Evaporative Cooling in Tropical Climate: Case Study of Campinas, Brazil

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ABSTRACT: In Brazil, a country with great territorial extension, a major extension of the territory is in tropical climate. So the challenge for researchers and designers is to achieve comfortable indoor temperatures and to contribute to energy saving. The objective of this paper is to present a discussion about the results obtained in a case study accomplished in cell-tests with roof evaporative cooling in Campinas, SP. Comparative monitoring of surface internal temperature of roof tiles, simultaneously with and without water spraying at different time intervals, as well as attic air temperatures of corresponding cell-tests are presented. The technique allowed verifying a significant difference in the tile surface internal temperature, even when water spraying occurred in small time intervals. Results show that evaporative cooling in fiber-cement tiles for heat attenuation with reduced time intervals of water spraying, even in season with high relative humidity could be a passive cooling technique for low-income housing, for which those tiles are frequently the only roof component.

Keywords: evaporative cooling, spray cooling, roofing, thermal behavior.

1. INTRODUCTION

The use of water to reduce the environmental temperature is not an innovative technique. Reports in the history of the architecture and the old civilizations prove the presence of water fountains, vegetation and cascades in patios (Figure 1a). Room openings facing these patios contribute to reduce hostility of hot and dry air in the interior of the residences (Figure 1b).

Figure 1a: Openings facing a patio with water pond [1].

Public buildings with higher occupation, such as palaces, schools and mosques also incorporated this technique, (Figure 2a). In the typical mosque architecture, there is a great patio with central fountain for the religion ritual [3]. Moreover religious significances, the water also provides maintenance of the internal microclimate of the mosque (**Figure 2**).

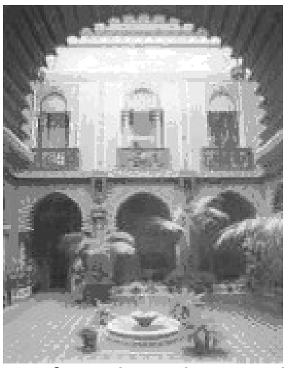


Figure 1b: Water fountain and vegetation in Arab residential patio [2].

In modern architecture, the evaporative cooling is regarded having in mind the development of air-conditioning industry of [4]. In the post-war period, the evaporative cooling as a technique for environmental conditioning has developed with new materials and noise attenuation, the contribution of air-conditioning machines. The evaporative cooling is a passive method that can save the fossils fuel reserves or contribute to prevent the use of gas CFC in the refrigeration, one of the possible causes of the global heating.

Figure 2: In the patio: water fountain located in front of opening room [1].

There are basically two different approaches to cooling buildings by water evaporation. The first is to cool outdoor air directly through evaporation, and then to introduce that air into the building. The air is humidified while its temperature is lowered and the indoor moisture content is elevated above the outdoor level. This is the direct evaporative cooling affecting the users and the interior materials in the cooled space. The airflow for direct evaporative cooling can be induced either by mechanical devices – fans – or passively by natural processes – utilizing the wind, temperature difference, or water spray in passive evaporative cooling towers. The second approach is to cool a given element of the building, such as the roof or a wall. The cooled element, in turn, serves as a heat sink and absorbs, through its interior surface, the heat that penetrates into the building through the envelope or that part of heat generated indoors. This approach is indirect evaporative cooling. With such systems the indoor radiant and air temperatures are lowered without elevating the indoor moisture content of the air. It is an efficient technique, since each gram of evaporated water consumes about 2,5 x 10^3 J [5].

Several techniques have been adopted and have been researched, based in the principles of the heat loss by convection process through water evaporation and conservation. Many researches have been sponsored by DOE - Department Of Energy of USA – and have been tested in some localities. Pittinger and White [4] proposed the "Energy Roof" in 1977/78 in Arizona. The "Cool Pool" was a system tested by Karen Crowther in California [4]. DOE's Researchers in partnership with an industry of California tested a cooling system of dipping roofing. A similar system was tested in the decade of 60 in Washington, DC, by Harry Thomason, but with little success. The accumulated results were not satisfactory to the "Roof Ponds", due to the proliferation of mosquito's larva, dirt and foliage in water. This kind of problems was also found in the system of "Water Filled Plastic Bags" many years after their installation. However the use of sprinkles in the roofing minimized the high temperatures due to solar irradiation without presenting the mentioned effects.

Givoni [6] proved the effectiveness of the water use in cooling towers for external environment acclimatization, first in the Expo92 in Seville, Spain. Latterly, he applied the cooling tower in localities of diverse climates, as California in the United States, Yokohama in Japan and Riyadh in Saudi Arabia, using both fresh and sea water. The results were considerable.

In hot humid climate of Yokohama-Japan, Givoni [7] tested the performance of shower cooling tower. The cooling performance depended on Wet Bulb depression and airflow generation, but it was relatively high during daytime. This result means that the technique deserves more researches for this kind of climate.

Tang et al [8] based their research on the exposure of "floating" wetted cloth to ambient air. It was covered with white cotton towels stretched on a densely perforated PVC panel supported by pieces of waterproof polystyrene keeping it just floating on the water surface. It seems that the higher efficiency of the tested technique is due to the thermal stratification created in water inside the pond, which more effectively resists to the transfer of heat gains from the sun and ambient air into the deep water of the pond.

The roofing offers many possibilities of applications of cooling passive techniques for buildings. It is the building element more exposed to the climatic conditions and is responsible for about the half of the thermal load in buildings is subject [9].

Brazil is a country where most part of the territory in tropical climate. Most of the Brazilian's houses of low-income population have fibre-cement roofing tiles without concrete slab as ceiling. Therefore a research for testing methods to reduce the surface internal temperatures of this kind of roofing can contribute to attenuate the heat transfer inside these houses, consequently, improving thermal comfort and life quality for this population.

2. OBJECTIVE

The paper's object is to discuss the evaporative cooling as passive technique in roofs, and their thermal behaviour. Roofing systems with fibre-cement tiles and ventilated attics in cell-tests were monitored in Campinas, Brazil.

3. MATERIALS AND METHODS

3.1 Study area

The research was performed in the city of Campinas, Brazil, at latitude 22º54' S, longitude 47º03' W, and altitude 680m. According to historical series of the climatic data for this region (period of 1998 to 2005, from the IAC (Campinas Agronomic Institute), the hottest months are from January until March with maximum averages between 29,4 and 29,7ºC, and the coldest ones are June and July with average minimum temperatures 13,3 and 12,7ºC respectively. The summer period is from November to March, and winter period from June to August. The average relative air humidity is 82,6% from December to June, and 76,1% from July to

November. The rains' period occurs from December to March, being the rainiest month January (287 mm).

The evaporative cooling monitoring in two cell-tests was applied in the experimental area of the School of Civil Engineering, Architecture and Urban Planning, University of Campinas.

3.2 Equipments

An automatic meteorological mini-station for data collection, CR10X, from Campbell Scientific Inc. was installed in the area. Data were recorded every 30 seconds, with averages every 10 minutes.

The station records the following external atmospheric elements: air temperature, relative humidity, wind speed, and predominant wind direction, global solar radiation, and rainfall.

The station is equipped with channels for connection of thermocouples type T for the monitoring the following parameters in the cell-tests: surface internal temperatures of the tiles, dry bulb temperature inside the attics, surface internal and external temperatures of concrete slab, dry bulb temperature indoor.

3.2 Study area

The cell-tests were identical. They were built on a basis of concrete (3,20 x 3,70 m²), with walls of solid mud bricks (½ brick/ 10 cm thickness), white painted in the internal and external faces. The external dimensions are 2,20 x 2,70 m and the internal ones 2,00 x 2,50 m, with an area of 5,00 m^2, and ceiling height 2,40 m. There is a ventilated attic between the fibre-cement tiles and a concrete slab (Figure 3a and b). The longer façades are oriented north and south.

There are two openings, with dimensions 1,20 x 1,00 m, and windowsill 1,10 m, oriented to north and west. For these studies a panel obstructs the openings with thermal resistance equivalent to that of the wall. There is no ventilation indoor (Figure 4).

Three sprinklers were installed on roofing in direction East-West. An analogical timer sets a water pump. A closed box received the exceeding water not used in the aspersion.

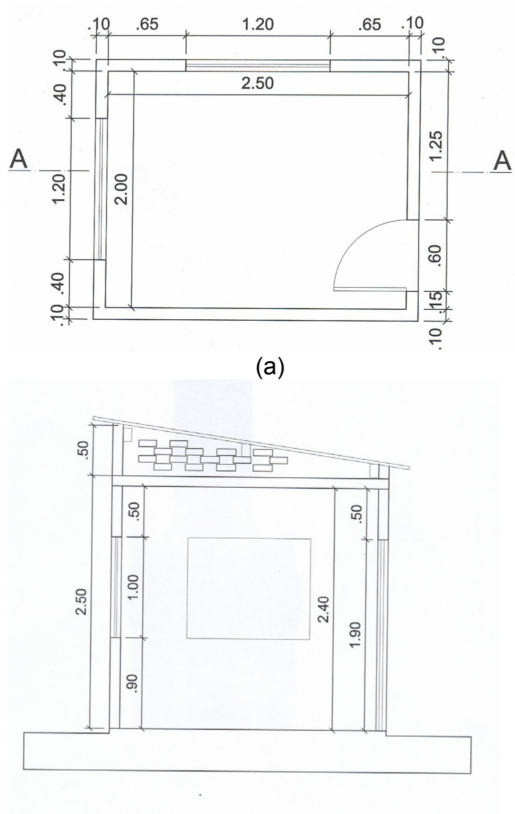
This system allowed relating the surface internal temperature of the tile with the external temperature, comparing also the surface internal temperatures in the hottest and rainiest period.

4. RESULTS

Measurements were accomplished in the period from September 29th to October 06th, 2005 and from January 20th to February 10th, 2006. It corresponds to the end dry period and beginning of humid period.

Table 1 shows data about the relative humidity, the averages of maximum and minimum temperatures, and the aspersion cycle used in the monitored period.

The system consisted of water sprinkling on the roofing through three sprinklers (Figure 5a e b), each one with average outflow nearly 30 l/h. The timer was programmed to test different cycles of sprinkling. The beginning was at 10:30h and finished at 20:00h.



(a)

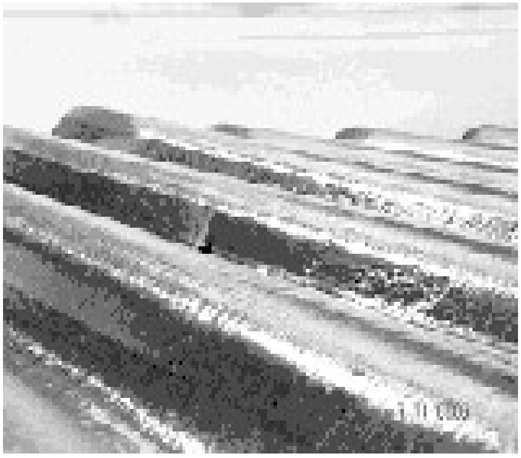
(b)

Figure 3: Cell-test - (a) Plan; (b) Section AA. All dimensions in meters.

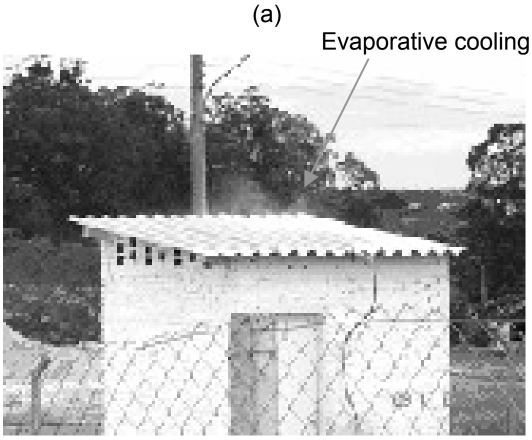
Figure 4: East view of cell-test in experimental field.

Table 1: Climatic data for the measurement period and aspersion cycles.

Date	Relative Umidity (%)	MinT (ºC)	MaxT (ºC)
Cycle 30 min per 30 min			
9/30/05	63,1	16,9	26,1
Cycle 30 min per 30 min			
1/21/06	51,8	24,4	32,3



(a)



(b)

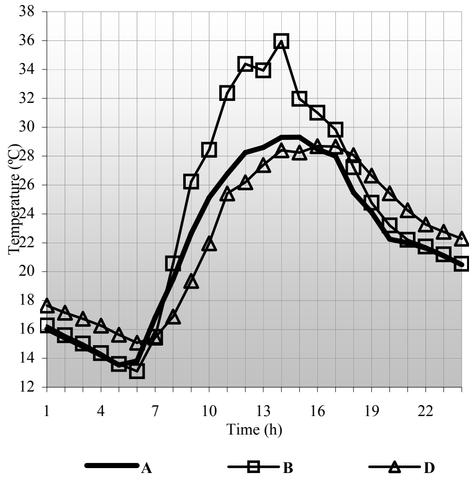
Figure 5: Evaporative cooling – (a) Sprinkler view, (b) Roofing spraying.

Graph 1 shows surface internal temperature of reference roofing tile in relation to the one with evaporative cooling system. From 8:00h the reference temperatures increase and are over those of external air. However, the corresponding temperatures of the roof with evaporative cooling system were reduced in comparison with external air. The system was turned on at 10:30h and turned off at 20:00h. There is an inversion in the curves of surface internal temperature after 18:00h.

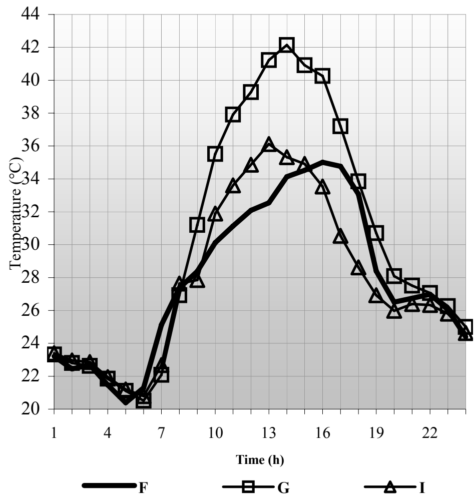
In Graph 2 similar behaviour is observed after 8:00h, however the surface internal temperature of evaporative cooling was above the external temperature. After 15:00h a decrease of the surface temperature with cooling is observed.

Graph 3 shows that attic air temperature of reference cell-test and of the one with cooling presented similar behaviour. Between 15h and 16h there is an inversion of curves in relation to external air curve.

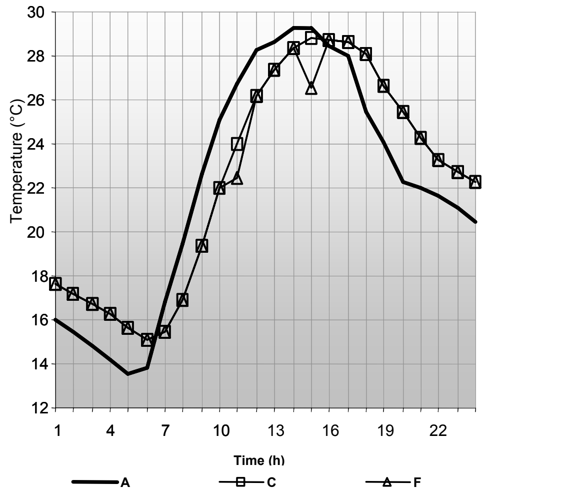
In Graph 4, the effectiveness of the evaporative cooling directly in the roofing becomes evident. The air temperature of the attic (J) is below those of the others curves.



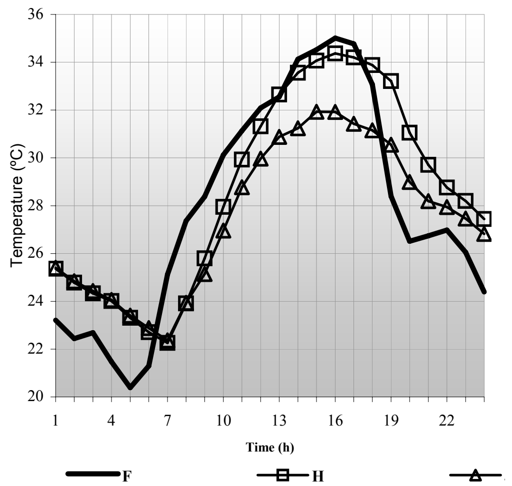
Graph 1: Results for 30/09/05. Curve A - external air temperature; B - surface internal temperature of reference roofing; D – surface internal temperature of cooling roofing tile.



Graph 2: Results for 21/01/06. Curve F - external air temperature; G - surface internal temperature of reference roofing; I – air temperatures of attic in cell-test with cooling roofing.



Graph 3: Attic air temperatures in 30/09/05. A - external air temperature; C – attic air temperatures of reference roofing tile; F – attic air temperatures with cooling roofing.



Graph 4: Attic Air temperatures in 21/01/06. F - external air temperature; H – attic air temperatures of reference roofing; J – attic air temperatures with cooling roofing.

The thermal properties of the materials that compose the roofing tile, predominantly the fibre-cement, generated a small thermal decrement.

In both systems the sprinkling cycle was the same, only the climatic conditions were different. The difference between the peaks of surface internal temperatures was 7,6ºC in Graph 1 and 6ºC in Graph 2.

5. DISCUSSION

This research is based mainly on Givoni's studies for humid climate regions. Therefore they were selected the hottest and rainiest months for application of evaporative cooling. The results show that this technique can be satisfactory for houses with fibre-cement roofing, without concrete slab, if it is considered only the surface internal temperature attenuation in January (one of the months hottest).

Better results than those obtained in the cell-tests, can be obtained through human interference propitiating cross-ventilation by opening windows and doors. In practice, this situation is recommended for zone 3 of Norm ABNT 15220-3 [10]. The evaporative cooling system with water sprinkling has no effects such as proliferation of mosquito larva or dirt, which is the case with water ponds, and a problem of public health.

However, mainly in summer, in many Brazilian cities there is interruption of water provision for some periods, which could be a problem for the successful application of the technique. On the other side, the evaporative cooling system does not require sophisticated installations or equipment in fibre-cement roofing. Therefore through the implantation of water reuse system and pluvial storage the cooling roofing system would be possible in houses, diminishing expenses with mechanical cooling and promoting rational water use.

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