Development and Some Applications of Earth Tube Heat Exchanger in Gujarat♣

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Abstract

This write-up describes the development and some applications of earth tube heat exchangers in Gujarat. Work outlined here was delivered as Nanubhai Amin Memorial Lecture at Electrical Research and Development Association, Vadodara as part of `Technology Day', 11 May 2004.

Earth Tube Heat Exchanger

Earth Tube Heat Exchanger (ETHE) is a device that permits transfer of heat from ambient air to deeper layers of soil and vice-versa. ETHE usually consist of loop(s) of pipe buried in the ground horizontally or vertically. Vertical loops go deeper . Horizontal loops are usually buried at one to four meter depth. Temperature regime at this depth and beyond is stable, with no diurnal fluctuation and with only a small seasonal or annual variation.

This stability is result of a natural physical phenomena. Temperature waves dampen as they penetrate through layers of soil. High frequency waves do so more rapidly. Accordingly diurnal fluctuations (one cycle

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per day) diminish within less than a meter . But the annual wave (one cycle per year) penetrates deeper. Its amplitude of fluctuation is much smaller. Large mass of soil at a stable , near constant, temperature permits its use as sink and source of heat.

Ambient air is pumped through buried pipes at moderate velocities. When it is warmer (as in summers) than the basic temperature of soil surrounding the pipes, heat is transferred from air to soil resulting in cooling. In winters or at nights the reverse takes place. Thus, ETHE can be used for cooling in summer and heating in winter.

ETHE based systems are increasingly being used to condition the air in commercial livestock buildings, greenhouses. Ground source heat pumps (GSHP) are used in North America, Europe to heat and cool houses, commercial complexes and offices. Over 550,000 units are reported to be in operation worldwide and some 66,000 are added annually (Geoscience Ltd, United Kingdom).

Advantages and Disadvantages

Being result of a natural phenomena deep ground as source and sink is available easily in most places in the world. Such a use is sustainable and equivalent to having a renewable energy source. ETHE based systems cause no toxic emission and therefore, are not detrimental to environment. Ground Source Heat Pumps (GSHPs) do use some refrigerant but much less than the conventional systems. ETHE based systems for cooling do not need water - a feature valuable in arid areas like Kutch. It is this feature that motivated our work on ETHE development. ETHEs have long life and require only low maintenance. However, initial installation costs are likely to be higher than the comparable conventional (refrigerant based) systems. Conventional systems can be customised easily for varied applications and industry is well developed. This is not yet the case for ground coupled systems.

Development in Gujarat

Cummins Foundation-IIMA Laboratory for Environmental Technology in Arid Areas has been engaged in development of ETHE in the recent years. As stated, this was motivated by need to find ways to cool greenhouses in hot-arid Kutch, with minimal or no use of water. Good quality water is chronically scarce there.

Year-long measurements of deep soil temperature in Ahmedabad indicated that mean temperature of ground is 27°C **[1].** Temperature regime at Ahmedabad can be described by equation (1).

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

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

ω	angular frequency (rad / day)
k	thermal diffusivity (m^2 / 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 (°C)

Equation shows what was stated earlier - that the amplitude reduces with depth and that higher frequencies dampen more rapidly. Waves at deeper levels are also out of phase (lag) with the one at the surface. At three-meter depth the fluctuations reduce to just 2.8°C. This suggested that a suitably designed ETHE placed at this depth could cool the air close to what (evaporative) air coolers do.

A 50 m long single pass ETHE was accordingly installed near Ahmedabad to check this out **[2]** . **Figure-1** shows a schematic diagram of the installation. 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. Performance tests were carried out each month for one full year. **Tables (1) and (2)** show the results respectively for the months of January when it was operated at night in heating mode and May in cooling mode. It is seen that the ETHE could warm-up the cold air by as much as 12 -13 °C. It could cool the air in May also by a similar amount, from 40.8°C to 27.2°C.

Using the empirical results, a mathematical model was developed which permitted study by simulation of the effects of varying various parameters **[3].** Simulations showed that increasing the length of pipe improves the performance. Reducing the air velocity , reducing the diameter of pipe also lead to improvement. Use of metal pipes make for shorter transience or quicker response. Fixing fins to the outer surface of the pipe also appears to be beneficial. Using these results, two working systems were built which are briefly described below.

ETHE Based airconditioning System Kamala Nehru Zoological Garden Ahmedabad

This system was installed in the year 2000 at Kamala Nehru Zoological Garden, Ahmedabad to condition (cool in summer warm in winter) the air in the dwelling of tigers. The system configuration is given in detail in **[4]**. **Figure-2** shows a schematic diagram. This system delivers air at 44.4 m^3/min (1600 cfm). It consists of two 20 cm diameter ms pipes placed in parallel at two meter depth in the moat near the dwelling . Pipes are 27 m long each and are separated horizontally by 1.5 m. Air is moved by a 1.2 kw blower.

This system cools the ambient air in hot summer by about 8^0C and warms the cold air in winter by about 10^oC. System was designed at the request of the zoo authorities and was preferred because it does not increase humidity in the dwelling as a desert cooler does. It is economical and easy to maintain. It was preferred also because it works as duel mode conditioner--cooling in summer and warming in winter.

Greenhouse Coupled to ETHE in Closed-Loop Mode at Kothara (Kutch)

This installation consists of a greenhouse standing directly above a specially designed large ETHE. Unlike the system in the Zoo, which is one way, here the greenhouse and ETHE are coupled in closed-loop mode. A detailed description of the installation can be seen in **[5]**. Greenhouse is of 6 m span, 20 m length and 3.5 m height at the ridge. Ridge is east-west oriented (**figure-3**). Cladding is 200 micron UV stabilized polyethylene sheet. There are three vents - two on the sides and one at the ridge. All vents are closeable.

ETHE lies directly below the greenhouse at 2-3 m depth. It consists of eight pipes arranged in two tiers. The first tier has four pipes placed at 3 m depth, the second also has four pipes and is placed 1 m above the first. Each pipe is 23 m long and 20 cm in nominal diameter. Thickness of pipe wall is 3 mm. Pipes are made of mild steel, and placed 1.5 m apart (**Figure-4**). There is a common header at both ends of each tier. Headers in turn are connected to specially fabricated ducting that rises above the ground to form inlet and outlet. Conditioned air is let into the greenhouse via a louvered opening, 6 m wide and 0.45 m high. Outlet on the opposite end is identical in construction to the inlet.

ETHE provides air at the rate of 194 m^3/min (7000 cfm). This is equivalent to 20 air changes in the greenhouse per hour. Blower is powered by a 4.2 kw 1440 rpm motor. **Figure-5** shows the fully furnished greenhouse.

First cropping trial commenced in December 2002. Tomato, chilli and capsicum were grown in the first round. Second round of cropping is now on. Tomato yield in the first round was 2.7 times of the open field yield. Water required was nearly half of the open field. These are satisfactory results.

ETHE system has been used in winter nights to warm the greenhouse. Night temperature in Kothara begin to drop below 18°C in December. January nights were colder with temperature going down to 8°C to 9°C. ETHE was operated at night from December 15 to February 15 when temperature in greenhouse fell below 15°C. The house was always closed at night. Temperature inside closed greenhouse at night was observed to be virtually the same as the ambient.

Operation of ETHE at night raised the greenhouse temperature to 22-23°C within about 30 minutes. An on/off schedule was adopted. ETHE would be turned on when temperature reached about 15°C, turned off when it reached 22°C. It usually took 70 to 80 minutes for temperature to fall back again below 15°C. **Figure-6** shows the temperatures inside greenhouse and the ambient on one of the nights (January 14-15). ETHE was able to meet the heating need easily, entirely and at only a small cost.

This greenhouse gains as much as 15°C in winter over the ambient when closed and 20-21°C in summer months. Cooling is needed practically all through the year during the day. low. The aim in the first cropping trial was to determine the cooling capabilities of three provisions, singly and in combination and the schedule of operation that could be feasible.

Opening the two side vents reduced the temperature gain significantly (**Table-3**). Opening the ridge vent together with side vents reduces it further. Fogging for 60 seconds every half hour was able to reduce the temperature by two another degrees. It also increased the humidity levels. ETHE operation (with all vents closed) reduced the greenhouse temperature by 6 to 7°C below the ambient.

Figures-7 and 8 show tomato and chili being picked in the greenhouse. ETHE appears to be satisfactory in cooling mode as well. This is a significant achievement in Kutch. Our effort now is to reduce the cost of installation and of running.

Summary

Gujarat is hot and arid in most parts. Earth tube heat exchangers appear to be especially appropriate to regions like Gujarat. Unlike evaporative cooling procedures these do not use water. These can be used both for cooling and warming.

Our experience has demonstrated that these systems are easy to build and maintain. The fact that space could be cooled without the use of water in Kutch promises to remove or at least greatly ease a major impediment in introduction of greenhousing in hot arid areas.

Experience has also shown that environmental control in the dwellings of animals in zoo can be done using ground coupled systems. Commercial livestock buildings--dairy cattle, poultry-- offer further opportunities for application. Improved comfort is known to lead to better health and productivity.

Table-1 : Air Temperature inside ETHE and Soil Temperature (JANUARY)

Hour of day	T_a (°C)	T_s (°C)	$T_{m/d}$ (°C)	T_o (°C)	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

T_a Ambient air temperature

T_s Soil temperature at 3 m depth

T_o Temperature of air coming out of the tube

T_{md} Temperature of air at 25 m along the tube

Table 2: Air Temperature inside ETHE and Soil Temperature (MAY)

Hour of day	T_a (°C)	T_s (°C)	$T_{m/d}$ (°C)	T_o (°C)	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

T_a Ambient air temperature

T_s Soil temperature at 3 m depth

T_o Temperature of air coming out of the tube

T_{md} Temperature of air at 25 m along the tube

Table-3 : Difference between empty greenhouse temperature and the ambient

Details	*February 2002 (°C)*	*April 2002 (°C)*	*June 2002 (°C)*
All vents closed	15.4	20.0	21.3
Only the side vents open	5.5	6.7	7.9
Side and ridge vents open	4.9	-	2.6

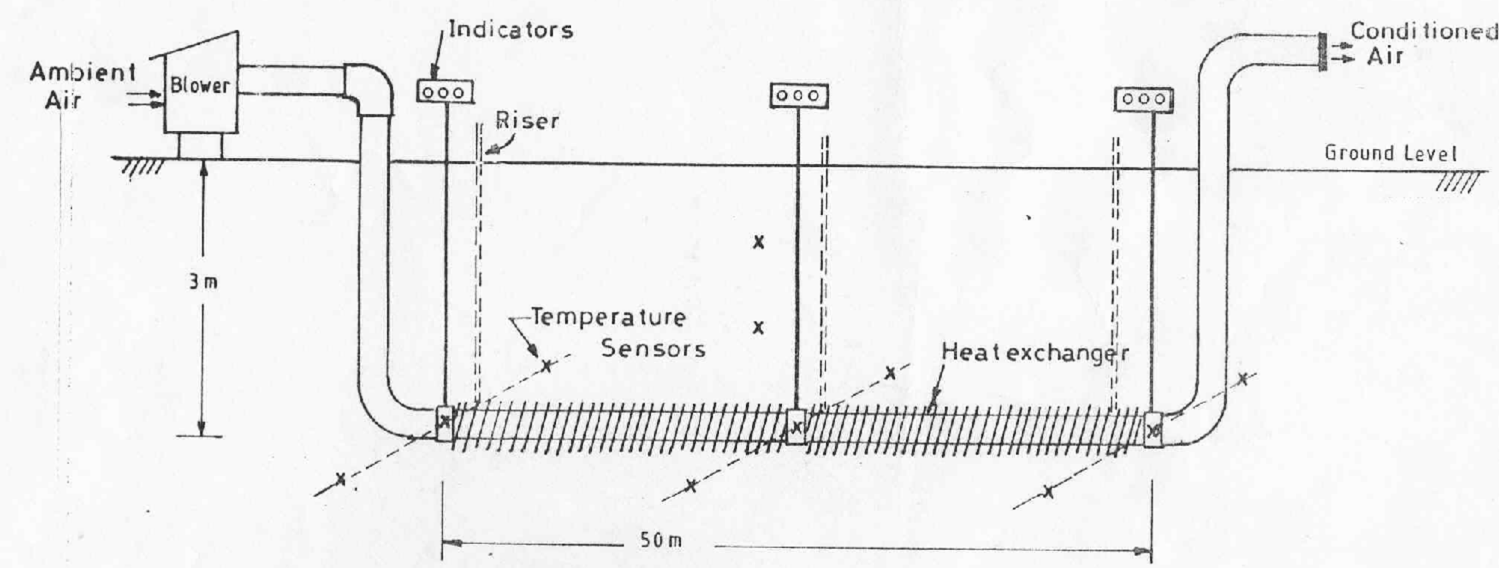

Figure-1

Single Pass Earth Tube Heat Exchanger (ETHE)

installed at Thor for R&D

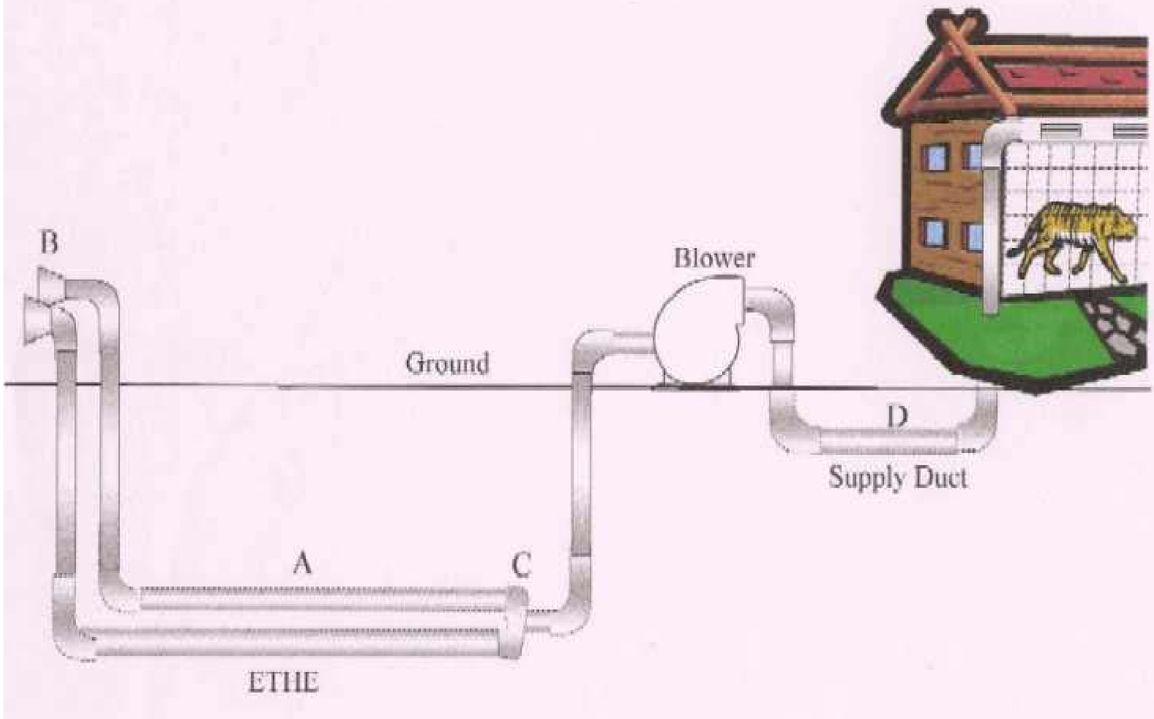

Figure 2

Earth Tube Heat Exchanger Airconditioning System at Kamala Nehru Zoological Garden, Ahmedabad

(schematic diagram)

Figure 3: Greenhouse Coupled to Earth Tube Heat Exchanger (ETHE) at Kothara (Kutch-Gujarat) - *Schematic*

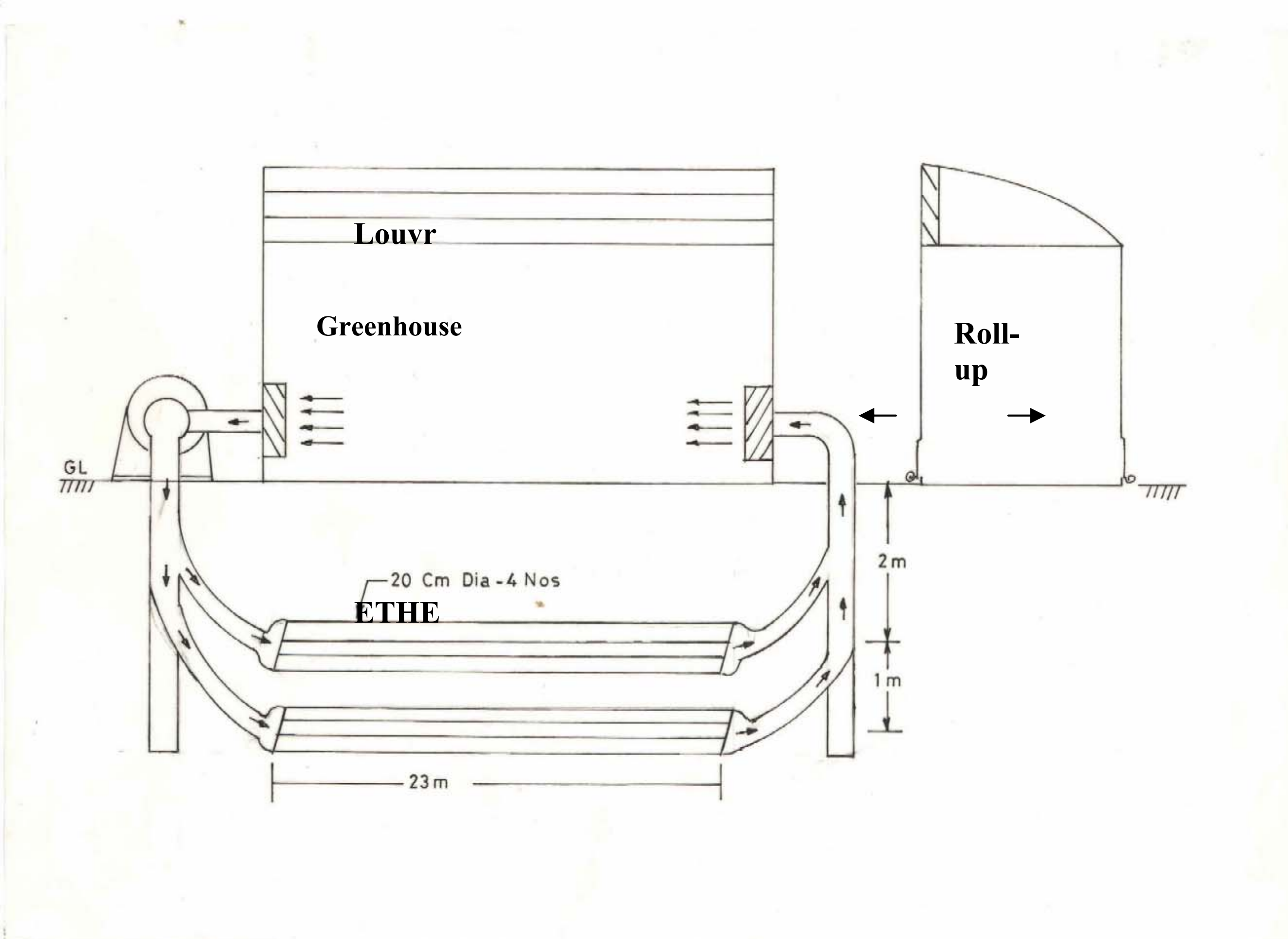

Figure-4: ETHE before being covered

Figure-5: Fully Furnished Greenhouse, Kothara-Kutch Showing
Blower and Suction Duct

Figure-6: Greenhouse and ambient temperature (Night of 14-15 January).

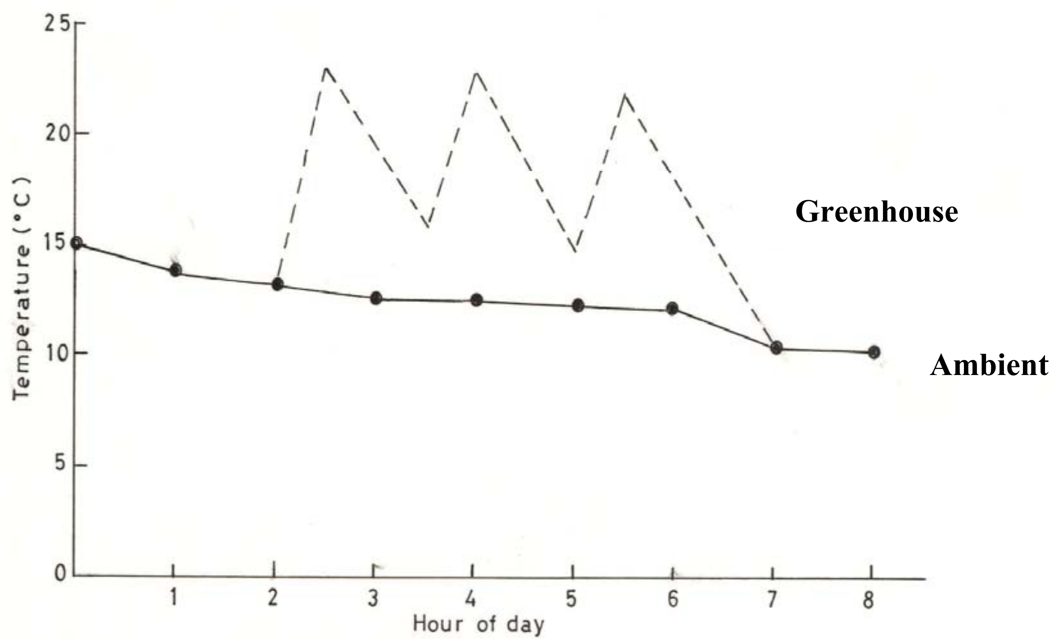

Figure-7: Tomato being picked from Greenhouse

Figure-6: Chili being picked

References

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