Study of Evaporative Cooling Roofing in Sub-tropical Climate

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ABSTRACT

In tropical regions, the main energy source and the responsible for heating of buildings is the solar radiation incident on the building components, especially on roofing. Due to the world energy crisis, one of the main focus in world researches has been the passive conditioning, either heating or cooling of buildings. Techniques of bioclimatic architecture, vernacular typologies, regional building materials as well as knowledge of climate location have been promoted around academic studies. Water usually is used in hot and dry climates for helping control the air temperatures mainly in indoor spaces, through evaporative cooling. In this work, the possibility of applying water on roofing in tropical climate with moderate air humidity (hot period) was analyzed. The research purpose was to verify the mitigation of the heat transferred through roofing. In the Southeast of Brazil, the region where the research was done, there is a hot and a cold period in the year. The hot period shows high temperatures and humidity and the cold one moderate to low temperatures and low humidity. The analyzed roofing system was made with asbestos cement tiles which are of common use in some Brazilian regions. Micro sprayers were installed on roofing with a system to get started at established time intervals. Air and surface temperatures and relative humidity were measured inside and outside. Good results were obtained showing how water can help to mitigate the solar heat gain in summer even in not dry conditions.

Keywords: evaporative cooling, water spraying, roofing, thermal behavior.

1 INTRODUCTION

Prior to the professional architect, man has wisely exploited his creativity in organizing spaces, whether in caves, villages, towns, etc... Over time, due to several reasons, alternating or simultaneous, as hierarchy, security, health, the spatial organization of buildings aimed to ensure power and preserve the species. During calmer times, civilized and contemporary, other foci are also evident in the practice of professional architect such as functionality, environmental comfort, ergonomics, aesthetics, technology, for the organization of spaces.

One issue have emphasized since the end of past century is passive techniques incorporation as a design tool for helping in energy efficiency. According to Givoni (???), roofing is a building component most exposed to climatic factors. The impact of solar radiation in clear days of summer or heat loss by long wave radiation at night, rain or snow in winter, affects roofing more than any other building element.

One issue emphasized since the end of last century is the incorporation of passive techniques as design tool for architects. as well as support for energy efficiency. According to Givoni (1994), roofing is the component of the building most exposed to climatic factors. The impact of solar radiation on clear summer days, the nocturnal heat loss by longwave radiation, the rains and snow in winter, affect more the roofing than any other part of the building.

The temperatures of external buildings surfaces become higher; so the energy flow transmitted to the interior of buildings. Therefore, indoor temperatures reach high values, especially in the afternoon or in the evening, oscillating according to building thermal mass. This phenomenon causes human thermal discomfort and an increase in the use of artificial methods for ambient cooling. Consequently, it generates an increase in energy consumption.

On the other hand, due to the globalization of architecture, building are constructed in different parts of the world, with similar, if not the same, materials and technologies, disregarding the regional characteristics such as climate, vegetation and local materials. This fact provides, mainly in metropolitan areas, the worst changes in natural conditions of local microclimate, besides the concentrated increase of energy use for air conditioning, enhancing human thermal discomfort and energy waste.

2 MAIN TEXT

2.1 Evaporative Cooling

Air cooling through water evaporation is not an innovative technique. In ancient times, in hot and dry locations, courtyards with vegetation and water fountains acclimatized the nearby environments, reducing the temperature and the hostility of dry air.

In modern times, the evaporative cooling is linked to the development of the industry of air conditioning. According to Cook (2002), in 1900 at the United States, C. F. Marvin published tables with the first psychometric data, showing a concern for understanding the relationship between vapor pressure, relative humidity and dew point temperature. In the post-war the development of new materials, power supplies and noise mitigation contributed to the evolution of evaporative cooling as a technique for environment conditioning.

There are basically two types of evaporative cooling. The direct evaporative cooling occurs when air cooling is achieved by the direct addition of water. The air is humidified; water evaporation tends to decrease its temperature. The flow of cooled air can be introduced into the building through mechanical as well as passive systems, such as wind, temperature difference inside and outside, sprayings, water fountains or water cooling towers.

The indirect passive cooling occurs in the solid-liquid interface. For example, a constructive building element that preferably receives direct sunlight, such as roofs or walls, in contact with fresh water provokes water evaporation. This process of water evaporation allows temperature reduction through the formation of steam bubbles which increase and are detached from the constructive element surface. The water sensible heat is transformed in water latent heat removing a large amount of heat that otherwise would contribute to raise the material temperature. In other words, there is heat transfer from the solid surface to the liquid due to the fact that water temperature exceeds the corresponding saturation temperature of water vapor pressure.

$$qs = h\,(Ts - Tsat) = h\,\Delta Te \qquad (1)$$

Where:
qs is the rate of energy transfer;

Ts is the surface temperature;
Tsat is the saturation temperature;
h is the convective heat transfer coefficient.

The amount of heat absorbed in the process of water evaporation is very high as compared with other heat transfer processes common in buildings. According to Rivero (1986) each gram of evaporated water requires around 2450 J.

The air can hold only certain amount of water vapor at a certain temperature. When this maximum value is reached, the air is saturated. If the amount of vapor mass in the air is increased, condensation, that is, the reverse process occurs. In other words, excess water steam turns into liquid water.

Therefore, the water evaporation process is strongly linked to local climatic conditions, that is, mainly to air humidity. The relationship between dry bulb temperature (abscissa axis), relative humidity (curved lines on the graph) and absolute humidity (ordinates axis) is shown in Figure 1. Being known the air temperature and relative humidity of a place, the ordinate axis will indicate the amount of water contained in air, in grams of water per kilogram of dry air.

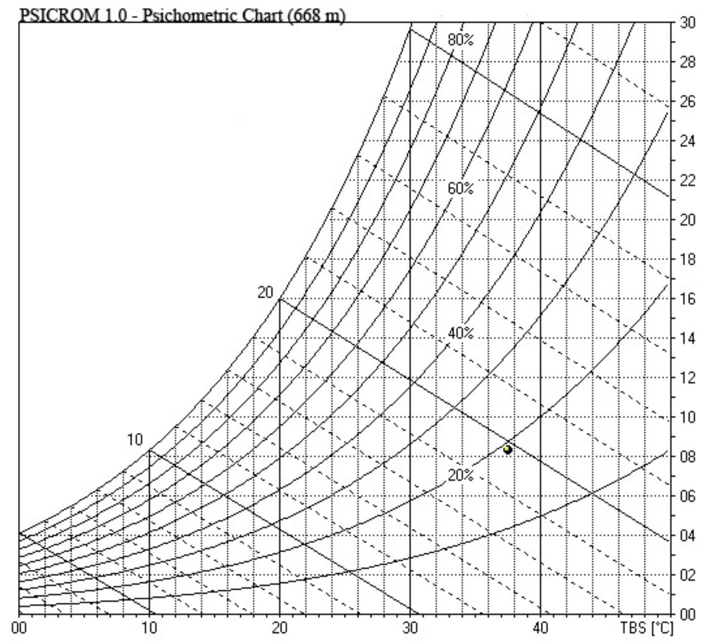

Figure 1 - Air humidity according to air temperature (Dry Bulb Temperature) and the saturation point
From: Roriz (2003).

2.2 Brazilian Bioclimatic Chart

The comfort requirements demanded through cooling techniques and or passive direct and indirect heating depend on the climate physical characteristics and design decisions referring to implantation, orientation and constructive materials of the building.

For a country like Brazil with most of its lands in tropical climate there is a great number of comfort requirements and providing energy saving is a challenge for the local designers.

In this direction, Brazilian Standards for thermal performance of buildings (ABNT, 2005) give recommendations for building guidelines and strategies for passive thermal conditioning. This Norm was prepared through the division of the country’s territory in eight zones with similar climatic characteristics (Figure 2). This division was based on the ASHRAE’s parameters and Givoni’s Bioclimatic Chart. It supplies data for thermal resistance, thermal capacity, time lag, and other properties for the most common building materials and their combinations in the horizontal and vertical envelope of ground floor buildings. This is an available tool that can be applied in the pre-design project by designers.

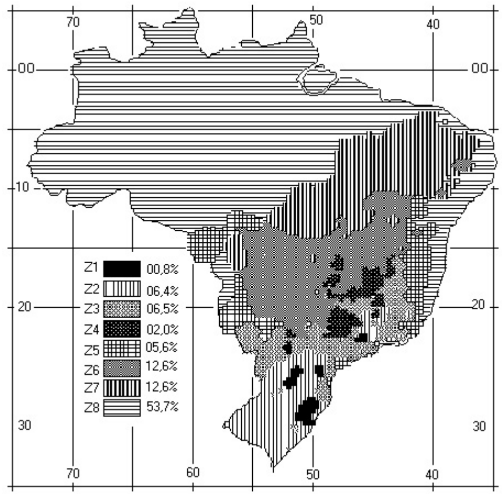

Figure 2: The Eight Brazilian Bioclimatic Zones. From: ABNT, 2005.

Average maximum and minimum temperatures and relative humidity are plotted on the chart for the city of Campinas (Figure 3). The passive strategies recommended for this city are indicated with the B, C, E and F letters, corresponding to building solar heating, heating thermal mass, selective nocturnal ventilation and roofing with higher thermal mass respectively.

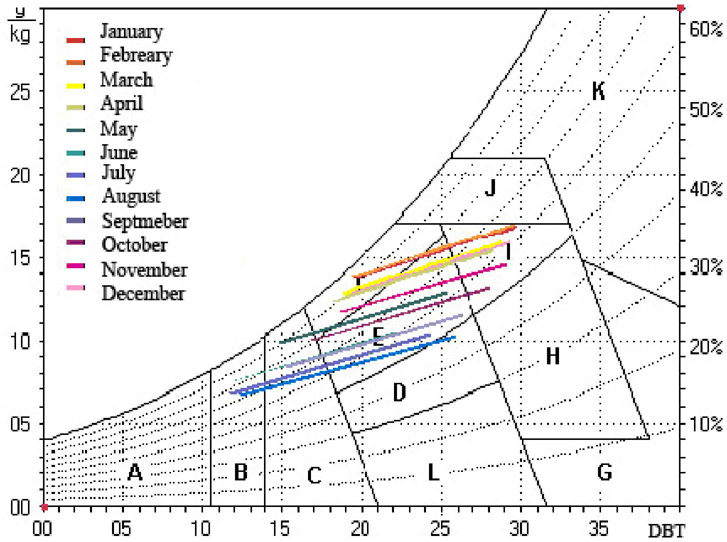

Figure 3: Campinas Bioclimatic Chart.

2.3Objective

The purpose of this paper is to investigate the thermal behavior of some roofing systems by using passive cooling in summer period in Brazil bases on the literature background. Givoni (1997), in Expo 92 in Seville, Spain, confirmed the efficiency of water use in cooling towers for outdoors air conditioning. After that, the same researcher applied the cooling tower systems in different places with distinct climates like California in the U.S., Yokohama in Japan and Riyadh in Saudi Arabia, even using brackish water.

In Brazil, the most common material in roofing systems is cement tiles. They are economically attractive and demand a light roofing structure in modern architecture. So this material was chosen as the study object of this research.

2.4 Method

The research was developed in the city of Campinas, Brazil. Its tropical climate is characterized by a summer period from November to March, with maximum average temperatures between 29.7 to 29.9º C in January and February respectively. The winter, which runs from June to August, has temperatures ranging between averages of 12.5 and 12.4ºC in June and July respectively. The rainy season begins in October and November, when the average relative humidity is around 67%, gradually increasing and extending to March, reaching average values of 76% in January with about 250 mm rains.

The experiment was carried out in two test cells, made of apparent massive brick seated with uncoated cement mortar and white painted. The internal dimensions are 2.00 x 2.50 m² with 2.40 m ceiling height. The wall thickness is 10 cm. One test cell was used as reference. The roof was cement tile on ventilated attic. An automatic meteorological mini-station for data collection, CR10X, from Campbell Scientific Inc. was installed in the area. In the cells the data acquisition was performed using thermocouples, and the data were registered every 10 minutes.

Three micro sprayers used for gardening were installed on PVC tubes above the cement tiles (Figure 4). A timer was used to control the spraying system in pre-defined intervals. This system allowed relating the internal surface temperatures of the tiles with external temperature, comparing also the internal temperatures in attic of each test cell. A pump system pushes the water stored in a water reservoir. The water not used in the spraying process is thrown back to the storage. This system allowed relating the surface internal temperatures of the tiles with external temperature and also with the indoor temperatures in the cells.

Figure 4 – Passive cooling – water spraying on roofing.

The passive cooling through water spraying was applied in the period corresponding to the end of the dry season, and the beginning of the wetter season, from September, 29 to October, 05th, 2005. The system consisted of spraying water on the roof for 30 minutes every 1 hour and 30 minutes, totaling one cycle every two hours, at an approximate rate of 30l/h.

The measurements period was from 10:30 am to 8:00 pm. The evaporative cooling used about 0.78 m³ of water to achieve cooling by spraying 5 m² roofing in this period. The internal surface temperatures of the tiles with evaporative cooling compared the reference model can be observed in Figure 5. Temperatures rise and stay above the outside air after 8 am. However, when it is observes the temperature curve of test cell with passive cooling, there is a drop in temperature between 10:30 am and 11:00 am, then between 12:00 am and 12:30 in the first two cycles of spraying water respectively. After the fourth cycle (from 15:00 h to 15:30 h) a temperature curve of passive technique follows in declining, always under the temperature curve of reference tile and outdoor air.

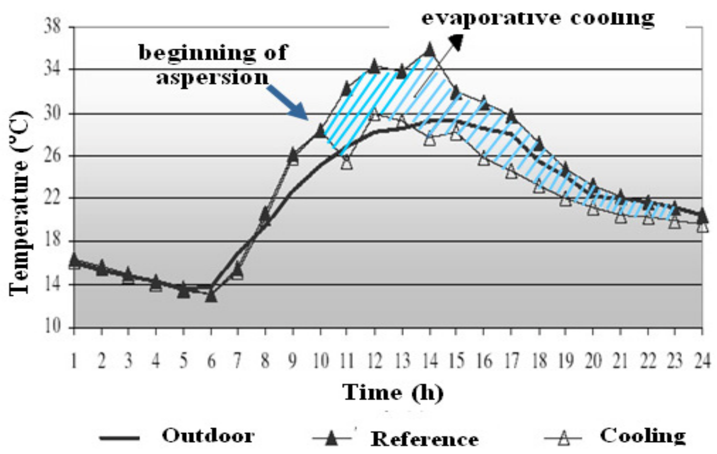

Figure 5 - Surface Temperatures of Tiles. Where: Outdoor – curve of outdoor temperature; Reference - internal surface temperature of reference tile; Cooling - internal surface temperature of evaporative cooling on tile.

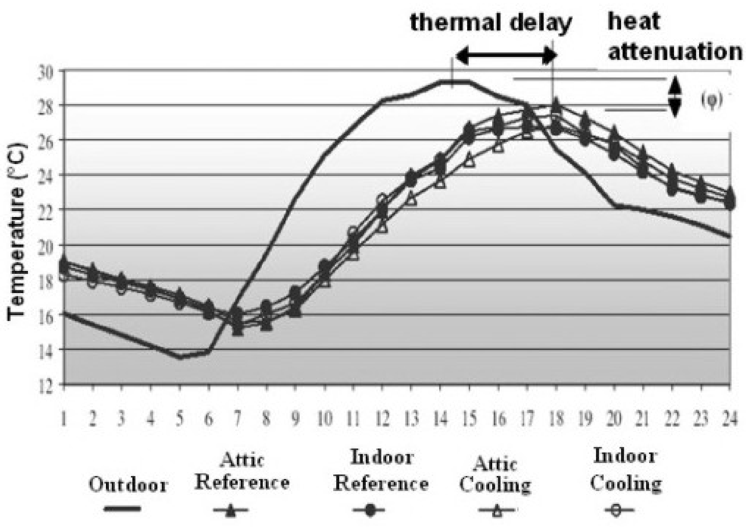

Figure 6 - Temperatures in test cells. Where: Outdoor – curve of outdoor temperature; Attic Reference - attic air of reference test cell ; Indoor Reference – indoor air of reference test cell ; Attic Cooling - attic air of cooling test cell; Indoor Cooling – indoor air of cooling test cell.

Figure 6 relates the attic air temperatures and the indoor temperatures in the test cell. It can be observed that all temperature curves stay above the external temperature curve after 17:00 h, due to tile property of absorbing more solar radiation. The air temperature in the attic with passive cooling is still rising while there is solar radiation, but its absolute values are smaller than the other temperatures. The passive cooling shows a temperature gradient of the curves after the sunshine period.

The fibercement of the tiles generated a thermal delay of maximum temperature peak around 3,5 h. The generated thermal attenuation was approximately 2 ° C, which is due to the fact that this is a light roofing system.

2.5 Conclusions

The water spraying for 30 minutes, in interval of 1 hour and 30 minutes, has showed an attenuation of indoor tile surface of more than 8 º C as compared to the reference roofing. The indoor temperature shows a difference of 0.6 ° C in the maximum value. In practice, the interference of occupants by opening windows and doors, would provide cross-ventilation indoor which can optimize results of indoor air temperature in practice, as it recommended by zone 3 in ABNT (2005).

The passive cooling system by water spraying did not provoke effects such as proliferation of mosquito larvae, dirt, algae and limbo. Water stored in contact with the external environment is a problem for controlling epidemics on public health, mainly in Brazil, a country predominantly tropical. However, nowadays with the knowledge about sustainable concepts, the use of rainwater or water re-using can be employed for this purpose.

This passive system does not require sophisticated facilities or equipment installed on pitched roofs. The provision of rainwater for storage should be designed since the beginning of design project, so that a system working by gravity, through dropping can allow benefits and cooling, adjusted to roofing dimensions. Its effectiveness can be improved in conditions of relative air humidity below 50%, as shown in the literature. However, this research has shown that for about 75% relative air humidity the goal of cooling can be considerably achieved for this location. These results contribute to energy saving as well as for the rational water use.

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