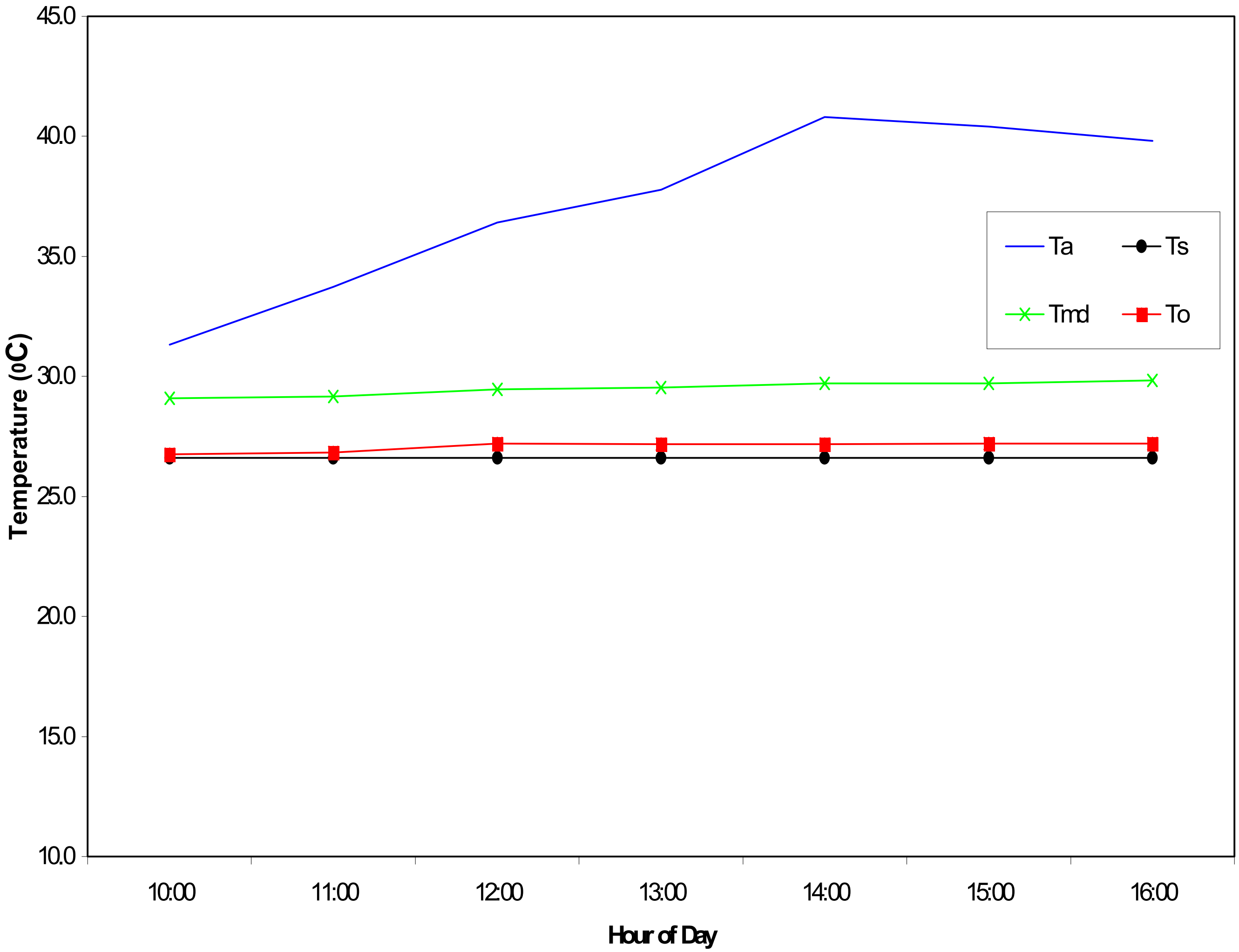

Figure-3 : Air temperature inside ETHE and soil temperature (May)

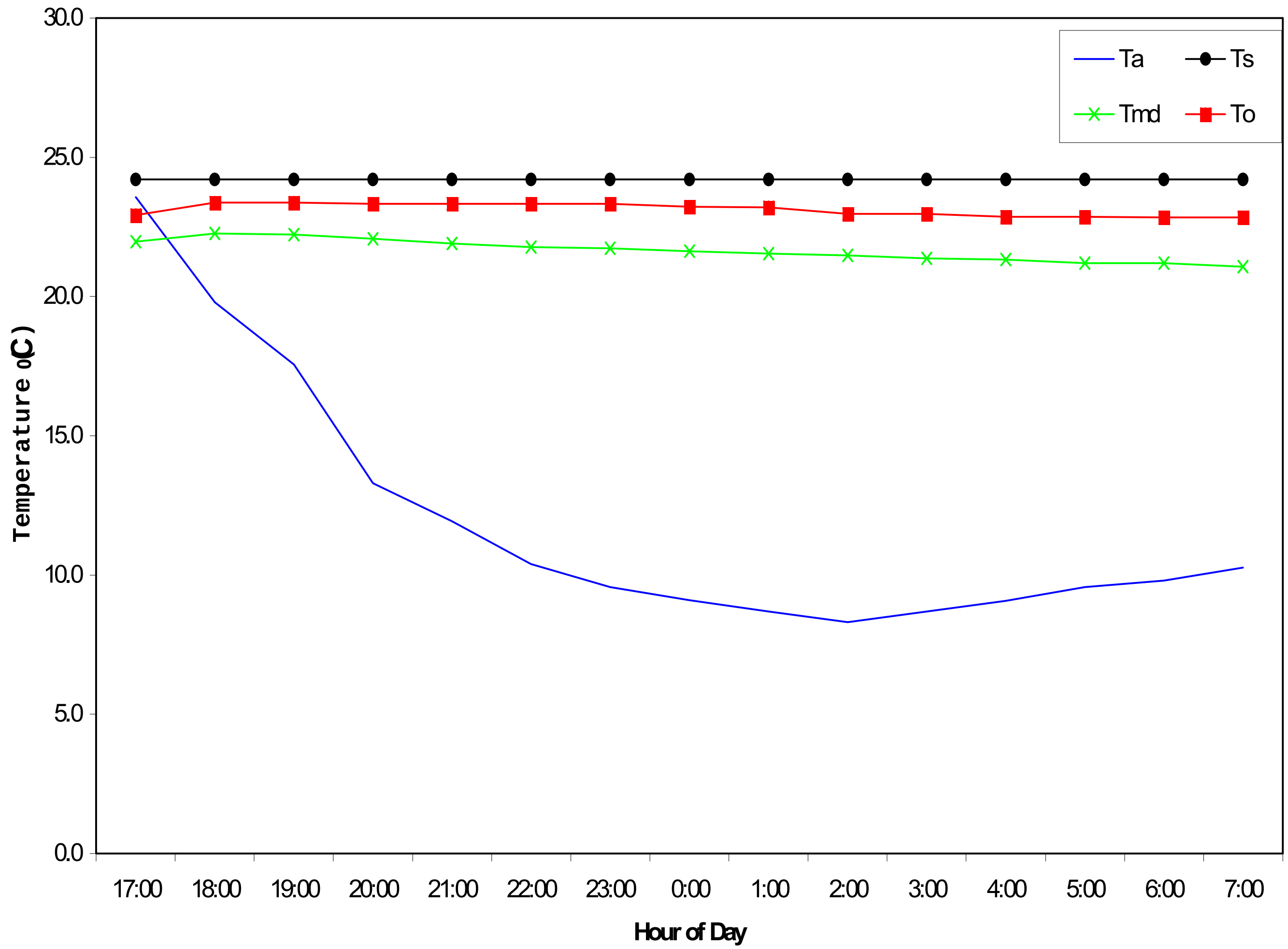

Figure-4 : Air temperature inside ETHE and soil temperature (January)

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