Performance of Greenhouse Coupled to Earth-Tube-Heat-Exchanger in Closed-Loop Mode

G. Sharan[1], H. Prakash[2], R. Jadhav[3]

Abstract

An experimental greenhouse coupled to an Earth Tube Heat Exchanger (ETHE) in closed-loop mode has been installed at Kothara (23° 40' N 72° 38' E), India. Area is hot and extremely arid. ETHE is used to warm the greenhouse in winter nights and cool it in hot days. The saw-tooth house is of 6 m span, 20 m length and has ridge height of 3.5 m. ETHE consists of eight ms pipes, each of 20 cm dia and 20 m long. A centrifugal blower powered by 7.5 hp motor moves the air through the system. Volume flow rate of air is 7200 m^3 per hour, which makes for about 20 air changes per hour. ETHE was able to heat the house easily from 9°C to 22-23°C in half hour in the cold winter nights. Opening of side and ridge vents from 11 A.M. to 4 P.M. and fogging at hourly interval kept the house below 34°C till the end of February. Operation of the ETHE became necessary from April. Operation of ETHE reduced the temperature by 7°C below the ambient. ETHE offers the advantage that it uses no water which is scarce. Results of the first cropping trial showed that tomato yield was 2.7 times the open field yield in this area, and water used for irrigation nearly 34% less than that used in open field.

[*Key Words* : *earth pipes, controlled environment agriculture*]

[1] Professor & Coordinator, Cummins-IIMA Lab for Environmental Technologies in Arid Areas, Indian Institute of Management, Ahmedabad 380 015.
Email : gsharan@iimahd.ernet.in

[2] Research Engineer, Cummins-IIMA Lab for Environmental Technologies in Arid Areas, IIM, Ahmedabad 380015

[3] Project Officer, Self Employed Women's Association, Ahmedabad.

Introduction

Kothara, where the experimental facility is located lies in Kutch district of Gujarat province in northwestern India. Agriculture and animal husbandry are the two main occupation here. Productivity of agriculture, grasslands and livestock is low. Low productivity stems from harsh agro-climatic features of this region. Kutch receives high amount of solar radiation. Ambient temperatures and wind velocities are also high. Annual pan evaporation averages to 1840 mm. In comparison, annual rainfall is only 400 mm and very erratic (c.v. 75%). Salt effected soils and poor quality groundwater occur widely. Open field agriculture is highly risk-prone here. Vast areas of land remain uncultivated. Such areas occur in other provinces in India as well such as Rajasthan. Increasing the productivity of such areas will greatly help.

Controlled Environment Agriculture in Arid Areas

Hot, arid areas occur in many parts of the world. Reports indicate that use of microwatering systems, mulching, covered cultivation, greenhousing etc. can help tackle some of the problems posed by such areas. Reports from Kuwait by Hassan 1985, from Abu Dhabi by Baqi 1985 from Jordan Valley by Or 1985, from Iraq by Salih 1985 and from California by Ayers et al 1985 indicate that use of micro-irrigation systems especially the drip made it possible and profitable to grow crops using in some cases highly saline water. El-Aidy 1990 grew tomato, cucumber and pepper in plastic tunnels in a semi-arid coastal region of northern Egypt. Some of the main advantages observed were: (a) this makes better use of limited water, (b) makes possible the use of saline water (2900 ppm or 4.5 dS/m), and (c) improves yield.

Mears 1990 also drew attention to the potential of greenhousing in hot areas. He stated, "while a greenhouse is generally regarded as necessary to provide a warm environment in cold climates, it has also been shown that with properly designed cooling system, it is possible to improve plant growing conditions under extensively hot conditions. Adaptation of modern cooling technologies to Indian conditions will undoubtedly lead to increased opportunities for production of high value plants and materials in areas where the environment is extremely harsh. Protected cultivation also has the potential benefit of substantially increasing plant productivity per unit water consumption, which is important in many areas where good quality water are severely limited." Chandra 1996 too while discussing the design aspects of greenhouse for hot arid areas drew special attention to the problem of cooling. Protected and controlled environment agriculture could be considered an alternate strategic option in making arid areas more productive. Our research program in Kutch is based on such a view.

Adoption of greenhouse technology in hot arid areas like Kutch, will need to overcome two constraints. First, it will be useful to find an alternative (even partial) to evaporative cooling, which consumers large quantities of water. Second constraint is shortage of agriculture-quality water. If large size desalination plants could be built, driven by solar energy, the second impediment will be removed.

Presently our effort is focussed on exploring the use of static ventilation and ETHE in the greenhouse. One of the earliest reports of use of ETHE is from Scott *et al* 1965, who used it to condition the environment in commercial livestock building. Interest in ETHE has increased recently [Spengler and Stombaugh 1983, Goswamy and Dhaliwal 1985, Puri 1986]. Sawhney *et al* 1990 used it to cool a guesthouse. Sharan *et al* 2001 used it to condition the air for a tiger dwelling in Zoo. Santamouris *et al* 1995 published a review of 18 projects using ETHE in greenhouses. Almost all these projects are from cold countries and ETHE was deployed to supplement heating. ETHE kept the greenhouse air several degrees above the ambient. In some cases, especially those that had thermal storage, significant part of annual heating requirement was met. They reported one instance where cooling was also accomplished successfully by similar systems. Their own greenhouse in Agrinion (38.5^{o} N lat) had 1000 m^2 floor was furnished with high inertia north wall as well as 4 plastic pipes of 30 m length, 25 cm diameter carrying air at 8 m/s. They reported that the operation of the system in summer (June) reduced greenhouse temperature by several degrees compared to the ambient.

Feuilloley et al 1990 discussed the desirability of providing sufficient static ventilation in greenhouse in Mediterranean region where summer temperatures after April render it difficulties to operate. They also determined the effect of vent area, vent location, wind speed and height of vegetation in a small experimental Quonset shape tunnel. Tietel and Tanny 1999 carried out experiments as well as developed transient mathematical model relating temperature and humidity ratio to the opening of roof windows, wind speed and solar radiation. The results are useful for design of vents and understanding of ventilation process. Our experimental greenhouse has closeable static vents on the side as well as on the ridge. In addition, the house is coupled to an ETHE in closed-loop mode. We present here details of the facility and the initial results of heating in winter, cooling in summer and production in the first cropping trial.

Experimental Set-up

Greenhouse

Greenhouse is of 6 m span, 20 m length and 3.5 m height at the ridge. Its floor is 120 m^2 and volume 360 m^3. It has saw-tooth profile. Ridge is east-west oriented (**figure-1**). Roof slopes from south to north. Frames are made of square, closed-structural of galvanized iron. The distance between two frames (bay size) is 2 m. It is designed for winds of 180 km/hr, besides the usual other live and dead loads. Cladding is 200 micron UV stabilised polyethylene sheet. At the base of both the long sides there are roll-up curtains for ventilation. Third vent is provided on the south side, at the ridge. This is also closeable and is made of polycarbonate louvers. It can be operated manually from the floor. All three vents (side and ridge) are of 0.5 m height when fully open. Total vent area is 30 m^2 which is 25% of the greenhouse floor area. Side vents account for 17% and ridge 8%. Side vents are covered with insect screen. Entrance to greenhouse is through a 3 x 2 m cut-off enclosure. There is provision for retractable shading screen, which can be spread over the roof above the house as also vertically on the south face, if needed. Shading screen is made of agronets of 50% shading.

Greenhouse is furnished with fertigation system and an array of overhead foggers for environmental control. There are a total of 39 foggers each with discharge of 7 lph at operation pressure of 4 kg/cm^2. Foggers are placed 3 m above ground supported on the frames. Drippers have discharge of 4 lph. Both the systems have manual and automatic modes. Each lateral has its own on/off valve. Thus, watering can be done for different duration in each line, if desired. Water at site has EC of 2 dS/m.

Earth Tube Heat Exchanger

Prior to the design of ETHE for to this greenhouse, year-long measurements were made of the temperature regime up to 3 m depth [Sharan and Jadhav 2002]. It was found that stratum between 2 to 3 m had stable temperature regime. Diurnal variations of course ceased completely, amplitude of annual wave is also diminished considerably. Amplitude at 3 m was just 2.8^{o}C, around the mean of 27^{o}C. After the study of deep soil temperature regime, one single pass ETHE was built in order to study the actual performance [Sharan and Jadhav 2003]. The ETHE was elaborately instrumented along its 50 m length. It was made of 10 cm diameter ms pipe. Performance of this system was studied for three consecutive days in each of the twelve months. It was found that it was able to warm-up the ambient air in January nights from 9^{o}C to 23^{o}C. In June it was able to cool the ambient air from 41^{o}C to 31^{o}C.

It was decided to set the volume flow rate of air from ETHE at 20 air changes in the greenhouse per hour. This meant the blower output of 7200 m^3/hr. Computations had shown that a higher change rate is desirable, but the system was tending to become unwieldy, and expensive. Air velocity of 8 m/s was set for each pipe. Pressure drop in the ETHE calculated using Longest Path method, worked out to 200 mm water gauge. Blower is powered by a 7.5 hp, 1440 rpm motor. Blower was tested before installation. It delivered 4000 m^3/hr to 7000 m^3/hr of air in its optimum working range of 200 mm to 225 mm water pressure gauge. There are 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. 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. Before being covered with earth, ETHE was tested for leakage by candle test. Conditioned air is let into the greenhouse via a louvered opening, 6 m wide and 0.45 m high. The entire opening is divided in six equal parts of one meter each. Bottom of the louvered opening is set at 0.6 m above ground.

Air velocity was measured with a portable anemometer at the louvers as it entered the greenhouse. It was noticed that the outer most sections of the opening (1 m on left and 1 m on right) had very little flow. The louvers of these two were therefore closed. The remaining four sections then had more uniform velocity close to the average of 1.1 m/s. Outlet on the opposite end is identical in construction to the inlet.

Instrumentation

An eight-channel data logger powered by chargeable 12 V battery is installed. Sensors include temperature, solar radiation, wind speed, humidity, soil temperature. Temperature sensors are placed at three locations in the greenhouse -- both ends and center. Sensors are placed 1 m above ground and have weather shield. Soil temperature sensors are two -- one placed at 30 cm depth and the other just below the surface. Relative humidity sensor is placed at the center of the house, 1 m above ground. This also has weather shield. Data logger has LCD display, real time clock calendar, serial output port for connecting it to PC with parallel interface to printer or memory module. Data logger is placed just outside the greenhouse in weather proof enclosure.

Heating of Greenhouse in Winter

First cropping trial commenced in December 2002. Tomato were planted in the early part of the month. Night temperature in Kothara began to drop below 18°C in December. January nights were colder with temperature going down to 8°C to 9°C. Night temperature rose above 18°C by about middle of February. 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.

It was observed that operation of ETHE at night raised the greenhouse temperature to 22-23°C within about 30 minutes. Keeping the ETHE on continuously was difficult because of wide fluctuations in voltage and consequent tripping of motor. 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-2** 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.

Cooling of Greenhouse

In the coolest part of the year, December-January day temperature vary from 25°C to 32°C. In hottest months, May-June, day temperature vary from 34°C to 45°C. There are a few days when the maximum could be as high as 46°C. This greenhouse gains as much as 15°C in winter over the ambient when closed and 20-21°C in summer months. In an air tight greenhouse cooling will be needed practically all through the year during the day. Major component of environmental control in this region thus is cooling, just as heating is in cold countries. It is useful to determine the strategy by which cropping could be prolonged and cooling costs could be kept 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-1**). Opening the ridge vent together with side vents reduced it further. Fogging for 60 seconds every half hour was able to reduce the temperature by two 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. More than about two hours of continuous operation of ETHE was usually not possible due to voltage fluctuations. When voltage is low, motor tends to heat up, necessitating a pause.

Till January 15, opening the three vents from 11 A.M. to 4 P.M. was adequate to maintain the greenhouse temperature below 34^{o}C. From middle of January to end of February, foggers needed to be operated as well. Fogging was done at hourly interval for 60 seconds each time. This (open vents and fogging) was adequate to keep the temperatures below 34^{o}C till the end of February. Only on a few occasions, at about 2 P.M. temperature exceeded this value. Beginning with March, the greenhouse was shaded from top. Fogging interval was reduced to half hour. This procedure kept the greenhouse at the ambient temperature, in fact on many occasions cooler by two to three degrees. By this time the tomato plants were nearly 84 cm tall and had well developed leaves and canopy. Beginning April, the above measures became inadequate as the peak time temperatures in greenhouse began to go above 37^{o}C. Operation of the ETHE reduced the temperatures by 6 to 7^{o}C. When possible it was operated longer, but mostly from 11 A.M. to 1 P.M.

First Cropping Trial

Table-2 gives a summary of cropping results. Very little (about 600 ha) tomato is grown in this region in open field. In the limited pockets where it is grown, it is planted in August and harvest is over by February. The best yields reported by the Department of Agriculture is 15 T/ha. Growers in this region corroborate this. The variety grown in greenhouse was not a hybrid, but an induced mutant variety from Annagi tomato of Tamil Nadu released in 1978 (notification status S.O. 540(E), dated 24.7.1985). The villagers like it for its flavour. Tomato in greenhouse was `off-season.' The yield obtained was 2.7 times that of the (normal season) open field crop. Growers in this region report that tomato is highly water consuming crop, requiring over 300 to 500 mm of water in open field. The water used in greenhouse works out to 147 mm, that is nearly half as much.

Foggers consumed 3000 liters during the entire season. Generally, fan-pad system of cooling uses 50 liter per m^2 pad area per hour. This house does not have this system. But computations were made just for comparison. A 7 m^2 pad would have been needed. Each day (6 hour) of operation of such a system would have used 350 liters. For 100 days of operation, it would have used 35,000 liters.

Conclusion

1. Greenhouse cultivation in hot, arid Kutch, appears feasible. It reduces water requirement and makes possible growing of crops beyond the normal seasons. First cropping trial has shown that (off-season) tomato yield was 2.7 times the best-reported open field yields in this region. Water used for irrigation was nearly half that used in open field.

2. Heating requirement is limited to two months. Heating was easily and economically done by the earth tube heat exchanger. This house had static vent area of 25% of the floor. Side vents accounted for 17% and the ridge vent for 8%. Opening the vents from 11 A.M. to 4 P.M. was adequate to keep the house below 34^{o}C till the middle of January. Subsequently, fogging and still later shading from top was added to this practice. April onwards, ETHE needed to be operated during noon hours. ETHE operation reduced greenhouse temperature by 6 to 7^{o}C below ambient.

Table-1: Difference between empty greenhouse temperature and the ambient

Details	February 2002 (^{o}C)	April 2002 (^{o}C)	June 2002 (^{o}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

Table-2: Summary of Cropping Results

Details	Tomato
Variety	Mahyco PKM-1
Planting date	01 January 2003
Spacing	45 x 45 cm
Planted area	35 m^{2}
First flowered	47 days from planting
First picked	65 days after planting
Fruit size (mean)	65 mm
Total yield	40 t/ha
Harvest ends	30 April 2003 (4 months)
Irrigation water applied up to harvest	143 mm

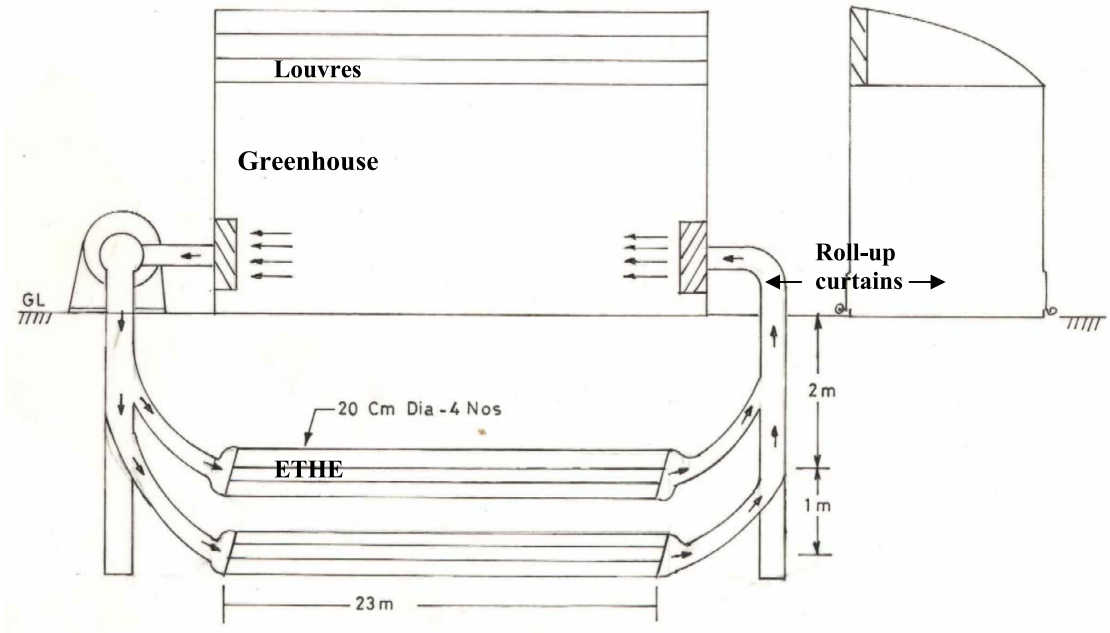

Figure 1: Greenhouse coupled to earth tube heat exchanger (ETHE) at Kothara (Kutch Gujarat, India) - Schematic.

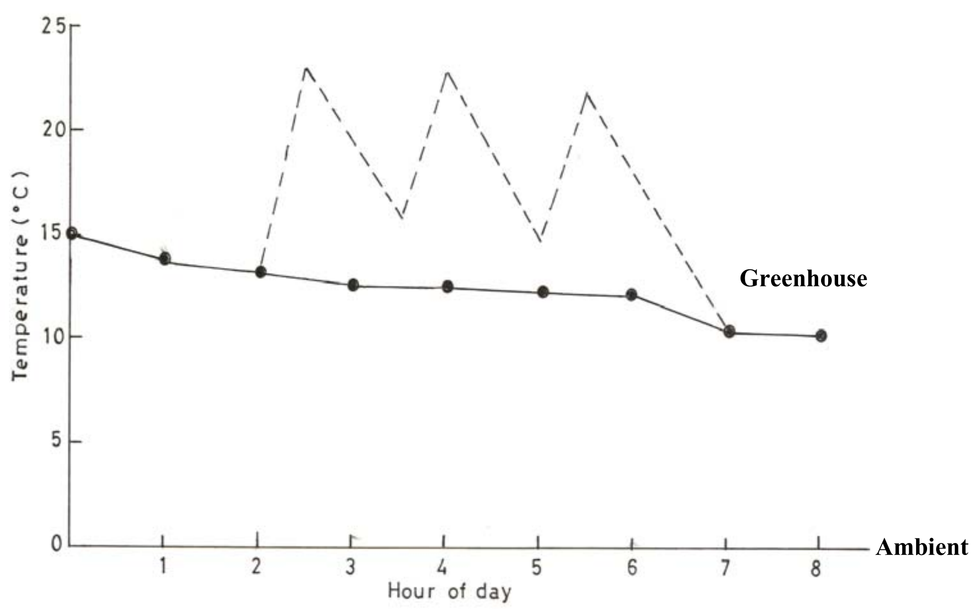

Figure-2: Greenhouse and ambient temperature (Night of 14-15 January).

Acknowledgements

The work was funded jointly by the Cummins Diesel (India) Foundation, Pune; Gujarat Energy Development Agency (GEDA), Vadodara; and Sir Ratan Tata Trust, Mumbai. We thank Dr. K.V. Doshi, Deputy Director (R&D), GEDA for permission to use their land in Kothara to set up the facility. We thank the Center for Management in Agriculture, Indian Institute of Management, Ahmedabad for use of their facility.

Reference

Ayers JS., RB Hutmacher, RA Shoneman, SS Vail, SH Pattan, and D. Felleke, 1985. Salt distribution under cotton trickle irrigated with saline water. In: Drip/Trickle Irrigation in Action. Vol.II, ASAE, SP 10-85, Elsevier.

Baqi O., 1985. Drip irrigation in United Arab Emirates. In: Drip/Trickle Irrigation in Action. Vol.I, ASAE, SP 10-85, Elsevier.

Chandra P., 1996. Greenhouse design consideration for hot arid areas. In: Proceedings of Symposium on Controlled Environment: Agriculture in Arid Areas, Institution of Engineers (Gujarat Chapter), Ahmedabad, India.

El-Aidy F., 1990. The advantage of using plastic cover on the production of some vegetable crop in the northern coastal regions of Egypt. In: Proceedings of Symposium on Controlled Environment: Agriculture in Arid Areas, Institution of Engineers (Gujarat Chapter), Ahmedabad, India.

Feuilloley P., C. Mekikdjian, J. Gratraud, 1990. Optimal static ventilation in greenhouses. In: Proceedings of XI International Congress: The Use of Plastics in Agriculture. Oxford and IBH Publishing Company Private Limited, New Delhi, India.

Goswamy DY., AS Dhaliwal, 1985. Heat transfer analysis in environmental control using an underground air tunnel. Journal of Solar Energy Engineering, 107, 141-145.

Hassan FA., 1985. Drip irrigation and crop production in arid region. In: Drip/Trickle Irrigation in Action. Vol.I, ASAE, SP 10-85, Elsevier.

Mears DR, 1990. Opportunities for collaborative Indo-US greenhouse research. In: Proceedings of XI International Congress: The Use of Plastics in Agriculture. Oxford and IBH Publishing Company Private Limited, New Delhi, India.

Or U., 1985. Jordan Valley drip irrigation scheme: A model for developing countries. In: Drip/Trickle Irrigation in Action. Vol. I, ASAE, SP 10-85, Elsevier.

Puri VM., 1985. Feasibility and performance curves for intermittent earth tube heat exchangers. Transactions of the ASAE 29 [2], 526-532.

Salih RO., 1985. Comparative studies on drip irrigation in Iraq. In: Drip/Trickle Irrigation in Action. Vol. I, ASAE, SP 10-85, Elsevier.

Santamouris M., G. Mihalakaha, CA Balaras,. AD Argirioua, M. Vallinaras, 1995. Use of Buried pipes for energy conservation in cooling of agricultural greenhouse. Solar Energy 35, 111-124

Sawhney RL., Buddhi, NM Thanu, 1990. An experimental study of summer performance of a recirculation type underground airpipe air conditioning system. Building and Environment 34, 189-196.

Scott NR., RA Parsons, TA Kohler, 1965. Analysis and performance of an earth-tube heat exchanger. ASAE Paper No.65-840. St. Joseph, Michigan: ASAE.

Sharan G., RK Sahu, R. Jadhav, 2001. Earth-tube heat exchanger based air-conditioning for tiger dwellings. Zoos Print 16 [5], May (RNI2:8).

Sharan G., R. Jadhav, 2002. Soil Temperature Regime at Ahmedabad. Journal of Agricultural Engineering 39 [1], January-March.

Sharan G., R. Jadhav, 2003. Performance of single pass earth-tube heat exchanger: An experimental study. Journal of Agricultural Engineering (forthcoming).

Spengler RW., DP Stombaugh, 1983. Optimization of earth tube heat exchanger for winter ventilation of swine housing. Transaction. of ASAE**,** 1186-1193.

Tietel M., J. Tanny, 1999. Natural ventilation of greenhouses: Experiments and model. Agricultural and Forest Meteorology, 96, 59-70.