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Full Length Research Paper

Thermal behavior in different roof coverings on classrooms

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This study was performed to evaluate the internal temperature behavior of classrooms in relation to outside temperature and the roof deck. The temperature was measured in four classrooms with a mean area of 75.5 m^2. Three classrooms were covered with asphaltic bitumen of three different colors (red tile, matte white and ebony black) the last one was covered with typical clay of the region. Two temperature sensors were installed in each classroom. The first one was fixed outside of the calssrooom at 0.40 m above the roof surface and the second one was installed 0.15 m below the ceiling. The temperature data were stored over ten minutes with a set of remote terminal units which form a wireless sensor network. The results showed significant differences in temperature between the four classrooms with a grade of significance of 0.05, and it showed that the color of the roof deck significantly influences the thermal behavior inside the classrooms. The influence of external temperature over the internal temperature was quantified with the r-Person coefficient, which was found at a mean value of 0.98.

Key words: Thermal behavior, color cover, thermal comfort, roof surface.

INTRODUCTION

The analysis of thermal behavior inside building is studied worldwide to find the ideal thermal conditions for comfort of the users in their social living places like office, dwelling or school, etc., (Chun and Tamura, 2005). The environmental parameters affect the indoor weather of the buildings for mentioning some: external temperature, solar radiation, relative humidity and wind speed (Suehrcke et al., 2008). The solar radiation causes temperature increment in cities, because of the exposure and warming for sun light of roofs and walls surfaces of buildings and houses. The roofs surfaces represent over 32% of the horizontal surface of the built areas in an urban zone (Okeil, 2004).

The increase temperature phenomenon causes change in the energy flow on urban ecosystems causing environmental problems (Oberndorfer et al., 2007; Shahmohamadi et al., 2010), such as the urban heat island and greenhouse effect (Takebayashi and Moriyama, 2007). In specific, the urban heat island effect is characterized for the increment of temperature over the cities ranging of 4 to 8°C, this increment depends of the city size and population (Karlessi et al., 2011).

Not only environmental parameters like temperature

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increase in the urban areas affects the people activities in the office, school and dwelling, Redman et al. (2011) have found some contaminates or factors inside buildings that affect the people health. Some of these factors are: forced ventilation in sealed buildings, walls and floor lined and uniform thermal environment. These factors sometimes describe the sick building syndrome (Sumedha, 2008). The obtained results from the sick building syndrome are seen in the occupant's poor performance, mainly in poorly ventilation buildings (Norbäck and Nordström, 2008).

Another factor that can cause thermal discomfort in people is the increase and decrease in relative humidity of the environment. The behavior of relative humidity with temperature increment makes changes in human confort in any place. The changes in the thermal comfort through the relative humidity and temperature had been researched in different places e.g. office buildings, schools and houses (Orosa, 2009).

Actions that can be taken to control the temperature and relative humidity is to modify physically the construction. Before construction begins, one can geographically target the building in the direction that the walls are not exposed directly to sunlight for several hours and avoid the increase of the indoor temperature, the use of paints with low absorption solar radiation and waterproof or coated to reflect solar radiation short wavelength (from 0.2 to 2.5 μm) (Etchechoury, 2002). Other way that the researchers found benefits is using different materials, such as the elements of the roof and walls for reducing thermal effects of the environment wheather urban or rural area (Hernandez and Dominguez, 2007). Exist materials, traditionally not used in the construction, these materials can be used to preserve the building and to maintain the weather inside it e.g. endemic plants over the roof.

In the study field of thermal comfort, some researchers have done studies with different organic or inorganic materials and other studies in the behavior of the wall and roof surfaces, also researches have been done in places of the buildings like passages. These investigations are to mitigate heat inside and outside the buildings or solve other problems caused for the buildings in urban zones.

Testing some organic materials, Liang and Huang (2011) in Taiwan used *Cynodon dactylon*, an endemic plant of Finland. This grass was chosen because of its rapid growth and its behavior in the times of drought. The grass has been used over the roof of the building under study. The thickness of grass that presented best results was 0.10 m. With this tickness, grass study confirmed that less long-wave radiation was emitted from the planted roof and heat flux transfer to indoor was greatly reduced under the same lawn planted area.

This mentioned results, confirmed that rooftop lawn contributes benefits on its surrounding environment and improved the beneath of indoor confort.

In Turkey, a study was made, which demostrated the total equivalent temperature difference for calculating cooling load due to heat gain in the space between the layers of walls and flat roofs. The results demonstrated that the thermophysical properties of the wall or roof materials had a great impact in the heat flux transfer to indoor causing temperature increment. Also, the research shows an increase in indoor heat as a result of the outside air temperatures and the geographical orientation effects, because the solar radiation flux is higher in the west when compared with other directions that had fewer hours exposed to the sunlight, causing the heat walls and indoor temperature increasing (Kaşka et al., 2009).

In other areas of the study of corridors, Chun and Tamura (2005) verified that in a tropical climate, the transition zone inside and outside a public building; the thermal comfort can be influenced widely for the relative temperature sources, such as open doors or air conditioned placed along the corridors. They conclude that thermal comfort in transitional spaces can be adapted widely when compared with comfort inside the buildings.

In the field of the physical modification, the roof surface color was changed and studied in this paper. The roof surface color used shows the solar absorbency rate, which determines the material ability to reflect or absorb solar radiation (Takebayashi and Moriyama, 2007). The dark and light paints have very different capabilities to absorp solar radiation (ebony black ≈ 100% and matte white ≈ 10%). But when compared with long-wave emission, these two colors have similar conduct. For this characteristic, the cooling of the light color surface or dark color is equal at the moment of releasing the stored heat and making the energy balance with the environment (de Brito et al., 2011).

Based on the absorption and reflection of long wave radiation that is known as thermal radiation, we know that is more important than the surface state. This is because, the smooth and polished surfaces are better than the rough surfaces for reflection and absorbtion of infrared radiation of long wave (de Brito et al., 2011). The thermal changes the behavior of different areas or surfaces of buildings due to the solar radiation-material interaction.

The aim of this work is to analyse the thermal behavior of indoor and outdoor of a scholar building that its structural concrete roof had been covered with a layer that conforms to bitumen-based asphalt waterproofing. The covers of bitumen based asphalt were selected in three different colors to compare the thermal behavior of each color. The colors used were red tile, matte white and ebony black and other non-common material in construction. The clay that is typical of the region is a non-common material used in construction, for this reason another classroom was chosen which was covered with

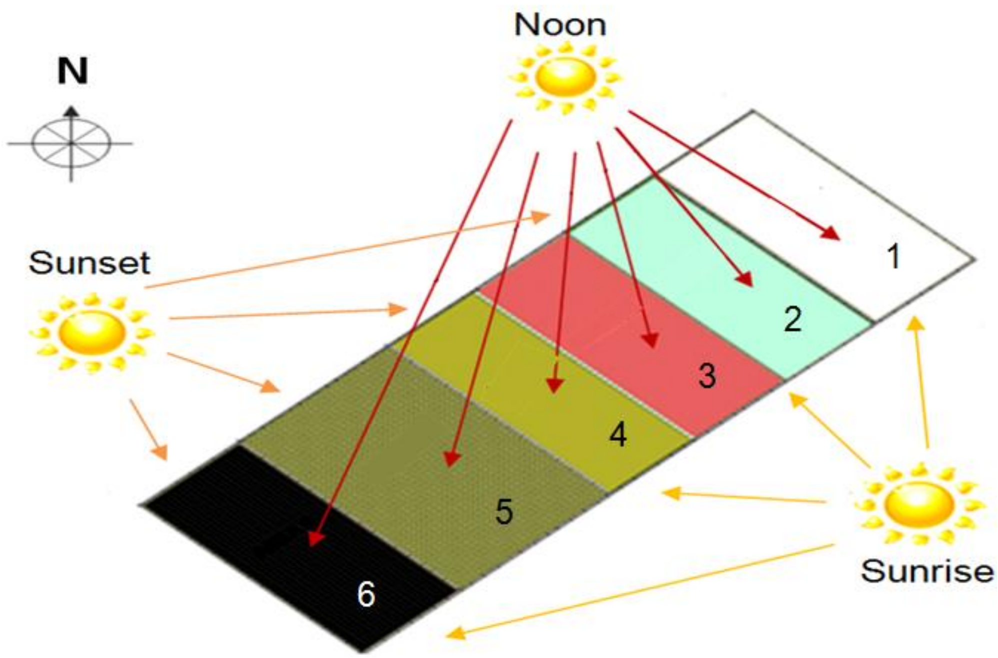

Figure 1. Top view orientation with the directions of the sunlight in sunrise; the facade is iluminated in the noon, the sunlight is over the roof and the sunset light is from behind the building.

the clay. Also, this clay was selected to know if an endemic material helps the conservation of buildings and thermal comfort of people.

With the obteined results of the thermal behavior of these colors and the material that were used in this study to cover the reinforced concrete slab (0.10 m thick), will can select one of them to maintain a comfortable condition in classrooms in a semi-desert area like the city of Queretaro, Mexico.

MATERIALS AND METHODS

Experimental site description

The experiment was conducted in the classrooms of the School of Engineering of the Queretaro State University located in the city of Querétaro. The wheather in the city of Querétaro is semi-arid and semi-hot as Köppen-Geiger classification (Kottek et al., 2006). The building is located at latitude 20°35'27.38"N and longitude 100°24'47.78" W and 1,818 m.a.s.l. The geographical orientation of the building in study is southeast. The geographical focus of the building causes only two sides of the building to receive direct sunlight at different times of day. In the morning, the sunlight is on the southeast and in the afternoon is on the northwest as shown in Figure 1.

The building has an area of 424.62 m^2 divided into 6 rooms as shown in Figure 1, only 4 rooms were selected to acquire temperature data from October 25, 2010 to November 26, 2010. In Figure 1, area 3 is covered with red bitumen based asphalt. This material is the most commonly used for waterproof in public buildings and houses in the region. This section of the building has an area of 61.488 m^2.

The areas marked with numbers 1 and 6 have an area of 69 m^2. Area 1 is covered with white bitumen based asphalt and area number 6 with black bitumen based asphalt. Finally, the area marked with number 5 of 102.44 m^2 area was covered with clay. The roof with clay will be called brown roof. This roof was made of 3 layers: (a) waterproof acrylic (0.02 m thick), (b) waterproofing membrane (0.02 m thick) and (c) substrate (clay thickness 0.12 m). The brown roof was an option to view a behavior as a thermal insulation material in the region. With the soil, we can see if it can reduce or maintain a comfortable temperature inside a building in the region.

Temperature monitoring system

We developed an inexpensive and simple circuit (Figure 2) that is energized by a 60 W solar panel connected to a battery of 12 V, 4 Ah. The battery powers the electronic circuits or nodes which are remote terminal units (RTU's) that make up the wireless sensor network of point-multipoint architecture. The RTU's are responsible for acquiring the data inside and outside each selected classrooms. The RTU's were placed on the classrooms girders. As shown in Figure 3, the sensors on the interior is at 1.5 m from point A to B. The external sensors are 4 m from point A to B. The rooms have a height of 2.8 m as the internal sensors are 2.65 m from the ground. The external sensors are on the roof surface to 0.4 m. The height of the standards set by the World Meteorological Organization (WMO internal and external sensors was taken with respect to the standards set by the World Meteorological Organization (WMO,

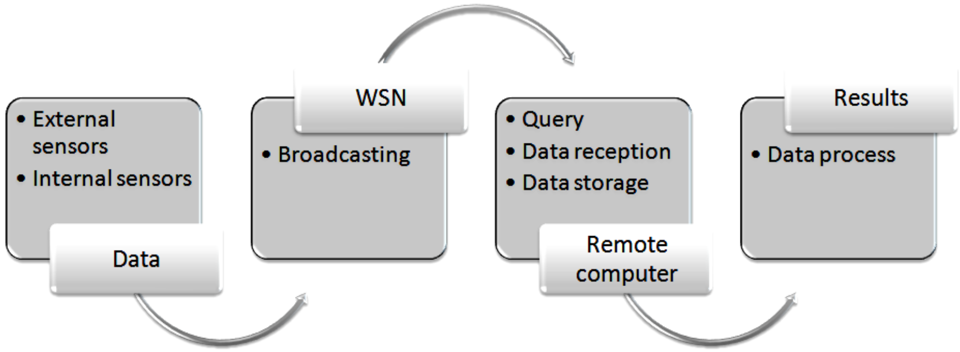

Figure 2. Block diagram showing the phases of the data acquisition system used to acquire the temperature data.

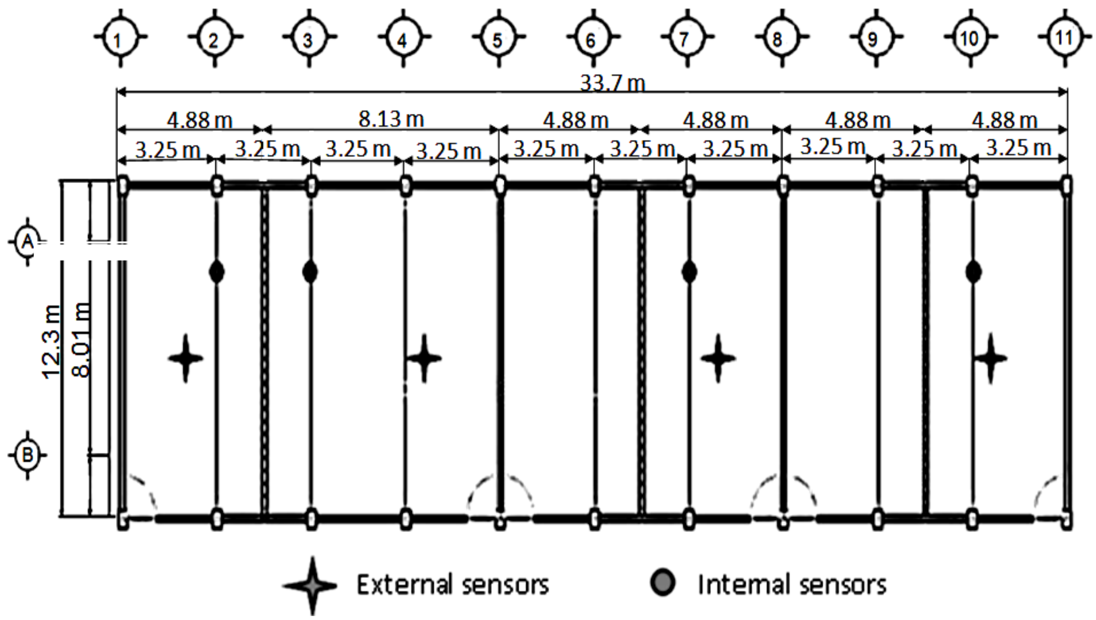

Figure 3. Sensors location in view of the architectural building plan and dimensions of the building in study.

2008). The RTU's internal and external communicate via wireless through the set of protocols that generate high-level known as ZigBee technology. This model of data transfer was chosen due to its low power consumption and easy integration (Gill et al., 2009). The acquired data are sent to a remote computer which is located in the room marked as area 3. The computer stores the samples from each sensor in real time in text files. Sampled data are subsequently exported to OriginPro 8 for further statistical analysis.

Measuring devices (RTU's)

The main element of the terminals is a digital sensor (STH11, USA) which measures temperature and relative humidity. This sensor delivers high accuracy digital output which makes it easier to interpret. This device has a capacitive part for measuring relative humidity and a "band-gap” type for temperature. Both measuring elements are connected to a digital-analog converter and a 14-bit serial interface circuit contained within the same chip. This measurement achieved fast high quality and immune to external shocks.

A microcontroller is responsible for manipulating the active and sleep modes of the sensor. It is also responsible for performing serial communication by controlling the Zigbee antenna.

Sampling

The data sampling is carried in several stages:

1. The sensor of each RTU sampling is 300 m/s which is the minimum time required for not having data leaks in the sensor.

Table 1. The r-Pearson analysis shows the correlation between the internal and external temperatures of the four classrooms with the different colors used in the study.

r-Pearson for temperatures	
Outside red roof **-** Inside red roof	1
Outside brown roof **-** Inside brown roof	1
Outside black roof **-** Inside black roof	0.96
Outside white roof **-** Inside white roof	0.96

Table 2. Descriptive statistical analysis of data temperature in each roofs classroom.

Roof	Samples	Mean	SD	Min.	Max.
Red	3098	19.44	4.89	6.00	30.60
Brown	3098	22.94	4.89	9.50	34.10
Black	3098	25.94	5.21	11.64	37.81
White	3098	24.02	4.76	11.30	34.70

2. The Matlab program executes the query of data in each node, thus generating a sampling cycle every 8 s.
3. Subsequently, the computer program processes the order to organize the files after 10 min of the sampling. Take the average with ensuring that there will be no errors in the readings for each sensor and these new data is stored in another text file.

Then, this file can be imported into other software which makes data processing and statistical analysis.

Statistical analysis

Data were statistically analyzed with the commercial software OriginPro 8 SR0 for Windows. A one-way analysis of variance (ANOVA) was performed to evaluate the degree of significance of the differences among temperature measurements inside and outside the classrooms with different color of the cover roof with a P < 0.05 level of significance. The degree of association among the temperatures inside and outside was quantified by the r-Pearson matrix analysis correlating the temperature data.

RESULTS

Internal data

The r-Pearson index measures the degree of covariation between the inside and outside temperatutures of each painted roof. Table 1 shows the r-Pearson correlation between the internal and external temperature in the four roofs with different colors and a perfect positive correlation in the brown and red roofs; with this results, we know that the variables are linearly related. Compared with the correlations of the white and black roofs which are 0.96. This results show "linearly related variables." This means that temperatures can beclosely related, but not necessary linearly, this happens for the absorbance coefficient of each color.

Comparing the behavior inside temperatures of the colors on the roofs. Table 2 shows that the black roof presented the maximum temperature of the 4 roofs being of 37.8°C about 8°C difference with maximum temperature of the red roof being the one with the lowest maximum temperature. The minimum temperatures in these two roofs is of 4.6°C difference, almost half of the difference of maximum temperatures between these roofs.

The white and brown roofs show similar behavior at maximum temperatures with a difference of 0.6°C and at minimum temperature of 1.8°C in contrast with the black roof at minimum temperature which increased by 0.34°C as the minimum temperature of white roof. The temperatures of white and brown roofs had a difference of about 3°C above the maximum and minimum temperatures showed in the red roof. In Figure 4, the behavior of the internal temperature sampled during the period of the study of the 4 roofs is presented.

Results that were important being the values produced by one-way analysis of variance (ANOVA one-way) were supported by the Tukey test (Table 4). With these results obtained between the roofs, we can see that the mean internal temperatures show a significant difference (P < 0.05). In Figure 5, we can see the significant differences of the mean of the internal temperatures of each roof found with the ANOVA analysis showing their standard deviation with capital letters.

External data

In the outside temperature shown in Table 3, we can see

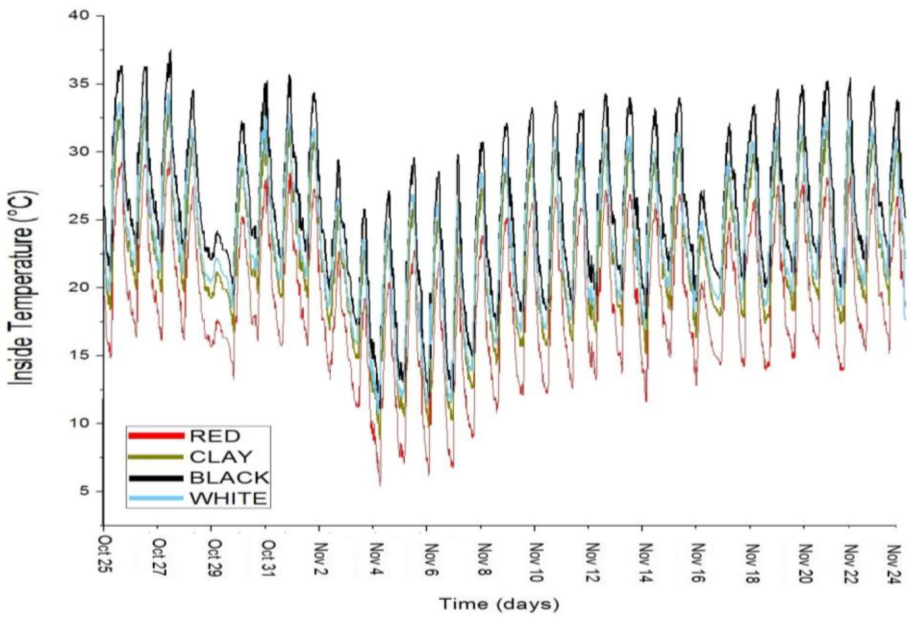

Figure 4. Internal temperature from 25 October to 26 November of 2010, data were acquired within the 4 rooms.

Table 3. Descriptive statistical analysis of the outside temperatures in the four classrooms with different coatings on the roof.

Roof	Samples	Mean	SD	Min.	Max.
Red	3098	19.44	4.89	6.00	30.60
Brown	3098	22.94	4.89	9.50	34.10
Black	3098	25.94	5.21	11.64	37.81
White	3098	24.02	4.76	11.30	34.70

a maximum difference of 4.7°C mainly from the red and white roofs, and a minimum difference of 0.7°C between the brown and black roof. Although, the minimum temperature difference of the white and black roofs was 0.8°C.

Minimum temperatures did not exceed 3.1°C being the black roof. This temperature was higher by 0.4°C, which is the minimum temperature of white roof. The minimum temperature of brown roof was almost 2°C lower than the temperature of the black roof. The deck color which present less temperature was the red; this one presented -2°C. The external temperature of the red roof in general is less temperature than other colors during the sampling period, this phenomenon can be observed in Figure 6.

In Table 5, the mean difference is not significant at $P < 0.05$ using one-way analysis of variance (ANOVA) between the black and white roofs. In contrast, all other outcomes between the roofs have a statistically significant variation ($P < 0.05$) in outdoor temperature. Figure 7 shows the results obtained by one-way ANOVA of the outside temperatures that have an average of 11.4°C for the red roof, 14.6°C for brown roof, 15.8°C for black roof and 16.1°C for the white roof.

DISCUSSION

Apparently, the reduction or increase, and therefore, the thermal comfort inside the building under study depends on the roof lining, rather than the material used to build it. The serious problem to be solved for each temperature increase is a necessity to make a cover of the ceiling depending on the temperature of comfort claimed to be inside the building. This thermal control is difficult to predict, because it depends on several meteorological factors; however, there is a clear trend of the phenomenon

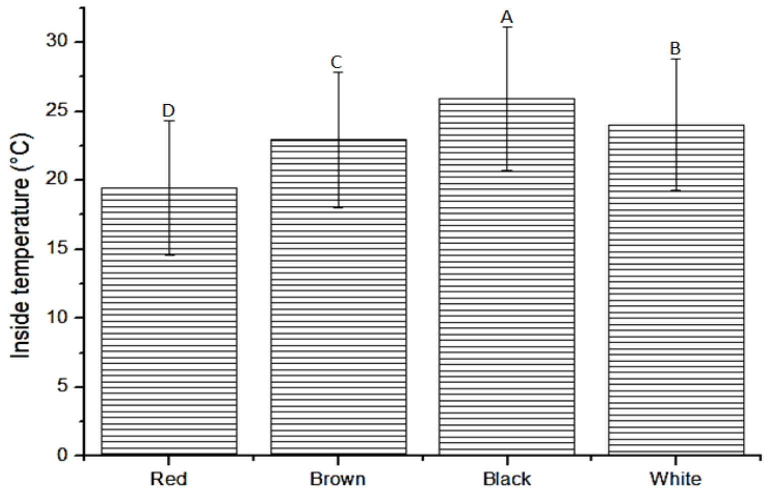

Figure 5. The mean interior temperatures of each roofs showing the significant differences between results found in ANOVA analysis inside each classroom.

Table 4. Analysis of variance showing a mean significant differences between the results obtained from the inside temperatures in each classroom.

One-way ANOVA for inside temperatures	
Inside brown roof **-** Inside red roof	1
Inside black roof **-** Inside red roof	1
Inside black roof**-** Inside brown roof	1
Inside white roof**-**Inside red roof	1
Inside white roof - Inside brown roof	1
Inside white roof - Inside black roof	1

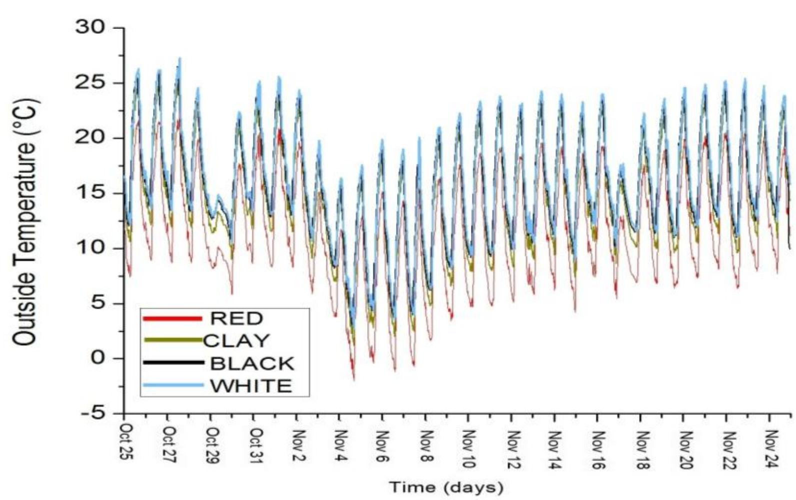

Figure 6. External temperatures from 25 October to 26 November of 2010, data were acquired within the 4 rooms.

Table 5. The means difference is not significant between the outside temperatures of the roofs cover with white and black, respectively. The other cases indicate that the means differences is significant in P < 0.05.

One-way ANOVA for outside temperatures	
Outside brown roof-Outside red roof	1
Outside black roof - Outside red roof	1
Outside black roof - Outside brown roof	1
Outside white roof - Outside red roof	1
Outside white roof - Outside brown roof	1
Outside white roof - Outside black roof	0

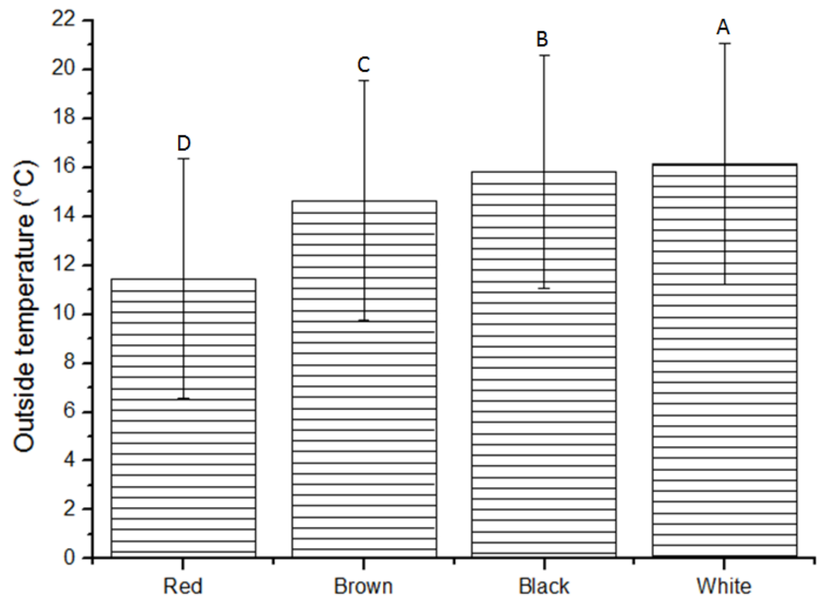

Figure 7. Differences between the external temperatures of each painted roof where can apresiated the minimun difference between the black and the white painted roofs like said the results of ANOVA.

studied here. For example, if we want to avoid heat island surrounding environment with maximum temperature increase, it can be avoided by the use of a white cover. On the other side, if we want a cooler environment inside the building with respect to the outside temperature, the black cover is the last choice.

On the other hand, the useof mulch still remains an excellent alternative. But as it is observed in this study, the ground has no nature cover to reduce internal temperature and the behavior with these conditions closely corresponds with the black cover.

Conclusions

To maintain a temperature within the study rooms in balance with users and the environment needs a coating, insulation and waterproofing with a mean solar absorbance coefficient. Particularly, in Queretaro depending on the weather (rainy, cloudy or sunny), the internal temperature of the buildings is above 35°C at a moments of higher occupancy. However, this temperature decreases at 5°C when the room is completely empty like early in the mornig of extremely cold days or days with high relative humidity and low temperature.

With this, we can conclude for the city of Queretaro, the waterproofing material that helps to control temperature inside buildings is the white asphalt bitumen bringing warmer temperatures in cold climate and comfortable temperatures in hot days. Also, the white asphalt bitumen is a good choice in the economical and environmental way. However, if there are financial resources to place another material like clay, this becomes another viable option to control the internal temperature of building in a semi-arid and semi-hot weather.

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