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# Potential of a wet fabric device as a roof evaporative cooling solution: Mathematical and experimental analysis

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ABSTRACT

The present work indicates the potential of a novel wet fabric device as a roof indirect evaporative cooling solution in comparison with a water roof pond and as a future reference for no water consumption devices. Theoretical and experimental models describe the thermal performance of three roof evaporative cooling solutions: I) water roof pond, II) water roof pond with floating fabric and III) wet fabric. Four built experimental cells were used to validate the numerical results. The theoretical model describes interior, roof, water and fabric temperatures, considering constant properties. Finite difference method is used to solve the governing equations for each case by using temperature, relative humidity and solar radiation measurements for three climate conditions: Hot sub-humid, hot humid and warm sub-humid. An experimental study is designed to test the numerical results for control and water pond cases. Numerical and experimental results show good agreement; for the reference cell and water pond cell, the difference between the numerical and experimental average indoor temperature becomes 0.1 K in both cases. The results show that the proposed wet fabric device has a cooling potential for three climate conditions, considering that it does not require substantial constructive modifications. The theoretical model is also used to show that fabric porosity has a pronounced influence on the interior temperature.

## 1. Introduction

Application of indirect evaporative cooling as a passive cooling technique on roofs has been widely investigated in recent years. A great variety of roof evaporative cooling systems have been developed, for example: water spray roofs [1,7], wetted roof [7,16], humid porous media [21] roof pond [12,17], roof pond with floating fabric [20], cool pool [18], and gunny bags [9]. Another solution is the roof pond with movable insulation, which has shown potential to achieve comfort conditions in an arid region [8].

Roof pond is an easy device to implement; furthermore, it has shown great thermal stability and high cost-benefit relation [10,32]. To improve the effectiveness of the roof pond many variants have been proposed, for example: roof pond uncovered with and without sprays, covered pond with and without sprays, energy roof, cool-roof [4], walkable pond, roof pond with gunny bags, cool-pool, shaded pond [11] and ventilated roof pond [20]. However, little attention has been paid to evaporative cooling performance of these devices in humid conditions.

To improve the efficiency of the roof pond system, Tang and Etzion [24] covered the pond with gunny bags keeping a constant water layer. Adding the floating fabric showed a reduction of the bottom pond temperature and a slightly better performance than a roof pond with movable insulation [24]. Regardless of the thermal performance, these evaporative cooling systems could cause serious structural problems because of the necessity of installing waterproof systems as well as a structural load increase on the building [22]. Furthermore, it is necessary to set in place water outlets, to prevent overflows caused by rainfalls.

The present work proposes a new evaporative cooling device, named wet textile fabric, and analyzes the cooling potential for three climate types (hot sub-humid, hot humid, and warm sub-humid), through a lumped model of inside air and temperature stratification in the water layer. In addition, a comparison between the proposed system, a roof pond, and a floating fabric in a water roof pond was made. The model describes the thermal performance of four cases:

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**Nomenclature**

| | |
|---|---|
| $A$ | surface area ($m^2$) |
| $C_a$ | specific heat of air (J/kg K) |
| $C_f$ | specific heat of fabric (J/kg K) |
| $C_{ro}$ | specific heat of roof slab (J/kg K) |
| $C_w$ | specific heat of water (J/kg K) |
| $d$ | depth of water film (m) |
| $e$ | water pond thickness (m) |
| $H$ | roof slab thickness (m) |
| $h_b$ | heat transfer coefficient from the enclosed air to the underground surface (W/$m^2$ K) |
| $h_c$ | heat transfer coefficient from the exposed surface of the roof with and without water film (W/$m^2$ K) |
| $h_{fw}$ | heat transfer coefficient from the roof surface to the water pond (W/$m^2$ K) |
| $h_i$ | heat transfer coefficient from inside surface of the roof to an enclosed room air (W/$m^2$ K) |
| $I$ | solar radiation on the roof (W/$m^2$) |
| $M_a$ | mass of air inside room (kg) |
| $M_w$ | mass of water over the roof (kg) |
| $n$ | porosity (%) |
| $P$ | pressure of the saturated vapor at temperature $T$ (N/$m^2$) |
| $Q_e$ | water evaporation heat loss (W) |
| $r_{ro}$ | fraction of solar energy that reaches the roof (%) |
| $r_w$ | fraction of solar energy that heat the water pond (%) |
| $T$ | temperature (K) |
| $t$ | time (s) |
| $U$ | overall heat transfer coefficient (W/m K) |
| $V$ | volume ($m^3$) |
| $v$ | wind velocity (m/s) |
| $y$ | position coordinate along the thickness of the roof and the water pond depth (m) |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | fraction of solar radiation absorbed by the surface |
| $\sigma$ | Stefan-Boltzmann constant |
| $\varepsilon$ | emissivity |
| $\phi$ | relative humidity (%) |
| $\lambda$ | thermal conductivity (W/m K) |
| $\rho$ | density (kg/$m^3$) |

*Subscripts*

| | |
|---|---|
| *0* | initial conditions |
| *a* | air |
| *b* | floor/ground |
| *reference* | reference cell inside temperature |
| *FF* | floating fabric cell inside temperature |
| *f* | fabric |
| *i* | enclosed room air |
| *WF* | wet fabric cell inside temperature |
| *R* | room |
| *ro* | roof slab |
| *out* | outside |
| *RP* | roof pond cell inside temperature |
| *w* | water |

reference, roof pond, floating fabric, and wet fabric. The mathematical model was tested against experimental results obtained in cells at Colima, Mexico. The proposed system does not require substantial constructive modifications; furthermore, a reduction of the operational quantity of water can be achieved. At the same time, an analysis of the influence of fabric porosity on the interior temperature is presented.

## 2. Method

### 2.1. Climatic conditions

The research was performed in the city of Coquimatlan, Colima, Mexico, at latitude 19° 12′ 41″ N, longitude 103° 48′ 23″ W, and altitude of 354 masl. According to Köppen's climate classification, in Colima the weather is classified as hot sub-humid [10], where thermal energy storage is a critical issue [3].

Fig. 1 summarizes the dry bulb temperature (dbt) and RH for Coquimatlán. The annual mean temperature is 28.0 °C and RH is 49%. The maximum temperature occurs in April with 40.8 °C and the minimum in February and March with 12.5 °C. For humidity, the maximum occurs in September with 82.7% and the minimum in March with 19%. Three seasons can be identified; warm sub-humid (in color gray) in the months of January, February and March with a mean temperature of 23.3 °C and mean RH of 43%. Hot sub-humid (in color orange) from April to June and December with a mean temperature of 25.2 °C and mean RH of 45%. Finally, the hot humid season (in color blue), from July to November, has a mean temperature of 25.3 °C and mean RH of 55%.

### 2.2. Experimental cells

The experimental analysis was done using four cells simultaneously and arranged as shown in Fig. 2, with inside dimensions of 1.35 m × 1.35 m × 1.35 m. The floor consisted of a 0.07 m thick reinforced concrete slab. The building walls were composed of clay bricks with 0.07 m of thickness; the outside faces were plastered with a 0.015 m layer of cement. The roof thickness is 0.07 m of reinforced concrete. The parapet block was annealed clay 0.14 m thick and 0.08 m high. The roof has a slight slope to drain rainfall. The module dimensions are shown in Fig. 3.

In order to minimize thermal energy transfer through the walls and the doors, the cells were thermally insulated with 0.04 m thick polystyrene plates on the outside walls and the top of the parapet, as is shown in Figs. 4–7. The U-value of the wall and door was 0.44 [W/$m^2$ K]. Two doors were made of the same material as the insulation to keep

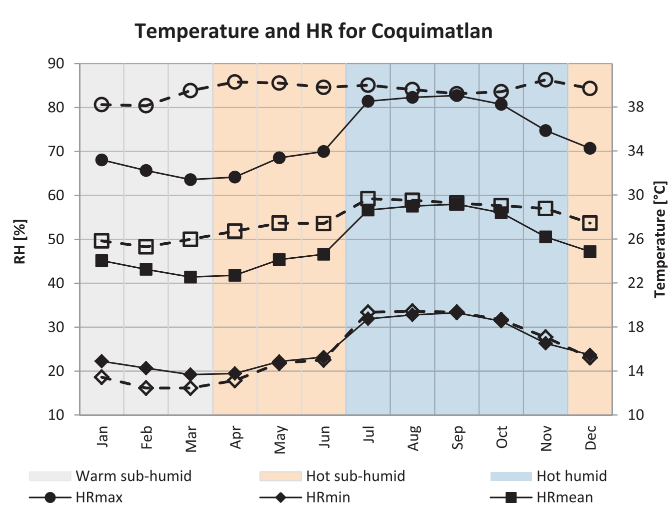


**Fig. 1.** Dry bulb temperature and relative humidity for Coquimatlan, Mexico. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)