Earth Tube Heat Exchangers for Environmental Control of Farm Buildings in Semi-arid Northwest India

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Abstract

A large part of Gujarat in the North-west region of India is semi-arid. The lands are less suited for agriculture. Animal husbandry is therefore common. Productivity of cattle is however also low due to problems of feed and due to climatic stresses, specially heat. Environmental control of farm buildings - animal houses, greenhouses- in semi-arid areas is a special challenge. There is widespread shortage of water; rural grid is prone to interruptions several times a day. Cattle owners do not give importance to animal comfort as a means to improve productivity. The HVAC industry and professionals have not made efforts to develop systems compatible with the region's environment and economics of farming. Towards that, the earth-tube-heat-exchanger based systems appear to be more suited for farm sector in semi-arid climatic conditions. We present the experience of using such systems for environmental control in dwellings of zoo animals, and greenhouse in arid area of Kutch. Mention has also been made of the ongoing work to install more such systems in the dairy cattle housing.

Key words: earth-tube-heat- exchangers, cattle houses, greenhouses in arid areas

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Earth tube heat exchanger

Earth Tube Heat Exchangers (ETHE) permit transfer of heat from ambient air to deeper layers of soil and vice-versa. Temperature regime at depths beyond a few meters is stable with only a small seasonal variation, and no diurnal fluctuation. This stability results from the fact that temperature waves dampen as they penetrate through layers of soil. High frequency components do so more rapidly. Accordingly diurnal fluctuations (one cycle per day) diminish within less than a meter. The annual wave (one cycle per year) penetrates deeper. Large mass of soil at a stable near constant temperature permits it to be used as sink and source, making the ETHE capable of both - cooling and heating. Sharan and Jadhav [2002] measured ground temperature at Ahmedabad using a special thermal probe up to the depth of three meters on hourly basis for one year. Using that data they developed an analytical expression for temperature regime in Ahmedabad region.

$$T(t,z) = 27 + 10e^{-az} \cos\left[\frac{2\pi}{365}(t-105) - az\right] \text{..........} 1$$

$$\alpha = \sqrt{\frac{\omega}{2k}}$$

ω	Angular frequency (rad / day)
K	thermal diffusivity (m2 / day)
T	day of the year with January 1 as origin (numbers)
Z	depth from surface (m)
T (t, z)	temperature at depth z, day t (oC)

Figure 1 illustrates the variation of temperature during the year at various depths in Ahmedabad region. At three meters, the amplitude of fluctuation reduces to about 4 ^{0}C. The soil mass at this strata would vary from 25 to 29 ^{0}C. Going deeper will further reduce this amplitude and the temperature will approach the long term mean, 27 ^{0}C. ETHE can be located at 3-4 m depth.

Cooling and heating of air in ETHE

Subsequently , a 50 m long single pass ETHE was constructed at Thor near Ahmedabad (Figure 2) to study the cooling and heating performance**.** Diameter of the ms pipe used was 10 cm. A blower of 400 watt moved air at 5.6 m^3/min (200 cfm). The tube was buried at 3 m depth and was elaborately instrumented. Tests were carried out over three consecutive days, over the twelve months (Sharan and Jadhav 2003). Tables (1) and (2) show for illustration the results for May in cooling mode and January night in heating mode. It is seen that the ETHE could warm-up the cold air by as much as 12 -13 ^oC on January nights. . The mean hourly COP was 3.8. It could cool the air in May also by a similar amount, from 40.8 ^0C to 27.2 ^0C. Mean value of COP over the test run of seven hours was 3.3.

Results from this facility were used to develop and validate a mathematical model of heat transfer to (or form) air into the soil mass as it moved through heat exchanger pipe buried at a depth (Sharan and Madhavan 2003). Simulations using the model showed that increasing the length of pipe improves the performance. Reducing the air velocity, reducing the diameter of pipe also lead to improvement.

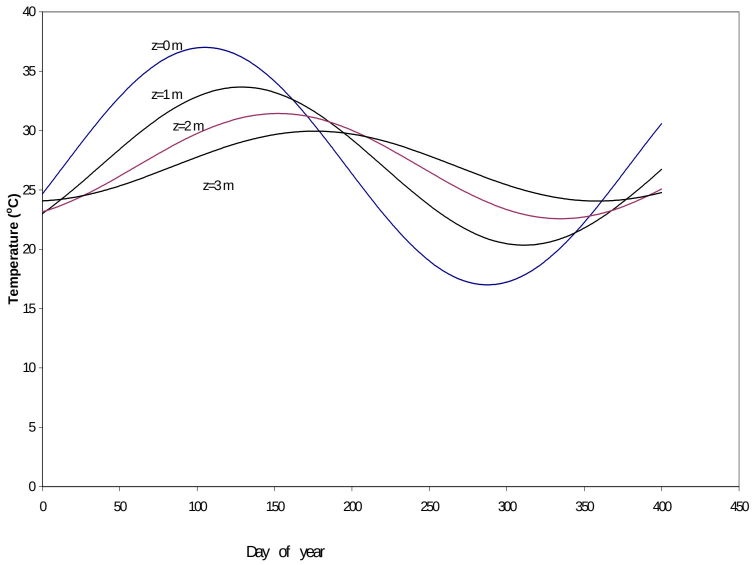

Fig 1: Variation of Temperatures during the year At various depth in Ahmedabad region

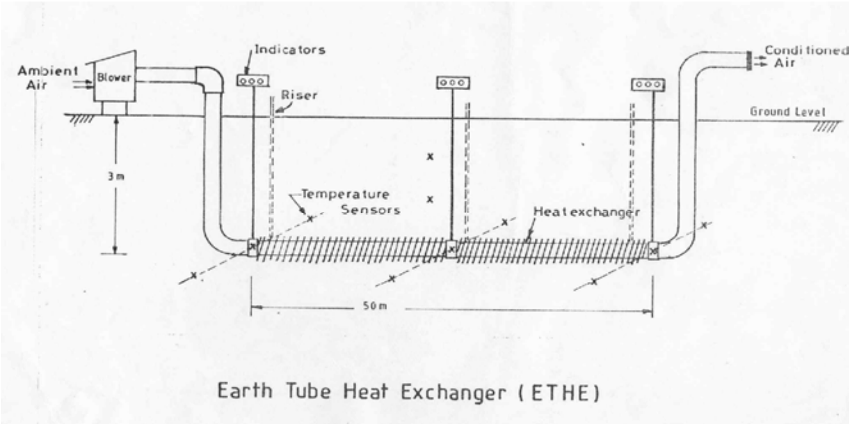

Fig 2: Single pass ETHE at Thor

Table-1: ETHE in Cooling mode - May				
Time	T_a	T_s	T_{md}	T_o
10:00	31.3	26.6	29.1	26.8
11:00	33.7	26.6	29.2	26.8
12:00	36.4	26.6	29.5	27.2
13:00	37.8	26.6	29.5	27.2
14:00	40.8	26.6	29.7	27.2
15:00	40.4	26.6	29.7	27.2
16:00	39.8	26.6	29.8	27.2
17.00	39.6	26.5	30	27.2
T_a Ambient temperature , T_s soil temperature , T_{md} air temperature in side tube at the mid point, T_o temperature of air exiting				

Table-2: ETHE in heating mode - January nights				
Time	T_a	T_s	T_{md}	T_o
18:00	19.8	24.2	22.3	23.4
19:00	17.6	24.2	22.2	23.4
20:00	13.3	24.2	22.1	23.3
21:00	11.9	24.2	21.9	23.3
22:00	10.4	24.2	21.8	23.3
23:00	9.6	24.2	21.7	23.3
0:00	9.1	24.2	21.6	23.2
1:00	8.7	24.2	21.5	23.2
2:00	8.3	24.2	21.5	23.0
3:00	8.7	24.2	21.4	23.0
4:00	9.1	24.2	21.3	22.9
5:00	9.6	24.2	21.2	22.9
6:00	9.8	24.2	21.2	22.8
T_a Ambient temperature , T_s soil temperature , T_{md} air temperature in side tube at the mid point, T_o temperature of air exiting				

Applications

The ETHE has been used elsewhere to condition the air in livestock buildings (Scott et *al* 1965; Spengler & Stombaugh 1983), greenhouses (Santamouris et *al* 1995). In India there has been only a limited interest in its study and use. Sawhney et *al* (1998) installed an ETHE based system to cool a part of a guesthouse. The Energy Research Institute, Delhi has an installation in one of its training facility on the outskirts. Agricultural buildings - livestock, greenhouses, poultry and piggery - offer greater opportunities for its use, but very little effort has been made in this direction. Gujarat, Rajasthan have high potential for its applications. Our initiative is aimed at promoting its use in Gujarat region. Two examples are briefly described below.

ETHE based air-conditioning system Kamala Nehru Zoological Garden Ahmedabad

A ETHE based air-conditioning system was installed at Kamala Nehru Zoological Garden, Ahmedabad (Figure 3) for dwellings of tiger (*panthera tigris*) in the year 2000. ETHE based system was considered especially suited because (a) it does not require the dwelling to be kept closed (b) it does not increase the humidity of the dwellings as would be the case if (evaporative) air cooler is used; and (c) it works as a cooler in summer and heater in winter; a feature not present in any other system. This is a single- pass system. The conditioned air is introduced into the dwelling from one end and exhausted into atmosphere from the other.

The system consists of pipes buried in the moat, one blower, supply ducts with baffles, and diffusers. The ETHE is made of two MS tubes, each 30-m long and 20-cm diameter. Tubes are buried at 2-m depth parallel to each other at a spacing of 1.5 m. Blower delivers 1600 cfm of conditioned air and are driven by a motor of 2-hp rating. Cooling load calculations were done by computing the heat gain by the dwelling from exterior walls, partitions, roof and the heat generated by the animal. Air change rate required to remove all that heat was then worked out. Finally, the size of blower and motor were determined. This system cools the ambient air in hot summer by about 8^0C. It warms the cold air in winter nights by about 10^oC (Sharan et al 2001). Air from the ETHE is used to ventilate the dwelling. It is economical and easy to maintain.

Greenhouse coupled to ETHE in closed-loop mode at Kothara (Kutch)

Adoption of greenhouse technology in hot and arid areas in north-west India is impeded by lack of good quality water. Besides irrigation, evaporative cooling uses large amounts. Provision of natural ventilation and coupling the house to earth-tube-heat-exchanger (ETHE) is being tried as alternative measures for environmental control, specially cooling (Sharan et al 2003). The experimental facility (Figure 4 a , b) , located in arid region at Kothara (φ 23° 14 N, λ 68° 45 E, at 21 m a.s.l.), is a single span saw-tooth greenhouse (20 X 6 X 3.5 m) coupled in closed- loop to ETHE buried 3m deep directly below. ETHE provides 40 air changes per hour. For natural ventilation, there are three continuous (closable) vents - two along the base of long sides and one on the roof. A retractable shading cover is provided over the roof. The ETHE was able to heat the greenhouse easily from 9°C to 22-23°C in half hour in the cold winter nights. Natural ventilation along with roof shading was effective for day time control till February keeping the temperature about 34°C inside. Subsequently, ETHE was operated. It limited the greenhouse temperature to 36-37°C with top shaded. ETHE and natural ventilation hold promise as environmental control measures. There is need to reduce installation cost of the ETHE. A more easily scalable design than the present one is also desirable.

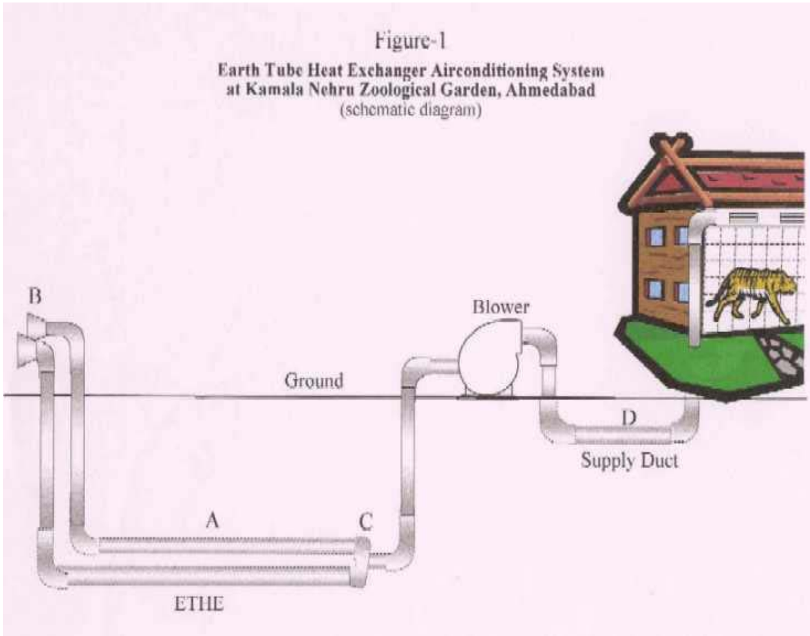

Fig 3: ETHE system at Kamala Nehru Zoological Garden Ahmedabad

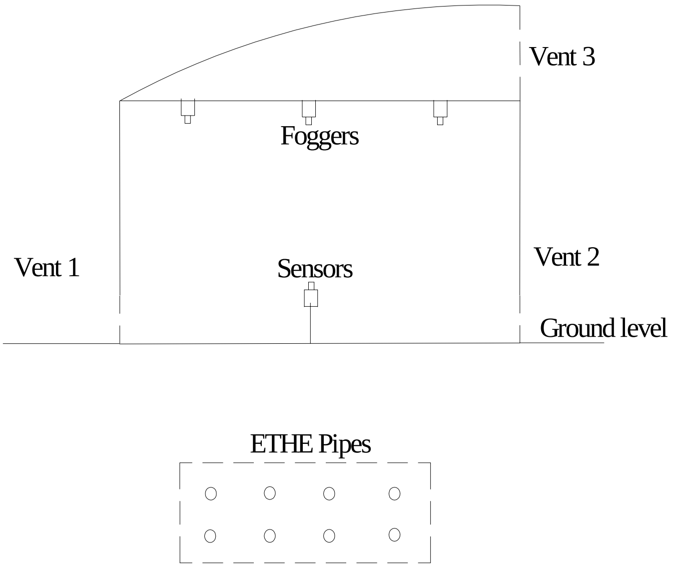

Fig.4(a). Arid Area green house schematic

Fig. 4 (b). Earth tube heat exchanger before backfill

Cooling systems for cattle houses - projects in progress

Work is in progress on four new installations - a large auditorium, three cattle houses in various parts of Gujarat including Junagadh, Anand and Anjar. The auditorium is located at the Science City Gandhi agar. It is a 30 m X 20 m building with straight side walls and semicircular roof made of corrugated galvanized iron. Total volume enclosed is approximately 2400 m3. Although there are windows on the sides the facility is not useable in summers. The client has preferred an ETHE -based system over the conventional. Three things are being carried out. The outer roof surface is being covered with insulation and a high reflectance foil. A 30 m X 1 m vent has also been opened along the centre line of the roof. And an ETHE system is being installed to provide tempered air for ventilation.

Livestock houses

Most parts of Gujarat are categorized as semi-arid. Rainfall is low concentrated to four months followed by a long eight month long dry season. Diurnal and seasonal temperature fluctuations are high. On a typical January day the mean temperature would be around 23 ^{0}C, the maximum 32 ^{0}C and the minimum 14 ^{0}C. On a typical day in June the mean temperature would be around 33 ^{0}C, maximum 36 ^{0}C and the minimum 29 ^{0}C. Relative humidity ranges from 55% to 75 % in most months but diurnal variations are large. Solar radiation levels are high- 900 to 1000 w/m^2. Soils are of poor fertility. Since these conditions are less suited for agriculture, people tend to keep large stock of cattle. However their productivity is also low due to fodder shortages and also climatic stresses.

Figure 5 shows a shed at the Cattle Breeding Farm of the Junagadh Agricultural University that houses expensive milch breed of cows. Such sheds protect the animal from sun and rain but not from hot and cold drafts. The local breeds are tolerant of the climatic conditions , but the exotic breeds such as the Jersey, Brown Swiss and Holstein-Frisian which are now being stocked are vulnerable. These sheds with roof but no walls do not modulate the ambient temperatures sufficiently to protect the animals from high ambient temperatures in summer.

Milk yields are known to decline (ASHRAE Handbook of Fundamentals 1985) when temperatures are upwards of 24 ^{0}C (Holsteins) , 27 ^{0}C (Jerseys). Commonly the cattle owners do not build for their stock the sheds of even this quality. Animal comfort is not considered economically important by the farmers in Gujarat. Indeed even the commercial dairy managers also do not consider it important. Cattle are homeotherms - they tend to maintain a constant body temperature in varying environment. But to improve the productivity of milch cattle it is important to reduce the environmental stresses by suitable control measures. Based on the discussions with the animal scientists and in collaboration with them, ETHE- based systems are now being installed at three places as demonstration. Tempered air from the ETHE will be used for ventilation. The systems would be single-pass as in case of the tiger dwelling described earlier.

Figure 5: Cattle Shed at Junagadh Agricultural University

Summary

Large parts of Gujarat are semi-arid. Farm buildings, animal houses, greenhouses in such regions need suitable environmental control systems. The ETHE based systems appear especially appropriate for such regions and such applications. Experience of using ETHE for greenhouse environmental control in Kutch region, has shown that it is capable of meeting the heating requirement fully and the cooling requirement significantly. Similarly, experience of using it for improving the comfort of tiger dwellings in Ahmedabad has been very satisfactory - it warms the dwelling in winter nights and provides cool air for ventilation in summers. There is need to develop cheaper ducting to construct ETHE. The HVAC professionals and Industry needs to develop capability to design and install. Presently in Gujarat region such resources are lacking.

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