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Performance of multistage evaporative cooling system for composite climate of India

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Abstract

An alternate type of cooling, which does not use CFCs and consumes much less energy is highly desirable. The evaporative cooling can be employed with low energy consumption. These systems only suffer from a drawback of being less effective in humid climates. Some places like Delhi (India) where ambient conditions remain hot and dry in April and May but hot and humid in the months of June. For such a location direct or indirect evaporative coolers are effective in April and May but not effective in June. This paper examines the usefulness of a multistage evaporative cooling system for summer months. A room coupled with such a cooling system has been simulated to obtain diurnal hourly values of room air dry bulb temperature and relative humidity for summer months of April to June for Delhi. The results of simulation indicate that the proposed system can be operated in direct mode to provide thermal comfort in the month of April and May. Indirect – direct evaporative cooling system can be used to provide relief cooling in the month of June which is hot and humid.

Keywords: Thermal comfort, multistage evaporative cooling, air cooler.

Nomenclature

ACH- Air change per hour; DEC- Direct Evaporative Cooler; IEC- Indirect Evaporative Cooler; IDEC- Indirect-Direct Evaporative Cooler; T_1- Inlet Dry Bulb Temperature (^{0}C); T_2- Outlet Dry Bulb Temperature (^{0}C); T_1'- Inlet Wet Bulb Temperature (^{0}C); $T_{S,1}$- Temperature of Secondary Air at Inlet (^{0}C); $T_{S,2}$ - Temperature of Secondary Air at Outlet (^{0}C); $T_{P,1}$- Temperature of Primary Air at Inlet (^{0}C); $T_{P,2}$- Temperature of Primary Air at outlet of Heat Exchanger (^{0}C); $T'_{P,2}$- Wet Bulb Temperature of Primary Air at Outlet (^{0}C); $T_{P,3}$- Temperature of Primary Air at Outlet to DEC (^{0}C); η_{HX}- Effectiveness of Heat Exchanger; η_{DEC-I}- Effectiveness of DEC I ; η_{DEC-II}- Effectiveness of DEC II.

Introduction

Excessive use of chlorofluorocarbons (CFCs) contributes to 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 is highly desirable. It is time to review the possibility of using evaporative cooling for thermal comfort in buildings, as it is economical, effective, pollution free and simple. Several researchers have made attempts in this direction. 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 the evaporative cooling could be used in more than 80% of the entire South Africa. Nation (1984) has performed a similar study for U.S. cities. He demonstrated that evaporative cooling could save from ten to one hundred percent of conventional mechanical cooling. A passive evaporative cooling system, which makes use of natural ventilation at the building facade, was proposed by Giabaklon *et al*.(1996). They found the proposed system is inexpensive, energy efficient and eco-friendly. Brown (1990) explored the possibility of integrating evaporative cooling technique with all HVAC configurations for energy conservation in buildings. Kant *et al*. (2001) have performed simulation study for building thermal comfort with evaporative cooling. They found that by proper combination of air changes per hour (ACH) and bypass factor of direct evaporative cooler, the room condition can be kept within the extended comfort zone suggested by Watt (1986). Attempts have also be made by many researchers to invent new cooling pad medias for better performance of evaporative cooling devices. Camargo *et al*. (2005) conducted experimental studies on direct evaporative cooler and determined convective heat transfer coefficients. Gunhan *et al*. (2007) evaluated the suitability of some local materials as evaporative cooling pads. Rawangkul *et al*. (2008) had tested evaporative cooling pad made of coconut coir in Thailand region. Evaporative cooling efficiency of coconut coir's pad was found to be around 50 % and close to that of the commercial paper pad (about 47 %).

In the present work, four different arrangement of evaporative cooling systems have been studied by simulation under the climatic conditions of Delhi. Room conditions with different types of evaporative cooling have been obtained by integrated simulation of a room and evaporative cooling system.

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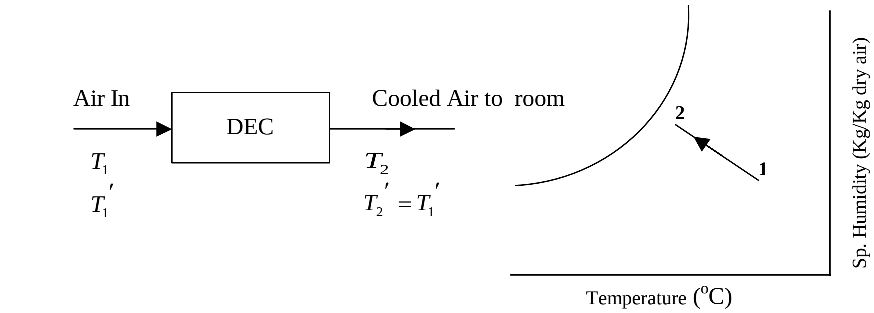

Figure 1(a) - Schematic of Direct Evaporative Cooler

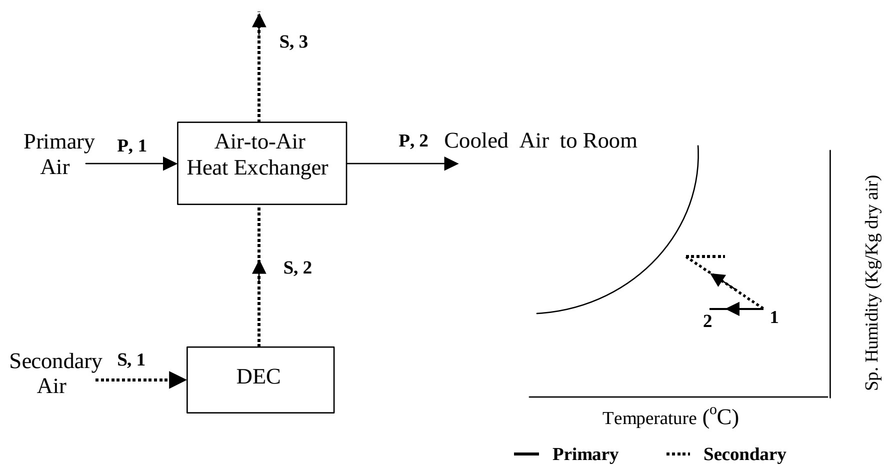

Figure 1 (b) - Schematic of Indirect Evaporative Cooler

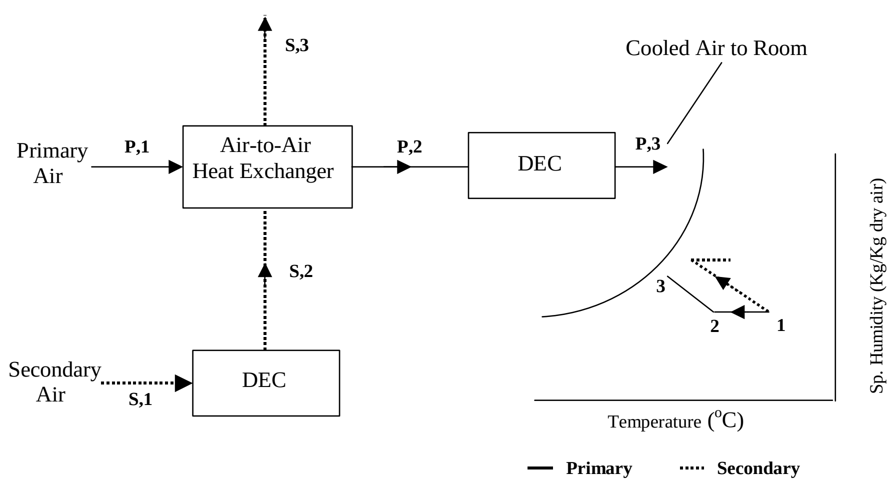

Figure 1(c) - Schematic of Indirect-Direct Evaporative Cooler

Multistage evaporative cooling system

Evaporative cooling can be used in direct, indirect and direct-indirect. In direct mode, heat exchange between water and air stream causes water to evaporate into air which reduces dry-bulb temperature and increases humidity ratio of air. In commercial direct evaporative cooler, either aspen wood fibers or rigid cellulose pads are used as wetted media through which air is introduced. Effectiveness of direct evaporative cooling system (Fig.1 a) can be defined as

$$\eta_s = \frac{T_1 - T_2}{T_1 - T_1'} \quad \text{......... (1)}$$

Indirect evaporative cooling use evaporative effect without adding moisture to the supply air stream. Fig. 1(b) represents schematic of indirect evaporative cooling system. Temperature of secondary air stream leaving DEC can be found out as,

$$T_{S,2} = T_{S,1} - \eta_{DEC-I}(T_{S,1} - T'_{S,1}) \quad (2)$$

Knowing heat exchanger's effectiveness (η_{HX}), Temperature of primary air stream leaving heat exchanger can be obtained as

$$T_{P,2} = T_{P,1} - \eta_{HX}(T_{P,1} - T_{S,2}) \quad (3)$$

Indirect-direct evaporative cooler is a combination of IEC and DEC as shown in figure 1(c). Temperature of air leaving the IDEC can be expressed as

$$T_{P,3} = T_{P,2} - \eta_{DEC-II}(T_{P,2} - T'_{P,2}) \quad (4)$$

For the present study, the effectiveness of direct and indirect coolers has been assumed constant (Stabat *et al.*, 2001). A practical multistage evaporative cooling system has been proposed as shown in Fig.2, which can be used in any of above mentioned modes.

Room specifications and simulation parameters

A room having size 4m X 4m X 3.6m in a multistory building have been considered for simulation study. It is assumed that only south wall with single glazed window having transmittance 0.8, is exposed to the solar radiation. Ceiling and floor have been considered as interior partitions. Since, brick wall is commonly used in India, standard ASHRAE wall Number 80 was chosen as exterior wall, which has U value of 2.6 W/m^2-K. Wall has interior reflectance 0.7 and exterior solar absorptions 0.8. It is also assumed that the room is occupied by 3 persons doing light work (activity level 5). The radiative gain due to light, equipments etc is 504

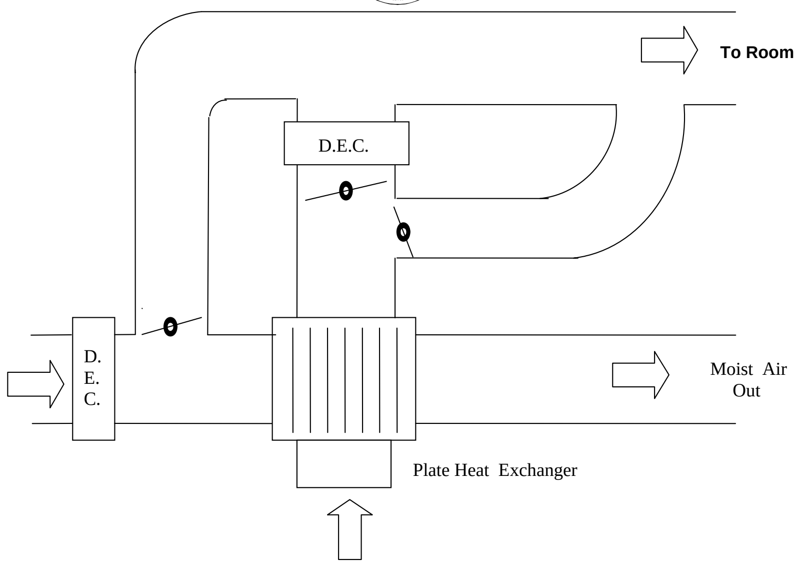

Fig. 2 Schematic of Multistage Evaporative Cooling

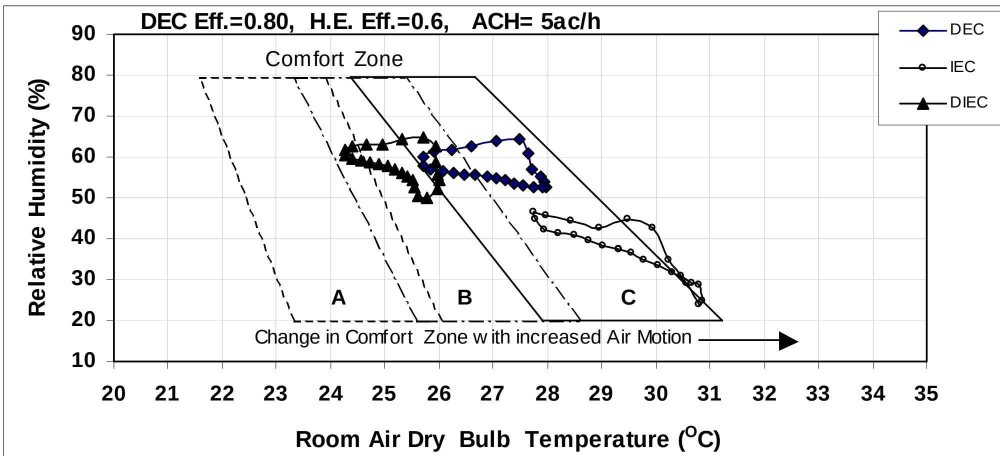

Fig.3 - Hourly Variation of Room Condition for Different Evaporative Cooling Scheme for the Month of April in Delhi

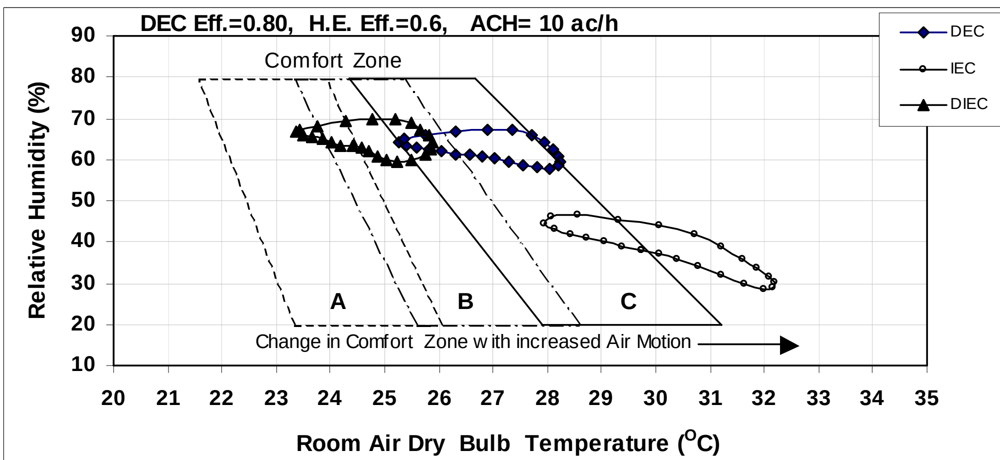

Fig.4- Hourly Variation of Room Condition for Different Evaporative Cooling Scheme for the Month of May in Delhi

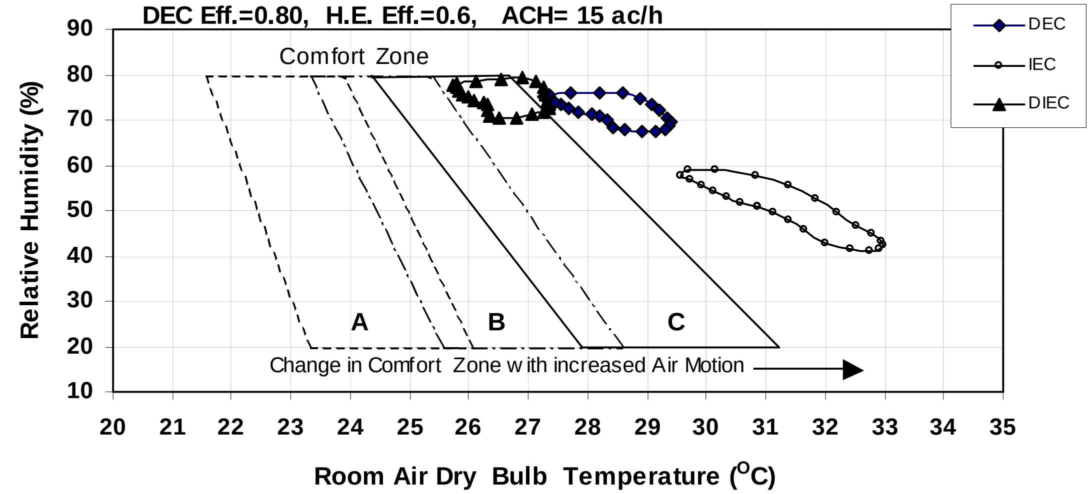

Fig.5 - Hourly Variation of Room Condition for Different Evaporative Cooling Scheme for the Month of June in Delhi

KJ/hr and capacitance of room air and furnishing is 1000 KJ/K. Direct evaporative cooler and heat exchanger of indirect cooling system have been assumed to have effectiveness of 0.8 and 0.6 respectively. The room has been modeled using transfer function approach as per ASHRAE handbook of fundamental (1993), using a transient simulation program TRNSYS (2006). Weather data for Delhi has been obtained from handbook of Mani (1981).

Results and discussion

Simulation has been carried out for summer months of April, May and June using transient system program, TRNSYS. Room conditions with supply air flow rate equivalent to 5ACH, have been obtained as shown in Fig. 3. It indicates that in the month of April, room conditions with direct, indirect and combined evaporative coolers are within the extended comfort zone suggested by Watt (1986). So in the month of April, direct type of coolers can be used economically. However, indirect and indirect-direct type of arrangements would also provide thermal comfort with higher power consumption. In the month of May (which is hot and dry), Indirect evaporative cooler is not very much effective but other two arrangements provide thermal comfort as room conditions are lying within the watt' comfort zone as shown in Fig. 4. In the month of June, climate becomes hot and humid. The combined indirect-direct evaporative cooling (Fig. 5) provides thermal comfort as the conditions are lying within the comfort zone. Whereas, direct and indirect arrangements are not effective.

Conclusions

It is found that if ambient dry bulb temperature and relative humidity are high, direct evaporative cooling systems are not effective to provide thermal comfort to occupants. For such climatic condition, combined indirect-direct evaporative cooler can be used. The proposed multistage evaporative cooling system can be used in locations where climatic conditions vary in different months (as in Delhi). The system can be operated in direct, indirect or combined mode as per climatic conditions prevailing in different summer months.

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