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"PERFORMANCE OF GREENHOUSES IN THE ARABIAN GULF"

Part I : Thermal Aspects

By

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ABSTRACT

This work is devoted to the gaining of insight into the operation of environmentally controlled greenhouse in hot and humid climates. Field data inside and outside the greenhouse, namely: solar radiation, dry and wet bulb ambient temperature, relative mumidity, wind speeds, rainful and the three-dimensional greenhouse temperature disrtribution are presented over a two-year period the life project. Based on the local climatological conditions, the operational schedule of greenhouse equipment for; evaporative coolers, mechanical coolers, ventilators, gas heaters and shading is identified. In this locality, evaporative coolers adequately control the daytime greenhouse environment except for several hot and humid summer weeks. Mechanical coolers are required for summer nights. Gas heaters are only employed for cold winter nights. For this particular type of greenhouse where the pads are placed opposite to the fans, two temperature zones are identified. The lower zone, characterized by the height of the plant - which is less than pad height - maitains a temperature much lower than that of the upper one.

INTRODUCTION

A greenhouse is a structure covered with transparent or translucent materials and utilizes solar radiant energy to grow plants. Greenhouses are used to control or modify many of the environmental factors that lead to proper growth of plants. Greenhouses are becoming important commercial production tools in several developing nations such as Turkey, Lebanon, Kuwait, United Arab Emirates, Qatar and Egypt. Many of these countries make use of simple forms of environmental control in order to satisfy the early market. The structure of greenhouse must be strong enough to withstand the forces of wind and hail. The greenhouse should also be thermally insulated in order to reduce the cost of auxiliary cooling and heating. In order to be useful, all these attributes must be achieved at an acceptable cost to the grower [1].

Greenhouses in hot, arid climates should be quite different from those in hot, humid climates. It is preferable if they are designed to reduce solar heat gain but simultaneously to admit sufficient light. They should also be designed to minimize the rate of water vapor loss from the plant by the adaption of modern hydrocultural methods of plant growth [2].

The plants inside greenhouses grow best when they are exposed to a relative humidity in the 70-80% range, and daytime air temperatures of 21-27° with night-time temperature close to 18°C. These conditions will minimize both moisture and temperature stresses on plant levels, thus, lowering the probability of wilting leaves, and increasing plant yields [3].

In high radiation climates similar to those in the Middle East, the air surface temperatures within a greenhouse are often too high for both the crop and its growers. The need for an economical cooling system is essential [5-6]. As the cost of air conditioning by refrigeration is prohibitively expensive, the most commonly used cooling system in greenhouses is the fan and wet pad cooling system, known as the evaporative cooler. With this type of system, exhaust fans are placed on one wall of the greenhouse and pads are placed on the opposite wall. Manufacturers have tried pad materials of wood, metal, mineral, glass, and recently a corrugated material composed of treated cellular material. The latter pads are gaining in popularity due to the better performance they provide at higher velocities 1 m^2 pad area per 1.2 to 1.75 m^3/s of fan capacity, [7].

A minimum ventilation rate of $^3/_4$ to 1 air change per minute is normally recommended for greenhouses. During full sunlight, the $^3/_4$ air change results in a temperature rise of about 6°C, - from pad side to fan side - whereas one air change results in a rise about 5°C. The preferred pad to fan distance is about 20-50 m. The velocity across any plant should be no more than 1 m/s [8]. Fans should be spaced no more than 7.5 m apart and preferably on the downwind side of the greenhouse. The pad area is selected based on ventilation rate. The area is adjusted to satisfy the recommended air velocity for a given material as reported in Ref. [9].

The Need for Greenhouses in the Arabian Gulf Region

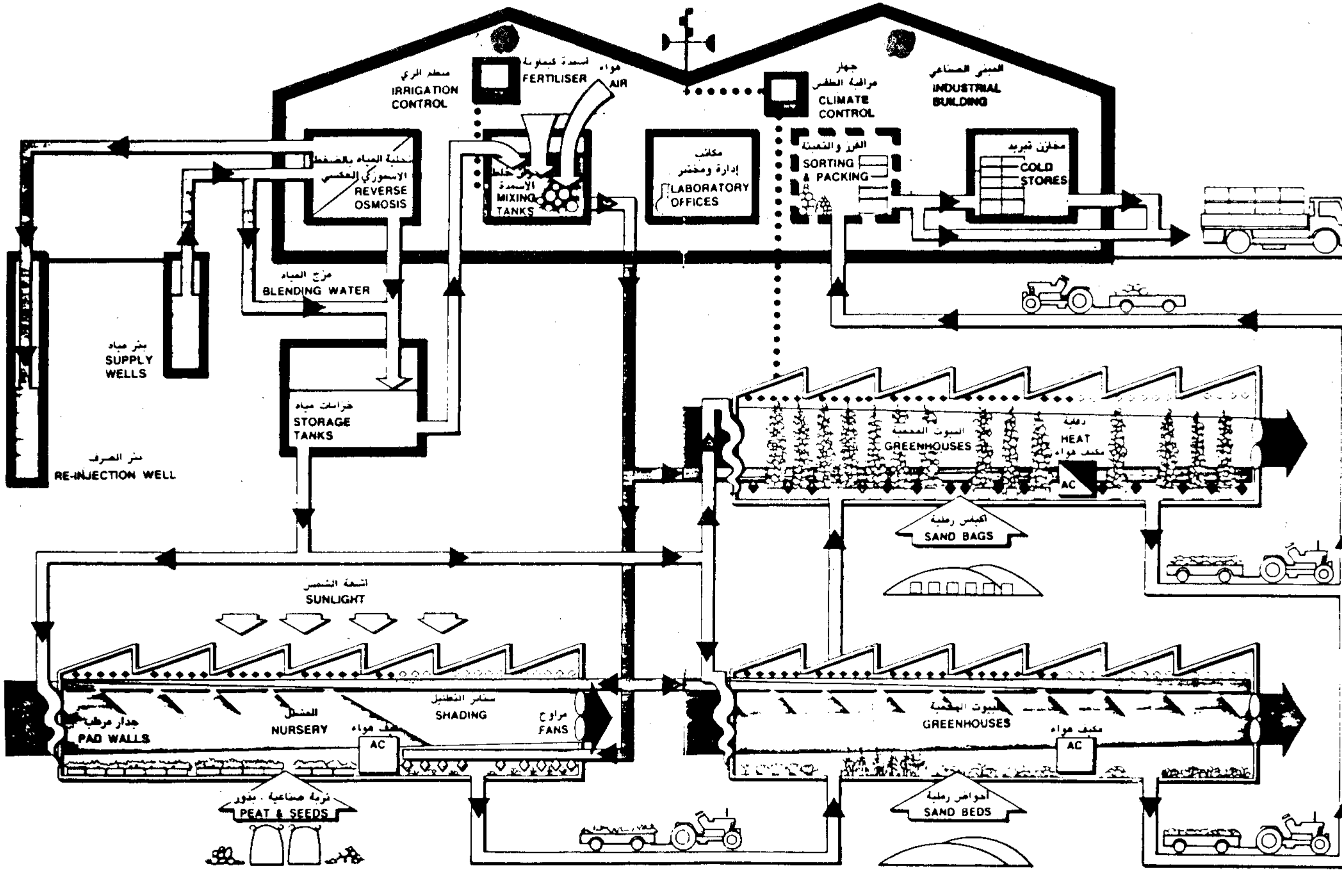
The Arabian Gulf region lies within the northern desert belt and indeed is in one of the most arid regions in the world. Few calm days are experienced in the year, and sand or dust storms are not infrequent. During the summer months, the temperature can rise up to 50°C in the shade and levels of relative humidity can be as high as 100% in the late night and in the early parts of morning. The average yearly rainful ranges between 50 to 70 ml. Water naturally availble for agricultural and domestic uses is limited in quantity and usually not of the optimum quality.

The production of vegetables in the Gulf area also hampered by major environmental problems raising out of infertile soil and salinity of the water used for irrigation. The presence of nematodes and soil born diseases further aggrivate the difficulties of the Gulf area farmer. Under these severe constrains, production in the open field registers low disappointing yields and is restricted to a few months in the year. Therefore, the utility of the greenhouses in the Gulf countries is enhanced and may be considered as the optimum solution for agricultural problems in the region. This study aims at assessing the feasibility of operating greenhouses in the State of Qatar, Arabian Gulf, located at 25.15°N and 51.34°L.

AL-SHAHANIYA PROJECT LAYOUT

1. Greenhouses

The greenhouses are divided into 12 separate units of 12 x 22 m each, as sketched in Figure (1). Access to a greenhouse is at either end of the aisle by large sliding doors which permit tractors and other equipment to be moved in and out for the different operations. Each greenhouse is separated into 19 bays each with length of 22 m and width of 6.4 m. If the aisle (width 4 m) is deducted through the gross area of the greenhouses, the cultivable area is 2185 m^2 per greenhouse. The total cultivable area of the project, including nursery amounts 26,200 m^2. A nursery of 3 bays in one of the greenhouses is completely isolated from the rest of the greenhouse. The greenhouses have been covered with 1.5 mm thick fiberglass, specially treated to prevent deterioration by ultraviolet light.



INDUSTRIAL DEVELOPMENT TECHNICAL CENTRE
GREENHOUSES PROJECT - SHAHANIYAH
EXPLANATORY DIAGRAM

Figure 1: Layout of Al Shahaniya Greenhouse Project.

The greenhouses have been equiped with the following systems.

a. The Evaporative Cooling System: consists of specially selected pads made of corrugated cellular, treated paper material and heavy duty exhaust fans. Water runs through these pads and air is cooled by the evaporation of water when air from outside is drawn across the width of the greenhouse by the exhaust fans, placed along the greenhouse wall opposite to the pads. The pads are placed over the length of the greenhouse on the upwind side. The pad dimensions are: a total length of 122 m, a height of 1 m and width of 0.2 m. The bottom of each pad is placed 1 m above the floor. This special thickness of the pad results in a through coolig of the air by a saturation efficiency of 94%. The pads can be closed from exposure to the outside with a shutter.

Each greenhouse contains 13 large exhaust fans rated at 1.14 kW (1.5 hp) a capacity of more than 10 m^3/s, at 0 mm static pressure. The outer diameter of each fan is 1.5 m. The fan centers are positioned 1.5 m above the floor. The desired range of temperature for each greenhouses is individualy controlled by a computerized control and data acquisition system located in the office building. This computer controls the number of fans required to maitain the desired temperature and wetting of the pads.

Relative humidity inside the greenhouse is generally rather high as a consequence of operating this cooling system. The evaporative cooling system is highly efficient in reducing temperature if relative humidity of the ouside air is low, regardless of temperature value.

b. Mechanical Cooling Units: are installed in each greenhouse. These units are used specifically during summer nights when outside temperature and high relative humidity do not permit evaporative cooling systems to function effectively.

Each greenhouse contains 6 units (electric power of each is 54 kW), whose operation is thermostatically controlled. The temperature inside the greenhouse can be reduced by approximately 10°C, compared with the outside temperature if all units are working.

c. Heaters: these heaters are diesel fired, and the operation of them is thermostatically controlled. Two heaters of 97 kW each are used per greenhouse.

d. Shading Systems: have been installed in each of the greenhouses. The screen with a 60% light transmission can be drawn across the top of the greenhouse - 2.2 m from the floor - automatically (on set time), or normally as desired.

e. Irrigation System: two types of irrigation systems are installed in the greenhouse. Drip irrigation is installed on approximately 75% of the cultivated areas and mist irrigation is installed in the rest. Drip irrigation is used for irrigation of the sand filled plastic bags and mist irrigation is used for irrigation of the sand beds. With both irrigation systems, nutrients are dissolved in the irrigation water. Each of the irrigation systems has its own fertilizer dosing system.

f. Water Desalination for Irrigation and Pad Coolers: is supplied by a reverse osmosis unit which desalinates underground water from about 1750 ppm to 50 ppm. The capacity of the plant is 25 m^3/hr of desalinated water. Its electric power is 2 kW/m^3. The treated water is stored in 4 storage tanks of 250 m^3 each. Three cold stores each of different size and set temperature with a conbined capacity of 247 m^3 are used to store the different products before these are sent to markets.

g. Stand by Generators: are available to supply power to the greenhouses if the main supply is interrupted. Given the hot climate conditions especially in summer, this is absolutely necessary. If one of the vital aspects like irrigation or climate control fails, an emergency alarm system is linked to the technical staff housing to signal a failure. The central area of the building is reserved for sorting and grading, also for packing the vegetables.

h. Rolling Stocks: comprise the following equipment; a tractor with front loader, a tractor with fork-lift, 2 trailers, a dumper, a crop sprayer (tractor mounted), a pulsfog, a block-making machine, a high pressure cleaner, tomato vibrators and various small field tools and equipment. A bagging machine for filling the litter plastic crop bag has a capacity of up to 500 bags/hr. Filled bags are stacked onto pallets and transported to the greenhouses if required.

FIELD DATA AND MEASUREMENTS

In this section samples of field data are presented to check the greenhouse inside conditions against the recommended values cited in the "introduction", and to propose operating monthly schedules to minimize the consumption of both water and energy, to assess the operation of the fully equipped greenhouse, and to make certain that the inside conditions are close to those recommended by greenhouse manufacturers. The basic barameters of interest of this study are: temperature and humidity patterns inside the greenhouse. The results obtained will help in determining the months of the year where the design criteria are closely satisfied inside the greenhouse. They are also expected to help identify the effectiveness and applicability of this particular design in such hot climate. These data are categorized as outside environmental data and inside greenhouse data. Both types of data were monitored hourly by a data acquisition system, and the measurements were all performed with standard instruments.

I. Environmental Conditions

The ouside greenhouse environmental conditions are basically: solar radiation, ambient dry and wet bulb temperatures, relative humidity, rainful and wind speed - measured and recorded at the site from 1986 to 1988

Solar radiation: Figure (2) presents the monthly average solar radiation flux on - a horizontal surface - outside and inside the greenhouse in the presence or in the absence of shading. The transmissivity of the fiberglass used to cover the greenhouse was measured over a three year period and found to have dropped from 80% to 40% (having an average value of 60%). The average value was used in estimating the solar flux inside the greenhouse. In general, the amount of solar radiation ouside the greenhouse was found to be more than adequate for plant growth all year round. However, shading is not recommended to be used during winter months. With shading, the natural light - that lies in the wave length range 400-800 NM - which is absorbed by the plant is below the normal requirement for the growth of the plants inside the greenhouse (50 W/m^2). Additionally, natural light was found to be needed to warm up the greenhouse in winter.

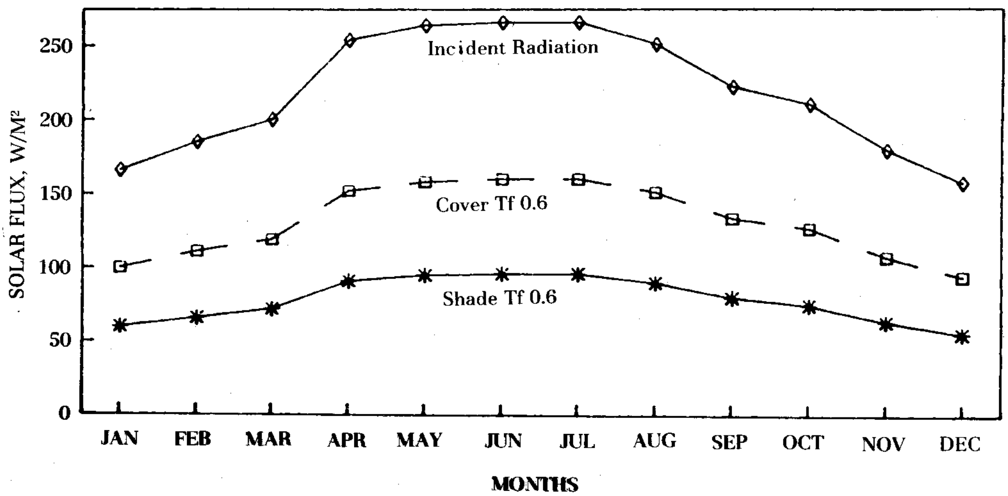


Figure 2: Monthly Average Solar Radiation at the Greenhouse Site, Cover, Cover/Shade Effects.

During spring and autumn seasons, shading may be needed for few hours around noontime, as shown in Figure (3). During summer months, however, solar radiation exceeds plant requirements, thus shading must be used to avoid overheating of the greenhouse, Figure (4).

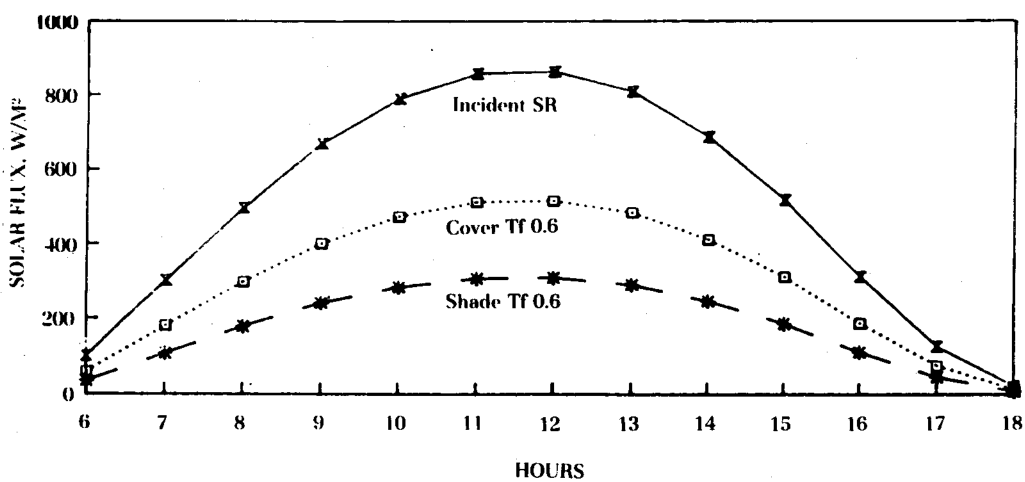


Figure 3: Hourly Values of Solar Radiation (Spring).

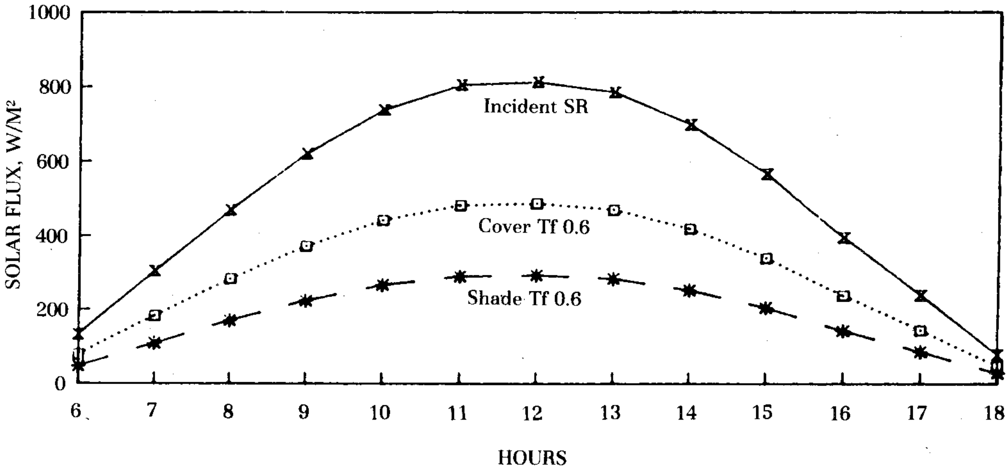


Figure 4: Hourly Values of Solar Radiation (Summer).

Ambient temperature: Figure (5) shows the variation of both the daytime dry and wet bulb ambient temperatures with the months of the year. The daytime dry bulb temperature from mid-November to mid-March, is a little bit below the

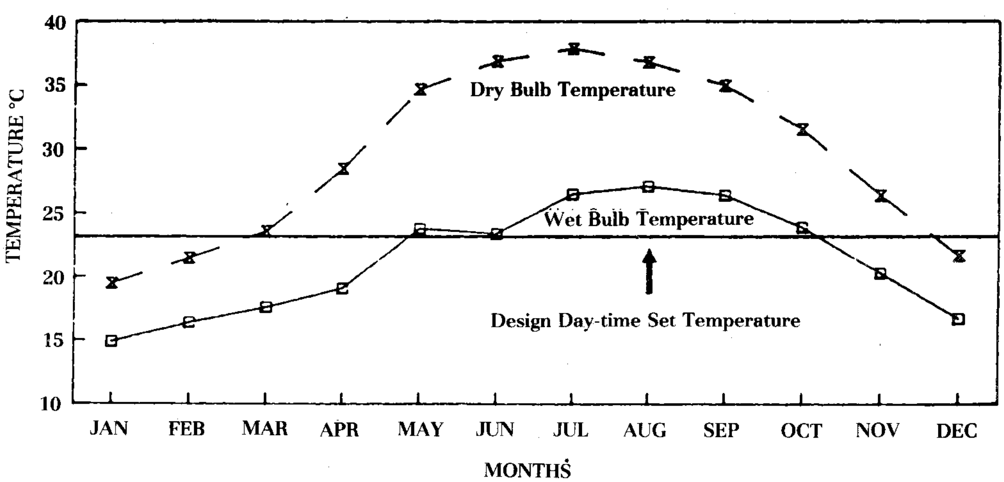


Figure 5: Monthly Average Day-time Ambient Temperatures.

design daytime set temperature (25°C). Heating by solar radiation may compensate for the difference. From mid-March to mid-November this outside temperature is higher than the inside set temperature, therefore, cooling of the greenhouse is a must.

The daytime ambient wet bulb temperature curve shows values of temperature below the daytime set temperature except for the period July to September, where temperatures exceed 25°C. This indicates the need for using a highly efficient evaporative cooling system (over 90%) in order to maintain a greenhouse mean temperature not far above the set temperature. In the hot and humid summer months (July, August and September), the mean greenhouse temperature is expected to exceed 30°C around noontime.

The night time, dry and wet bulb ambient temperatures are shown in Figure (6). From December to February, night heating is required to keep the greenhouse temperature near the set value (18°C). From March to May and from November to December, ventilation or cooling by evaporative coolers may maintain the greenhouse near the night set temperature. From June to October, the wet bulb temperature - which represents the minimum attainable greenhouse temperature when using evaporative coolers - is much higher than 18°C. Therefore, mechanical cooling must be used with the aid of shading when the greenhouse is to be utilized in those hot summer months.

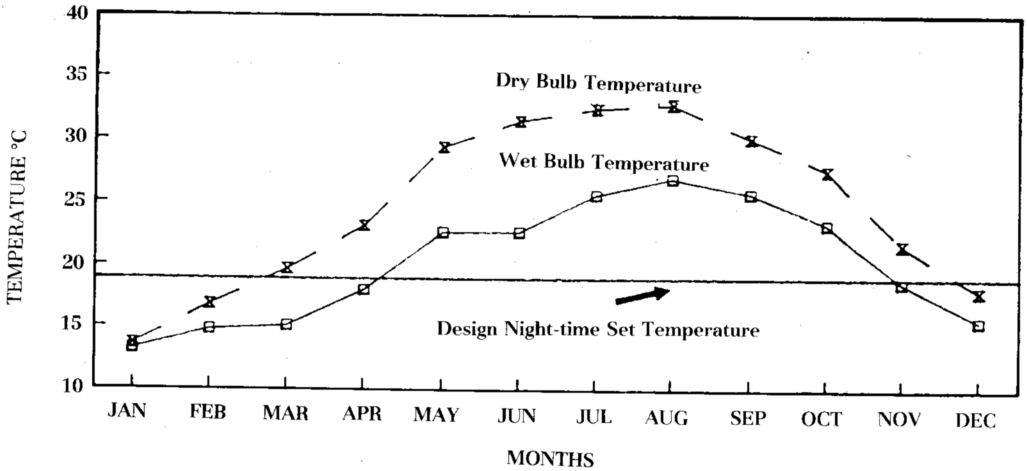


Figure 6: Monthly Average Night-time Ambient Temperatures.

Relative humidity: To show the effectiveness of evaporative pad coolers over the hours of the day, Figure (7) presents the relative humidity hourly distribution for two days representing winter and summer seasons.

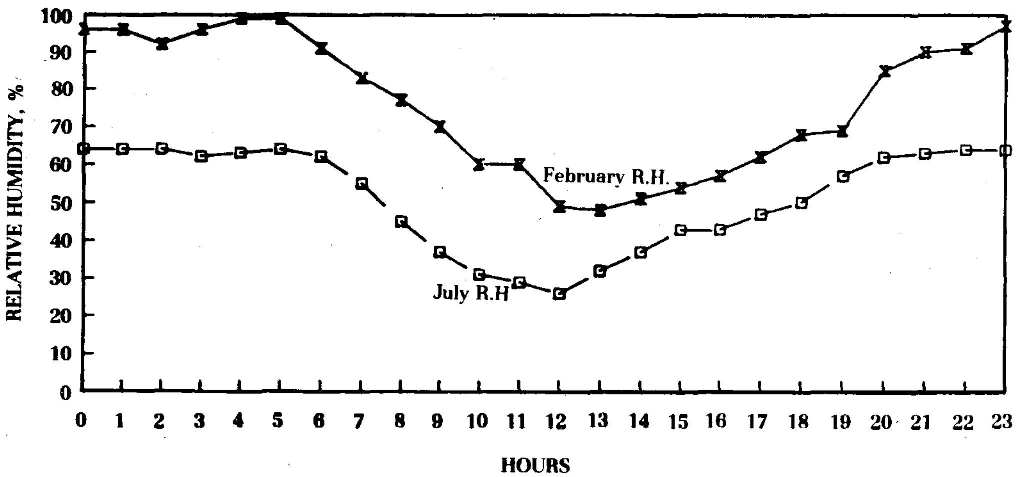


Figure 7: Hourly Values of Relative Humidity (February-July).

As is shown, the maximum values of the relative humidity are from late night to early morning, and the minimum values are the daytime ones. As a result, evaporative coolers can be used effectively, during daytime and early nights, whenever the need arises.

Wind speed: Wind speed versus months of the year is presented in Figure (8). The yearly mean wind speed averages 4.5 m/s, and the yearly mean highest sustained averages 14 m/s. The average high wind speed coupled with the sandy nature of soil, make the vegetation on open fields questionable over some months of the year.

It is found that vegetation in open fields is impaired by diseases, carried by wind. Greenhouse pad walls help eliminate those diseases. Structure integrity of greenhouse should be carefully accounted for under winding environment.

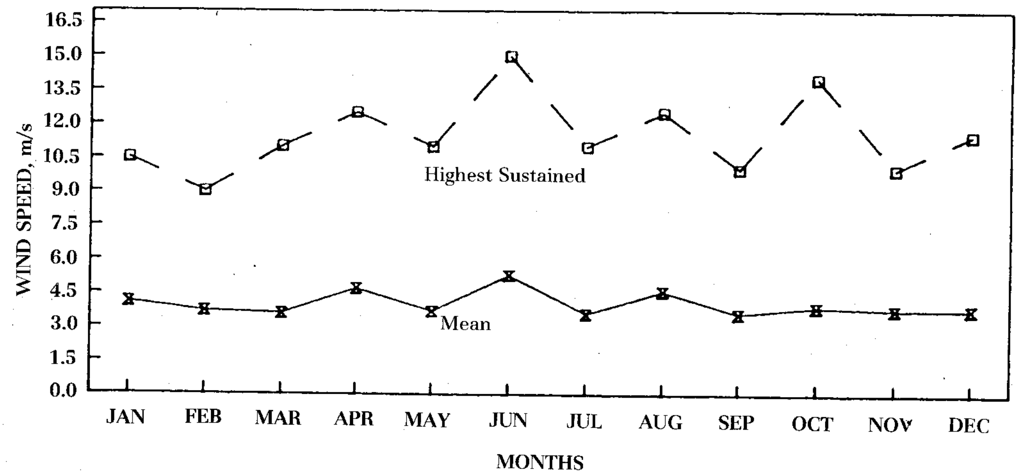


Figure 8: Mean and Highest-sustained Wind Speed.

Rainful: **The rainful values in Qatar, shown in Figure (9), indicate that the** amount is totally **insufficient for open field cultivation (6.5 mm/month).**

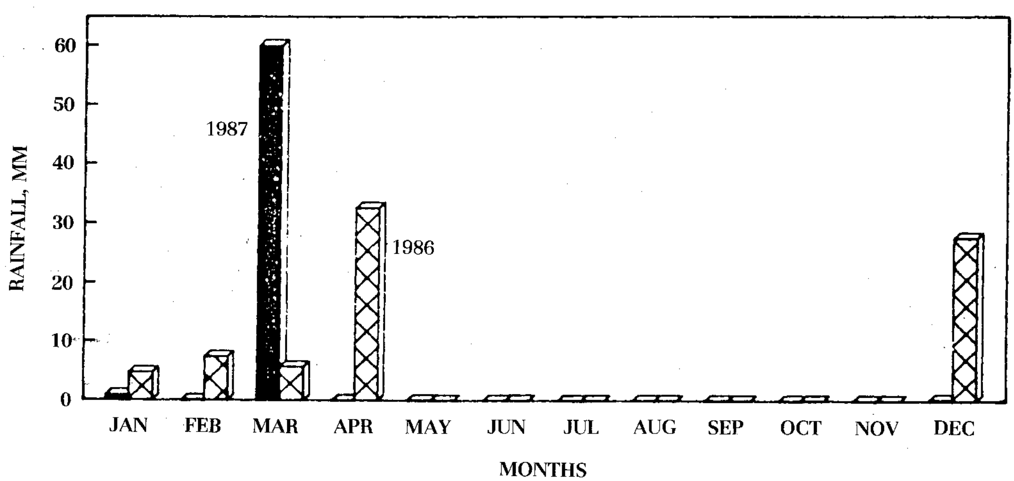


Figure 9: Monthly Total Rainfall (1986-1987).

II. Inside Greenhouse Data

To examine the effectiveness of the evaporative cooling system constructed for the greenhouse, the temperature distribution in the three main directions of the greenhouse, as well as temperature distribution through the pad wall, are described for three selected greenhouses; one with big plants (1.9 m tall), a second for small plants (1.1 m tall) and the third for an empty greenhouse. Measurements were taken when all the fans set in operation in order to maintain a constant ventilation rate. This produce facilitated the discussion of the results.

Transverse temperature distribution: The transverse temperature distribution taken at 1.0 m height in the middle of two greenhouses growing big and small plants of cucumbers with all fans in operation are shown in Figure (10). The temperature was scanned from the pad wall to the fan face. For the well grown plants, the noontime temperature (22/6/1988), varied linearly from 25°C at the pad wall to 30°C at the fan face, showing a temperature rise of 5°C, which is due to the greenhouse heat gain. For the case of small plants, the air temperature reached 30°C shortly after leaving the pad wall side and remained constant thereafter. This peculiar trend may be attributed to strong circulation near pad wall, resulting from a large temperature difference between the pad wall (25°C), and the roof (40°C).

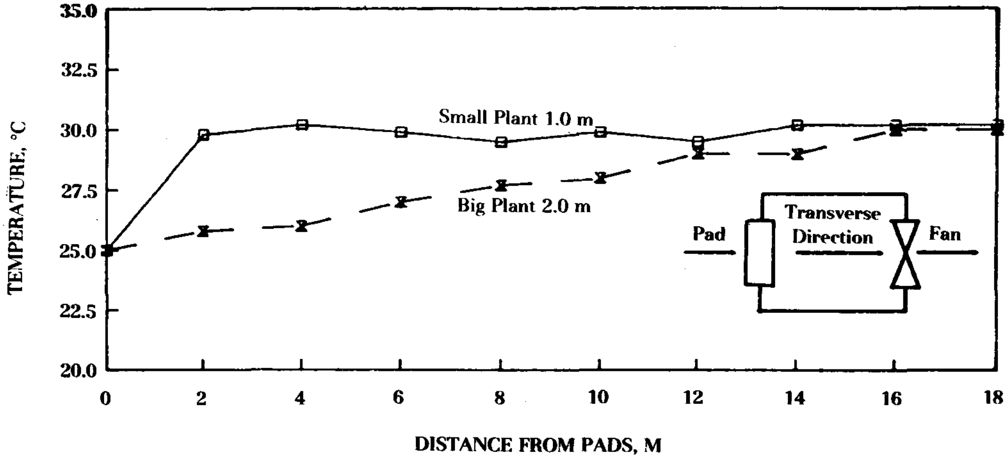


Figure 10: Transverse Dry-bulb Temperature Distribution inside the Greenhouse (Readings at Height =1 m 11:00 am, 22/6/1988).

Although, the temperature rise for both greenhouses was the same (5°C), the small plants greenhouse was exposed to higher temperature levels. This was attributed to an evapotranspiration effect.

Longitudinal temperature distribution: The longitudinal temperature distribution in the east-west direction is presented in Figure (11) at three stations: 1, 9 and 18 m from the pad wall. Generally, the temperature is uniform, except at the south-west fan side, where additional solar heating was experienced at that time (12.30 pm). As opposed to the 5°C temperature rise across the greenhouse, end effects at both the south-east and south-west sides, tend to increase that value, reaching a maximum rise of 10°C.

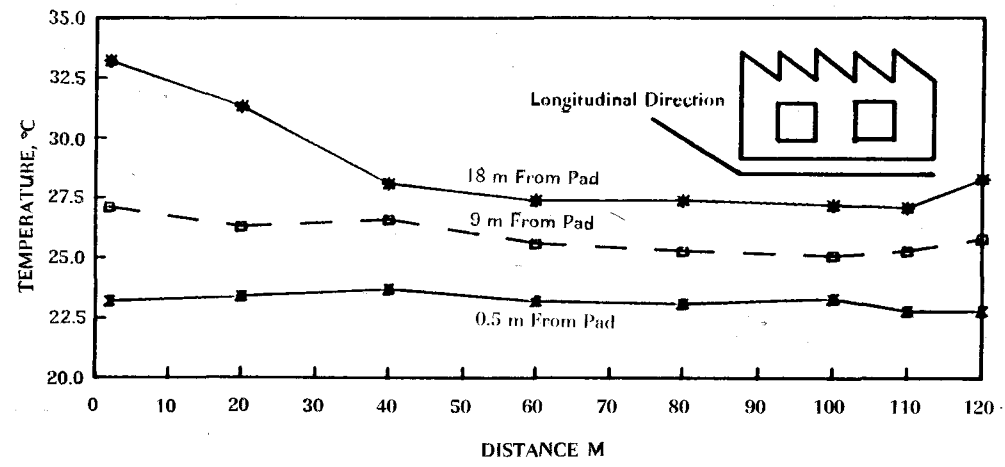


Figure 11: Longitudinal Dry-Bulb Temperature Distribution (Readings at Height = 1.5 m, 12:00 pm, 12/6/1988).

Vertical temperature distribution: Vertical temperature distribution at three stations: pad wall, center and fan side, at the middle of a greenhouse, with well grown plants, is presented in Figure (12). The curves clearly show two distinct temperature ranges; the first from the ground to the top of the plant, and the second from the tip of the plant to the roof of the greenhouse.

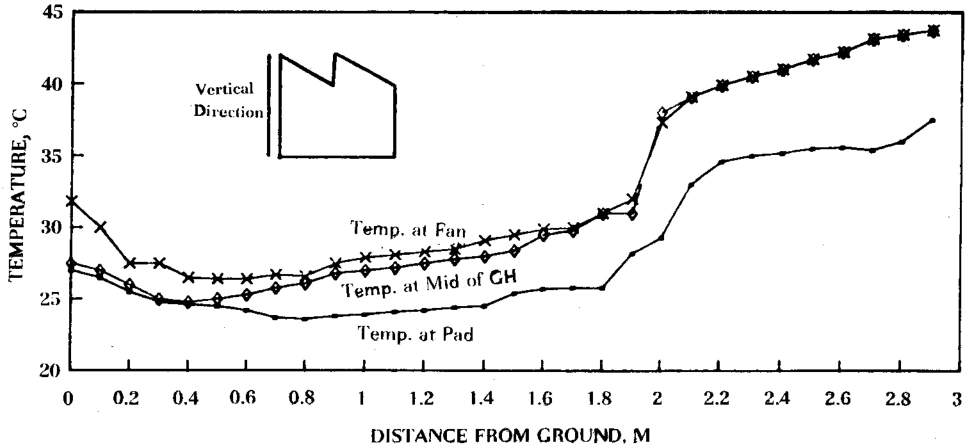


Figure 12: Vertical Dry-bulb Temperature Distribution (Plant Height = 1.9 m, 1:00 pm, 27/6/1988).

The temperature in the lower planted zone varied slightly over the plant height, registering 12°C less than that in the top zone. This indicates that cooling caused by both evaporative coolers and evapotranspiration is much more effective in the planted area no matter how high the plant is (as will be shown later). Temperature levels near the ground were 3°C higher than the average temperature in the planted area due to heating by the part of solar radiation absorbed by the ground. The figure also shows, that the temperature rise from the pad side to the fan side, at any height, is within 5°C.

To further investigate the effect of plant height on the vertical temperature distribution, Figure (13) is prepared with measurements taken at the center of three selected greenhouses. For the empty greenhouse, the height at which the temperature starts to increase sharply is 1.6 m, some 0.4 m lower than the height of the pad wall, indicating a downward movement of cool air as it leaves the coolers. For medium size cucumbers this height was close to that the plant, indicating that the location of the interface is primarily related to the height of the plant rather than the height of the pad coolers.

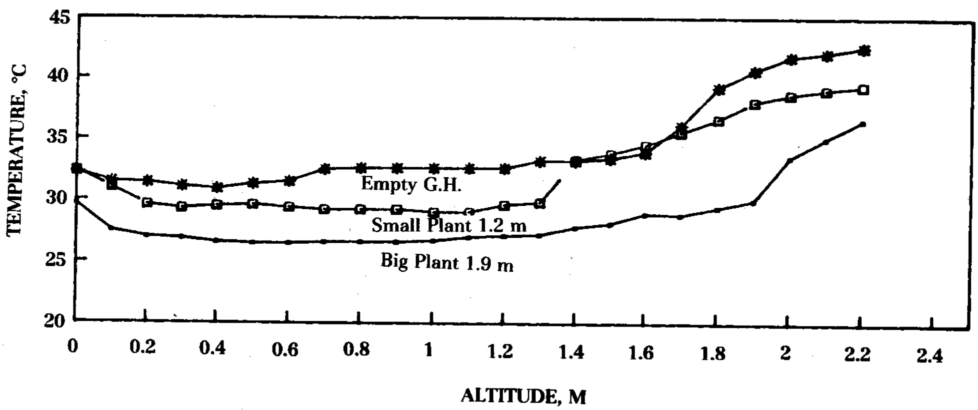


Figure 13: Vertical Dry-bulb Temperature Distribution in Three Greenhouses having Different Plant Heights.

For the fully grown plant (1.9 m), some 10 cm lower than the top surface of the pad coolers, the curve shows that cooling zone was up to the tip of the plant. This, once more, emphasizes the effect of plant height on the vertical temperature distribution. It should be mentioned that the fully grown plant contributes a 4°C cooling due to evapotranspiration from plant leaves.

<u>Temperature distribution through pad wall:</u> Temperature distribution through pad wall is shown in Figure (14), over a wide range of relative humidities. In general, temperature dropped off sharply in a 3 cm distance and approached its steady state value afterwards. The air temperature leaving the evaporative pad coolers was very sensitive to changes in relative humidities at their lower values and insensitive to changes at higher values. Thus, when relative humidity was greater than 70% evaporative pad coolers were not effective.

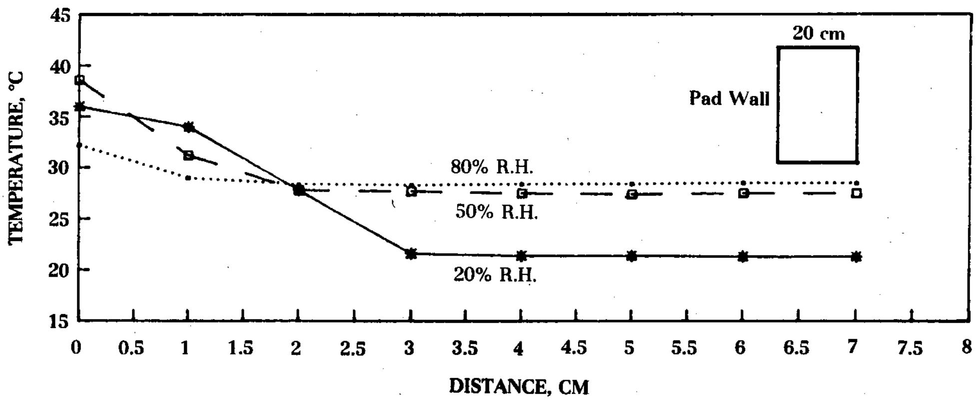


Figure 14: Dry-bulb Temperature Distribution through Pad Wall under Different Environmental Conditions.

III. Interaction Between Ouside and Inside Greenhouse Temperature

a. Hourly temperature distribution:

To show the greenhouse response to variations in ambient conditions (temperature and humidity), Figure (15) presents the hourly variation of both outside and inside mean temperatures, for a representative summer day (July 1987). During daytime (8 am to 8 pm) the outside temperature varied by 15°C while the inside temperature was maintained at about 27°C due to the use of evaporative coolers. Late afternoon, the inside temperature increased by about 20°C, while the outside temperature dropped by 12°C. This increase in the greenhouse inside temperature is attributed to the increase in outside wet bulb temperature despite of the significant drop in the outside dry bulb temperature.

Over summer night time, evaporative coolers were replaced by mechanical cooling units, maintaining an inside temperature near the night set point (18°C) irrespective of the outside environmental conditions. Two transitional periods are identified in the graph. The first one from 6-8 am, resulted from switching

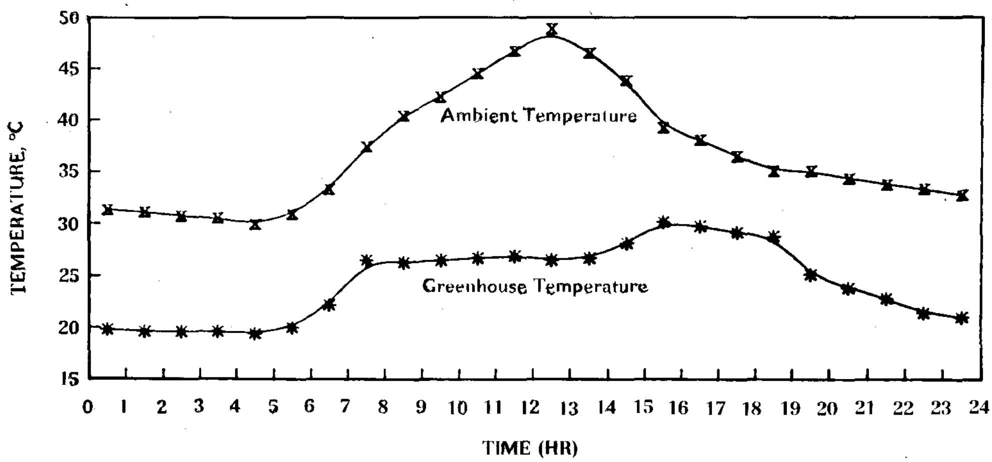


Figure 15: Inside and Outside Hourly Dry-bulb Temperature Distributions for Summer (July, 1987).

off the mechanical cooling system while keeping the greenhouse unventilated. The second period from 6-8 pm, when operation of evaporative coolers was replaced by that of the mechanical cooling units.

For a representative winter day (February 1987), Figure (16) shows the hourly variation of the inside and the outside temperatures. During night time (6 pm to 7 pm), as the outside temperature was lower than the night set point, diesel fired air heater was activated to maintain the inside temperature around 18°C. Over daytime (7 am to 6 pm), the inside temperature was maintained at about 23°C as result of operating the evaporative coolers.

b. Monthly temperature distribution:

To show the average monthly noon-time temperature distribution at the centre of the greenhouse, where the ambient temperature and solar insolation peak, Figure (17) presents the inside and outside dry bulb temperatures. While the outside temperature far exceeded the daytime set point of the greenhouse for more than eight months, inside temperature did not exceed the set point by more than 3°C. This difference in temperature may have reached 5°C over some days of the summer months, when relative humidity was very high.

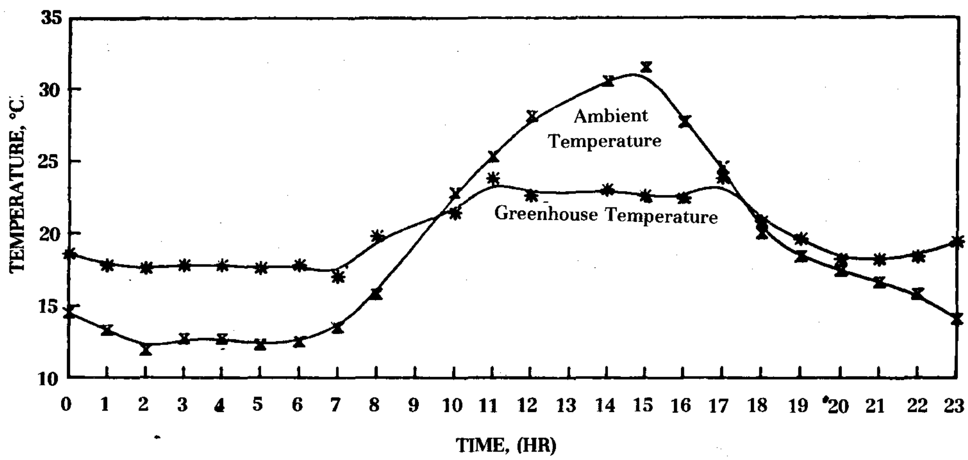


Figure 16: inside and Outside Hourly Dry-bulb Temperature Distribution for Winter (February 1987).

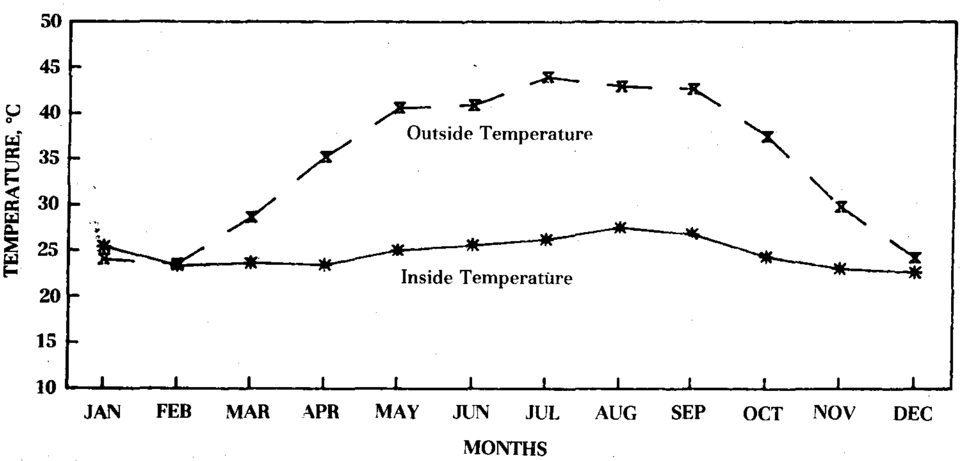


Figure 17: Inside and Outside Monthly Average Noon-time Temperature.

c. Hourly relative humidity:

The variation of the hourly inside relative humidity measured at the centre of the greenhouse owing to the variation of the outside relative humidity is presented in Figure (18) for two days representing spring and summer seasons. Generally, the relative humidity inside the greenhouse is maintained within the optimum range cited in the introduction only during daytime. The higher values of the outside night-time relative humidity gives a sign about the effectiveness of the evaporative coolers during the spring and autumn months.

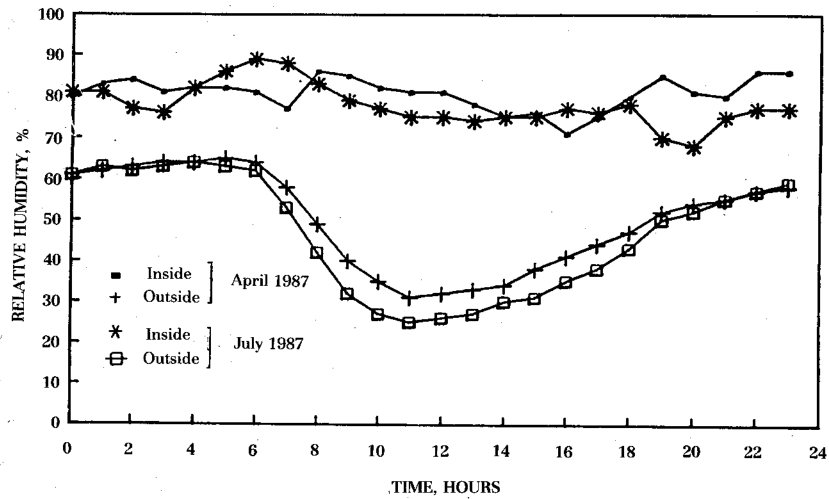


Figure 18: Inside and Outside Hourly Relative Humidity Distribution for April and July.

d. Ground temperature:

Figure (19), shows the noontime temperature values at the ground locations (at surface and 5 cm below surface), for the outside soil and for three different types of inside soil; dry, partially wet, and totally wet. The maximum temperature drop due to moisture content did not exceed 5°C. The inside ground temperarture was about 12°C lower than the outside one as a result of using evaporative cooling.

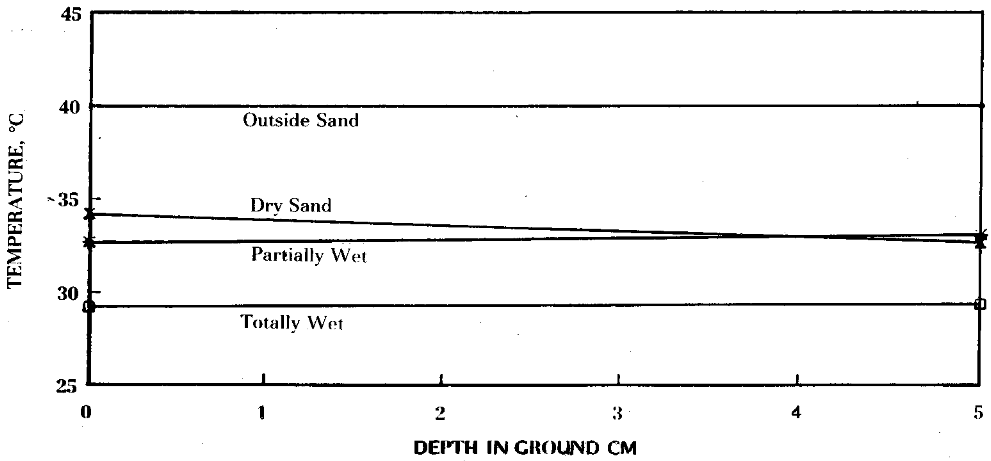


Figure 19: Ground Temperature for Dry-partially, Wet and Totally Wet Soils.

IV. Effect of Shading on Greenhouse Temperature

To investigate the effect of using shade material inside the greenhouse at 2.2 m high (plant level), Figure (20) gives the dry bulb temperature distribution, over

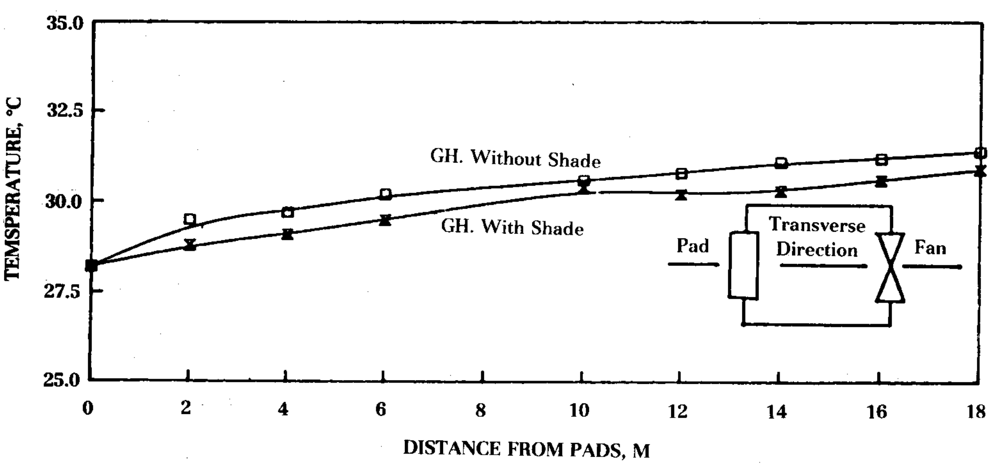


Figure 20: Effect of Shading on Greenhouse Temperature.

the 22 m width of the greenhouse. The decrease in temperature due to the use of shade did not exceed 1.5°C. This unpredicted finding, may be attributed to trapping of solar radiation inside the greenhouse regardless of the presence of the shade. Although, the amount of solar radiation is drastically reduced to 25% in the planted area underneath the shade, the rest is trapped between the cover and the shading material. This in turn heated up the upper zone of the greenhouse and raised the average greenhouse temperature, approaching that of a greenhouse without shading. Therefore, it is believed that, shading may be more effective on the outside, eventhough this may not sound practical.

CONCLUSIONS

The field results of solar energy, temperature and relative humidity distribution inside the greenhouse can be summarized as follows:

1. Solar radiation flux in the Gulf area is adequate in winter months for maintaining greenhouses during daytime close to their design conditions. Auxiliary heating by gas fired heaters is needed only for few cold nights.

2. For spring and autumn periods, where the ambient dry bulb temperature is higher than the greenhouse set temperature, even evaporative coolers proved effecient for removing the greenhouse heat gain all day long.

3. Over summer months (June-September) evaporative coolers are only efficient during the day-time except during the month of August where humidity is extremely high. For the hot and humid summer nights of August, the non-economical mechanical coolers are to be used to maintain the greenhouse near 18°C.

4. Under normal ventilation rate, the maximum temperature difference across the greenhouse from the pad side to fan side did not exceed 6°C all year round. This temperature is in agreement with the recommended design values.

5. For this particular greenhouse design, and from the measured vertical temperature distribution, under the operation of evaporative coolers, it was found that only the planted zone maintained a temperature near the set temperature. The upper zone experienced very high levels of temperatures much closer to the ambient dry bulb temperature.

6. Internal shading is found to be more effective over night-times as it acts as an insulation and less effective during the hot sunny day-time where most of the solar energy is trapped inside the greenhouse.

7. Evaporative pad coolers were found to operate at 94% saturation efficiency. Maintaining high pad efficiency is a must in areas of hostile climates.

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