Studies of Thermal Behaviour of Radiant Cooling in Tropical Climate

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ABSTRACT: This paper presents studies about the performance of the built environment according to application of radiant cooling in roofing systems for the city of Campinas, SP. Studies involving the local architecture, constructive techniques, materials and climatic conditions are of increasing importance, indicating the roof as constructive element more exposed to the climatic conditions in a building. The radiant cooling systems (sticking aluminum film - RCF) were applied to metallic and PVC pressured membrane covering. Expected results are to contribute to adapt projects to the local climatic characteristics, to transfer knowledge to the designers and to provide energy saving.

Conference Topic: Case studies
Keywords: radiant cooling, cooling roof, passive techniques, thermal comfort, roofing types

1. INTRODUCTION

The thermal behaviour of buildings depends on several factors such as implantation, orientation, materials and constructive components. To provide internal comfort, the designer should consider the climatic conditions of the place, having in mind that the built environment acts as a control mechanism of the climatic variables, through the building envelope (walls, floor, roof and openings) and the nearby elements (presence of masses of water, vegetation, constructions around, soil type, and others). In this context, roofing is the building component responsible for the main thermal load due to direct solar heat gain.

Especially with the worldwide energy crisis, research related to alternative sources of energy received strong development, especially in architecture and civil construction, through the concern of life-cycle materials and expended energy for the manufacturing of the products.

1.1 Bioclimatic Architecture

Studies on Bioclimatic Architecture emphasize the relation of the architecture with the local climate. A pioneer researcher in this field was Victor Olgyay in the fifties. In his well-known Bioclimatic Chart [1] there are indicated values of temperature and relative humidity which define the thermal comfort zone.

Some years later Givoni [2] adapted Olgyay's Chart, considering different outdoor temperatures of indoor's and allowing climatic considerations for building design and urban planning. This new Chart was developed over a Psychometric Diagram. Considerations about developed and developing countries are shown in figure 1.

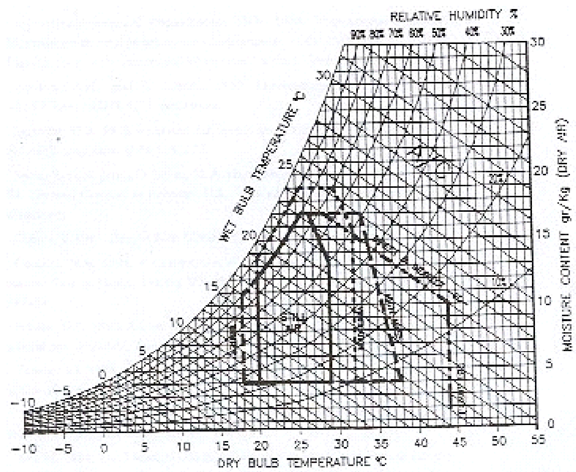

Figure 1: Bioclimatic chart for developed and developing countries [2]

In Brazil, an energy internal crisis increased the interest from part of some segments in civil construction to the reduction of energy consumption and a more efficient use of energy materials. The constructive techniques allied with the correct physical properties of the materials provide the improvement of the comfort in the built environment and, consequently, the rational use of the energy in determined climatic conditions.

In tropical climates, the necessity to reach indoor comfort in the buildings demands effort and dedication of the designers in applying passive cooling techniques. Decision about the implantation and orientation are the first steps for a bioclimatic project, able to optimize the natural ventilation and avoiding or protecting openings in the critical cases of direct solar radiation. Attention to the choice of envelope materials can lower the heat transference to the indoor of the building and to reduce air conditioning systems energy demand. The building design can be optimized through cross natural ventilation, use of vegetation around and isolated roofing of the building.

1.2 Brazilian Bioclimatic Zoning

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 the comfort requirements are innumerable and providing energy saving is a challenge for the local designers.

In this direction, some authors prepared a Project of Norm [3], which considers 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 of thermal resistance, thermal capacity, time lag, and other properties of the most used building materials and their combinations in the envelope the enveloping horizontal and vertical of ground floor buildings. This is a tool available and which can be applied in the pre-design project by designers.

Brazilian Bioclimatic Zoning

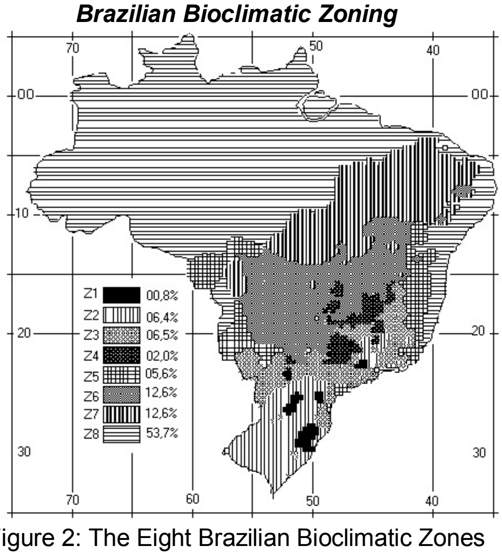

Figure 2: The Eight Brazilian Bioclimatic Zones

Roofing system, as horizontal component of building envelope receives the most strong direct solar radiation incidence. Therefore, the use of passive cooling strategies for roofing system can be useful to propitiate lower heat transference indoors.

There are few studies about these techniques in the country, so this fact stimulated the authors to verify their application in the climate of the city of Campinas, to recommend this strategy for the improvement of indoor comfort.

1.3 Radiant Cooling

In tropical climates, the high humidity and the need for optimisation of natural ventilation, radiant cooling is an important instrument for passive acclimatization.

Radiant cooling is a common phenomenon at the earth's surface and is an important natural cooling mechanism that can, under certain circumstances, be adapted to the thermal control of buildings. When Solar energy reaches the earth, some of this abundant energy is reflected back into space as visible light and a small fraction is converted to chemical energy by photosynthesis. Fundamental physical principles insure that each object emitting radiant energy also absorbs energy in the same proportion and all objects emit infrared radiation. The intensity of this radiation depends on the temperature and emissivity of the surface. A highly reflective or transmissive material has an emissivity near zero, with infrared emissivities for clean polished metal surfaces being typically $\varepsilon \approx 0,05$. Most other common materials show high emissivities in the infrared, $\varepsilon \approx 0,9$, including water, concrete, glass, vegetation [4].

The use of material with high albedo or reflectance (white painting), low emissivity and high reflectivity (aluminum film) will improve the thermal performance of the roofing system, which will depend directly on the sky clearness.

During the day, the surface with high reflectivity, attenuates the solar heat gain indoors. In the night the inverse process occurs: the external environment receives the heat of the covering, cooling the building. A high solar reflectance reduces the heat flow though the building envelope. The idea of white envelope to reject heat has been known since antiquity. In the vernacular architecture, the ancestors already had developed techniques to attenuate bad weather in the envelope of the buildings.

This study used two techniques for the different types of roofing (natural fiber tiles, metallic tiles and pressured membrane of PVC): white painting and sticking aluminum film – RCF (Radiant Energy Control Film). This film was obtaines through the technology of Radiant Energy Control Film - RCF - developed by Technology's Center at the University of Campinas.

2. OBJECTIVES

The purpose of this paper is to report measured data for radiant cooling roofing with different materials. In the roofing system white painting and sticking aluminum film were applied and thermal behaviour was monitored.

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.

The climate of Campinas is classified as tropical continental, with a summer period from November to March, and winter from June to August. The summer is longer than winter, and therefore there is a predominance of hot season.

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, direction of predominant wind, wind speed, global solar radiation, and rainfall. It is equipped with channels for connection of thermocouples type T to monitor the parameters in the prototypes.

THE METEOROLOGICAL STATION

Figure 3: The Meteorological mini-station installed in the study area.

3.3 Description of the prototypes

They are six prototypes (fig.3), built on a basis of concrete (3,20 x 3,70m), with walls of solid mud bricks (½ brick/10,0 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. 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 the openings were obstructed with a panel with thermal resistance equivalent to that of the wall. There is no ventilation indoor. There is a ventilated attic between the tiles and a concrete slab. Measurements were accomplished in December of 2004, in summer period. In this work the results obtained with the passive techniques for 15 days.

Measurements were carried out for the surface internal temperatures of the concrete slab, radiant (black globe) temperature in the attic and dry bulb temperature inside the prototypes in two periods for the two groups of roofing. The RCF film was applied in the internal surface, facing the ventilated attic of the roofing.

Results are presented for the following roofing systems:

Prototype A: double metallic roofing tile, with polyurethane foam filling, trapezoidal

Prototype B: double metallic roofing tile, with filling of polystyrene, trapezoidal

Prototype C: simple, trapezoidal metallic roofing tile,

Prototype D: pressured membrane of PVC, coated in the inferior face with film RCF

Prototype E: simple, trapezoidal, coated metallic roofing tile with RCF film in the inferior face.

PROTOTYPES

Figure 4: The prototypes with the panel obstruct.

Figure 5 shows the diagram of roof construction. The attic is natural ventilated by openings that had made in connection of bricks (fig.4). There are two walls having openings and its façades are oriented north and south. The ceiling heights of attic are 0,60 and 0,15 m.

THE ROOF CONSTRUCTION

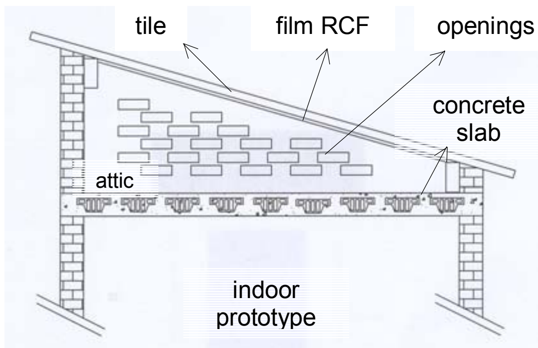

Figure 5: Diagram of the natural ventilated attic and roof construction of prototype

4. RESULTS

4.1 Radiant Temperature

Figures 6 and 7 show the radiant temperature in the attic for the two groups the roofing. The thermocouple was placed in the centre of the black globe thermometer in the attic.

RADIANT TEMPERATURE - GROUP I

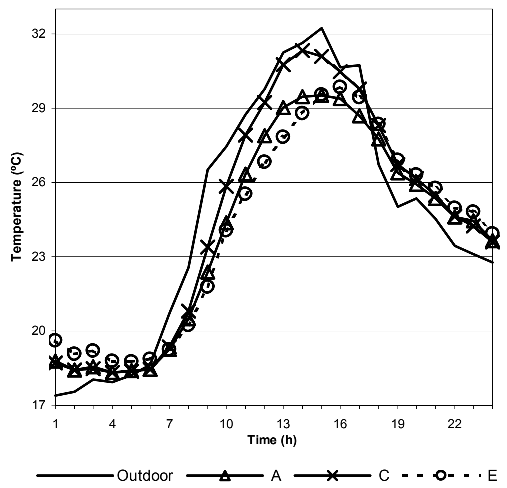

Figure 6: Radiant Temperatures in the attic for prototypes A, C and E.

Figure 6 shows the radiant temperature in each prototype of roofing group I, according to the nomenclature:

A: metallic roofing tiles with polyurethane;
C: metallic roofing tiles;
E: metallic roofing tiles with RCF.

RADIANT TEMPERATURE - GROUP II

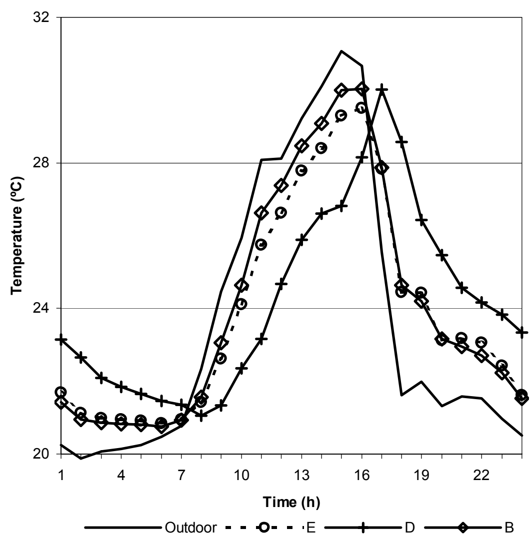

Figure 7: Radiant Temperatures in the attic for prototypes E, D and B.

In figure 7 are shown the results for roofing group II:

E: metallic roofing tiles with RCF;
D: pressured membrane of PVC with RCF;
B: metallic roofing tiles with polystyrene.

4.2 Indoor Temperature

Figures 8 and 9 show the indoor temperature in each prototype. The thermocouple was placed in the center of the building at 1,5 m height from the floor. During the measurement, the openings were closed.

INDOOR TEMPERATURE – GROUP I

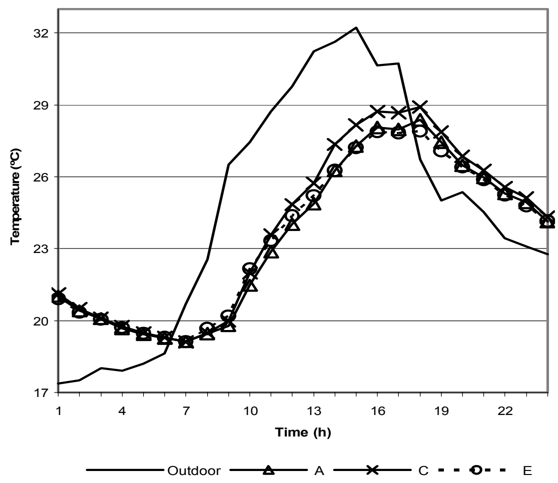

Figure 8: Indoor Temperatures in the prototypes A, C and E.

In figure 8 it is shown the indoor temperature in prototypes of roofing group I, following the nomenclature:

A: metallic roofing tiles with polyurethane;
C: metallic roofing tiles;
E: metallic roofing tiles with RCF.

Figure 9 shows graphs for roofing group II:
E: metallic roofing tiles with RCF;
D: pressured membrane of PVC with RCF;
B: metallic roofing tiles with polystyrene

INDOOR TEMPERATURE – GROUP II

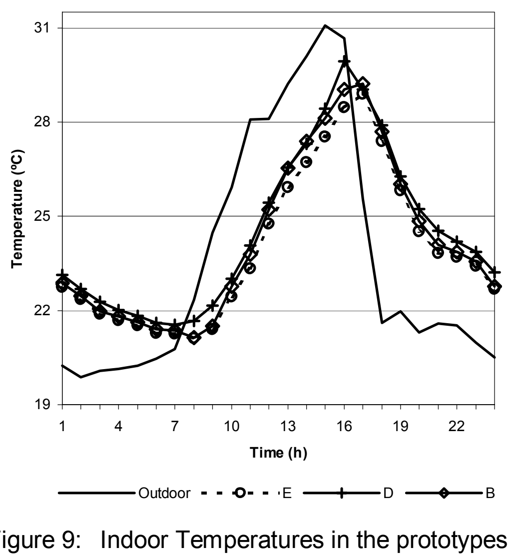

Figure 9: Indoor Temperatures in the prototypes E, D and B.

5. DISCUSSION

Since the two groups of coverings have been monitored in different days, the analysis of the graphs will be given inside of each group.

It was verified in figure 6 that the worst situation is in prototype C, which roofing did not undergo any treatment. RCF metallic roofing presents mild temperatures during the day, below the outdoor temperatures. In the nocturnal period it was verified that polyurethane tile was the one with the lowest temperature, however the difference between this and RCF metallic were smaller in this period.

In figure 8 the worst situation is for the indoor temperature of prototype C. It is also verified that metallic tiles did not undergo any type of treatment. About the polyurethane tiles, it could be verified that these ones showed the lowest indoor temperature during the day. In the peak of the outdoor temperature, the temperatures of RCF metallic and polyurethane tiles had practically been equalled.

In the beginning of the night the indoor temperature of the prototype with RCF metallic tiles, was lower, however it was equalled by polyurethane tiles in most time of period. The thermal delay for this group of roofing was between 3 and 2 hours.

For the group of roofings with RCF metallic tiles, pressured membrane of PVC with RCF and polystyrene metallic tiles (figures 7 and 9) the analysis is carried through figures 6 and 8. During the day the lowest radiant temperature was registered in the roofing with the pressured membrane. Its peak was near 18:00 h when the external temperature was already falling. By this time this roof element showed the highest temperatures. In the nocturnal period the polystyrene metallic tiles registered the lowest radiant temperatures.

In figure 9 it was observed that the highest indoor temperatures were in the prototype with RCF pressured membrane and the lowest in the RCF metallic tiles. For the first one the time delay was about 1h while for the other two roofing it was of 2 hours.

It conclusion, it could be seen that for the city of Campinas, in summer, the RCF metallic roofing show the best thermal performance, that is, lower temperatures indoor, some times oscillating with the polystyrene and polyurethane foam roofing. The pressured membrane presented for a period the lowest radiating temperature in relation to the other roofing types. This fact must be credited to the white external colour of its membrane. Prado and Ferreira [6] give a good description of albedo behaviour of some materials. With high albedo, the surface reflects radiation and consequently it absorbs less heat than the metallic roofing tiles, which are painted light grey colour, therefore with a lowest albedo.

Other experiments with these roofing types with film RCF in the external face will be made considering the albedo of the displayed surface. It is worthwhile to emphasize the importance of carrying on more tests with other roofing types and in other season so that we can have a more complete picture of their thermal performance.

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