# Analysis and Simulation of the Performance of an Evaporative Cooling System Related with a Building for Different Climates

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ABSTRACT

The overall objective of this current work is to present some points related to evaporative cooling system and its effect on building air conditioning.

This work contents :

- An analysis and a presentation of climatic data and free evoluting indoor space conditions on the psychrometric chart for different climates related to different climatic zones.

- A computer simulation for representing indoor conditions related to evaporative cooling system use in different climates.

- The effect of solar heat gain on the evaporative cooler devices.

- Hourly and daily computer simulation for different air conditioning treatment related to building.

- A study of the effect of the thermal mass on the performance of the system.

## 1. EVAPORATIVE COOLING : INTRODUCTION

The process of evaporative cooling has been used to improve human comfort conditions from long time. It remains one of the least expensive techniques to bring high dry bulb temperature down to a more comfortable range. These systems base their cooling effect on the law of adiabatic saturation. They must operate on 100% outside air creating a flow rate through the room, directed to the outdoor, usually through windows opened on the opposite side of the room from the unit.

In the field of direct evaporative cooling and from the references, one may conclude that it is possible to reduce the temperature of the treated air by increasing its moisture content. Since the dry-bulb temperature depression is always limited by the wet bulb temperature of the external condition, the conditions of cold air supply would not necessarily produce acceptable comfort condition; thus high flow rate up to 50 vol/hr are required.

Normally comfortable room conditions can be achieved by adjusting the air dry and wet bulb temperatures, and air velocity inside the conditioned zone. So, lower volumetric airflow supply may be used for lower moisture content and lower air temperature.

Evaporative coolers cannot remove latent heat from the room, only sensible heat. Thus the evaporative cooling system works best in hot, dry climate, where the maximum evaporative cooling will result, and where the added moisture is not objectionable. Evaporative cooling used in a moist climate produces insufficient cooling and too much humidity.

The most successful and still the most widely evaporative cooling system used is the single-stage direct unit. There are literally millions of these units in use in most of the world's arid hot regions, and they do a good job of cooling as long as the outdoor wet-bulb temperature is below 18.3°C. We can see that the operation and the effectiveness of cooling of this direct evaporative cooling system is limited by the wet-bulb temperature, as well as the high value of renewal air flowrate which leads to uncomfortable conditions due to noise and high speed of air inside the rooms.

Indirect evaporative cooling system is an interesting method to pass some of these limits. Fresh outside air stream is cooled without gaining humidity by thermal conduction to wet air stream in evaporatively cooled heat exchangers.

The Australians have been most innovative designers of the successful indirect evaporative coolers, concentrating their attention on the development of thermal heat exchangers in this system. Many designed indirect air coolers were built and tested.

Not manufactured, but of interest is the use of thermal storage system with evaporative cooling system. Usually rock bed is used as storage medium which can be charged nightly by blowing evaporatively cooled air through it. The rock bed is chilled enough to cool outside air passed through it in the next day. Practically many limitations inhibited the use of this method. Such a coupling of systems seemed attractive to us from many points of view.

In our present work and for the evaporative cooling system, we studied the thermodynamic process of evaporative cooler in building, the relation with outside climate conditions, building thermal mass and the effects of solar heat gain. A daily analysis of the process in the building with different strategies of air treatment was achieved.

## 2. CLIMATIC ANALYSIS

### 2.1 External Conditions

We have established two groups of points to characterize a given climate for its yearly evolution on the bioclimatic chart :

- the first group is composed of the monthly average of the daily maximum temperature and corresponding monthly average of the daily minimum relative humidity.

- The second group is composed of the monthly average of the daily minimum temperature and corresponding monthly average of the daily maximum relative humidity.

The area delimited by these two groups represents all the yearly possible weather conditions. Those groups have been plotted on the psychrometric chart (see Figure 1.a) for two climates (Nice, F - Bagdad, Irq).

The bioclimatic control comfort zones as defined by Givoni (for summer conditions) have also been plotted on the chart.

Comparison of the previous area with these zones allows to analyse the strategies to be adopted to improve comfort conditions in a given climate (ventilation, thermal mass, shading, evaporative cooling, active cooling).

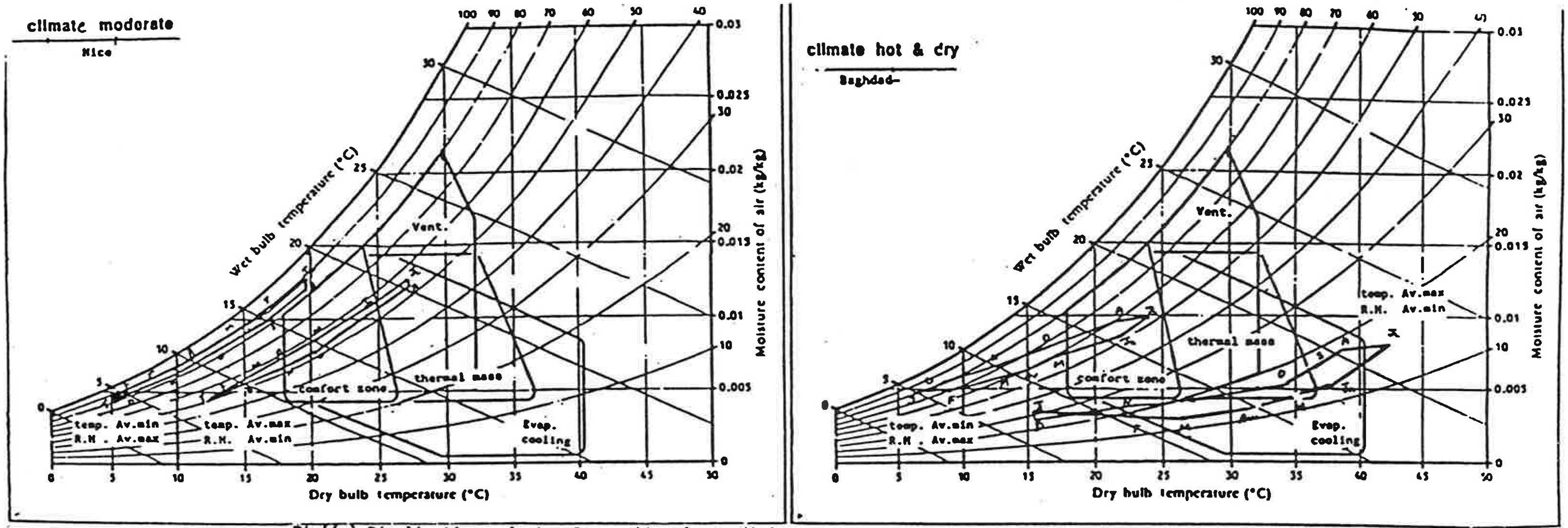
### 2.2 Internal Conditions

A given test cell defined in paragraph 3 was simulated for a typical day representing each month. This day was built from the two values used to define previously two groups of points.

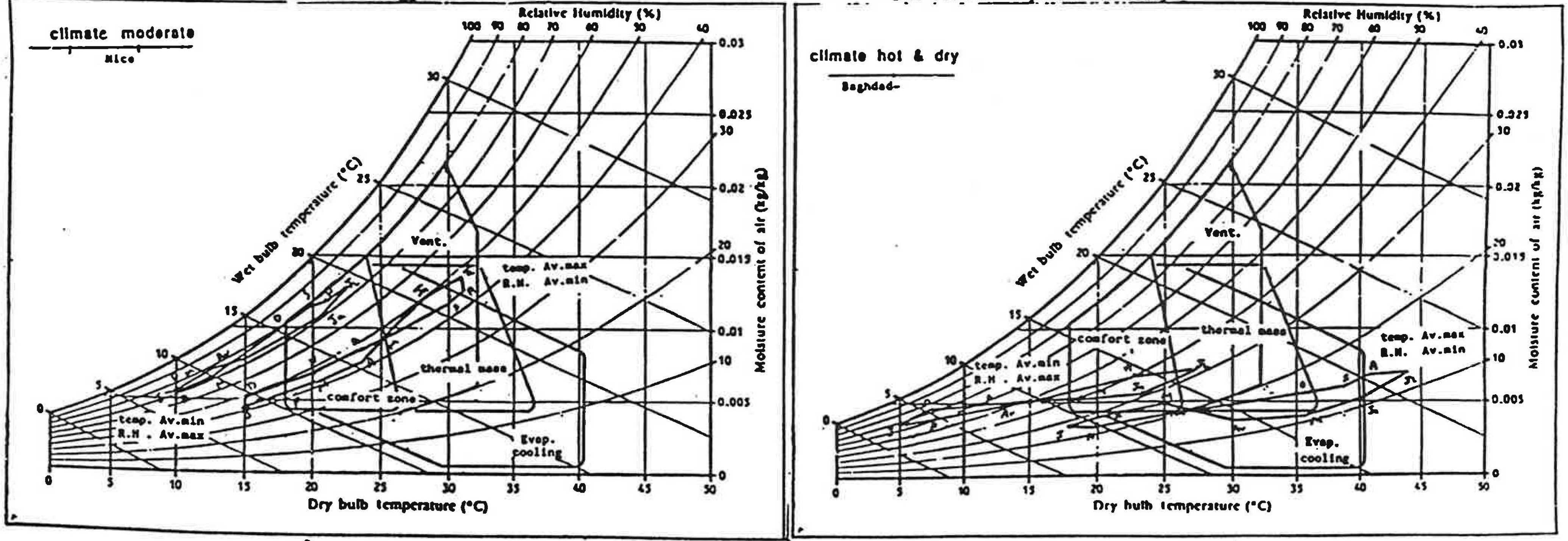
The simulation allows to get the indoor temperature and corresponding relative humidity for this typical day.

Two new groups could then be defined as for external conditions previously characterising internal conditions.

Another comparison between the new area (between the two new groups of points) and control zones of Givoni can be made (Figure 1.b).



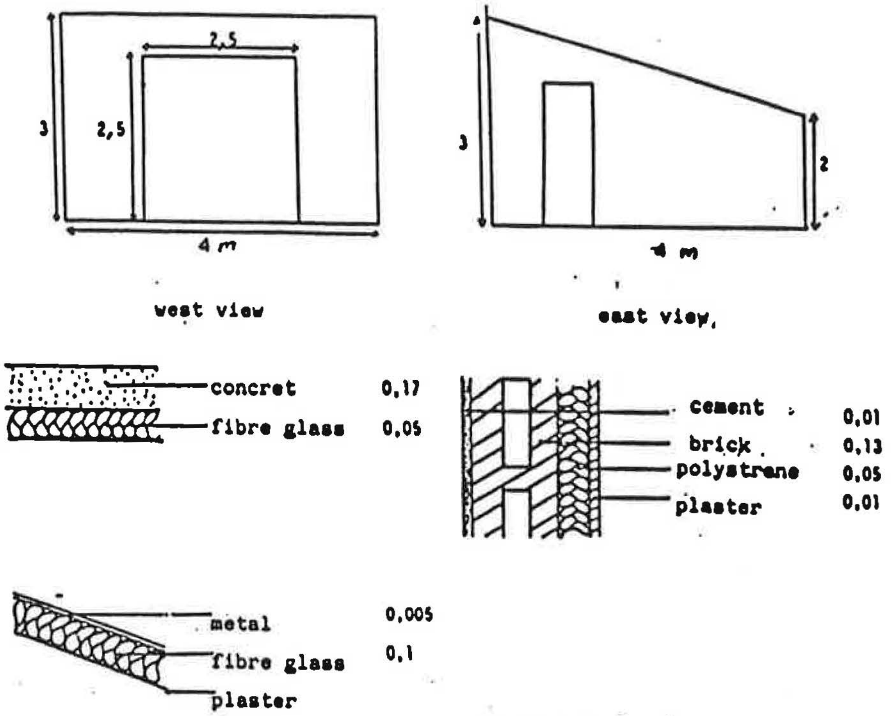

Fig(1a) Bioclimatic analysis of the climatic conditions according to outdoor temp. and humidity




Fig(1b) Bioclimatic analysis of the indoor climatic conditions (considering thermal mass of the walls )

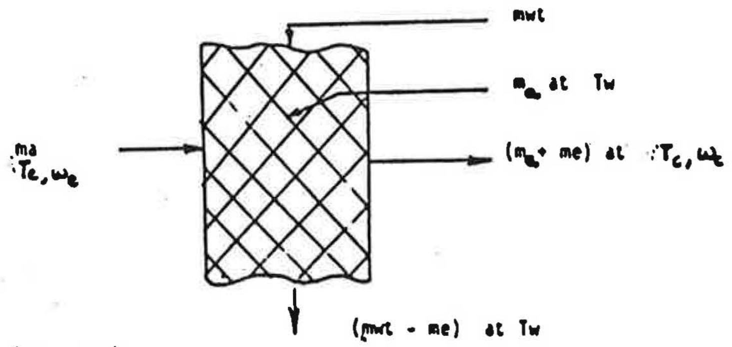
## 3. EVAPORATIVE COOLING, COMFORT CONDITIONS

Thermodynamic process of evaporative cooling in the spaces has been studied. Indoor temperature, relative humidity and water evaporated rate are calculated as function of climatic conditions. Calculations were carried out for a 40 $m^3$ test room supplied by an evaporative cooling system at different external climates. Description of the configuration of this test room is shown on Figure 2.




Fig( 2 ) test cell configuration

The heat and mass balances on the evaporative cooling system pad are shown below.




$$m_e = m_a (w_c - w_e)$$

$$m_a = Cp_a (T_e - T_c) + m_e (h_{fg} + Cp_g \cdot T_e - T_w \cdot Cp_w) = 0$$

where :

| | |
|---|---|
| $m_{wt}$ | water flow rate (kg/hr) |
| $m_e$ | evaporated water rate (kg/hr) |
| $m_a$ | air flow rate (kg/hr) |

$T_e$ external ambient temperature (°C)
$T_c$ outlet cooled air temperature (°C)
$T_w$ water temperature (°C)
$Cp_a$ specific heat of dry air (kJ/kg)
$Cp_g$ specific heat of water vapor (kJ/kg)
$Cp_w$ specific heat of water (kJ/kg)
$w_e$ air moisture content at external condition (g/kg)
$w_c$ air moisture content after evaporative cooling (g/kg)
$h_{fg}$ latent heat of vaporization (J/kg)

Building Thermal Calculations

a) Thermal balance

Thermal calculations are carried out by utilising computer program E.S.P.

1. heat transfer through walls; $q_1$
2. solar gain; $q_2$
3. internal sources; $q_3$

Total load = $q_1 + q_2 + q_3$

$$(T_{in} - T_c)(m_a \cdot Cp_a + m_a \cdot w_e \cdot Cp_g + m_e \cdot Cp_g) = \text{load}$$

where

$T_{in}$ : room temperature (°C)

b) Water mass balance

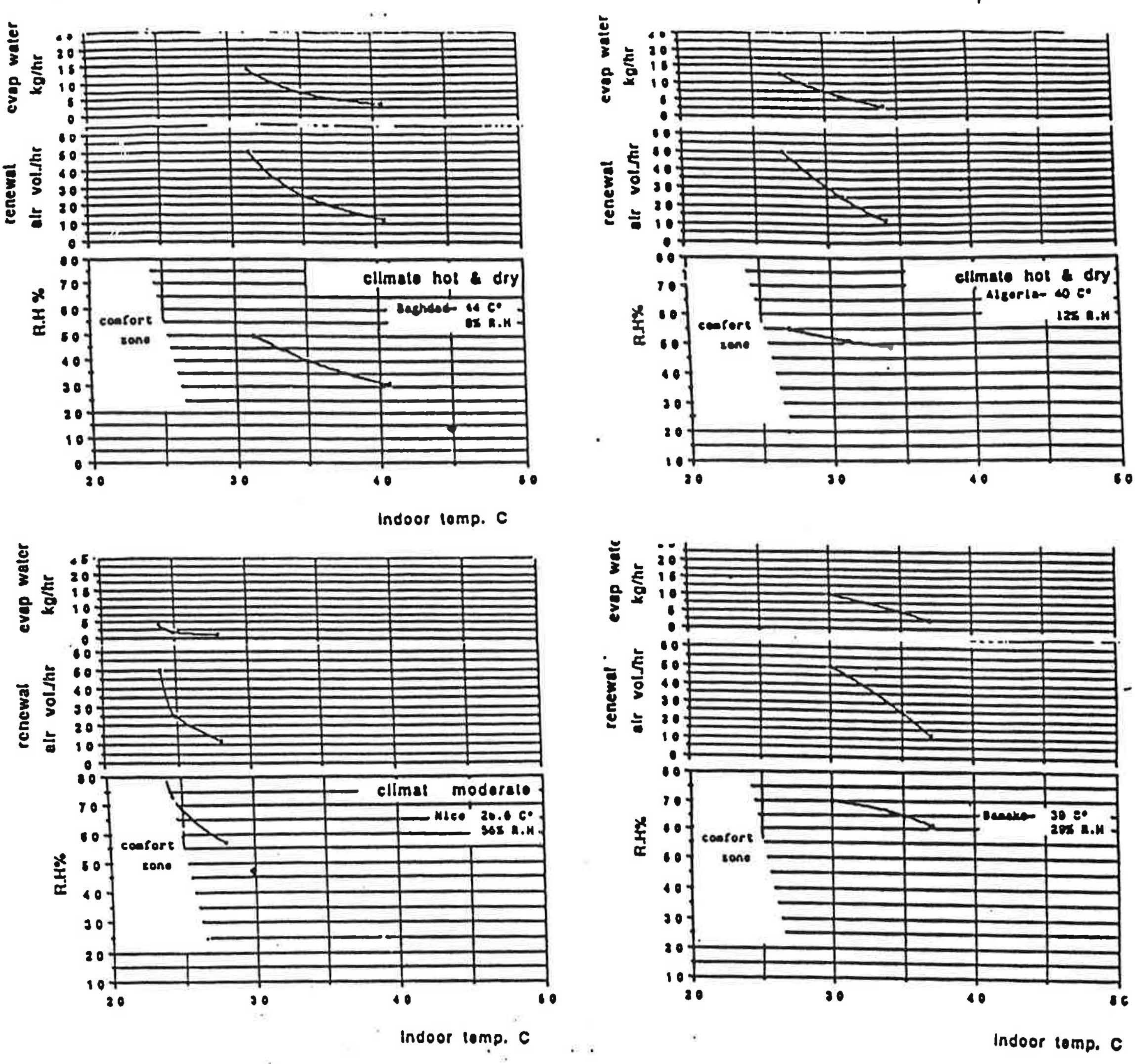
$$m_e \cdot w_c + m_{e.in} = m_a \cdot w_{in}$$

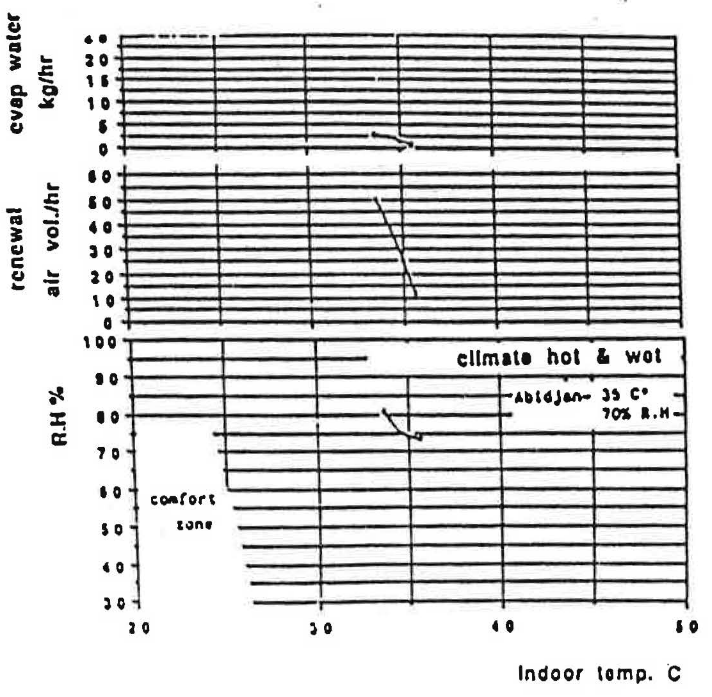
where

$m_{e.in}$ evaporated water rate due to internal sources (kg/hr)
$w_{in}$ air moisture content in the room (g/kg)

Numerical results are indicated in Figure 3. For different climates evaporated water flow rate, air renewal rate are indicated as function of indoor temperature and the comfort zones are defined by Givoni.

It is clear from the figures that this system is working with better performance at low humidity external conditions. Internal condition is improved and moved towards the comfort zone. The internal condition is improved with high air flow rate as well as high evaporated water rate. With the control of the quantities of evaporated water rate and renewal air flow rates, evaporative cooler can improve the internal conditions at different external conditions with certain limits.




Fig(3) Indoor air condition, evaporated water and renewal air at different climates

## 4. EVAPORATIVE COOLER; SOLAR HEAT GAIN EFFECT

Most of the evaporative coolers are placed on exposed area and usually on the roof of buildings, so they receive direct solar radiation. Generally, this effect is not taken into account with much attention by the designers of the systems compared to the other design factors.

The purpose of this work is to evaluate the effect of diurnal solar gain on the performance of the evaporative coolers.

A mathematical model of commercial air cooler is constructed and simulations were carried out utilizing E.S.P. program under hot, dry air of July in Bagdad (33,3°C) for analysing the magnitude and the effect of solar gain (direct and diffuse) on each surface of the coolers (Figure 4). Simulation of the performance of the system with solar gain effect and solar gain prevention were carried out at different applied air flow rates and at constant water flow rate within the system.

$$m_a \cdot Cp_a (T_e - T_c) + m_e (h_{fg} + Cp_a \cdot T_c - T_w \cdot Cp_w) - Q = 0$$

$$Q = Q_{rad} + Q_{conv}$$

$$\eta_{sat} = \frac{T_e - T_c}{T_e - T_{w.b}}$$

where

$\eta_{sat}$ saturation efficiency
$T_{wb}$ wet-bulb temperature

An improvement in the cooling effect was achieved with this prevention (without solar gain) (Figure 5). This means that the evaporative coolers operate more efficiently during night time with the same operating conditions.

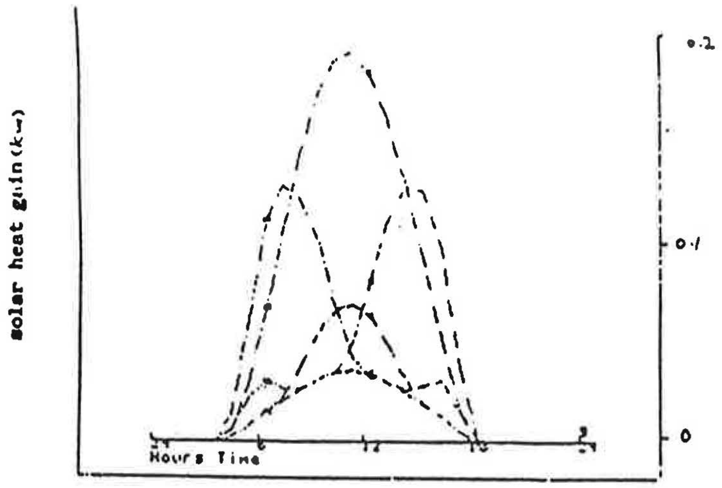
## 5. EVAPORATIVE COOLING AND VENTILATION; INTERNAL CONDITIONS

Simulations were carried out for representing some methods of air conditioning for the same test cell and with the condition of hot, dry climate.

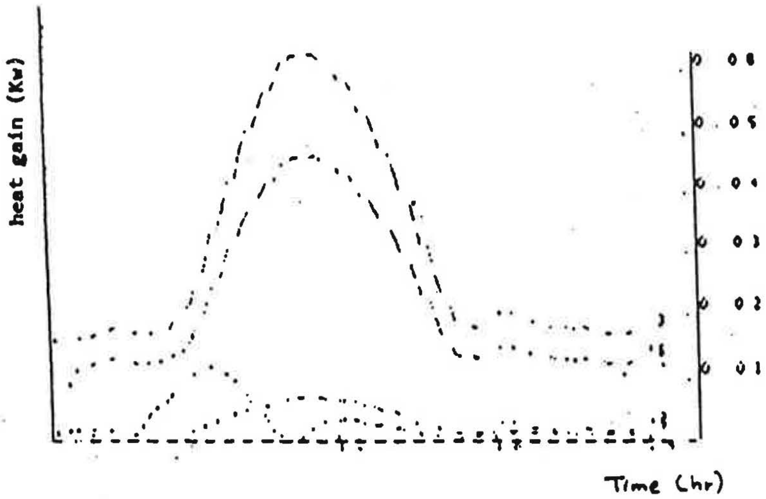
1. Day time air ventilation at rate of 8 vol/hr (Figure 6). It is clear that providing air ventilation at external condition is not satisfactory.

2. Day time operation of evaporative air cooler at rate of 1000 $m^3$/hr (25 vol/hr) [Figure 7]. Evaporative cooler at this range of ventilation improves the indoor condition until certain limit.

3. Night time evaporative air cooler operation to pre-cool the space at rate of 2000 $m^3$/hr (50 vol/hr) and day time operation at lower air flow rate 500 $m^3$/hr (12 vol/hr) [Figure 8]. Indoor condition has been improved with this operation.

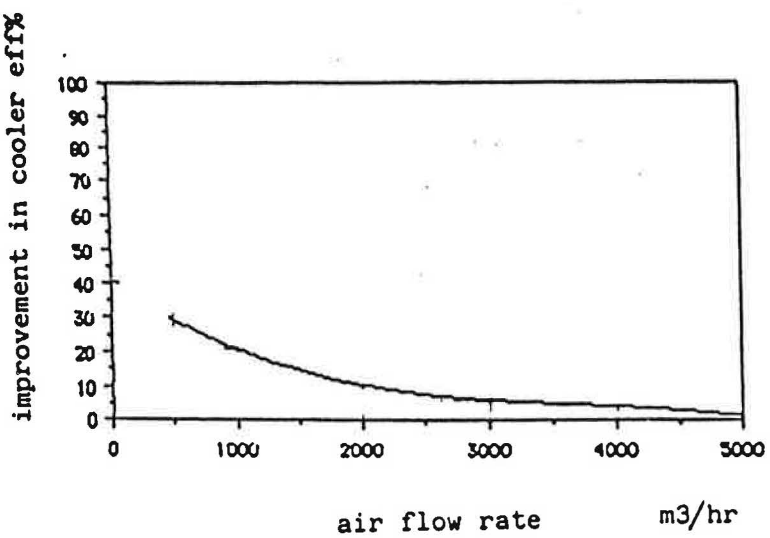



radiated solar heat gain on the cooler sides

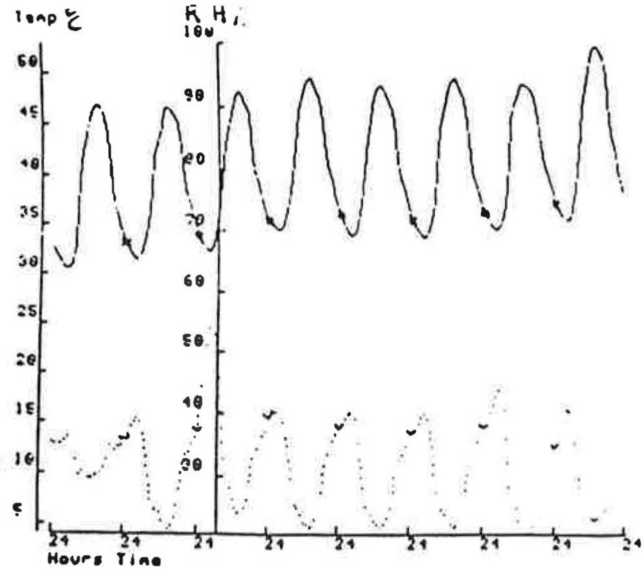



convection solar heat gain on cooler sides

Fig(4)




Fig(5) improvement in the performance
of the cooler with solar gain prevention




Fig(6)

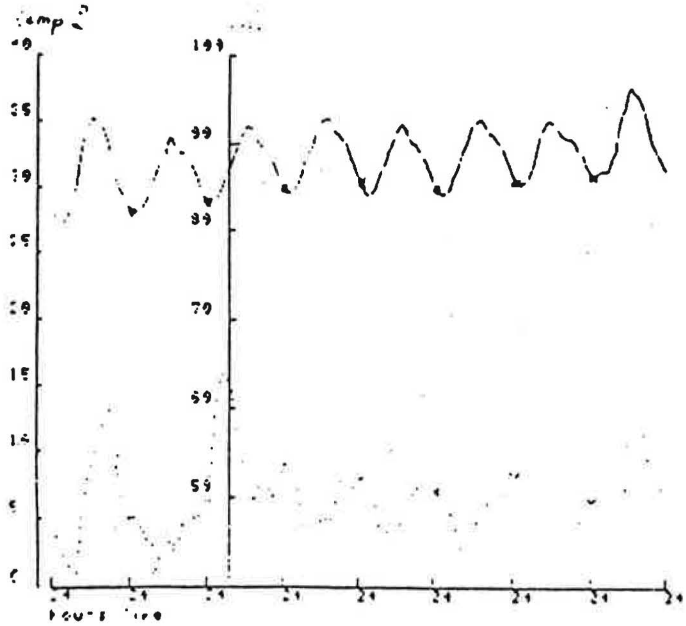
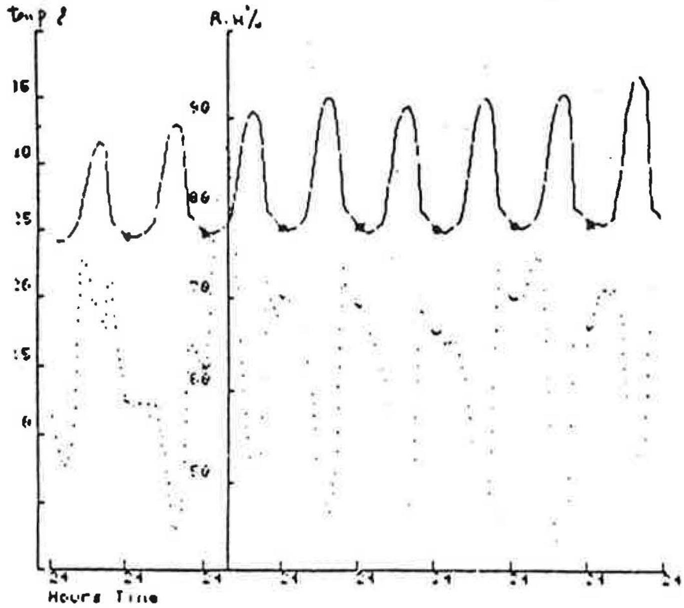
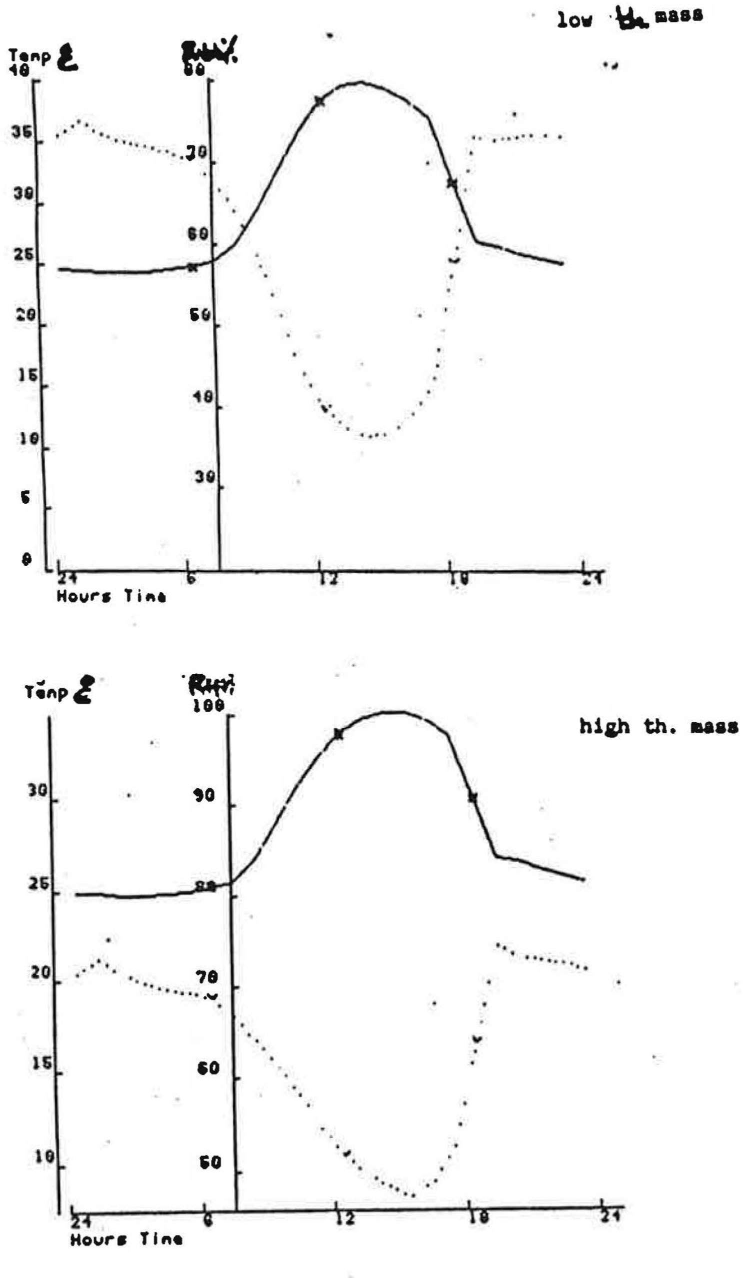



Fig.(7)




Fig(8)

The effect of thermal mass in building on the thermodynamic process of evaporative cooler is studied. For a given air and evaporated water flow rate, the comparison can be seen in Figure 9. One can observe a certain improvement in the performance with high thermal mass.




Fig(9) The effect of the thermal mass on the evaporative cooler performance in building at the daily operation

## 6. CONCLUSION

Evaporative cooling involves cheap and simple design devices. In this work are presented some points dealing with the performance and characteristics of this system related to building. We are interested in continuing the work with an integral indirect evaporative cooling system integrated with the structure of building. Such an integrated system could be widely used with a better performance than the today operated systems and under different conditions.

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