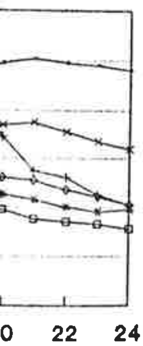

PRELIMINARY INVESTIGATION OF THE EFFECT OF A PASSIVE DIRECT EVAPORATIVE COOLING SYSTEM ON A COURTYARD AT UCLA

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ABSTRACT. This paper reports the preliminary stage of a research project to study the performance of a passive direct evaporative cooling system in the model of a courtyard space at a UCLA Laboratory. Two experiments were conducted to evaluate the proposed design, namely: (1) quantify the system's average air velocity, ventilation air flow, cooling and humidifying efficiency, (2) observe the effect of the system on the thermal variations of the courtyard. Results indicate that the new design is capable of providing thermal comfort in outdoor spaces. Preliminary data were recorded during the period of December 1990 - February 1991. Statistical evaluation of the recorded data was carried out for the proposed design. Finally, the results are presented graphically.

1. INTRODUCTION

Passive cooling and natural ventilation systems have been studied by various scholars, but their work was mostly theoretical and limited to indoor spaces (Bahadori,1985; Wu and Yellott, 1987; Cunningham and Thompson, 1986). However, passive cooling and natural ventilation systems can also be used effectively for thermal comfort in <u>outdoor</u> spaces (yards and courts, or in "free standing" areas such as public rest areas, walkways, etc.) through the lowering of air temperature and increasing air velocity. Givoni (1989) has designed an evaporative cooling system for an outdoor space at the '90 EXPO in Spain. This system consists of an open vertical shaft at the top of which water is sprayed. The falling fine drops draw a large volume of air, resulting in an inertial air flow. Evaporation of the fine drops cools the air close to the ambient WBT. In the design used in the present study, evaporative cooling is increased by adding to the system a wind catcher, allowing more air to circulate downward. In other words, the new tested system is an enhanced version of Givoni's model. Therefore, this study presents two experments to evaluate and analyze the preformance of the new design: (1) quantifying the system

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influence of the system on the thermal conditions of the courtyard. Statistical analysis of the recorded data shows that the system is efficient in providing cool air.

2. SYSTEM DESIGN DESCRIPTION

The proposed design of a passive direct evaporative system is illustrated in Fig. 1. It consists of three main parts: a wind catcher, an evaporative column, and a water pond. The design of this system is based on the concept that a wind catcher can force a large volume of air downward in an open vertical column at the top of which water is sprayed. The falling thin drops come in contact with the hot air and cool it through latent heat transfer to a temperature close to the Wet Bulb Temperature (WBT) of the ambient air. Water is collected in a pond located at the bottom of the evaporative column. It is then recirculated by means of a pump. In addition to the evaporative cooling, there is a sensible cooling of the air when the water temperature is lower than the ambient WBT. The difference in temperature between the ambient air and the air in the shaft increases the density of the air and thus it creates inertial flow and a higher flow rate. The wind catcher allows the wind to enter the column from any direction. This part has cross vertical barriers (+) to deviate the airflow downward without allowing it to leave through the opposite openings. The second part, the evaporative column allows full utilization of the airflow evaporative cooling potential by spraying very tiny water drops. At the top, four water spraying humidifiers (shower heads) spray the water vertically downward. A plastic sheeting covers this part. The third part is a water pond which consists of a bucket and a submersible electrical pump. The pump is connected to the head showers by a plastic pipe to recirculate the water. A galvanized metal sheeting surrounds the water pond and rises vertically to channel the flow of cooled air to the entire space of the courtyard.

3. THE COURTYARD CHARACTERISTICS

Figure 1 shows a plan and section of the proposed system and the courtyard dimensions. The courtyard was set up in the UCLA Laboratory in 1989. It is constructed of wood framing with plywood and insulation material (4" thick and R=11). The exterior and interior are painted in white to minimize the effect of solar radiation. The north half of the courtyard is open to the sky with a movable door at the south side. The system is located at the center of the courtyard.

4. INSTRUMENTS AND MEASUREMENT METHOD

Two instruments for temperature and air velocity measurements were used in this study. The first was Bacharach Sling Psychrometer used to read Dry Bulb Temperature (DWT) and Wet Bulb Temperature (WBT) outside the courtyard 4' above ground level, at the point where the air exits from the system, and inside the courtyard. The water temperature was recorded continuously. The second instrument is a digital air velocity recorder with an accuracy of ± 0.5 m/sec. Figure 1 shows the reading points of the DBT and WBT and air velocity (V).

5. EXPERIMENT #1: QU
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THE SYSTEM

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the wind speed was moderate.
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The First Method: The air exi
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total average air velocity 1.18

Having found the air velocity
following equations:

$Q_i = A \cdot V_i \cdot V$

where

Q_i = air flow r
A = area of th
V_i = exiting ai
V_c = velocity
velocity o

In order to calculate the cooli
inlet of the wind catcher an
following equation can be us
air at a given time (Givoni,

$C_i = Q_i\ (2(T_{in}$

where

C_i = cooling
T_{in} = inlet ai
T_{out} = outlet a

5. EXPERIMENT #1: QUANTIFYING THE AVERAGE AIR VELOCITY, VENTILATION FLOW, COOLING LOAD, AND HUMIDIFYING EFFICIENCY OF THE SYSTEM

On December 3, 1990, the weather was clear, the ambient air temperature was 80°F and the wind speed was moderate. The system was operated and two experimental methods were used to quantify the average air velocity and total ventilation flow of the system.

The First Method: The air exit opening of the system was divided into 8 equal areas (A, B, C, D, E, F, G and H). Air velocity readings were recorded at the center of each area with the probe tip placed in the plane of the opening. This allows the air to flow perpendicularly through the duct probe tip. It was found that the air velocity values were non-uniform and the average air velocity was 1.18625 m/sec. Figure 5.a shows the recorded air velocity and total air flow ventilation.

The Second Method: Each one of the 8 equal areas was divided into 10 subopenings. Air velocity readings were recorded at the center of each subopening area with the probe tip placed in the plane of the opening. The collected data presented in Figure 2.a shows the location of the reading points. The average air velocity was 1.182 m/sec. The findings of both methods show that air velocity was almost the same. Threfore, it is possible to minimize the number of air velocity measurements, but average air velocity at the four openings should be multiplied by a ratio of the average air velocity and the total average air velocity 1.186 m/sec.

Having found the air velocity, we can calculate ventilation flow and cooling using the following equations:

$$Q_i = A \cdot V_i \cdot V_c \qquad (1)$$

where

Q_i = air flow rate at second i in F^3/sec or m^3/sec
A = area of the exit air in F^2 or M^2
V_i = exiting air velocity the at second i in F/sec or M/sec
V_c = velocity correction ratio of average air velocity of a given opening = 1.182 MPH

In order to calculate the cooling of the system, the difference in temperature between the inlet of the wind catcher and open air exit (outlet) should be known. Therefore the following equation can be used to find the amount of heat extracted from the courtyard air at a given time (Givoni, 1991):

$$C_l = Q_i\,(2(T_{in} - T_{out})) \times 0.33 \times 3600 \qquad (2)$$

where

C_i = cooling load (extracted heat (heat loss)
T_{in} = inlet air temperature (F°)
T_{out} = outlet air temperature (F°)

0.33 = volumetric heat capacity of air (ws/Cm^3)

(Note: Calculations were converted from Britsh unites to US units in this study).

The hidifying efficiency of the system is a measure of the completeness of the humidifying process using a spray chamber. It (E_h) can be calculated using the following equation (Clifford, 1984):

$$E_h = \frac{T_{in\text{-}D} - T_{out\text{-}D}}{T_{in\text{-}D} - T_{out\text{-}W}} \qquad (3)$$

where

E_h = humidifying efficiency
$T_{in\text{-}D}$ = DBT of air entering the system (F°)
$T_{out\text{-}D}$ = DBT of air leaving the system (°F)
$T_{out\text{-}W}$ = WBT of air leaving the system (°F)

Air velocity, ventilation air flow, cooling load and humidifying efficiency will be used for calculation in the evaluation of the system based on thermal variations in the courtyard.

6. EXPERIMENT #2: THE EFFECT OF THE SYSTEM ON THE THREMAL VARIATIONS OF THE COURTYARD

DBT & WBT readings were taken outside and inside the courtyard, as well as at the open air exit at the base of the tower. The water temperature was also taken. This was done on February 4, 1991; the sky was clear and wind speed low. Fig. 3 represents 4 time periods of one and a half hours each. The systems performance is shown in phases 2 and 4. In phases 1 and 3, the system was not operating. The graph shows that DBT inside the courtyard in phases 2 and 4 are substantially lower than in phases 1 and 3. Furthermore, the DBT inside the courtyard in phase 4 are lower than those in phase 2. This is due to the fact that they were recorded at different periods of the day. In phase 2, which is the phase where cooling is most needed, the graph shows an average DBT reduction of 4°F inside the courtyard. The exiting air DBT is close to the outdoor air WBT, with a range 0.0 to 0.75°F. This demonstrates the cooling efficiency of the system. On the other hand, phase 2 shows that the water temperature rises by an average of 4°F, due to heat exchange between the air's sensible heat and the latent heat of the water droplets. Fig. 4 represents average air velocity measurements through 4 exiting air openings (C, D, E and F) and ambient air. It was found that air velocity averaged 3.872 Ft/sec. in phase 2 and 3.937 Ft/sec. in phase 4. The air velocity value changes from one opening to another because air velocity depends on two factors: the speed of downdraft air captured by the wind catcher and the water pressure sprayed in the column (inertial air flow). Fig. 5 shows the graph of ventilation air flow generated by the system with an average 32.500 Btu/Ft^3 per hr in phase 2 and 4. This air flow increases the ventilation potential in the courtyard which is characterized by lower pressure. Thus, the air flow

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4. Fig. 7 shows the humidify
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7. CONCLUSION

The proposed system can s
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8. ACKNOWLEDGEMENT

The author is grateful to pro
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This study was in part fund

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leads to a comfortable living condition. Fig. 5 shows the cooling effect produced by the system in the two phases 2 and 4. The heat extracted from the courtyard (cooling) depends on the difference between DBT of the air entering the system and DBT of the exiting air. The higher the difference the more effective the cooling of the system. The average cooling load recorded was 35000 Btu/hr in phase 2 and 15000 Btu/hr in phase 4. Fig. 7 shows the humidifying efficiency of the system. Humidity fluctuates between 63% and 94% in phase 2 and between 50% and 88% in the phase 4.

7. CONCLUSION

The proposed system can supply air to the courtyard space at higher flow rates. Furthermore, the air delivered to the courtyard space is cooled by evaporation. Two experimental studies conducted to evaluate the proposed system were carried out successfully and may be used for designing passive direct evaporative cooling systems. Additional applications are being investigated such as quantify the system's water and energy consumption, the effect of wind catcher on the system performance, and the effect of the water quality (brackish and sea water) on the performance of the proposed system.

8. ACKNOWLEDGEMENTS

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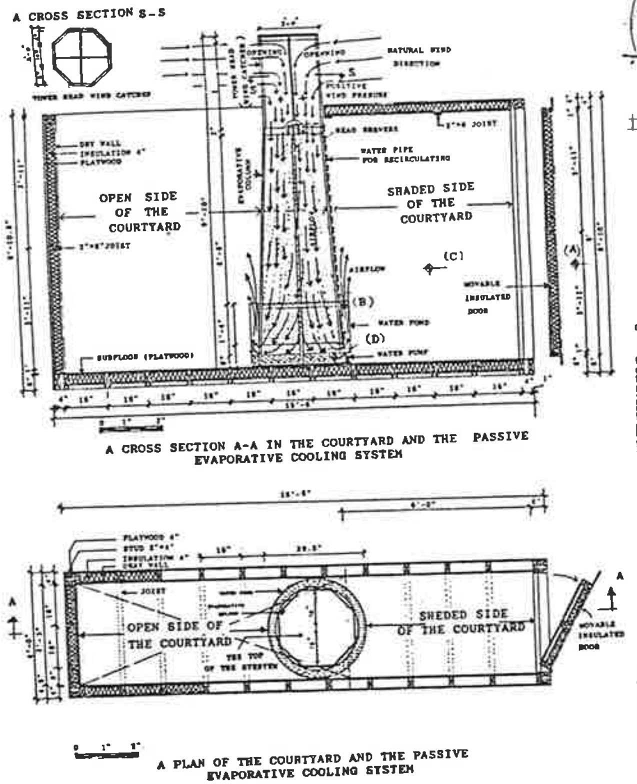


Fig. 1 Detaild plan and section of the passive direct evaporative cooling system in the model of a courtyard space at UCLA Laboratory.

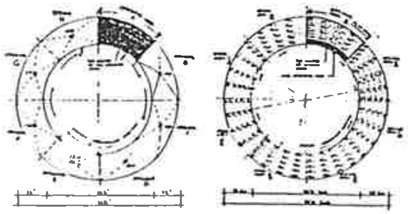


Fig. 2.a The recorded air velocity and total ventilation air flow for experimant method #1.

Fig. 2.b The recorded air velocity and total ventilation air flow for experiment method #2.

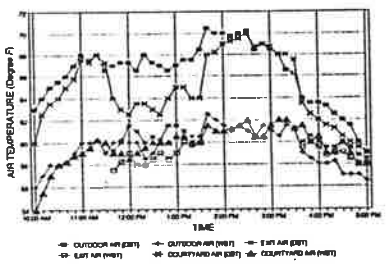


Fig. 3 Profiles of the DB and WB temperature of the outdoor air, tower exit air and courtyard air, and water.

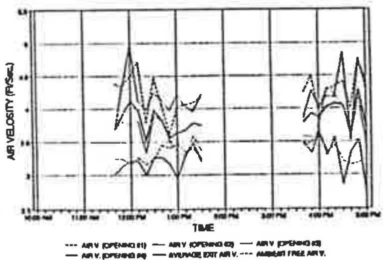


Fig. 4 Average air velocity through 4 exit air openings and ambiant free air velocity.

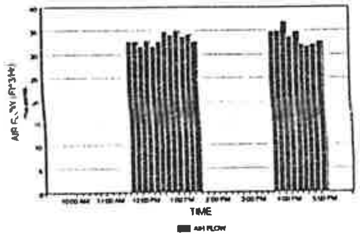


Fig. 5 Profile of the ventilation air flow generated by the system.

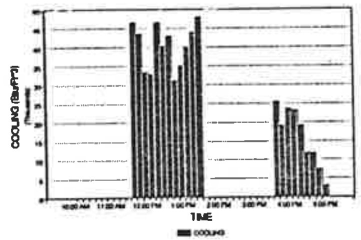


Fig. 6 Graph of the cooling load.

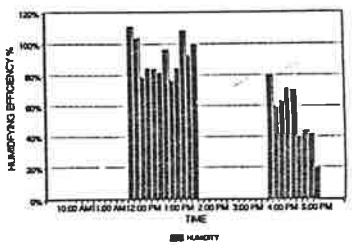
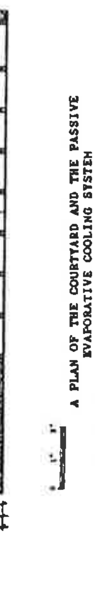


Fig. 7 Graph of humidifying efficiency.



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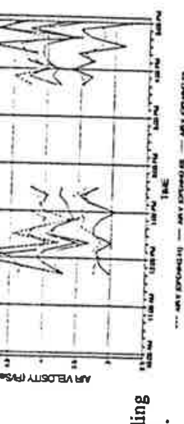

Fig. 4 Average air velocity through 4 exit air openings and ambiant free air velocity.

Fig. 7 Graph of humidifying efficiency.

Part 6

BUILDING ENERGY ANALYSIS

Chapter 1

Climatic Data