Topic 2. Passive heating, passive cooling, and renewable energy for buildings

Monitoring of Passive Cooling on Typical Roofing of House in Subtropical Climate

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Keywords: Passive cooling, Roofing, White coatings, Water spraying.

SUMMARY

The thermal behaviour monitoring of construct elements is necessary for improving the life quality of human beings. The solar radiation is one of main direct energy source in inter-tropical areas, and contributes to raise indoor temperatures in buildings. The aim of this work is the monitoring of fiber cement tiles in Brazil. Two white coatings have been used: acrylic and impermeable painting. The following situations were used on monitoring: on and off water spraying in rainy and no-rainy periods. Rain water storage was used for water spraying on roofing. It was observed attenuations around 6ºC and 10ºC on surface temperature of tiles either on rainy days or with solar radiation. A gradient around 9ºC was observed for the same coating tiles in no-rainy days. Thus the work results allow to conclude that the use of passive cooling techniques can bring about possibilities to obtain good attenuation of surface temperatures of tiles.

INTRODUCTION

Brazil is the biggest country in South America continent. Its lands go from Monte Caburaí in the extreme North, at north latitude 5º16’ to Arroio Chuí, the extreme South, south latitude 33° 45'. Due to this fact, the country covers different kinds of climate: from equatorial to temperate.

It is known that the country has welcomed a huge number of people from several nationalities, mainly from locations of latitudes over 40ºN, in the past. Those people brought with them their culture, habits and ways of living and to construct. Some constructive characteristics had to be adapted to new conditions of natural resources, types of soils and mainly, different weather characteristics. Nevertheless, they were commonly found heavy and compact buildings which ensured a stable indoor temperature regardless of climatic outside variations.

In the last century, the industrialization of production processes led to the construction industry. The concern with rationalizing civil construction systems and with applying elements in buildings stands out allowing more useful area but not providing comfortable indoor conditions (thermal and acoustics) to accomplish the several human activities.

The indiscriminate use of air conditioning as well as the waste of energy for HVAC cannot be tolerated in the current global context. Researchers have made efforts to develop new technologies, and heating-cooling systems, which should be applied on current constructive systems and materials to provide an improvement in indoor thermal comfort in buildings.

According to Givoni (1994), the roofing is the most exposed building component to climate factors. In this sense, in this work the thermal effects of passive cooling system on cement fibre tile in an existing house in the city of Campinas, Southeast of the country, has been monitored. The cement fibre tile is used in many types of buildings in Brazil, from houses to industrial plants, due to its low cost and low load for structural system of buildings. As the roofing receives the largest amount of direct solar energy mainly on one pavement buildings, the purpose of this work is to present the data on house roofing both with and without use of passive cooling technique.

PASSIVE COOLING ROOFING

This work presents two combined different kinds of cooling roofing system: evaporative cooling and reflective cooling to subtropical climate.

Reflective cooling

The thermal performance of a building is affected by the solar absorptance (α) of the roof. In locations between the Tropic lines - tropical areas with latitude 23.5º or less - outdoor temperatures and solar radiation levels are sufficiently high so that even during winter buildings do not require heating.

The solar reflectance (ρ) is the ratio between the intensities of reflected solar radiation on a surface and that of incident solar radiation. In other words, for an ideal white object - perfect reflector – ρ = 1. When all three processes are considered – absorption, reflection and transmission, the following relation applies:

$$\rho + \alpha + \tau = 1 \quad \textbf{(1)}$$

Where ρ is the reflected energy coefficient of the surface material (from 0 to 1); α is the solar absorbed energy coefficient (from 0 to 1); τ refers to the transmitted energy through the material (from 0 to 1).

Daytime heat flow through a sun exposed roof is essentially only in downward direction which is generally undesired, as it tends to overheat the building or to introduce extra load on air-conditioning systems. The downward heat flow from the roof can be reduced through the use of a light roof color, reflective foil or roof insulation.

Akbari et al (1997) reported results about monitored roofing with high solar reflectance (ρ) in a house and two schools in Sacramento, USA. The energy reduction considered cooling the roofing and walls with high solar reflectance surfaces. In the residence, the saved energy was 2.2kWh/day after changing ρ from 0.18 to 0.73. The pick demand in cooling by air-conditioning was reduced from 0.6 to 0.2kW. Comparing the data for the two schools, results revealed that white roofing (ρ = 0.68) used only 3% of energy for cooling as compared with a school with metallic roofing and yellow walls in Southeast facades.

According to Prado and Ferreira (2005) in a study about the solar absorptance (α) and the surface temperature of several roofing materials, the low reflectance is an indicator of high susceptibility for material degradation due to the infrared spectrum region. The absorptance for UV radiation area can cause alterations in atomic structure of some materials causing effects as material discoloration or degradation that would be permanent. They concluded that the high reflective roofing has its cost paid already in the moment of installation, reducing the use of mechanical cooling.

Evaporative cooling

Cooling the air through water evaporation is not an innovative technique. In antiquity, rooms were usually acclimatized in hot and dry climate due to the presence of patios with vegetation and water fountain which produced temperatures decrease and softened the dry air. The evaporative cooling is already linked to the development of air conditioning industry in the modernity.

Basically, there are two cooling types through water evaporation. Direct evaporative cooling occurs when the air is cooled through the direct addition of moisture. Once the air is humidified, the water evaporation tends to reduce the air temperature. This flow of cold air can be introduced in buildings through mechanical or passive systems as wind, internal and external temperature difference, water fountain or cooling towers.

Indirect evaporative cooling happens on interface solid-liquid. For instance, a given constructive element in building which preferably receives direct solar radiation, for example roofing or walls in contact with fresh water. This process is responsible for transforming sensible in latent heat, removing a great amount of heat that would contribute to elevate temperature of constructive element. In other words, there is heat transfer from the solid surface to the liquid when water temperature exceeds the temperature saturation corresponding to water vapour pressure.

$$q_s = h\,(T_s - T_{sat}) = h\,\Delta T_e \qquad \textbf{(2)}$$

Where q_s is the energy transfer rate**;** T_s is the surface temperature; T_{sat} is the saturation temperature and h is the convective coefficient of heat transfer.

The amount of absorbed heat in this water evaporation process is very high in comparison with other processes common of heat transfer in buildings. For some time, roofing was cooled with water-full plastic compartments. However, with the advent of thermal insulation and water spraying techniques on the roofing, according to Yellot (1961 apud Cook, 2002), the application of this technique has become rarer, in spite of its effectiveness in reducing the surface temperature of roofing in summer days.

The technique of exposing floating heavy wet woven on panels of expanded polystyrene and polyvinyl chloride - PVC - on water tanks was compared with other several passive cooling techniques by Tang et al. (2003) in Israel. Five other techniques were monitored; however they didn't overcome the results of this technique. The efficiency was due to the creation of thermal layers on water tank which showed more efficient thermal resistance to heat transferring.

The water floating bags technique on tank surface was analyzed on the study of Tang and Etzion (2004). The authors established empirical correlations and the simulated results indicated about 20 cm concrete roofing with about 5 cm of metallic material deck. The effectiveness of this kind of technique depends more on material type which is made the roofing below the tank than technique.

It is important to observe also that the systems of water tanks on roofing, "RoofPonds", accumulate unsatisfactory results due to the algae, mosquito larvae, limb and dirty proliferation. This kind of problems were also found many years after on "Water Filled Plastic Bags", a kind of water bags on roofing. In this sense the water spraying was tested in different countries.

The authors Ghosal et al. (2003), validated an experimental model to greenhouse for climatic conditions of New Deli, India, during the summer. They collected data for greenhouse in three situations: shaded and with water flow, only shaded, and the third one without shading and water flow. Some parameters were studied involving effects of water flow, roofing dimensions, air relative humidity and absorptance of roofing materials, which implied on results for indoor temperatures in the greenhouse. The authors verified a reduction of 6ºC in the shaded and water flow greenhouse and 2ºC in the shaded greenhouse in comparison with simple greenhouse.

The performance of evaporative cooling in buildings conditioned with water mini sprayers was studied by Silva et al. (2005), through computer simulation. The simulation model for performance of evaporation and building behaviour was evaluated through a series of parametric tests. The model showed to work only for the restriction condition described in the work because the operation of evaporative cooling is very complex.

METHODS

The research was developed in the city of Campinas, Brazil, at -22º48' latitude, -47º03 longitude and 640m altitude. Its subtropical 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. But it should be noted that in the winter season the daytime temperatures reach around 24ºC and the sky does not contain many clouds. 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 250mm rains.

The experiment was carried out on roofing of house. This house is inserted in the suburb of the city, an area consolidated over 30 years. The monitored roofing is in the frontal part of house that has garage and balcony with 11.0 m x 4.5 m. It is oriented West as shown in Figure 1. The average age of the tiles is around 30 years. The tiles contained dirt and limb accumulated so they were washed and cleaned for installation of cooling system. The roofing was divided in 3 parts for different kind of coatings: white impermeable painting on area number 3, white acrylic painting on area number 4 and natural tile color on area number 5 It was fixed a surface temperature sensor for each part. Water micro sprayers were fixed on each part of roofing which received painting.

A) Roofing localization *B) Roofing áreas*

Figure 1. Roofing sketch with localization and coatings. In A): the number 1 is the monitored roofing and the number 2 is the house. In B): the number 3 has white impermeable painting; the number 4 has white acrylic painting and the number 5 has the natural tile color on the monitored roofing.

The passive cooling through water spraying was applied in the period corresponding to early rainy season. For water spraying it was prepared a water storage system which retained all rainwater. The spraying system worked in intervals set up by surface temperature sensor. Four situations were used on the monitoring: on and off water aspersion; rain and no-rain periods.

RESULTS

Solar radiation (RS), relative humidity (RH) and air temperature (Air T) were collected for analysing together surface temperatures: impermeable white painting on tile (Imp T); acrylic white painting on tile (Acry T) and natural tile (Nat T) in different situations. Areas I and II showed typical days of this period, with the highest levels of solar radiation, low-average relative humidity of air and clear sky. Days with highest solar radiation, clouds and rain are in area III, as shown in Figure 2

The fiber cement tiles were monitored with the passive cooling techniques in early rainy season. Even in days with hours of rain, the solar radiation shows significant values considering a surface that was receiving thermal load because it was exposed to solar radiation for whole day. There is also a larger difference among the surface temperatures of white painting tiles and the tile with natural coating when there is water presence on roofing surface.

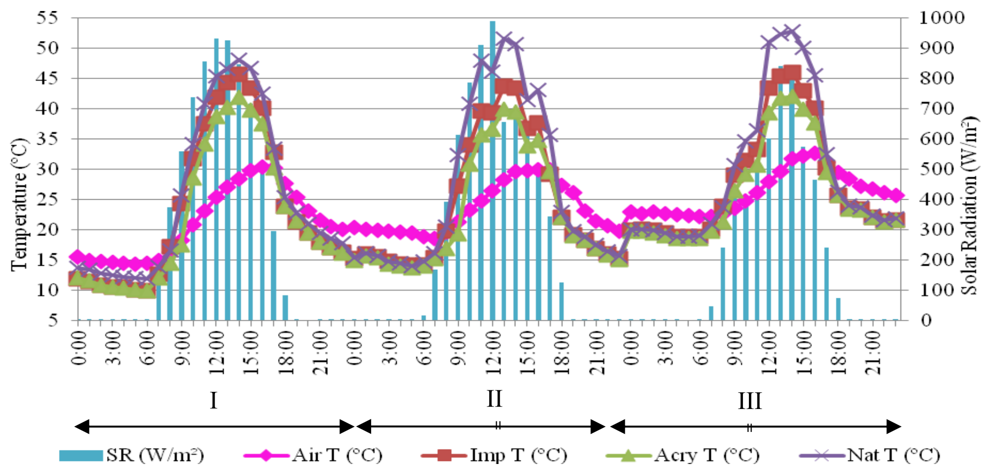

Figure 2. Passive cooling on roofing and solar radiation. Where I is the solar reflective technique and II is the solar reflective + evaporative cooling on no-rainy days; III is the solar reflective technique on rainy days.

In relation to relative humidity of the air, the evaporative cooling worked with the increase of surface temperature of tile which happened on hours of larger solar radiation intensity and lower relative humidity of air consequently (Figure 3). Nevertheless, in area III, the values of relative humidity of air were not so low. Due to the characteristics of rain and sun hours during the whole day, when the wet roofing surface begins to receive solar radiation, it tends to delay the increase of its surface temperature by water film evaporation on surface tile.

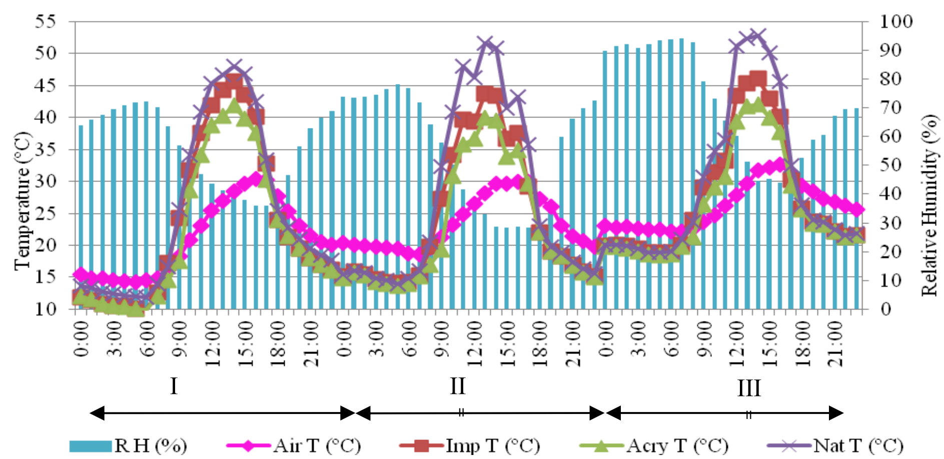

Figure 3. Passive cooling on roofing and relative humidity of air. Where I is the solar reflective technique and II is the solar reflective + evaporative cooling on no-rainy days; III is the solar reflective technique on rainy days.

On Table 1 it can be observed mainly the difference of surface temperature (ΔT) for passive techniques and different weather conditions. Curves of surface temperatures of white painting presented better thermal behaviour than those with natural coating. In other words, the colour of tile coating represents a temperature difference on surface of constructive element, and in this case it is around 6ºC on the tile with acrylic white painting on no rainy days. In the best situation, with water spraying or rainy days, the difference between tile with acrylic white painting and natural tile reached values above 9ºC.

Table 1. Maximum values of surface temperature of tiles with passive techniques on day hour.

		Time	Meteorological data	Surface tile temperatures		
No-rainy days	Peak values	Reflective cooling – Area I				
		12h	SR 933 W/m², RH 37.9%, Air T 25.4ºC	Nat 45.4ºC	Imp 41.9ºC	Acry 38.7ºC
				ΔT of coatings (ºC)	(Nat – Imp) 3.5ºC	(Nat – Acry) 6.7ºC
		Reflective + evaporative cooling - Area II				
		12h	SR 992 W/m², RH 36%, Air T 26.5ºC	Nat 46.2ºC	Imp 39.4ºC	Acry 36.6ºC
				ΔT of coatings (ºC)	(Nat – Imp) 6.8ºC	(Nat – Acry) 9.6ºC
Rainy days	Peak values	Reflective – Area III				
		14h	SR 801 W/m², RH 44.8%, Air T 21.6ºC	Nat 52.8ºC	Imp 46.1ºC	Acry 42.1ºC
				ΔT of coatings (ºC)	(Nat – Imp) 6.7ºC	(Nat – Acry) 10.7ºC

DISCUSSION

Roofing surfaces are exposed to all kinds of interference, from climate elements to shading by other buildings. In tropical areas with higher temperatures the concern about cooling of constructive components is constant for planners who try to obtain indoor thermal comfort to their users.

Yellot (apud Cook, 2002) had already observed in Arizona, USA, in 1965 that the evaporative cooling was effective in roofing of low thermal inertia, with any or almost any thermal isolation. It was reported a difference among dry and wet roofing of 1.1ºC to 4.4ºC.

In this work, according to ABNT (2010) the thermal resistance of fiber cement tile is 0.007 m²K/W, in others words, it has low thermal inertia. Additionally, the best white coating was acrylic painting with difference from natural tile of 6.7ºC on no-rainy days and without evaporative cooling.

The evaporative cooling system is not easy to analyse in situ as Silva et al. (2005) and several authors demonstrated in their works. It is possible to have an idea of how the system will work and to esteem its results in simulated cases, because it works with pre-fixed environmental conditions.

This work showed results for roofing cooling of house in Brazil with the described passive techniques which were obtained in these real conditions. The water presence on roofing helped to retard the increasing of surface temperature. In others words, less thermal load will be transferred into the house and less energy used to cooling indoor environment.

Another point to stand out is how much the color makes difference in solar absorptance. However, other properties of white coatings should be studied. There are meaningful differences among the thermal behavior of white coatings as illustrated on Table 1.

The solar radiation showed the highest and almost constant values in the monitored period. The evaporation process occurred on rainy and no-rainy days, with low and high relative humidity of air, although many papers report that only in conditions of low relative humidity of air it is possible to obtain good results.

CONCLUSIONS

The reflective cooling has shown effective in reduction of surface temperatures of the fiber cement tiles with low thermal inertia. However, the combined use of two cooling techniques: reflective cooling and water spraying improves the obtained results.

For constant and high solar radiation, the relative humidity of air is not so preponderant because it was lower on worst time with the maximum solar radiation. Also there are differences in thermal behaviour of surfaces with different white colours coatings. Many papers have already reported the colour should not be decisive for choosing of element constructive coating, but the choice among different types within a colour should be analysed carefully.

ACKNOWLEDGEMENT

The authors acknowledge financial support from FAPESP, the Research Founding Agency of São Paulo State.

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