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Abstract

In hot, arid regions, yields are low and unstable, growing season limited to one. Greenhouses can stabilize and improve yields and extend seasons. But their adoption is impeded by the requirement of large amount of water for (evaporative) cooling. Arid Area Greenhouse (AAG) is being developed to reduce or eliminate this need by employing earth-tube-heat-exchanger (ETHE). A prototype AAG was installed in the year 2002 at village Kothara (φ 23° 14 N, λ 68° 45 E, at 21 m a.s.l.).

AAG is of 20 X 6 X 3.5 m size. ETHE is buried 3m deep and coupled to AAG in closed-loop. ETHE provides 20 air changes per hour. There is provision of closable vents - two along the base of long sides and one along the ridge. A retractable shading curtain is provided over the roof.

By now five rounds of cropping have been done. ETHE was able to heat the greenhouse from 9° C to 22-23° C in half hour in the cold winter nights. Static ventilation along with shading was effective for day time control till early March. Subsequently ETHE was operated. It limited the greenhouse temperature gain to just 2.5° C. Yield of tomato was 1.5 to 2 times, water used 44% of that in open-field. Water used was mostly for plants, only a small part was for foggers which were some times needed as supplement. ETHE and natural ventilation hold promise as environmental control devices for greenhouses in hot arid regions.

Keywords: greenhouse, arid environment, earth-tube-heat-exchanger

Introduction

Kutch region, in the north-western part of India, is characterized by low and erratic rainfall, high ambient temperatures, salt-affected soils and poor quality water. Open-field cultivation is prone to failures and yields are low. Technology that can reduce the risk of crop failure, improve yields and make better use of scarce water would be greatly desirable. Greenhouse technology could help achieve these goals. But it is still relatively new in India, and the installations are mostly in colder regions so far. Its potential usefulness in making the hot arid areas more productive has not been appreciated; nor researches carried out to adapt it to such areas. Mears (1990) drew attention to this.

> "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

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> 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 is severely limited."

Common methods of cooling are - fan and pad systems and mist nozzles or foggers. Estimate of water required for cooling under climatic conditions of Bhuj (90 km from project site) showed that a five month crop needing cooling for about 120 days will use up over 700 mm of water, comparable to that needed in open-field. This is one major impediment. Alternative cooling procedure that would need less (or no) water would be desirable. One possible alternative could be the earth-tube-heat-exchanger (ETHE). Natural ventilation may be another.

Greenhouses in the southern Mediterranean area too have the same problem. Kittas et al.. (1996) observed - “development of the greenhouse area in Mediterranean and arid regions calls for efficient greenhouse summer acclimatization. Natural ventilation is the most common system used for greenhouse cooling.” Cooling needs will be more prolonged in Kutch area. But at the same time it is windy. For instance mean wind velocity during the day (10 am to 4 pm) in the month of April typically is 6 m/s, May 8 m/s and in June 9 m/s. Reliance on natural ventilation would also be appropriate, in view of the fact that electricity is expensive and supply unreliable.

Survey of literature

Santamouris *et al.* (1995) reviewed a set of eighteen greenhouse installations drawn from different countries using ETHE. In all these it was deployed to supplement heating. The cover it provided to total heating requirement varied from 28% to 60 %. In some cases the performance was stated in terms of increase in greenhouse air temperature over the ambient on coldest days which varied from 3° to 10° C.

Use in cooling mode, if any, was not mentioned. But they demonstrated via simulation that ETHE would be an equally attractive supplement for cooling. Using TRNSYS simulations were done for a greenhouse coupled to ETHE and operating under Athens (37.5° N lat) environment . Climatic and ground temperature data of Athens was used. Air temperature of the greenhouse in summers was predicted and compared with measurements from their 1000 m^2 glass-covered greenhouse at Athens coupled to a set of four underground parallel pipes made of plastic. Simulations showed that continuously ventilating the greenhouse with air from the buried pipes will keep the inside air temperature below 40° C. In summers of Athens, temperatures in closed, unventilated greenhouse commonly go up to 45° C, they stated. In Kothara (23° 14 N lat) a closed house in October showed 55° C at 1400 hrs, November 46° C, December 38° C, January 34° C, June 59° C. Here a ETHE with air change rate higher than Athens might be needed.

Extensive work on natural ventilation has been reported from the Mediterranean region and some also from parts of the USA. Boulard and Baille (1995) , Boulard and Draoui (1995) developed useful expressions to predict ventilation rates from roof vents after extensive measurements in a 416 m^2 two span plastic greenhouse at Avignon (France). One of the several models to compute the ventilation rate, given the roof vent size and wind speed is:

$$G = S/2 \ A_1 \sqrt{CW} \ V \qquad \text{.............} \ 1$$

Where G is ventilation rate, S vent area, $A_1 \sqrt{CW}$ empirically determined dimensionless coefficient, for wind regimes of 6 to 9 m/s $A_1 \sqrt{CW}$ was determined as ($0.20 \pm .008$), V Wind speed. **Table (1)** shows the empirical coefficients determined by several other authors.

Table 1: Empirical Wind-coefficients for Vents without Screens

Source	Roof	One side	Both sides	Roof + one side
Papadakis, et al. (1996)	0.246	0.142	-	0.210
Kittas, et al. (1996) Tunnel	-	-	0.23	-
Kittas, et al. (2002)	0.288 without screen 0.136 with screen	-	-	-

Kacira et al. (1998) used Computational Fluid Dynamics (CFD) software to study air change rates, wind flow patterns in greenhouse of sawtooth profile with vents on the side and roof. Simulations indicate that air change rate is influenced significantly and positively by the wind speed , location of vents with respect to wind direction . Side vent on the windward side is more effective than the roof vents. For instance , in empty condition in a two span house with external wind of 2 m/s , the air change rate was 4.05 Ac/min with the windward side vent open along with the two roof vents. Without the side vent , the rate declined to just 0.7 AC/min - one sixth . The side vent area was 9 % of the floor area, each of the two roof vents 12% of the floor. All three vents had an area of 33% of the floor. At slower winds, decline was proportionately greater. The wind flow patterns obtained from simulations are interesting and help in understanding the usefulness of vent size and location.

Ted Short (1998) made actual measurement of temperature and air-change rate in a naturally ventilated Quonset house - four and a half span, gutter connected , double poly clad in Wooster, Ohio - and reported a very satisfactory results. The house had side vent on the west (windward) side and leeward opening roof vents. " For westerly winds , the volumetric air exchange was found to be 0.9 air-changes per minute; inside temperature never exceeding outside by more than 5° F. In most cases the inside temperature was within 2° F of the outside." Based on the results it was suggested that the roof vent opening should be 15-20 % of the floor area and open leeward to the wind. Side opening should be windward and equal at least one roof vent in size.

Openings in the greenhouses are covered with insect-screens, which reduces the ventilation rate significantly as can be seen from results of Kittas et al. (2002) in **Table 1**. Miguel et al. (1997) tested seven different screen materials , determined pressure drop across screens and estimated the permeability. They showed that the pressure drop was best described by the well known Forcheimer equation. Muñoz (1999) developed information on two important parameters - discharge coefficient for the vents and the wind–effect coefficient for the structure - needed to compute ventilation rates in a given house of given vent size and location.

Let us recapitulate. Greenhouse technology can improve productivity of hot arid areas. To facilitate its adoption it would be desirable to develop methods of cooling that require less or no water, and that are economical also on electricity use. Efforts are on at several places to adopt natural ventilation in greenhouses in the Mediterranean area to reduce cooling costs. The ETHE and static ventilation appear promising for hot arid areas like Kutch in India. These need to be tried out.

Objective

A facility was built at Kothara consisting of a greenhouse coupled to ETHE in closed-loop mode and furnished with side and roof vents and retractable shade nets on top. The entire assembly is termed Arid Area Greenhouse (AAG). Work reported in this paper was carried out at this facility with following objectives.

1. To determine the extent to which environmental control (cooling in summer and heating in winter if required) is achieved in AAG with the use of static vents and ETHE.
2. To carry out cropping trials to determine the extent to which AAG is able to increase yields , reduce water use and extend cropping season compared to the open-field cultivation.

A detailed description of the experimental facility and the experience of growing a high yielding variety of tomato , can be seen in Sharan et al. (2003 c). A brief description of the facility is given here . It is followed by presentation of results of growing a hybrid cultivar of tomato more common among commercial growers.

Experimental Arid Area Greenhouse

In the year 1998 , when our initiative to introduce controlled- environment- agriculture in the arid region started, there was no local data-base on deep ground temperature regime, nor of course any example of ETHE application. Considerable amount of basic work had to be done to build local data base. First, the deep ground temperature regime was characterized. Sharan and Jadhav (2002) reported that the temperature regime at 3 m depth is stable , with mean of 27° C and a small seasonal amplitude of fluctuation. Then a single pass ETHE built and tested in heating and cooling mode (Sharan and Jadhav 2003 a; Sharan and Madhavan 2003 b). Then one actual system using ETHE was installed at Ahmedabad Zoo to cool the dwellings of tigers (Sharan, Sahu and

Jadhav 2001). Experiences from all these were used to design and build the facility at Kothara.

Greenhouse

The greenhouse is a saw-tooth structure with frames made of square closed-structurals of galvanized iron . It has 6 m span, 20 m length and 3.5 m height at the ridge; with floor area of 120 m^2 and enclosed volume 360 m^3 (**Figure 1**). The gutter is east-west oriented. Cladding is 200 micron UV stabilised PE film.

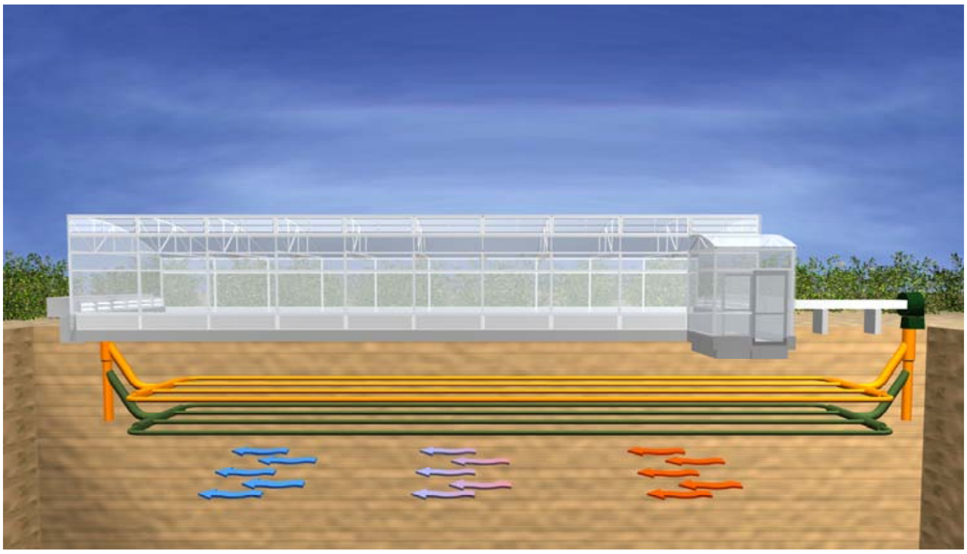

Figure 1: Experimental Arid Area Greenhouse - Kothara

Vents

Although some work has been initiated , there are as yet no standards for air change rates for naturally ventilated greenhouses in India (Pitam Chandra personal communication). The ASAE standard is 0.75 – 1 air change per minute. **Equation 2** gives the relation between the air flow rate and the heat to be removed (ASHRAE 1985 Fundamentals),

$$Q = \frac{H}{(Cf_2)\,(T_i - T_o)} \qquad \ldots\ldots\ldots\ldots\ 2$$

Where Q is air flow rate (m^3/h) , H heat to be removed form the space (W), cf_2 a computational coefficient (0.34), Ti and To the temperatures inside and outside the space (K). **Table 2** shows temperature difference for given air change rate obtained from above equation. With air change rate of about one, one can expect the inside temperature to be within two degrees of the outside. We selected to achieve a air change of one per minute or 360 m^3/min in the Kothara facility. So now we need to determine the total area and location of vents. Vents will have screens and there will be crop inside in operation.

Table 2: Air change rate and temperature difference

Delta T (°C)	Air change rate
1	2.1
2	1.1
3	0.8
4	0.7

Location

Two openings placed on opposite sides increase the air flow rate; also some vertical distance between openings is needed for flow to be caused by thermal gradient (ASHRAE Fundamentals 1985). Sides-and-roof configuration has been commended by Feuilloley et al. (1990), Short (1998) was adopted. It was decided to have three vents - two opposite each other on the sides at the same level and one on the ridge (roof). The side vents are continuous, and ridge vent is framed in segments. As all three vents are manually closable, this configuration would permit flexibility in operation.

Size of openings

The peak wind speeds in the summer period – March to June - are 8 to 10 m/s in Kothara area. We will take 4 m/s (half of the peak) for determination of the vent size. Using the wind coefficients given by Papadakis (1996) the height of vent opening (length taken equal to the length of the side or ridge- 20 m) for the configuration - one on side one on roof opposite- was found to be 0.53 m (each). This will have a ventilation rate of one. As it was selected to have three vents, all were made equal - 20 m X 0.5 m. Total vent area amounts to 25% of the floor area - 17% on the sides, 8% ridge. Vents are screened . There is provision for retractable shading cover over the roof made of non-woven shade -nets with 50% shading.

Coefficients for the three vent configuration – two on side one on roof- were not found in literature. Also, at the time (2000) when the facility was built, wind-related coefficients were not readily available for screened vents. Therefore it was not possible to determine , *a priori*, exact rate of ventilation that would actually result. Visual observations were made of the flow of smoke out of the greenhouse. Smoke was generated at three points in the closed and empty greenhouse. In one test all three vents were simultaneously opened. The wind direction at the time was south-west. Most of the smoke went out of the vent at the bottom on the north side. A much smaller amount exited through the top vent. House became apparently clear of smoke in just a few minutes.

Earth Tube Heat Exchanger

Procedure to design or select a fan-pad system for greenhouse of given size at any given location is well established along with the prescribed standards for components. This is not the case with the ETHE based systems. In computing the ventilation requirement of the greenhouse (air changes per hour) it was assumed that the greenhouse has crop canopy (not empty), and is kept shaded at peak times. The ETHE actually in place provides 20 air changes in the greenhouse per hour. Computations had shown that a higher ventilation rate is desirable, but the system was tending to become unwieldy, and expensive. It was therefore decided to limit the size to twenty air changes , and provide foggers to augment cooling at peak times. Air is moved by a centrifugal blower powered by a 4 KW , 1440 rpm motor.

ETHE is made 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 diameter. Pipes are made of mild steel, with 3 mm wall thickness. Such pipes are commonly used as tube-well casing . Pipes are set 1.5 m apart. There is a common header at both ends of each tier. Air is drawn from the greenhouse, cycled through the buried pipes and returned to the greenhouse. There are 39 foggers with discharge of 7 lph and operating pressure of 4 kg/cm^2.

Fertigation unit

There is a fertigation unit and dripper lines for watering and application of fertilizers.

Instrumentation

A eight-channel data logger powered by chargeable 12 V battery is installed. Air temperature and relative humidity, wind speed (three cups anemometer at 5m above the ground) were measured and recorded on site every hour by a data logger (Weather Technologies India). Temperature measurements accuracy is ± 0.2 °C (resolution ± 0.1 °C), relative humidity accuracy is ± 3 % (resolution ± 0.1 %), wind speed accuracy is better than ± 0.5 m/s with a stalling speed of 0.3 m/s. Three weather shielded temperature sensors are placed 1 m above ground at three locations on the centre line - ends and middle. Of the two soil temperature sensors, one is placed at 30 cm depth and the other just below the surface. Relative humidity sensor is placed over the centre line at the middle 1 m above ground. Data logger has LCD display, real time clock calendar, and serial output port for connecting it to PC with parallel interface to printer or memory module.

Environmental control

Natural ventilation

With crop inside (tomato 1.9 m high trellis supported) and top-shaded a closed greenhouse in June showed a peak gain of 9.8° C (**Table 3**) . It reduced to 3.1° C when all vents were opened. It is not expected that these results will be identical to those at other locations. But it is interesting to compare these with results reported by Tietel and Tanny (1999). They studied transient behavior of greenhouse located in the south of Israel (31.28 N . 34.38 E , 75 m a.m.s.l.). The facility was four-span saw tooth structure with 960 m^2 floor and continuous roof windows of 67 m^2 total area i.e. 6.9% of the floor. It had pepper trailed to a height of 2.8 m during the tests. On one of several days of test (1 July) greenhouse allowed to heat up for an hour after being closed. It was hotter by 6.3° C from the ambient - 32.5° C - at 10 am when the roof vents were opened. The house began to cool and reached steady - state in about 38 minutes . By then the house had cooled to just 1.2° C above the ambient which had remained nearly constant , about 31° C. During the test the radiation level was closely around 872 W/m^2 and the wind 2.5 m/s. Tests were repeated over several days with similar results.

Table 3: Temperature Gain (crop inside greenhouse shaded June 2005)

Status of Vents and Cooling System	Gain June 2005 2 pm (° C)	Water used if foggers on (liter/hr)
All vents closed	9.8	off
All vents open	3.1	off
All vents closed ETHE turned on at 10 AM turned off 4 PM	2.5	off
All vents closed ETHE on from 10 AM to 4 PM Fogger 30 min off, 2 min on	1.2	18
Note: tests done from June 16 to 22; solar radiation and wind speed sensors were malfunctioning. On days just before tests mean radiation levels between 10am and 4 pm was 883 w/m^2 and mean wind speeds 8 m/s.		

Operation of ETHE

When ETHE system is operated, all vents are closed. ETHE alone is able to limit the gain to 2.5° C. When along with the ETHE system , fogging is also done (2 minute bursts every half hour) the gain is reduced further to just 1.2° C. Increasing the frequency of fogging further was tried but it did not help appreciably. The table also shows the amount of water lost in providing supplementary evaporative cooling - 18 liters per hour at two bursts of 120 s each per hour.

ETHE provides for 0.33 air change per minute. The air change rates from the three vents was expected to be near one if there was no screen and no crop inside. Screens reduce the flow rate significantly (see Kittas et al.. 2002 Table 1). Presence of tall crop reduces it further. Feuilloley, et al.. (1990) investigated the effect of vent size , location, wind speed and height of vegetation on ventilation rates and reduction in temperature achieved in experimental Quonset tunnel. They reported - “the best ventilation system has top and bottom openings and bottom opening area greater than top opening area. The optimal total opening area for this system is 32% (15% top , 17% bottom).” They measured the ventilation coefficient (air change rate per hour) using (CO_2) gas tracer technique. Opening area of 32% achieved ventilation coefficient of 76 on bare ground and 40 with 1.8 m high ‘vegetation’. Effect of plant height on ventilation coefficient was simulated by erecting plastic windbreaks inside the tunnel. It is plausible that with tall crop inside and screened vents the three-vent configuration at Kothara provides air change rate of less than one. The ETHE forces the air mechanically and its output is not influenced by the crop. Thus the closeness of performance may be reasonable.

Heating by ETHE

Night temperature in Kothara generally begins to drop below 18° C in December. January nights are colder with temperature going down to 8° C to 9° C. Night temperature rises above 18° C by about middle of February. The temperatures in closed greenhouse at night were observed to be virtually the same as the ambient. Heating is therefore needed from December 15 to about February 15. It has been reported elsewhere (Sharan et al. 2003 c) that heating is very effectively done with ETHE. When temperature inside fall below 15° C, ETHE is turned on. It raises the temperature to 22-23° C within about 30 minutes. An on/off schedule can be adopted - turning it on when temperature reached about 15° C, off when it is raised to 22° C. It usually took 70 to 80 minutes for temperature to fall back again below 15° C.

Schedule of environmental control

In colder months - November, December and January and part of February - simply opening the vents for two hours around noon is adequate. Heating is needed at night which can be easily done by ETHE. Beginning February, top is shaded and vents are opened for four hours around noon. This procedure keeps the inside temperature below 34° C. Beginning April ETHE is operated and on occasions fogging is also used. This procedure keeps the inside temperature about 34° - 36° C. Cropping is done till the middle of May. Greenhouse is closed from May 15 to June 30. Cropping is resumed in July.

Tomato cultivation

In the second cropping trial a hybrid cultivar of tomato (cv Avinash F2 of Sygenta) was grown which is more common among commercial growers now (**Figure 2**). Seedlings were planted on October 28, 2004 (**Table 4).** The last picking was on May 15, 2005. The crop was maintained in the greenhouse till the third week of June only for tests and other observations. April onwards the produce was getting better price because March onwards there is no standing crop of tomato any where in the whole province. But by the end of May fruit size reduced, quantity picked per week also reduced and it became too hot. Being able to carry out cropping well into summer is a very important achievement in this area.

Figure 2: Tomato in Arid Area Greenhouse – Kothara

Table 4: Summary of Cropping Results

Sr. No.	Details	Tomato
1.	Variety	Avinash F2 hybrid
2.	Plant spacing Planted area	45 x 45 cm. 95 m^2
3.	Planting date First flowered First picking Last picking	28 October, 2004 30 days after planting February 16 (100 days after planting May 15 2005 (195 days after)
4.	Fruit size	Major axis 5.5 – 6.0 cm
		Minor 5.2 – 5.8 cm
5.	Plant height	190.0 cm
6.	Yield	56.3 t/ha
7.	Total fogger water applied	0

Economy in use of Water

Total irrigation water applied was 211 mm. This is only about half of that used in the open-field cultivation of tomato, which as stated earlier yields less and ends the season in March. Although in the course of the first trial foggers were occasionally used, during this trial foggers were not used. The reason for not using the foggers was that particles of water that landed on leaves appeared to cause tiny dull brown spots looking like salt-burn injury.

Increase in yield per round of cropping

Total yield was an equivalent of 56.3 t/ha. In immediate neighborhood in this district itself the best yield in open-fields is reported by growers to be just 15 t/ha. In other parts of this province however, which are humid, the best yield reported is 30 t/ha. Thus the AAG yield is nearly two times that of the best open -field yields in humid areas of the province**).**

Summary and Conclusion

Greenhouse technology with suitable adaptation can be used in hot, arid areas to improve yields, extend cropping season and make better use of scarce water. Earth-tube-heat-exchanger and static ventilation are the two promising adaptations which can be used for environmental control. ETHE also provides an effective means of heating in winter nights. The facility with these features is termed Arid Area Greenhouse.

AAG at Kothara had static vent area equivalent to 25% of the floor area - the two side vents accounted for 17% and the ridge vent for 8%. The ETHE has capacity to provide twenty air changes per hour. It is embedded in the strata between 2 to 3 m below the house where mean temperatures are 27° C with small annual amplitude of fluctuation.

1. Opening the vents from 11 A.M. to 4 P.M. and shading from top was adequate to keep the house below 34° C till the middle of January. Subsequently, ETHE needed to be operated. ETHE operation limited the temperature gain and kept the inside near 36° C. Further increase in air change rate may be desirable.
2. Water required to raise a crop of hybrid tomato was nearly half of that required in the open field in Gujarat. Yield was nearly two times that of the open field.

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