EXPERIMENTAL COMPARISON OF HEAT FLOW THROUGH CONCRETE ROOFING FLAGSTONES WITH DIFFERENT COATINGS

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Abstract

The predominant climate in most of Mexico is hot and sunny, divided between humid in the southern coastal areas and dry in the north. One of the most common materials used to build roofs today is reinforced concrete. This material allows a better use of the available space, but its thermal insulation characteristics are inadequate. This causes the levels of comfort inside the houses to be much worse than the minimum required. The current tendency to make better use of energy in buildings has led to the development of a new generation of roof coatings that offer a greater resistance to heat transfer. Thus, there is now a need for experimental mechanisms capable of evaluating the thermal behaviour of these products. In a hot and sunny climate, the effect of solar radiation reaching the roof is very important. In summer, under a clear sky, up to 1,000 W/m^2 can reach the roof of any given house. Depending on the reflectivity of the roof surface, between 10% and 95% of the incident radiation is absorbed and converted to heat. This adds to the convective heat transfer generated by the temperature difference between the interior and exterior air. This work presents the results of a series of experiments in which 12 different roof coating systems commonly used in Mexico were subjected to identical operating conditions. For this, we built an experimental shed whose roof was designed to hold 12 concrete test-probes, insulated from each other, and coated with the substances to be tested. The coated test-probes were subject to the same exterior weather conditions, with the inside of the shed under constant air-conditioning. Temperature measurements were taken on both faces of each slab, which made it possible to compare their heat transfer rates and thus the performance of each coating. The system was monitored over several weeks, with simultaneous measurements taken every two minutes. The results show that applying a few millimeter coating of white acrylic paint with polymer microspheres has the same effect as insulating the slab with 1" of polyurethane foam covered with conventional red acrylic paint. We also compared the heat flows obtained with the 12 different coatings during the day and night.

1. Introduction

The vast majority of single family households in Mexico use concrete slabs as the basic element in roof construction. In most cases, waterproofing coatings are applied over the slab and, if enough economic resources exist, a thermal insulation layer is applied before the waterproofing coating. A majority of the homes in Mexico are built with low-sloped roofs (almost horizontal), mainly due to the low risk of snow accumulation, a danger only present in the Mexican highlands. Single-family homes with quasi horizontal concrete roofs are the most common in Mexico, and because of the latitude, rooftops are the construction elements with the greatest thermal flows between the environment and the building's interior. In order to limit the amount of heat that flows through roofs, one can either increase the roof's thermal resistance or reduce the quantity of solar radiation that is absorbed by the surface of the waterproofing coating. To increase the roof's thermal resistance, thermally insulating polyurethane or polystyrene foams are commonly used. A waterproofing coating is needed for all types of roofs, whether it is applied over the concrete slab or over a thermally insulating material; however, due to the small thickness (0.4 to 2 mm) of the coat, it has always been thought that its contribution to the roof's conductive thermal resistance is negligible.

In order to obtain products with a better thermal performance, diverse coating manufacturers have aimed to reduce the thermal conductivity of their waterproofing coatings by adding hollow microspheres made from ceramics, glass, and polymers. Laboratory tests have shown that the microsphere addition does reduce the thermal conductivity (increases the resistance) of the waterproofing material, but because the coating has such a small thickness, its contribution to the total roof resistance can be considered to be negligible. Nevertheless, empirical tests in houses or small models with heating and cooling showed a reduction in the heat flow and temperature of the surfaces where the coating was applied. However, due to diverse experimental conditions, different times, and physical models used in the tests, the results were not conclusive or even comparable. The measurement of thermal and optical properties of the materials can be done in any laboratory, yet, the effects these properties have in the heat flow through roofing elements (subject to both convection and radiation) are not so easy to evaluate analytically. It is hard to know several of the intervening parameters in said phenomena, such as temperatures, solar and infrared emissivity and reflectivity, convective coefficients, etc., also due to the fact that said parameters vary continuously during the day and night.

The use of roof coatings that provide greater resistance to heat flow can provide economic savings by reducing the energy consumption destined for artificial ambient conditioning of buildings (Akbari, 2003; Akbari *et al*., 1999; Jo *et al*., 2010), at the same time it represents a reduction of CO_2 emissions, especially if the coating increases the roof's solar reflectivity (Akbari *et al*., 2009). Experimentation is used to determine the heat flow through the coverings of buildings to validate the methods used for the calculation of thermal loads (ASHRAE, 2009). Other experiments have been done recently to compare the thermal behavior of different insulating materials commonly used for covering in buildings. Some studies have been developed in real houses and other types of buildings, or in situ (Jo *et al*., 2010; Michels *et al*., 2008), while other authors have used experimental stations. Levinson *et al*. (2007) made a comparison between the thermal resistance and the heat gained between painted roofs using colors that featured high infrared reflectivity and conventional ones, 6 scaled models of buildings were used. Önder and Yumrutas (2009) determined the heat flow through 8 different types of walls and 2 types of roofs in 2 experimental stations by applying the Total Equivalent Temperature Difference (TETD) method. Jo *et al*. (2010) compared the thermal performance of a conventional coating against a new reflective coating, based on experimental temperature data in the inner and outer faces of a roof of a building in Phoenix, Arizona (USA), by performing a simulation using EnergyPlus software. The results reported savings of 8.4 to 12.6% in the monthly electrical energy consumption destined towards building cooling. Cabeza *et al*. (2010) used a series of insulated experimental stations with diverse materials in order to make a temperature comparison of the inner surfaces of the walls and roofs; they also calculated the energy consumed (kWh) by the ambient conditioning equipment used for all the stations.

This work presents the experimental results obtained by comparing the heat flows generated through a series of 12 concrete slabs fabricated with the same material and featuring the same thickness. These probes had diverse thermal insulators and/or waterproofing coats and were subjected for extended periods of time to identical external and internal environmental conditions. To meet the requirements above, an experimental station was designed in which the roof housed the probes (concrete slabs with their respective coatings). The probes were exposed to the same external climatic conditions for a period of three weeks in the months of October and November, 2010. Inside the station, the ambient conditions were maintained almost constant by means of an artificial ambient conditioning system (mini-split). The temperatures were measured simultaneously in the geometric center of both faces of each concrete slab every 2 minutes, for a total period of 21 days. The objective of this study was to experimentally determine the heat flow through the 12 probes and, consequently, through the different coatings used in each of them. Due to the similar geometric and climatic conditions of the experiment, and also due to the simultaneous measurements done with a multichannel Data Logger, it is possible to make an objective comparison regarding the coating's heat flow reduction efficiency.

Thermal interaction between the roof of the station and the environment represents a superposition of the heat transfer mechanisms of convection, solar radiation, and infrared radiation; which are difficult to measure separately. However, the net resulting heat (once it is incorporated to the external surface of the roof) flows by means of conduction through coatings and concrete slabs. By knowing the thickness and thermal conductivity of the concrete slab, the net heat flow can be obtained once the temperatures in the faces of the slab are known. This way, one can evaluate the combined effect of the coating's optical properties (solar and infrared reflectivity, infrared emissivity) and the conductive thermal resistance of the set comprised of slab + insulation + coating, under similar climatic and interior ambient conditions. Given the fact that the concrete slabs are identical, the climate effect is the same for all, and the comparison of heat flow magnitudes between the various probes effectively shows the performance of the insulation + coating sets (or only the coating if no insulation is included in the probe). This experimental method is relatively simple to implement and easy to understand, reason for which it can be a very useful tool to compare different construction options for roofs. With this methodology, coating developers can evaluate the efficiency of their products as heat flow restrictor in roofs. This allows a comparison not only against other waterproofing coatings, but also against existing conductive insulating systems.

Current Mexican norms regarding the thermal efficiency of materials used in building construction, including norms NOM-018-ENER-1997 y NMX-460-ONNCCE-2009, only consider the thermal resistance of the materials used in roof construction without any reference to the optical characteristics of the external coating itself. Active norms in other countries do take into account the optical properties of the coatings and, additionally, the experiments done in this work corroborate the importance of having reflective-emissive roofs. Having a high solar and infrared reflectivity in the external surface of the roof prevents the absorption and further penetration of a great part of the irradiation that reaches the house. The high infrared emissivity increases the roof's capacity to dissipate large heat quantities through infrared radiation to the atmosphere, generating a passive cooling effect. If the effect of diurnal solar irradiation acting over the surfaces (which is variable from dawn to dusk) is taken into account, it is relevant to observe that the passive cooling resulting from the infrared emission of the roof towards the atmosphere works during the 24 h of the day, reason for which its effect can be very important if the atmospheric conditions are adequate, such as having a low relative humidity in the air. This work represents the first effort to have Mexican norms recognize the importance of optical properties of roof coatings, especially as an alternative for the reduction of heat flow in houses situated in warm and sunny climates, which is the case in most of Mexico.

2. Methodology

2.1 Heat Flow measurement

The heat transfer mechanisms (convection and radiation) occurring in a building's roof are shown schematically in figure 1. In any given house, it can be assumed that the size of the roof is sufficiently large to have a one-dimensional net heat flow. With this assumption, the net heat flow that crosses the external surface of the roof is the same conductive heat flow that goes through the concrete slab, and it is the same heat flow between the slab and the air inside the house. The magnitudes of the heat flow by convection and by radiation are difficult (but not impossible) to measure. However, heat conduction through the concrete slab can be easily calculated if the temperatures of the exterior and the interior surfaces, along with the thermal conductivity and the thickness of the concrete slab are known.

This study defines T_e as the external air temperature, T_i as the internal air temperature, T_{se} as the external surface temperature of the probe, and T_{si} as the internal surface temperature of the probe, h_e y h_i correspond to the convection heat transfer coefficients that occur in the exterior and interior sides of the probe (figure 1).

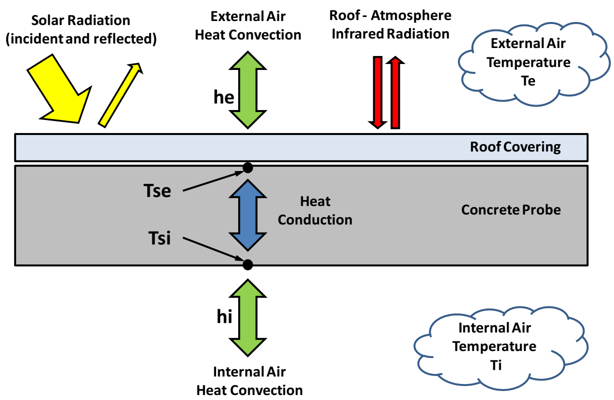

Fig. 1: Heat transfer mechanisms in building roofs.

2.2 Similar working conditions

In order to experimentally compare the performances of different kinds of coatings, it is required that the external and internal climatic conditions are identical for all probes. If the roofs are located in different houses, it would be difficult to have a certainty regarding the achieved climatic similarity. Moreover, the structure of the roof itself can vary significantly between houses, it would be required to have a house for each coating to be tested and, additionally, one would have to remove the existing roofs or have additional houses whenever new coatings need testing.

2.3 Experimental Station

A mobile experimental station was designed with a roof that could house 12 identical probes that could be removed. The station was built using pre-constructed thermo-panels (polyurethane layer sandwiched between two metallic sheets), and a mobile air-conditioning system maintained the internal conditions controlled. The concrete probes were fabricated from a single concrete casting which was molded using specially designed molds that ensure products with identical thickness and dimensions. The used cement-gravel-sand mixture is commercially sold in Mexico (GCC - Dinamix) and, according to the technical data provided by the mixture manufacturer, the thermal conductivity was 1.28 W m^{-1} K^{-1}.

In order to find the minimum probe size that could be used, a two-dimensional heat flow was modeled in the probe, as a function of its size and under extreme temperature conditions, by using a finite element analysis approach. The obtained temperatures in the geometric center were compared to the ones predicted by a one-dimensional heat flow analysis. It was determined that, starting at 40 cm of length, the edges of the probe only introduce a 0.1ºC error when assuming one-dimensional heat flow in the slab's geometric center. Figure 2 shows the exterior of the station and the roof structure where the probes were placed. The station was oriented with a 5° slope towards the South; this was done to have a direct incident solar radiation during the day.

Fig. 2: Experimental station, A) Air-conditioning, B) station access, C) Inside view of probe stations, D) Probe placement

In order to have a controlled atmosphere in the inside of the station, and also to provide a continuous temperature gradient between the interior and the exterior of the station itself, an air-conditioning equipment with a cooling capacity of 12,000 Btu/h and a heating capacity of 13,500 Btu/h was installed.

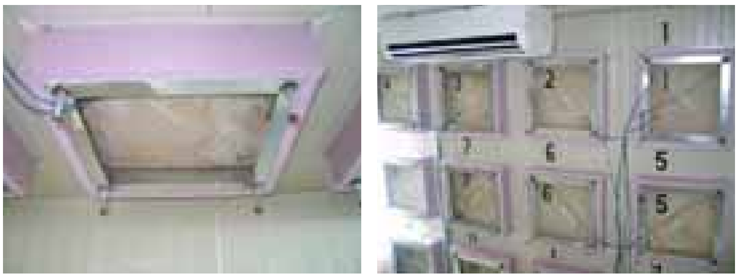

Fig. 3: Probes viewed from the inside of the experimental station

Figure 3 shows the probes placed in their respective supports. The positioning screws allowed the leveling of the external surfaces of the probes with the external surface of the roof. The lateral insulation was placed to prevent the horizontal heat flow. The air-conditioning system and the thermocouples for temperature measurement are also shown above.

2.4. Instrumentation of the station

An Agilent model 34970A was used for the temperature acquisition and post-processing. Two 20-channel multiplexor cards 34901A for T-type thermocouple connections were also added. Aside from measuring the external surfaces (Tse) and internal surfaces (Tsi) of the 12 probes, the external air (Te) and internal air (Ti) of the station were measured and stored in a personal computer. Additionally, climate data was obtained with a portable meteorological station.

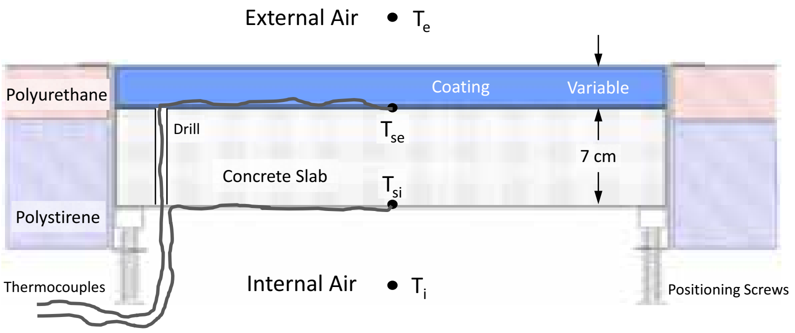

Fig. 4: Probe schematic

2.5. Coating application

Thermocouples were installed in the geometric center of the probe's external surfaces; they were fixed in place using aluminum tape over the union and paper tape over the cables. The upper thermocouples were guided to the inside the station through bore holes placed in the edges of each probe; this was done to avoid interfering with the heat flow at the center. On the upper surface of the probes, different coatings were applied following the standard application techniques used in real house roofs. The coated probes and the installed upper thermocouples were placed in the roof's supporting structures; the lower thermocouples were installed afterwards in the internal surfaces of the probe.

2.6. Temperature measurements

The temperature measurements were carried out every 2 minutes during a continuous week for a total of 3 nonconsecutive weeks. The processing of the obtained data was done using an electronic spreadsheet, which yielded numerous graphs depicting the daily temperatures in each probe.

2.7 Heat flux determination

From the temperature measurements of the concrete probe surfaces, the calculation of the instantaneous heat flux that flows through it, $q"_{cond,i}$ (W m^{-2}), can be obtained in the following manner:

$$q"_{cond,i} = k\left(\frac{T_{se,i} - T_{si,i}}{d}\right) \qquad [eq.1]$$

Where k is the thermal conductivity (W m^{-1} °C^{-1}), d is the thickness of the probe (m) , $T_{se,i}$ is the external surface temperature (°C), and $T_{si,i}$ is the internal surface temperature (°C). Given the fact that continuous measurements were taken every 2 minutes, the instantaneous heat flux values for those times were also obtained and, therefore, it was possible to analyze their variation as a function of time. According to equation [1], there is a heat flow towards the inside of the station when $q"_{cond,i}$ is positive, conversely, negative values indicate a thermal flow towards the outside of the station (heat losses).

2.8 Total accumulated heat flow

From the instantaneous heat flux values, one can calculate the total heat flow per unit area during a specific time across each analyzed coating. For this, one has to numerically integrate, with respect to time, the area under the curve described by the instantaneous heat flux.

In the climatic conditions where the experimental runs where carried out, corresponding to Chihuahua City, Chihuahua, Mexico, heat gains during the day and losses during the night were observed. The low air moisture (characteristic of this northern region of Mexico) causes ample oscillations between the day and night temperatures (approximately 20ºC), and the natural conditions enhance the passive cooling in emissive surfaces. To obtain the total amounts of lost and gained heat during extended periods of time, both the positive and negative heat flows were separately added, accumulating the totals occurring during one week periods.

3. Evaluated coatings

The analyzed coatings in this study include:

1) Thermo-insulating materials commonly used in Mexico such as expanded polystyrene (**EPS**) and foamed polyurethane (**PU**), applied to a thickness of 2.54 cm (1 inch).
2) ***Normal*** (regular) waterproofing acrylics, colors red (**NRAC**) and white (**NWAC**).
3) Waterproofing acrylic coatings with added polymeric microspheres, identified as ***Cellular***, colors white (**CWAC**) and red (**CRAC**).
4) A newly developed thermo-insulator named ***Polinsulate***, consisting of a nonwoven textile material that incorporates microspheres into its structure.
5) A bare concrete probe without any coating, used as a reference.
6) An uncoated probe that was manufactured using a different type of concrete named ***Cellular Concrete with Polymeric Microspheres (*CCPM*)***, to which polymeric microspheres were added instead of air during the concrete casting, making it ***Cellular*** and, consequently, very light (density 1.2). This CCPM exhibits a greater thermal conductive resistance than the other 11 concrete probes used in this study (thermal conductivity of CCPM: 0.18 W m^{-1} K^{-1}).

A total of 11 identical concrete slabs and 1celular concrete slab, with the same thickness, were fabricated. The applied coatings to the 10 left probes are listed below in table 1.

Tab. 1: List of analyzed coatings

Probe	Description
1	Bare concrete (Reference slab)
2	CWAC (1.5 L/m^2)
3	CWAC (3 L/m^2)
4	1" PU Foam + NRAC (1 L/m^2)
5	1" EPS sheet + NRAC (1 L/m2)
6	1" EPS sheet + CWAC (1.5 L/m^2)
7	White acrylic cellular textured paste (2 L/m^2)
8	½" Polinsulate + CWAC (1.5 L/m^2)
9	NWAC (1 L/m^2)
10	NRAC (1 L/m^2)
11	CRAC (1.5 L/m^2)
12	CCPM (un-covered)

Microspheres

The microspheres used in all the cellular products of this study were polymeric hollow expanded humid microspheres (brand ***Akzo Nobel Expancel***, type: ***461 WET 40 d25***), which have an average diameter of 30-50 µm. The addition of microspheres to waterproofing acrylics is known to reduce its thermal conductivity and apparent density; this can be observed in Figure 5 for diverse cellular and conventional waterproofing coatings commercialized in Mexico (ONNCCE, 2011). However, the conductivity reduction of a waterproofing coating by microsphere addition doesn't explain the strong effect in the reduction of heat flow when it is applied to the roof of houses, considering that the waterproofing coating is only 0.4 - 2 mm thick. The reduction in the heat flow caused by the application of reflective/emissive waterproofing coatings was previously empirically observed, but it hadn't been quantified objectively.

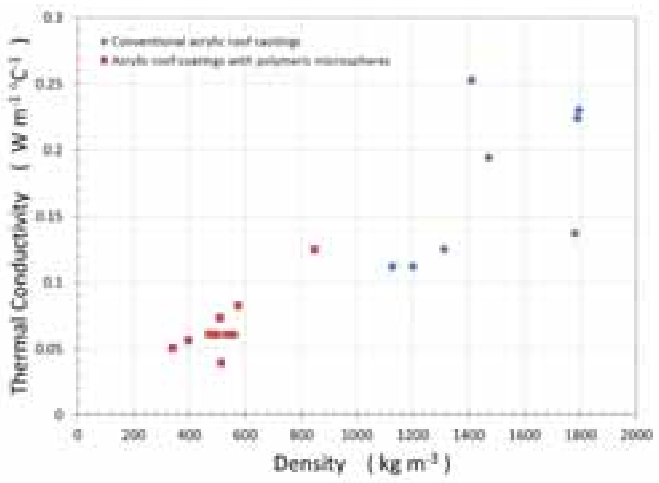

Fig. 5: Thermal conductivity vs. density of conventional and cellular waterproofing acrylic coatings

4. Results

4.1 Experimental conditions

The tests to determine the heat flux in the experimental station were made during three weeks in the months of October and November 2010, in Chihuahua City, northern Mexico. The temperature readings were taken every 2 minutes and the climatic data was recorded in 15 minute intervals. During the measuring period, the temperature varied from 6°C to 32°C, the maximum solar irradiation happened around 13:00 with values ranging from 725 to 920 W m^{-2}. The artificial ambient conditioning system in the station was programmed to maintain a temperature of 20°C. The temperature and heat flux results shown in this work correspond solely to the 10th of October, 2010. Similar graphs were obtained for the other 20 measured days.

Once the temperature data in the faces of each concrete slab was obtained, the instantaneous heat fluxes for each probe and for each day were calculated. By doing a numerical integration of the instantaneous heat flux curves, the gained and lost heat flow through each probe during the given time periods was obtained. The daily thermal losses and gains were separately added for one-week periods. The total lost and gained heat (by m^2 and by week) objectively shows how efficiently each type of analyzed coating performs as a thermal load reducer in a house. The total heat gains and losses throughout each of the three weeks were calculated; however, this study only shows the results corresponding to the week ranging from the 10th to 16th of October, 2010. The results of the other two weeks are qualitatively similar to the ones here presented; only their total magnitudes vary due to the local climate changes caused by autumn's arrival.

4.2 Temperature profiles

The temperature profiles of each probe show a detailed description not only of the magnitude and gradient evolution, but also of the effect of the coating's thermal emissivity. One can observe in Figure 6 that the naked probe (1) reached surface temperatures of 43ºC (11ºC above air temperature), while the probe with the cellular acrylic coating only reached 30ºC (2ºC below the external air).

Figure 7 shows that, in a 1" thermally-insulated probe, the substitution of regular red acrylic (approved by the current Mexican norms) with white cellular acrylic (considered to be similar to the regular red acrylic according to Mexican norms), not only leads to a reduction of external and internal slab temperatures, but also to a reduction in the thermal gradient.

One can observe in figure 6 that, during the nocturnal period, the probes without conductive thermal insulation maintain their exterior surface temperatures below the ones exhibited in both the internal surface and the external air. This lower temperature implies that, during the night period, heat flows from the inside of the station towards the outside and also from the external air towards the external surface of the probe. This proves the existence of a strong effect of passive cooling due to the emission of infrared radiation by the external surface and, because of the absence of thermal insulation in the probe, there is heat flow from the inside of the station. On the other hand, figure 7 shows that the probes with conductive thermal insulation are maintained at a higher temperature than the exterior air; additionally, the thermal gradient indicates a very reduced heat flow through it. The high internal surface temperature of the probe indicates undesirable comfort conditions, due to the infrared radiation emission towards the inside; it also indicates that, without any artificial ambient conditioning systems, the house remains hot during the night. Figure 8 shows the effect of applying polymeric microspheres to a coating of the same kind and color. It is observed that, during the daytime, the temperatures of the probe with microspheres are between 3 and 5ºC lower.

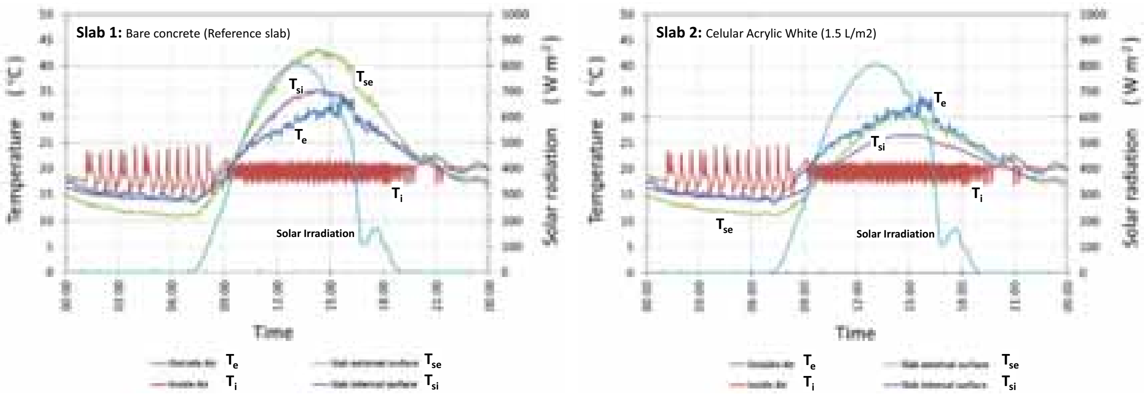

Fig. 6: Temperature profiles in probes 1 and 2, October 10th, 2010

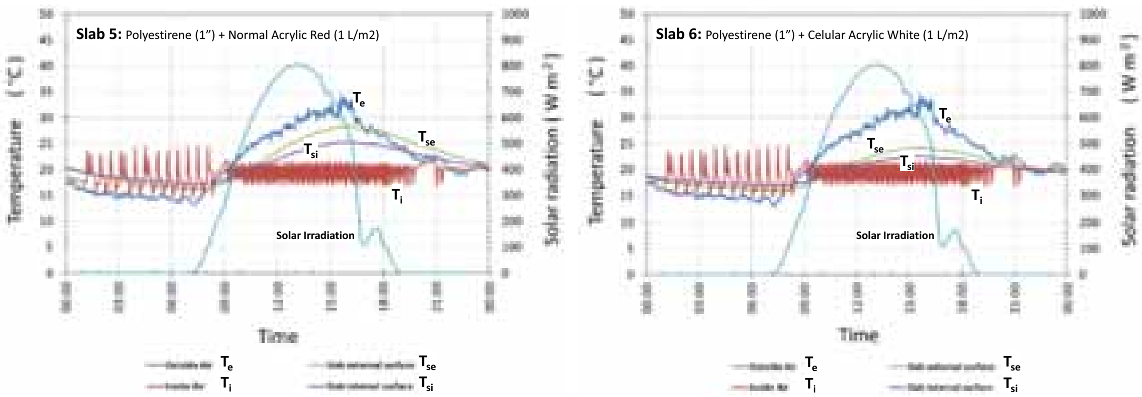

Fig. 7: Temperature profiles in probes 5 and 6, October 10th, 2010

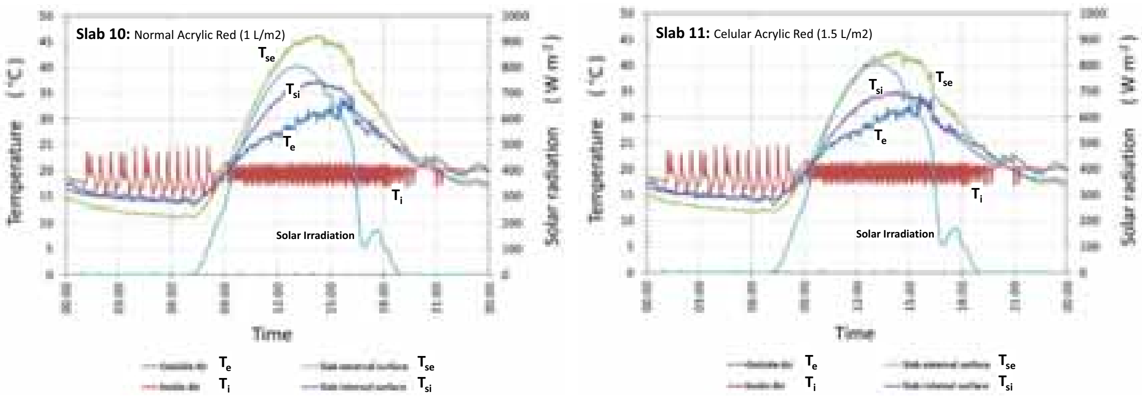

Fig. 8: Temperature profiles in probes 10 and 11, October 10th, 2010

4.3 Heat flux profiles

One can observe in figure 9 that applying CWAC over the concrete slab results in a reduction of heat gain from 180 to 80 W m^{-2}. It can also be noticed that, during night-time, the coating doesn't offer any appreciable protection against heat losses because both probes behave almost identically. The period during which passive cooling happens ranges from 21:30 until 9:00 (11.5 h) for the naked probe, while it ranges from 21:00 until 10:00 (13 h) in the CWAC-coated probe.

Figure 10 shows how, in a probe with conductive thermal insulation, the application of CWAC instead of NRAC causes a reduction in the maximum heat flux from 70 to 42 W m^{-2}. It can be observed that the passive cooling period is increased by 2 h, changing it from 1:30 am -10:00 am (9.5 h) with NRAC, to 0:30 am -11:00

am (10.5 h) with CWAC. When figures 9 and 10 are compared, it can be seen that roofs with conductive thermal insulation (Figure 10), have a maximum flux approximately one hour later than un-insulated roofs. Additionally, the heat stored during the day continues to flow to the inside of the house even after midnight; while roofs without thermal insulation have heat flowing towards the inside of the house only until approximately 21:00, when the flow stops and the inverse process (passive cooling) commences. This phenomenon is very important if one considers that the majority of houses of social interest (very economic, but abundant) lack of air-conditioning systems and are situated in geographical zones with predominately hot and sunny climates. Houses with conductive thermal insulation limit the flow of diurnal heat to the inside; however, the heat that gets through during the day stays trapped inside the house during several more hours into the night. On the other hand, if the roof only has reflective/emissive coatings, it restricts the amount of solar radiation that is absorbed and penetrates the house, giving it the same effect as insulators; but whenever the solar load ceases, the coatings ***do allow*** the flow of stored heat back to the outside.

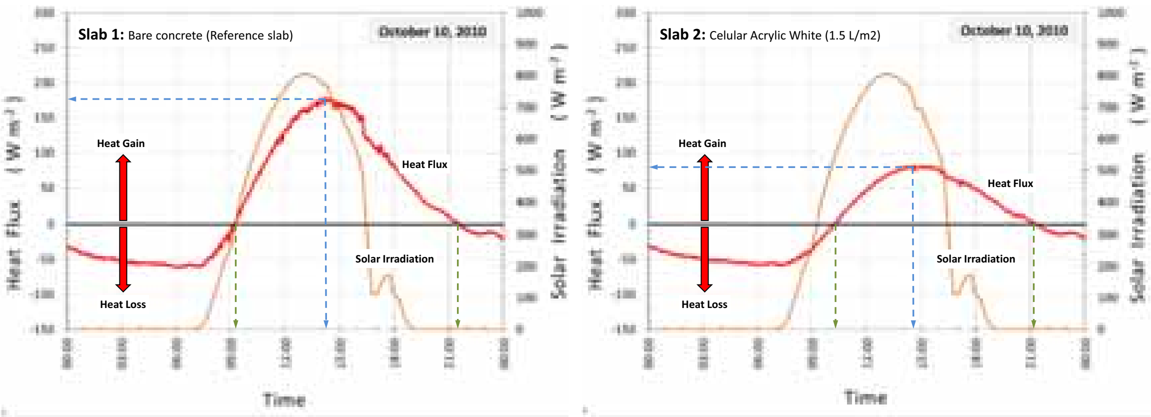

Fig. 9: Heat flux profiles in probes 1 and 2, October 10th, 2010

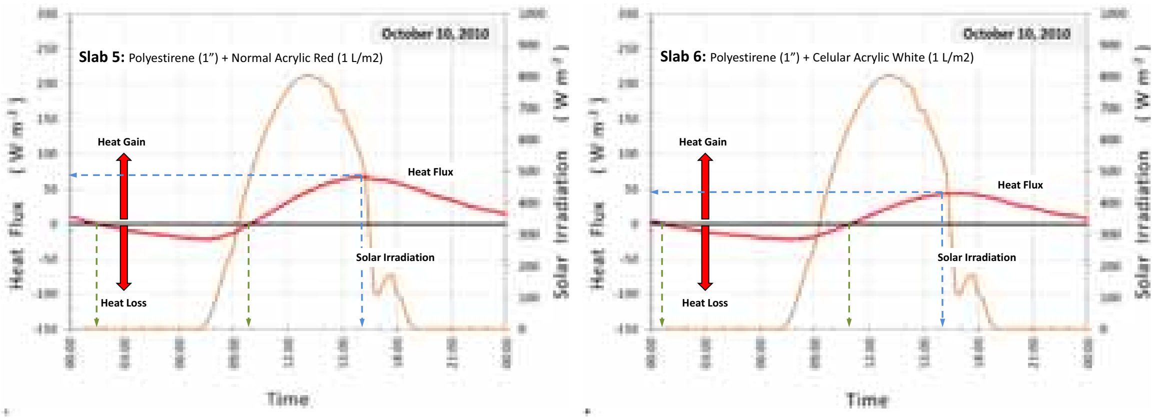

Fig. 10: Heat flux profiles in probes 5 and 6, October 10th, 2010

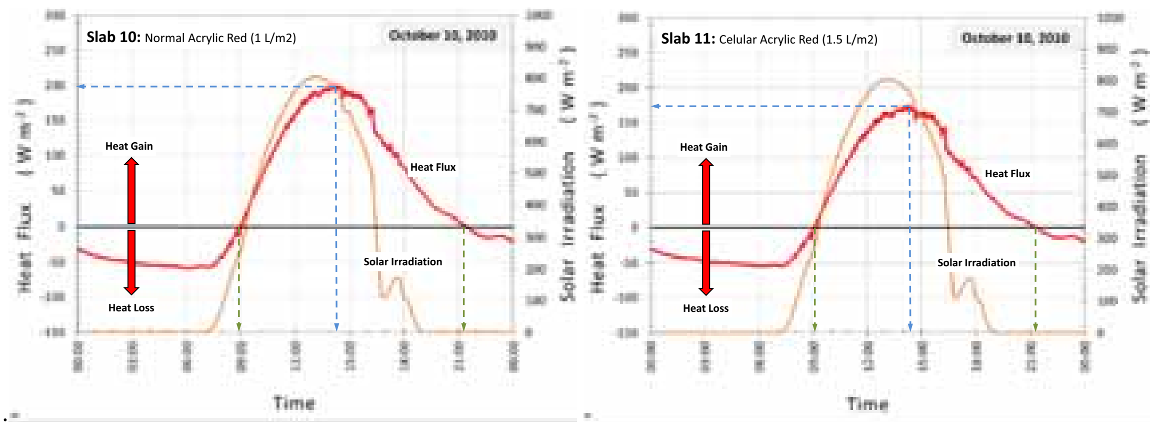

Fig. 11: Heat flux profiles in probes 10 and 11, October 10th , 2010

One can observe in figure 11 how the addition of microspheres to the same red acrylic coating reduces its maximum heat flux from 200 to 170 W m-2. This effect is attributed solely to the optical properties the microspheres contribute to the coating. It can be inferred from the graphs that the probes have the same heat flows during the nocturnal period, which means similar conductive thermal resistances

4.2. Total heat gained and lost

Temperature measurements where performed during 21 days, in 3 nonconsecutive week periods. This yielded 21 similar graphs to the ones shown before for each probe. Through numerical integration, the total daily heat gained (area under the flux curve) and lost (area above the flux curve) was obtained. The gains and losses were added separately during each week to obtain the weekly totals. The separation of heat gains from heat losses turned out to be very important to allow the comparison between the different behaviors of the systems with conductive thermal insulation against the systems with reflective/emissive coatings.

Figure 12 shows the daytime heat flows obtained during the week from 10th to 16th of October, 2010. The results for the other two weeks are not shown; however, they are very similar and coherent to the ones shown. To have a greater appraisal of the obtained results, figures 12 and 15 depict the probes and coatings according to name, probe number, composition (structure) of the coating (with the added conductive insulation or not), microsphere content in the waterproofing coating, and color. The heat flows during the test week (October 10-16, 2010) are shown in figure 12, and it can be observed how the best materials turned out to be the two new developments which are not yet commercially available (probes 8 and 12). Probe 6 obtained the lowest accumulated heat flow of all the tested commercial products, due to the fact that it had 1” of conductive insulation and was covered with CWAC. It is of special interest for the current conditions in Mexico to see how probes 4 and 5, which were coated with 1” of conductive insulation and comply with the active norms for energy savings, allowed a greater heat flow than probe 2, which only had a CWAC coating with a maximum thickness of 2 mm. Mexican norms don’t consider this type of coating as a technology for heat flow reduction in roofs.

Figure 13 shows the percent reduction in heat flow caused by each tested coating (taking the behavior of bare concrete as the reference). It is observed that probe 6 reduced the heat flow by 71%, probe 2 reduced it 58.3%, probe 5 reduced it by 51%, and probe 9 reduced it by 44%. Probes 5 and 6 have the same conductive insulation but, when the coating is changed from NRAC to CWAC, there is an additional 20% reduction of the total heat flow. If the results obtained from probe 2 (CWAC) are compared to the ones of probe 9 (NWAC), which differs in the CWAC’s addition of microspheres, a 34.3% greater heat flow is observed in probe 9 than in probe 2. The same comparison between probes 10 and 11 (colored red) resulted in 18.5% additional heat flowing through probe 10 (NRAC) when compared to probe 11 (CRAC). Figures 14 and 15 show the total heat flows during the nocturnal period (heat losses). The graphs show that, during the night and in the presence of cold climatic conditions, only the coatings with added conductive thermal insulation provide a reduction in the heat flow. The reflective/emissive waterproofing coatings do not add conductive thermal resistance due to their small thickness (1 - 2 mm).

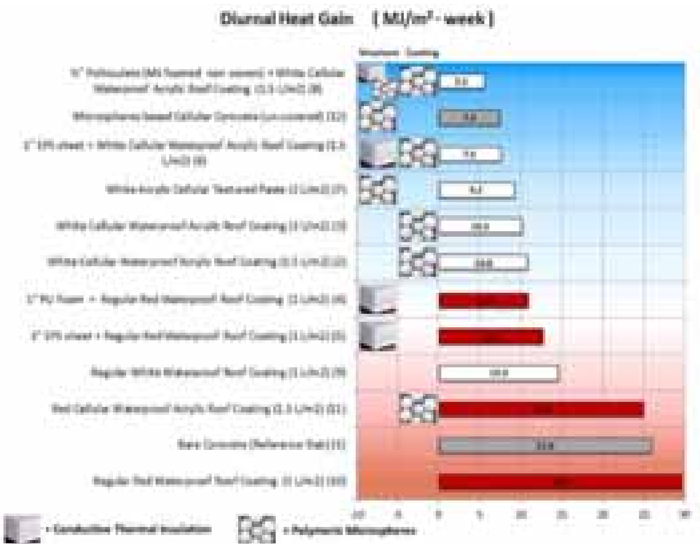

Fig. 12: Total diurnal heat gain for the week of October 10th - 16th , 2010

Fig. 13: Total diurnal heat reduction gained during the week of October 10th - 16th, 2010

Fig. 14: Total nocturnal heat lost during the week of October 10th - 16th , 2010

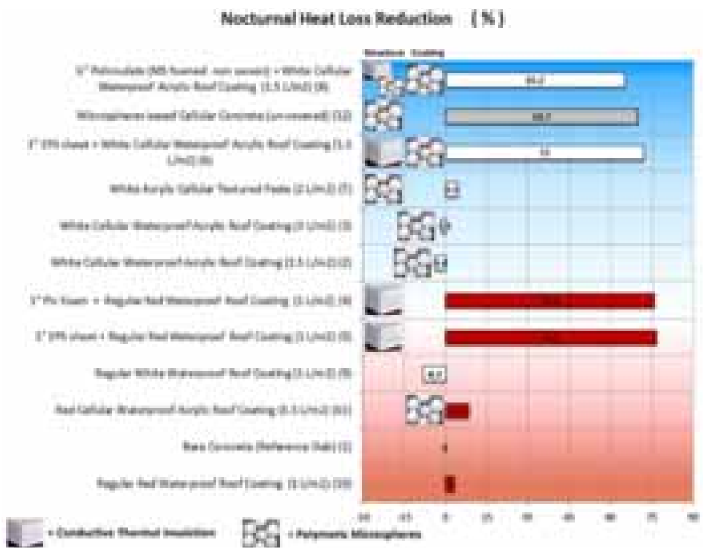

Fig. 15: Total nocturnal heat loss reduction for the week of October 10th - 16th , 2010

5. Conclusions

A methodology to determine the heat flow across roof coatings is presented in this study. This methodology allows the evaluation of the thermal performance exhibited by any coating materials. This experiment compared the thermal performance of two uncoated probes made of different kinds of concrete, six concrete probes coated solely with waterproofing acrylics, and four probes with thermal insulation and coated with waterproofing acrylics. With the obtained results, it is concluded that the best reduction of diurnal heat flow was exhibited by the combinations of a thermal insulating material (which increases the conductive thermal resistance) and a white cellular waterproofing coating. During nocturnal periods and/or cold conditions, the thermal insulating material is an indispensable element for the reduction of heat losses. Moreover, the different behaviors between CCPM and conventional concrete are explained by the strong difference between their thermal conductivity values, caused by the addition of polymeric microspheres to the CCPM.

Due to the high levels of insolation present in most of Mexico, the use of highly reflective and emissive coatings can be the simplest and most economical solution in order to strongly reduce the energy consumption destined for artificial ambient conditioning. Only in regions with cold climatic conditions there is the need to use conductive thermal insulation. The usage of conductive thermal insulation in hot regions is not only much more expensive, but it also impedes nocturnal passive cooling of houses without any air-conditioning; it also impedes good thermal comfort for its occupants because the house's internal surfaces remain warm for a longer period of time. It is important to stress the necessity for current Mexican norms to value, evaluate, and encourage the usage of reflective and/or emissive coatings. These important products reduce the energy consumption required for ambient conditioning in houses, and they also improve the thermal comfort for its occupants.

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