AN ALTERNATIVE COOLING SYSTEM FOR HOT, ARID REGIONS

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ABSTRACT

Double evaporative cooling system has been suggested as an alternative cooling system and investigated according to comfort conditions for a typical detached dwelling and a large building used as a conference hall in an arid climate. Double evaporative cooling system mainly involves a heat exchanger and two direct evaporative coolers. The system is integrated with the conditioned space.

Comprehensive energy analysis has been carried out on the system for determining the suitability of the proposed system. According to detailed computer simulation results, the double evaporative cooling system provides desired comfort conditions such as indoor temperature, relative humidity, air quality, and air motion for both a large-volumed conference hall and a typical detached dwelling in an arid climate. While indoor temperature is at comfort level, indoor relative humidity varies between 45% and 70% . Indoor air changes per hour is between 4 and 15. This is satisfactory for comfort conditions. A remarkable property of the system is the use of 100% of outside air continuously. Therefore, the system can provide adequate clean and fresh air into the occupied space. The results indicate that the double evaporative cooling system can achieve all comfort conditions without using any conventional air-conditioning system and it is suitable and applicable in arid regions.

INTRODUCTION

Evaporative cooling is one of the oldest forms of cooling known and has been used by man since 2500 B.C [1,2]. Nowadays, evaporative cooling systems are suggested as alternative cooling systems and used in many regions of the world [3,4,5,6,7]. These renewed interest in evaporative cooling has some deserved reasons of its own. First, the cost of energy for cooling is steadily rising. Evaporative cooling systems are energy-efficient systems. Second, evaporative cooling systems are environmentally benign and no negative impact to environment. Third, evaporative cooling systems can provide easily the demand for better air quality. Fourth, evaporative cooling systems do not use cholorofluorocarbons(CFCs), which are responsible for depletion of earth's protective ozone layer.

A number of studies have shown that evaporative cooling systems have the potential to satisfy comfort conditions especially in arid regions and can be applied to both commercial and residential buildings [8,9]. It was also reported that evaporative cooling systems can be combined with mechanical refrigeration and large HVAC systems for precooling supply air and reducing investment and energy costs [10,11] .

Evaporative cooling is especially used successfully in hot and dry regions and is suitable in climates which have high dry-bulb temperature and low wet-bulb temperature overtime[4,5]. Therefore, the double evaporative cooling system has been suggested as an alternative cooling system for arid climates. The system has been evaluated according to comfort conditions in South-Eastern Anatolia which has an arid climate.

EVAPORATIVE COOLING

Evaporative cooling is based on a simple principle; as water evaporates into air stream, the latent heat of vaporization is absorbed from air stream. As a result, dry-bulb temperature of air is lowered and so cooling can be achieved.

Evaporative cooling systems can be divided into three main categories according to the method used to cool the air supplied to the conditioned space. The first is direct evaporative cooling. In direct evaporative cooling, the air stream is cooled by evaporation of water into air and the moisture content of air is increased. This isenthalp process occurs along constant wet-bulb temperature line on the psychrometric chart. The lowest possible dry-bulb temperature of leaving air is equal to the wet-bulb temperature of the inlet air. Indirect evaporative cooling is the second type of evaporative cooling system. It is popular because the moisture content of air to be cooled stays constant. In indirect evaporative cooling system, there are two air flows; primary air that flows into the building and secondary air which cools the primary air. The primary air is cooled sensibly when it flows through one side of a heat exchanger. The other side of the heat exchanger is used for the secondary air which is cooled by direct evaporation of water. The minimum possible outlet temperature of primary air in an indirect cooler is equal to the wet-bulb temperature of the secondary air flow. This can be achieved only when both the effectiveness of direct evaporative cooler and heat exchanger are 100% . The third type of evaporative cooling systems is combined evaporative cooling which combines direct and indirect cooling at different stages. Generally, combined evaporative cooling systems are integrated with the conditioned space.

DOUBLE EVAPORATIVE COOLING SYSTEM

Double evaporative cooling system which consists of two direct evaporative coolers and a heat exchanger has been proposed as an alternative cooling system for the South-Eastern part of Turkey which has an arid climate. Figure 1 shows double evaporative cooling system schematically and figure 2 shows the system on the psychrometric chart.

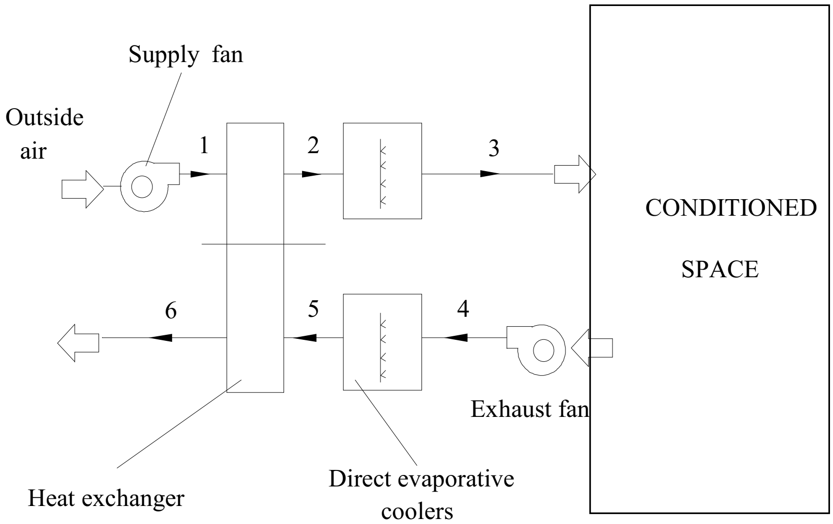


Figure 1. Double evaporative cooling system

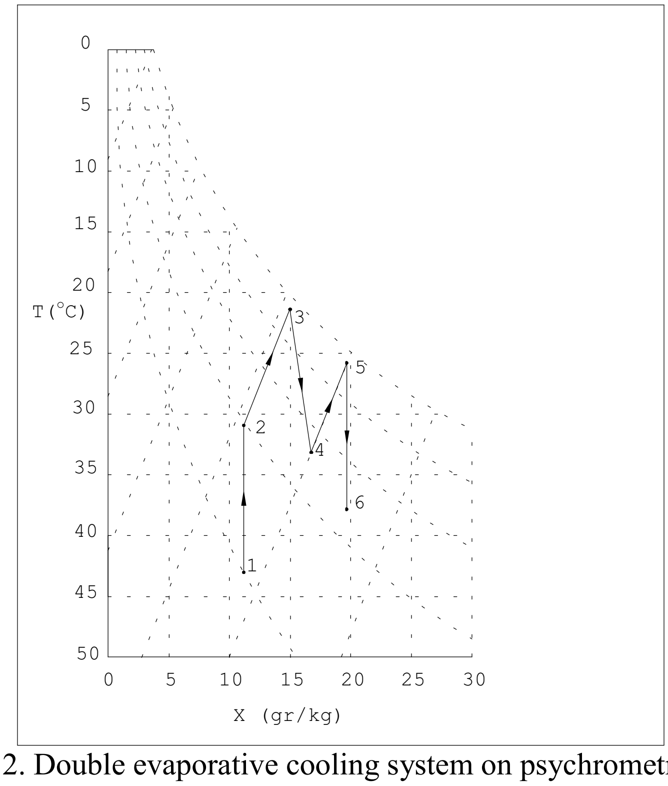


Figure 2. Double evaporative cooling system on psychrometric chart

The system operates as follows: When the outdoor air passes through the heat exchanger, it is cooled to a certain value depend on the efficiency of the heat exchanger (process 1-2). This precooled air is humidified in the first direct evaporative cooler (process 2-3) and then is given to the occupied space by taking into account of the sensible heat ratio of the room (process 3-4). The room air is drawn into the second direct evaporative cooler and so, more humidified and cool air is attained (process 4-5). This humidified and cool air flows into the heat exchanger and cools down the outdoor air and it is discharged into outside space as exhaust air (process 5-6).

EVALUATION OF THE SYSTEM

Comprehensive energy analysis must be carried out for determining the suitability of the proposed system. It is known that outdoor climate conditions have great influence on the total heat gains of buildings. Hence, the climate data of the city of Şanlıurfa which is one of the main provinces of South-Eastern Turkey and involves South-Eastern Anatolia Project (GAP) are described with mathematical functions[12]. The data required were taken from State Meteorological Office (DMİ). The data recorded for 14 years between 1980 and 1993 were used for obtaining functions. A Computer program has been developed for calculating hourly total heat gain of buildings during cooling season (May 1- September 30).The system were examined according to comfort conditions using another computer program developed that shows the processes on the psychrometric chart. The outside climate conditions, cooling load and some properties of the cooling system such as efficiency of heat exchanger were entered into the computer simulation program. It is assumed that the effectiveness of the first and the second direct evaporative coolers is 90 % and the efficiency of heat exchanger is 70 % and no cooling is required when outdoor dry-bulb temperature is below 26 ^{o}C.

In calculation of cooling load of the detached dwelling, it is assumed that there are 5 occupants, light power is 15 Watt per meter square of floor, total power of electrical appliances such as television, refrigerator is 550 Watt and lighting is on from 18:00 p.m. to 6:00 a.m.

In calculation of total heat gain of the meeting hall, it is assumed that 350 occupants are in the meeting room, light power is 20 watt per meter square of floor, total power of sound devices is 1500 Watt, and lighting is on from 18:00 p.m. to 6:00 a.m.

Both indoor relative humidity and air changes per hour are divided into four intervals in order to assess the comfort level. Table 1 and table 2 show these intervals.

Table 1. Intervals for indoor relative humidity

Interval	Indoor Relative humidity
1	40 %≤ RH ≤50%
2	50 %< RH ≤60%
3	60 % <RH ≤70%
4	70 % <RH <80%

Table 2. Intervals for air changes per hour

Interval	Air changes per hour
1	0< n ≤5
2	5< n ≤10
3	10< n ≤15
4	15< n ≤20

Figure 3 and 4 show the plan of the typical detached dwelling and the meeting hall, respectively.

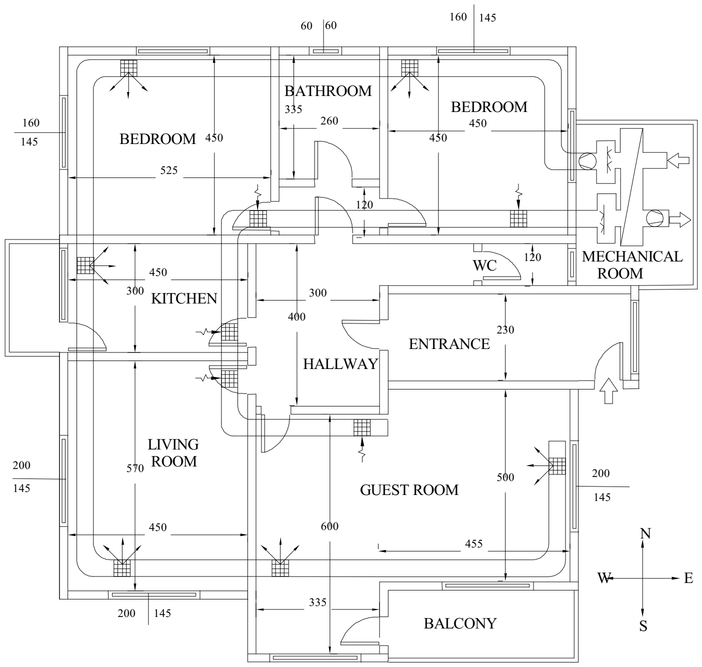


Figure 3. Plan of the detached dwelling

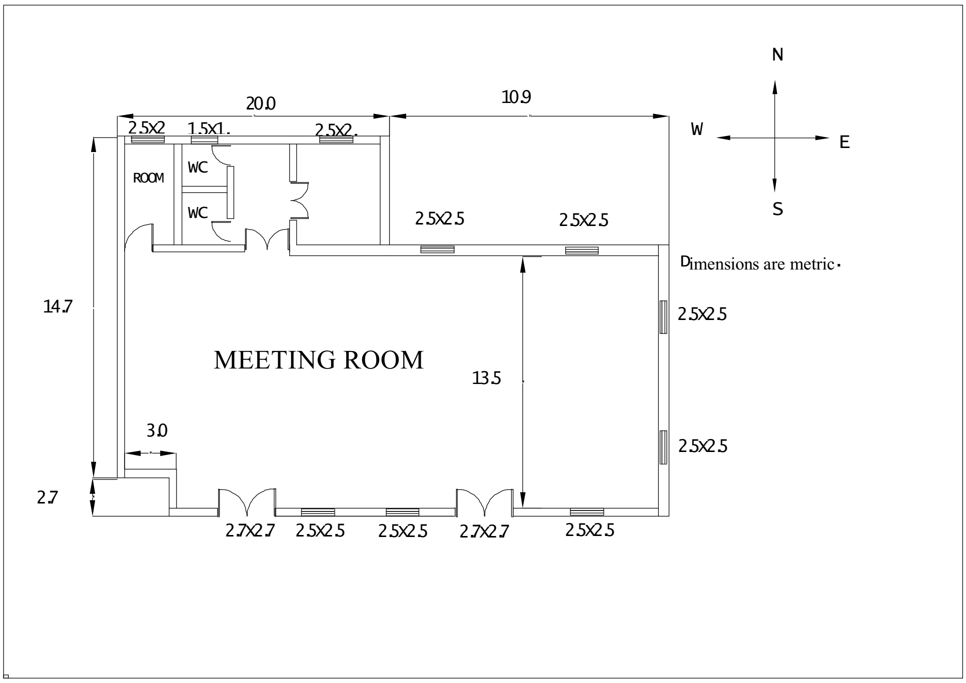


Figure 4. the plan of the meeting hall.

SIMULATION RESULTS FOR THE DETACHED DWELLING

Table 3 shows thermal comfort analysis of the double evaporative cooling system during cooling season for the detached dwelling.

Table 3. Thermal comfort analysis of double evaporative cooling system for the detached dwelling

Month	Total days	Total hours	Total no cooling hours $T_{out}<26\ ^oC$	Total cooling hours $T_{out} \geq 26\ ^oC$	Interval	Hours for relative humidity	Hours for air changes
May	31	744	446	298	1	0	61
					2	287	237
					3	11	0
					4	0	0
June	30	720	256	464	1	11	78
					2	385	386
					3	68	0
					4	0	0
July	31	744	186	558	1	3	66
					2	415	492
					3	140	0
					4	0	0
August	31	744	186	514	1	19	74
					2	391	440
					3	104	0
					4	0	0
September	30	720	334	386	1	0	105
					2	349	281
					3	37	0
					4	0	0

The fourth interval for indoor relative humidity was not encountered at all during the cooling season. For indoor relative humidity, 2% total cooling hours is in the first interval, 82% of total cooling hours is in the second interval, and 16% of total cooling hours is in the third interval. Figure 5 shows hourly variation of indoor relative humidity for various days of cooling season. The relative humidity stays in a certain band and varies between 50% and65%. It does not fluctuate during day time.

As one can see from table 3, the third and fourth intervals for air changes were not encountered et all during cooling season. 17% of total cooling hours is in the first interval and 83% of total cooling hours is in the second interval. This shows that the system provides comfort. The air quality is essential, not just for comfort but also for health and productivity. Figure 6 shows hourly variation of indoor air changes per hour.

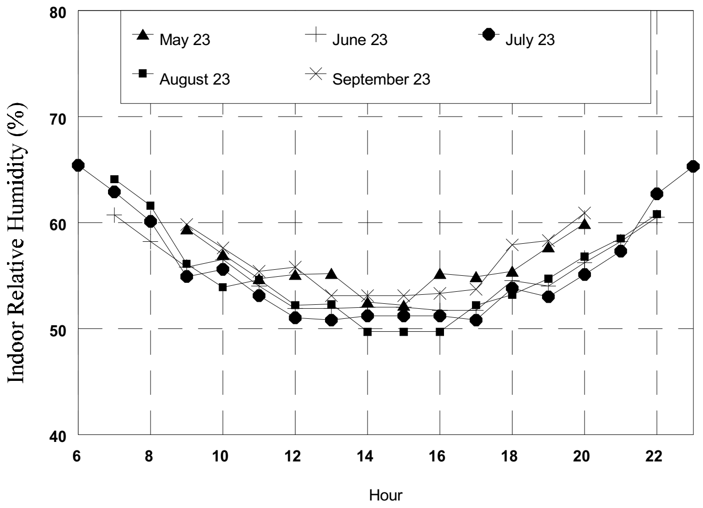


Figure 5. Variation of indoor relative humidity during daytime

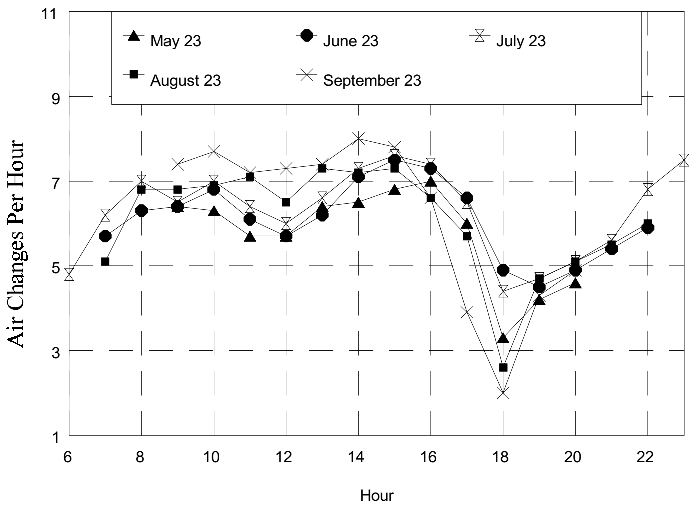


Figure 6. Variation of air changes per hour during daytime

SIMULATION RESULTS FOR THE MEETING HALL

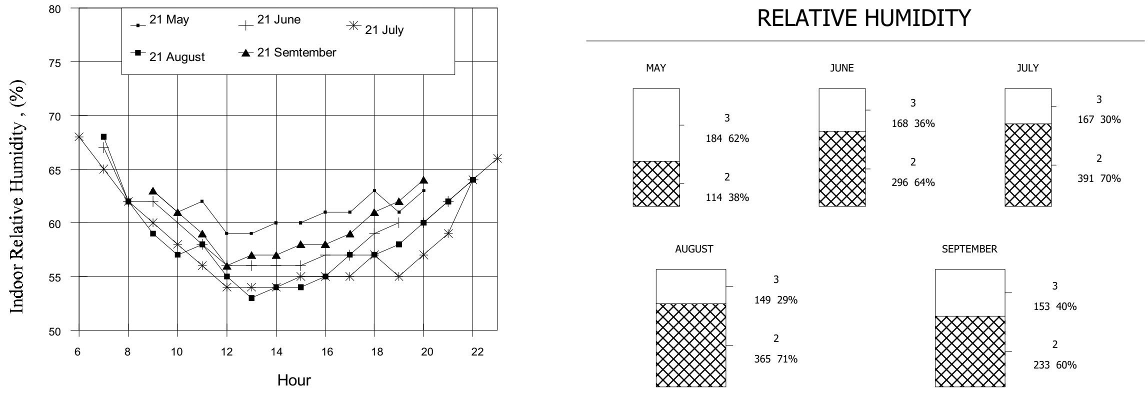
Table 4 shows thermal comfort analysis of the double evaporative cooling system for the meeting hall. Total hours, total no cooling hours, total required cooling hours, intervals of relative humidity, and air changes per hour are given in table 4 during the cooling season.

Table 4. Thermal comfort analysis of the double evaporative cooling system for the meeting hall

Month	Total days	Total hours	Total no cooling hours	Total cooling hours	Interval	Hours for Relative Humidity	Hours for Air Changes
May	31	744	446	298	1	0	0
					2	114	223
					3	184	75
					4	0	0
June	30	720	256	464	1	0	0
					2	296	289
					3	168	175
					4	0	0
July	31	744	186	558	1	0	0
					2	391	339
					3	167	219
					4	0	0
August	31	744	186	514	1	0	0
					2	365	301
					3	149	213
					4	0	0
September	30	720	334	386	1	0	0
					2	233	197
					3	153	189
					4	0	0

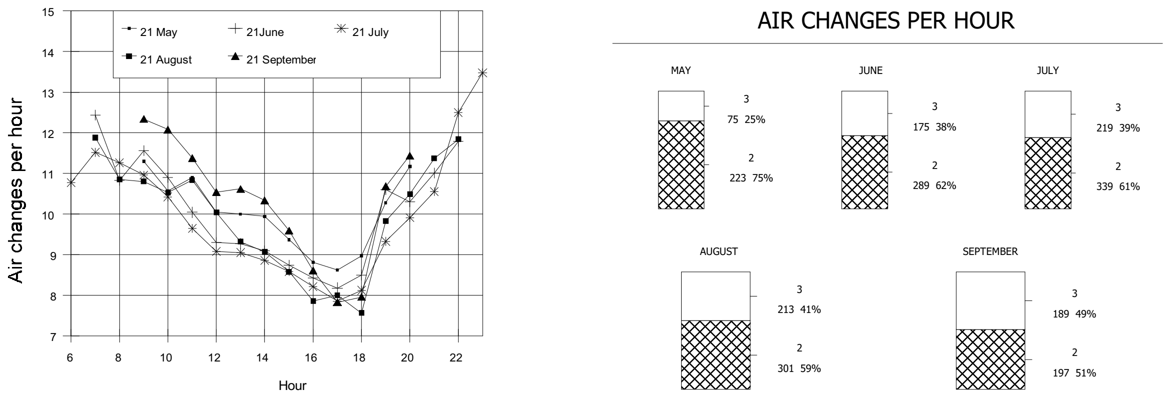
The first and fourth intervals were not encountered et all for relative humidity during cooling season. For relative humidity, 63% of total cooling hours is in the second interval and 37% of total cooling hours is in the third interval. This is satisfactory for comfort. Figure 7-a shows the variation of relative humidity during day time. It is seen that relative humidity is between a certain band interval and does not change too much during day. The variation of indoor relative humidity during cooling season is given in figure 7-b.

The first and fourth intervals were not encountered for air changes per hour during cooling season. For air changes per hour, 61% of total cooling hours is in the second interval and 39% of total cooling hours is in the third interval. This shows that the suggested system achieves air changes at comfort level. Because it is an important criterion for comfort to supply enough fresh air to indoor space in such hot climates. Figure 8-a shows the variation of air changes per hour during day time. Figure 8-b shows the percentages of occurrence of different intervals for air changes per hour during cooling season.



-a- **-b-**

Figure 7. Variation of indoor relative humidity



-a- **-b-**

Figure 8. Variation indoor air changes per hour

In this study, temperature difference between indoor and outdoor air was limited to a maximum value of 10 ^{o}C to provide comfort conditions. High temperature difference may have thermal shock effect on the occupants. The indoor temperatures depend only on the outdoor temperatures. Figure 9 shows indoor dry-bulb temperatures calculated using the outdoor temperatures.

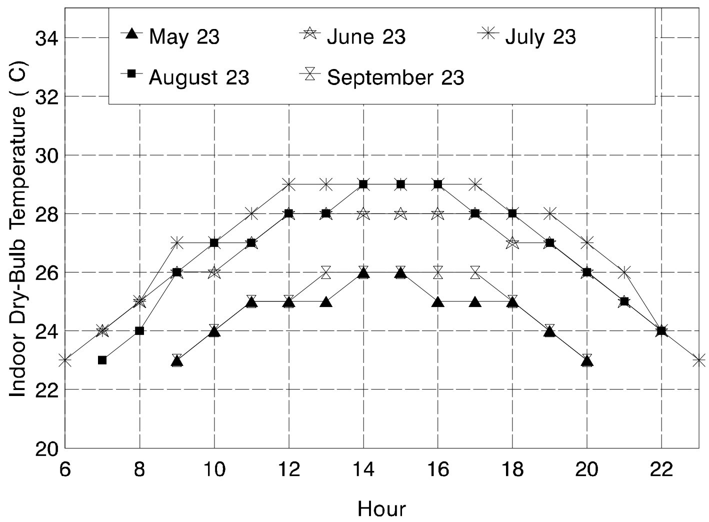


Figure 9 Variation of Indoor Dry-bulb Temperature during daytime

The fan power requirement of the proposed system was determined by taking into consideration of the pressure drop in the heat exchanger and in the channels. The coefficient of performance (COP) for this system can be defined as the ratio of the cooling capacity to the required fan power. COP for the detached dwelling ranges from 24 to 37 and from 29 to 39 for the meeting hall. These values are very high compared with the COP values of conventional cooling systems.

CONCLUSION

The main aim of air conditioning is to supply a comfortable environment for human beings. Indoor air temperature, relative humidity, velocity, and air quality must be at desired comfort conditions. There are many types of air-conditioning systems and there exist some limitations such as environmental impact, comfort conditions, economics, and initial and maintenance costs to select appropriate one. Environmental problems and economical considerations are on the agenda nowadays. Environmentally safe alternative cooling systems must be investigated instead of conventional systems which consume a significant amount of energy and are responsible for damaging the environment. In this view, the double evaporative cooling system has been suggested as an alternative cooling system and investigated according to comfort conditions for a typical detached dwelling and a large building used as conference hall in an arid climate. According to computer simulation results, the double evaporative cooling system achieves indoor temperature, relative humidity, air quality, and air motion at comfort conditions for both the large-volumed conference hall and the detached dwelling. While indoor temperature is at comfort level, indoor relative humidity varies between 45% and 70% . Indoor air changes per hour is between 4 and 15. This is satisfactory for comfort. A remarkable property of the system is the use 100% of outside air continuously. Therefore, the system can give adequate clean and fresh air into occupied space. It has been ascertained that the double evaporative cooling system can achieve all the comfort conditions without using any conventional air-conditioning system and it is suitable and applicable in arid regions.

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