Thermal comfort in an evaporatively cooled building: effect of exterior wall orientation and exposure

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ABSTRACT
Evaporative cooling can provide comfortable conditions inside a living space with low energy. Thermal performance of a building with evaporative cooling is dependent on climatic conditions as well as on building design. This paper examines the possibility of achieving thermal comfort in a room of a multi-storey building coupled with direct evaporative cooler and the effects of building wall orientation and exposure on thermal comfort inside the building. A room of size 4 m × 4 m × 3.6 m in a multi-storey building has been simulated. It is assumed that each exposed wall has a single glazed window. Ceiling and floor have been considered as interior partitions. Simulation has been carried out to obtain diurnal hourly values of room air-dry bulb temperature and relative humidity for summer months of April, May and June in Delhi (India).

The results of simulation indicate that, in a room with its east wall exposed, relatively high temperature is attained in daytime and relatively low temperature during night time (i.e. after around 6 p.m.) in all three months as compared to a room with west wall exposed. In April and May minimum temperature is obtained with north wall exposed and in June with south wall exposed. For a room having two of its walls exposed, north and south exposed walls lead to lower room air temperature as compared to the other combinations. In a room having three of its walls exposed, S–W–N walls combination offers lower room temperature in daytime whereas S–E–N walls combination offers lower temperature in night time. If the room has three or all four walls exposed thermal comfort conditions are not achieved with evaporative cooling. Results indicate that a reduction in room temperature up to 1.5°C is possible by simply providing shading to the exterior wall.

INDEX TERMS
Evaporative cooling; Thermal comfort; Orientation

INTRODUCTION
Overuse of chlorofluorocarbons (CFCs) is one the causes of global warming. Conventional air conditioning is one of the major contributors of CFCs into atmosphere. An alternate type of cooling, which does not use CFCs and consumes much less energy as compared to conventional air conditioning, is highly desirable. Evaporative cooling is one of the alternatives that can provide solutions to such problems. Evaporative cooling refers to cooling of air by evaporation of water into it adiabatically. Several researchers have made attempts to exploit its potential for thermal comfort in buildings. Mathews *et al.* (1994) have studied the possibility of achieving thermal comfort in a well-designed building using direct or regenerative evaporative cooling in various parts of South Africa. They found that the evaporative cooling could be used in more than 80% of the total South Africa. Nation (1984) has conducted similar study for U.S. cities. He demonstrated that evaporative cooling could save from 10–100% of conventional mechanical cooling. Kant *et al.* (2001) have conducted a simulation study to examine the possibility of obtaining thermal comfort in a building using evaporative cooling. They found that by proper combination of air changes per hour (ACH)

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and by pass factor of direct evaporative cooler, the room condition can be kept within the extended comfort zone suggested by Watt (1986). The performance of evaporatively cooled building is dependent on the climatic conditions as well as on building design. Other factors that influence room conditions and thermal comfort include building orientation, window design, solar shading, internal heat load, ventilation system, room air circulation, etc. The present work is primarily concerned with building orientation. An optimum orientation of the building is required to reduce the solar heat gain through walls and windows. The aim of the present work is to investigate the effect of wall orientation and exposure on thermal comfort in an evaporatively cooled building.

SIMULATION METHOD

A room of size 4 m × 4 m × 3.6 m in a multi-storey building has been considered for simulation study. It is assumed that each exterior wall has a single glazed window having transmittance 0.8 and loss coefficient 3 kJ/hr m^2 k. Ceiling and floor have been considered as interior partitions. Standard ASHRAE wall Number 80 (common brick wall) was chosen as the exterior wall, which has U value of 2.6 W/m^2 K. The wall has interior reflectance 0.7 and exterior solar absorptance 0.8. It is also assumed that the room is occupied by three persons doing light work and total heat gain from the occupants is 555 W. The radiative gain due to light, equipments etc is 504 kJ/h and capacitance of room air and furnishing is 1000 kJ/K. The room has been modelled using transfer function approach as per *ASHRAE Handbook of Fundamentals* (1993) using a transient simulation program TRNSYS (Klein *et al.*, 1990). Mean hourly values of solar radiation, ambient air temperature and relative humidity for different months were obtained from the handbook of Mani (1981). It has been assumed that the room is coupled with direct evaporative cooler, which has a constant saturation efficiency of 90%. Since, the saturation efficiency of direct evaporative cooler is expressed by

$$\eta_s = \frac{T_1 - T_2}{T_1 - T_1'} \qquad (1)$$

where T_1 and T_2 are cooler inlet and outlet dry-bulb temperatures, respectively, and T_1' is the wet bulb temperature of inlet air. The room supply air temperature is obtained from the following expression:

$$T_2 = T_1 - \eta_s (T_1 - T_1') \qquad (2)$$

Assuming a constant air change rate of 10 ac/h the resultant room air-dry bulb temperature and relative humidity were obtained by simulation for different orientations of exterior wall(s) for one, two, three and four walls of the room exposed. The simulation study has been carried out for the summer months of April, May and June in Delhi (India).

ANALYSIS OF ROOM CONDITIONS FOR THERMAL COMFORT

Watt (1986) has suggested an evaporative cooling comfort chart, which is simply a psychrometric chart containing three overlapping comfort zones A, B and C for indoor air circulation velocities of 0.5, 1.5 and 3.5 m/s, respectively. Upper and lower limit of relative humidity for the comfort chart have been considered to be 80 and 20%, respectively. To predict thermal conditions inside the building, room conditions are plotted with dry bulb temperature on x-axis and relative humidity on y-axis. The room conditions falling outside the boundaries of comfort zone are considered to be uncomfortable for occupants of the building.

RESULTS AND DISCUSSION

The results of simulation for the room with one wall exposed are plotted in Figures 1(a)–(c). In such a room with its east wall exposed, relatively higher temperature in day time and low temperature in night time is attained as compared to that in a room with west wall exposed in April, May and June in Delhi. The relative behaviour with north or south wall exposed changes from one month to another. Lower room temperatures are attained with north wall exposed in April and May and with south wall exposed in June. However, room conditions for April and May are within comfort zone. In June perfect comfort is not achieved using evaporative cooling with air change rate of 10 ac/h as illustrated in Figure 1(d).

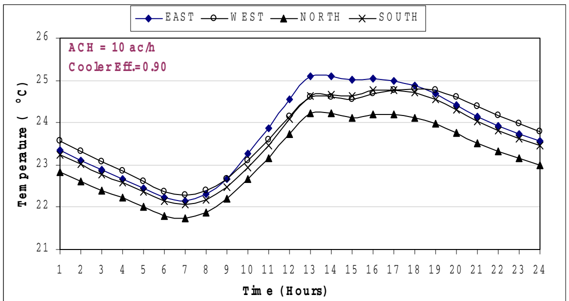

Fig.1(a)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed wall for the Month of April in Delhi

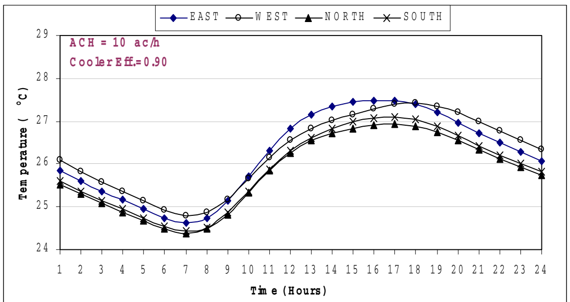

Fig.1(b)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed wall for the Month of May in Delhi

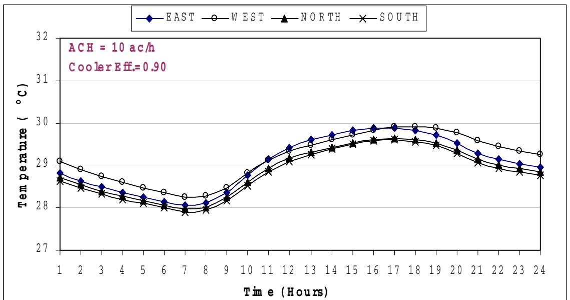

Fig.1(c)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed wall for the Month of June in Delhi

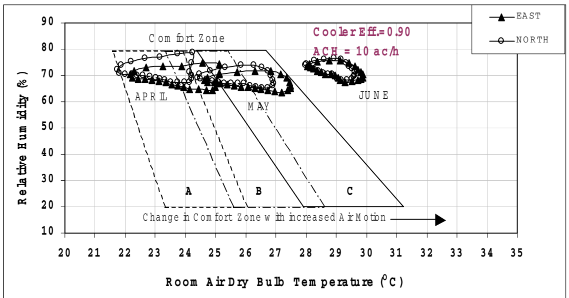

Fig.1(d)-Hourly Variation of Room Condition for Different Orientations of Exposed Wall in Delhi

A room with two of its walls exposed can have a total of six possible combinations. Simulation results for all such possible combinations are plotted in Figures 2(a)–(d). It is found that east and west exterior walls cause higher and north and south exterior walls cause lower room air temperature. Figure 2(d) shows hourly room conditions on a comfort chart. It indicates that room conditions in April and May are within the comfort zone whereas in June perfect comfort is not achieved.

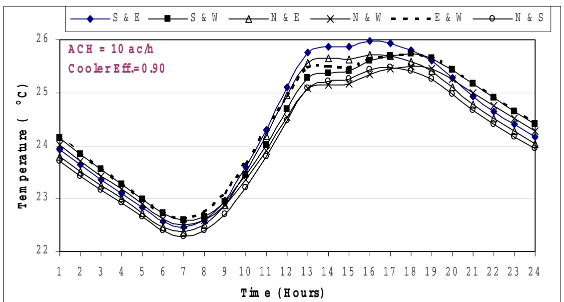

Fig.2(a)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed wall for the Month of April in Delhi

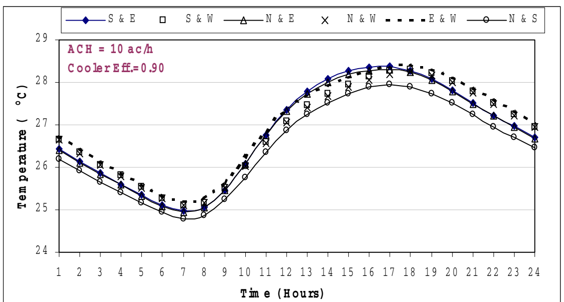

Fig.2(b)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed wall for the Month of May in Delhi

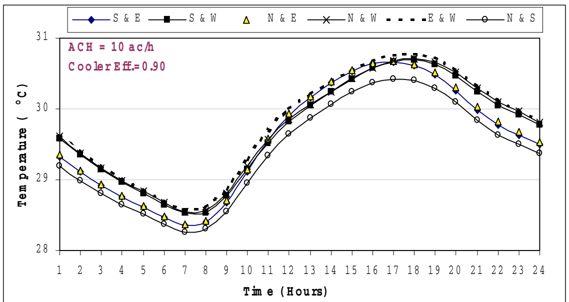

Fig.2(c)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed wall for the Month of June in Delhi

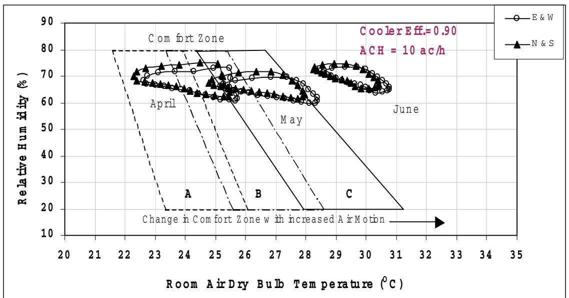

Fig.2(d)-Hourly Variation of Room Condition for Different Orientations of Exposed Wall for Delhi

A room with its three of walls exposed can have a total of four possible combinations of exterior walls. Figures 3(a)–(d) show the simulation results. It is found that East–West–South exterior walls cause higher room air temperature as compared to other combinations. South–West–North combination offers relatively lower temperatures in daytime, whereas South–East–North combination offers lower temperatures in night time. In such a room, thermal comfort is not achieved with evaporative cooling as indicated in Figure 3(d).

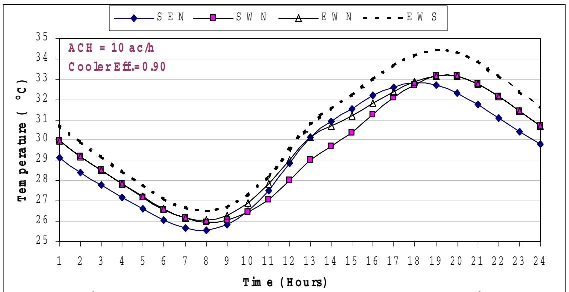

Fig.3(a)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed walls for the Month of April in Delhi

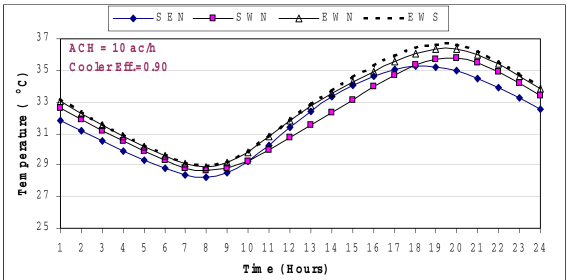

Fig.3(b)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed walls for the Month of May in Delhi

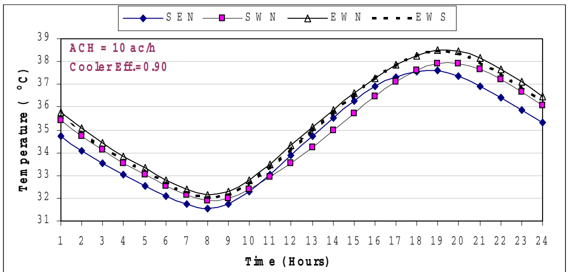

Fig.3(c)-Hourly Values of Room Dry Bulb Temperature for Different Orientations of Exposed walls for the Month of June in Delhi

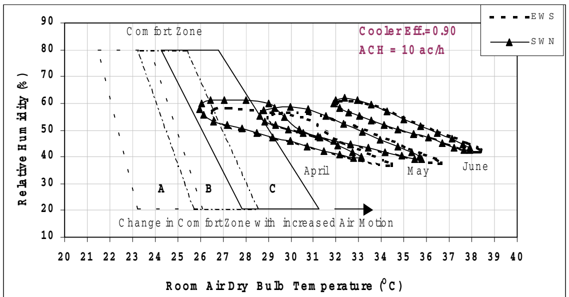

Fig.3(d)-Hourly Variation of Room Condition for Different Orientations of Exposed Walls for Delhi

In a room with all of its four walls exposed, direct evaporative cooler does not provide thermal comfort. Results of the simulation study are shown in Figures 4(a) and (b).

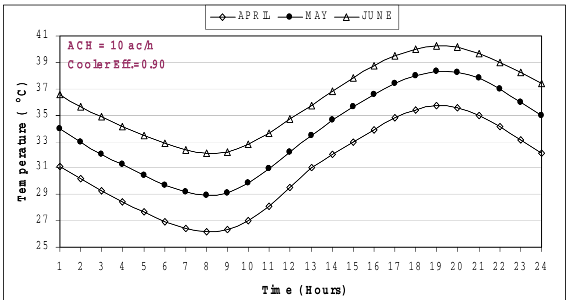

Fig.4(a)-Hourly Values of Room Dry Bulb Temperature for Different Months (Room with Four Walls Exposed)

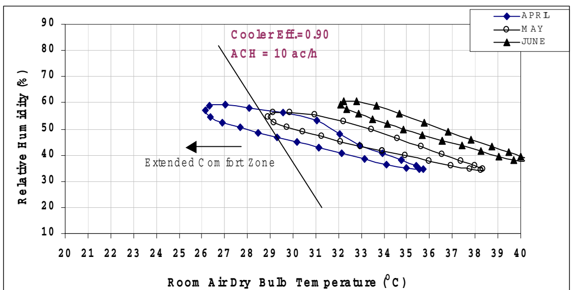

Fig.4(b)-Hourly Variation of Room Condition in Different Months (Four Walls Exposed to Solar Radiation)

In some situations, a room may have an exterior wall shaded by an adjacent corridor or a porch. The exterior wall of such a room is not exposed to solar radiation. The simulation study carried out to compare the results with exposed and unexposed exterior walls, in summer months of April, May and June, indicates (Figures 5a–d) that, reduction in room air temperature up to 1.5°C is possible by simply providing shading to exterior wall.

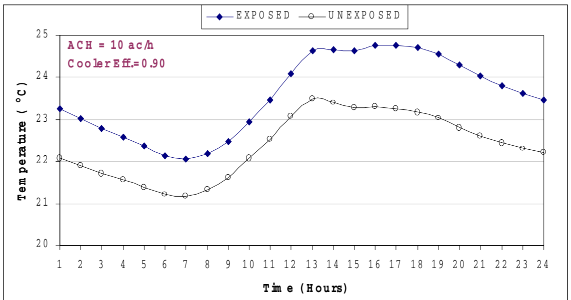

Fig.5(a) - Hourly Values of Room Dry Bulb Temperature for the Month of April in Delhi

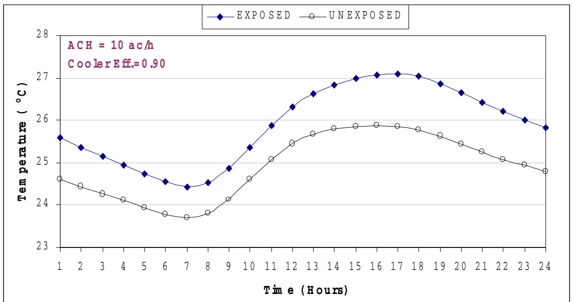

Fig.5(b) - Hourly Values of Room Dry Bulb Temperature for the Month of May in Delhi

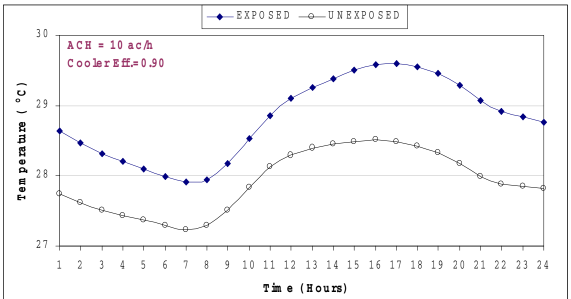

Fig.5(c) - Hourly Values of Room Dry Bulb Temperature for the Month of June in Delhi

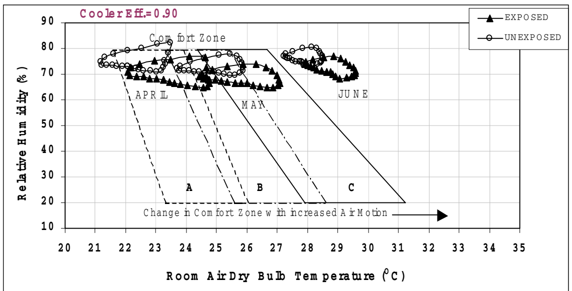

Fig.5(d) - Hourly Variation of Room Condition with Exposed and Un-exposed wall for Different Months in Delhi

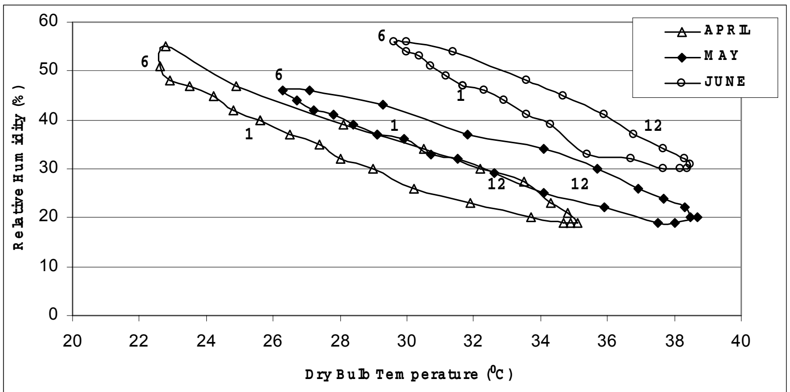

Fig.6 Variation of Outdoor Conditions for Different Months in Delhi

CONCLUSIONS

Orientation of exterior wall/walls has been found to have considerable effect on room air conditions in a building with evaporative cooling with 10 ac/h under climatic conditions as shown in Figure 6. Such a study for any given building and location would be helpful to the building designers to optimize building design to reduce the solar heat gain through walls. When the number of exposed walls is increased, the room conditions start departing from comfort zone. For the present case, evaporative cooling has been found suitable for rooms with one and two exterior walls only. Shading of exterior wall can reduce the room air temperature up to 1.5°C.

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