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Assessment of the Temperature of Waterproofing Membrane When A Recycled Crushed Glass Finish Layer Is Used On Flat Roofs to Protect From Sun Radiance

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Abstract

The aim of this research was to determine the impact of the use of a recycled crushed glass finish coat on flat roofs to reduce the transmission of heat from sun radiance to indoor spaces in the buildings. This research forms part of previous studies carried out by LiTa on the application of cool roof products to reduce the energy required for air-conditioning inside buildings. Many flat roofs are finished with crushed stone aggregates of natural or artificial origin. The use of recycled crushed glass as a cool roof is potentially a double opportunity to reduce the environmental footprint: it is a recycled material and it may reduce air-conditioning demand. In order to evaluate the real efficiency of recycled crushed glass, this research compared the results with other technical alternatives that are generally applied in real conditions.

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Keywords: recycled crushed glass, sun radiance protection, flat roofs, finish layer

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1. Background

1.1. The flat roof

In the catalog of the exhibition entitled "The flat roof, a walk through history", created to commemorate the 50th anniversary of the company Texsa (2005), Dr. Ramon Graus [1] stated that flat roofs are particularly predominant in climatic zones that have low rainfall annual. Their origin dates back to the pre-industrial era, when the roof was considered an additional outdoor area where activities that take advantage of direct solar radiation could take place, such as drying agricultural products and laundry. However, significant concerns arose about heat emission from flat roofs into buildings, especially during the night when inhabitants area sleep. In the industrial era, modern architecture extolled the virtues of the flat roof as a way to recover the area occupied by the foundations of the building. The use of impermeable industrial membranes became popular and contributed greatly to the extension of the flat roof in many other places with diverse climates. However, overheating of roofs caused by the incidence of direct solar radiation rapidly deteriorated the material of these membranes. This led to the development in the 1950s of inverted waterproofing (an upside-down roof), in which upper layers are comprised of thermal insulation products that protect membrane temperature fluctuations caused by climate day and night, summer and winter.

At the same time, scientists have been providing evidence that climate change is raising the average temperature of the planet's biosphere due to greenhouse gases that are emitted as a result of the use of fossil fuels. This has focused attention on coatings called "cool roofs" that increase the reflectivity of the decks, thereby reducing their surface temperature and the surface temperature of the waterproofing materials beneath them. There is already an abundant supply of various finishing materials that employ the adjective "cool roof" but predominant among them are roof coverings made of ground natural minerals. This study assesses the use of crushed recycled glass products that are now available in abundance. They could replace mineral aggregates that must be extracted from nature and contribute to a new range of finishes in future architecture.

1.2. Crushed recycled glass

Glass is a silicate that melts at about 1200 degrees and is composed mainly of silica, soda and limestone and other materials that are used to vary its brightness and color. Glass is one of the materials that is easiest to reuse because it is found in large amounts in solid domestic waste, and is collected separately in many countries by local government. In a study conducted at the Autonomous University of Mexico by Alejandro Mata and Carlos Galvez [2], it was determined that the most commonly used colors of glass are currently:

- Green (60%), used extensively in bottles.
- Light (25%), used in soft drinks, for medicine, etc.
- Extra clear (10%), used in mineral water bottles, canning jars, etc.
- Amber or topaz (5%), used in beer bottles and chemical-pharmaceutical bottles

Glass recycling is a process in which 100% of waste glass is recovered for reuse. The process can be repeated many times, by either tritulating the glass to melt it again, or reusing the entire container after washing. Most of the glass that is recycled (42%) is from the domestic sector, from which most glass is recovered. According to the 2014 Sustainability Report by Ecovidrio [3], a 68.9% recycling rate has already been achieved, which corresponds to 19.21 kg per inhabitant per year statewide (897,828 tons). New glass obtained from recovered glass needs 26% less energy to produce than glass made entirely from natural raw materials. Emissions into the atmosphere due to the manufacturing process are reduced by 20% when recycled glass is used and 40% less water is needed. Every ton of waste that is recycled glass prevents 315 kg of carbon dioxide from being released into the atmosphere during the manufacture of new glass. Thus glass recycling provides many potential benefits:

- Save raw materials, as materials do not need to be extracted from nature to produce new glass.
- Save energy, as less energy is required to melt recycled glass, which therefore contributes to reducing associated air emissions
- Reduce the volume of urban solid waste dumps

Another potential benefit may be a reduction in energy consumption due to cooling of buildings under flat roofs on which natural aggregates have been replaced by crushed recycled glass.

1.3. "Cool roof" deck coatings

Numerous studies [4] support the benefits of coating roofs of buildings with suitable materials to protect the rooms underneath from the direct impact of solar radiation in climates with high temperatures and intense sun. The suitability of these materials lies in their reflective properties (percentage of reflected radiation with respect to radiation received) and emissivity (ratio of intensity emitted by the surface of the material evaluated and the intensity that would be emitted by a black body of the same temperature and wavelength). The lower the emissivity, the better the surface insulates by reflection, with 1 being the maximum value.

On a practical level, the combined parameter is called the Solar Reflectance Index (SRI), which is a measure of the ability of a deck's covering to reject solar heat from incident radiation. It is defined on a scale from standard black coating (reflectance 0.05, emissivity 0.9) with a value of 0, to standard white coating (reflectance 0.8 and emissivity 0.9) with a value of 100. For example, standard black coating has a temperature rise of 90°F (50°C) when it is exposed to full sunlight, while standard white coating has a temperature rise of 14.6°F (8.1°C). Once the maximum temperature increase of a particular material has been determined, the SRI value can be calculated by interpolating between the values of 100 for white and 0 for black. The SRI index is thus a dimensionless scale of 0 to 100, where 0 is the most suitable for absorbing and radiating heat value (as is the case of a tar coating) and 100 is the value of the most reflective material, which reduces the amount of heat (as is the case of ice).

Why use a "cool roof" deck coating?

- To reduce the air temperature in the living spaces below deck.
- To reduce the temperature of the lower deck's construction elements, which prolongs their life?
- To obtain savings in energy consumption associated with artificial cooling systems, by reducing the demand for air conditioning.

How is it shown that a coating material for a deck is a "cool roof"?

The US Green Building Council [5] issues Leadership in Energy and Environmental Design (LEED) stamp credits for buildings that incorporate various actions that are favorable to the environment. Among these, assessment of the reflectivity and emissivity of deck coating materials has gained ground, both in itself and in some LEED official building codes. LEED certification credits for "cool roofs" are given for coatings

R1 varied crushed glass	R5 black decorative crushed glass	R9 baked clay unglazed tile 14x28x1.3 cm
R2 topaz crushed glass	R6 violet decorative crushed glass	
R3 domestic crushed glass	R7 gray decorative crushed glass	R10 white limestone gravel
R4 flat transparent crushed glass	R8 green decorative crushed glass	

that meets one of the following alternative requirements:

- Option 1: Solar Reflectance Index.
Apply to at least 75% of the roof a deck coating that has a Solar Reflectance Index (SRI) greater than or equal to the following:
For (low slope) flat roofs, the SRI must be greater than or equal to 78.
For (high slope) pitched roofs, the SRI should be greater than or equal to 29.
- Option 2: Apply a "green" (plant) coating to at least 50% of the total surface of the roof.
- Option 3: Apply a reflective coating in combination with a "green" coating, to meet the following criteria: (area reflective coating/0.75) + (coating area "green"/0.50) >= total roof area.

2. Hypothesis

From the perspective of architects and builders, the opportunity arises to use recycled waste such as crushed glass recovered from municipal solid waste as a deck coating to achieve the "cool roof" standards. This could add the environmental benefits of recycling to the environmental benefits of "cool roof" coatings in climates where more energy is used to cool buildings than to heat them. Thus, there is an opportunity for a preliminary study to assess the scope and circumstances of potential benefits in a Mediterranean climate, considering:

- The bright nature of the glass may also produce a decrease in temperature in the glass itself in the sun.
- Crushed glass from the recovery of municipal solid waste, because it comes mostly from food packaging, has convex and concave curved surfaces. Therefore, a stack of this glass could create micro air chambers that could collaborate by improving the effective thermal insulation of the deck.
- Crushed glass from waste recovery has different colors that could modify the heating of the material when it is exposed to sunlight.
- A layer of crushed glass could behave better than many other "cool roof" coatings in the case of low-slope roofs.
- The use of "cool roofs" comprised of crushed cullet could lead to monetary savings during construction, because this is an aggregate that does not need to be extracted, it is easily crushed and could reduce the thickness of the layer of insulant material required on the roof.

3. Experimental studies

To perform this preliminary comparison, an experimental study was carried out on the roof of the Vallès School of Architecture (ETSAV) building at the *Universitat Politècnica de Catalunya* (UPC), located in the town of Sant Cugat del Vallès (Barcelona) (+41.470336 GPS coordinates N + 2.071592 W). For years, this deck has been equipped with a set of cubes for measuring at various points the thermal impact of the use of building systems (see Figures 2 and 3) [6].



Figure 01. Detailed view of the various crushed glass materials in their respective boxes



Figure 02. Aerial view of the position of measurement cubes on the deck of the Vallès School of Architecture

The samples of crushed glass for comparison were placed in separate containers with wooden fretwork, to allow the passage of air. The probe for measuring the temperature was placed at the bottom of each wooden box and then a layer of the coating material was added for comparison until it covered the deck at a depth of about 5 centimeters. The probes measured the temperature every 15 minutes and the data was stored in the corresponding datalogger. Measurements were made in June, July and August when the solar radiation incident on the flat roof is most intense

at this latitude. The temperature data were collected with dataloggers from the software firm TESTO, and collected every 15 days to verify the absence of errors or incidents during the measurement period (see Figure 6).



Figure 3. Overview of selected modules of the various boxes of crushed glass, placed on respective decks no. 1, 2 and 3

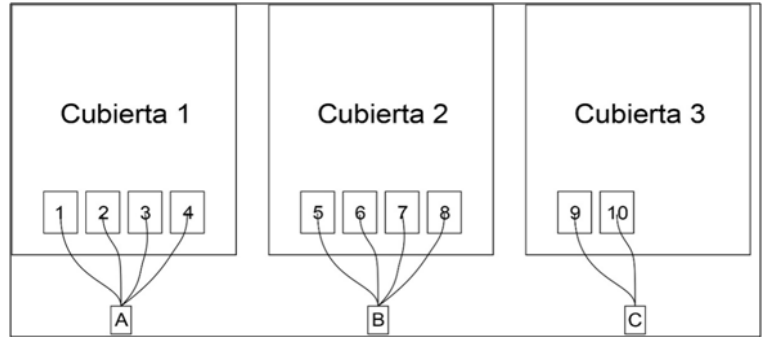


Figure 4. Diagram showing the location of the boxes of crushed glass on each of decks no.1, 2 and 3. The respective temperature probes were connected to the same datalogger for each deck, respectively called A, B and C

Three modules were selected; called deck 1, deck 2 and deck 3 (see Figure 4).

Boxes 1 to 4 were placed on deck 1. These boxes contained four types of completely different crushed glass (see Figure 5.1).

Boxes 5 to 8 were placed on deck 2. These boxes contained crushed glass of the same shape and particle size, but different colors (see Figure 5.2).

Boxes 9 to 10 were placed on deck 3. These boxes contained two types of conventional coatings for use on flat roofs: white limestone gravel, and unglazed cooked clay tiles (see Figure 5.3).



Figure 5.1. From left to right:

- R1 varied crushed glass
- R2 topaz crushed glass
- R3 domestic crushed glass
- R4 flat transparent crushed glass



Figure 5.2. From left to right

- R5 black decorative crushed glass
- R6 violet decorative crushed glass
- R7 gray decorative crushed glass
- R8 green decorative crushed glass



Figure 5.3. From left to right

- R9 baked clay unglazed tile 14x28x1.3 cm
- R10 white limestone gravel

Figure 6 shows the measuring equipment that was used:



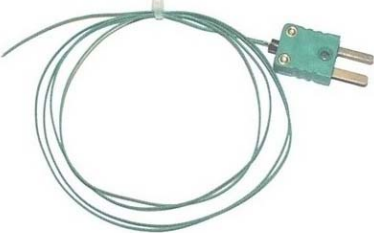


Image measuring instrument	Reference	Description
	Testo 177-T4	Two lines, 4-channel capacity, battery 5, temperature range -200 to + 1000°C; memory: 48,000 readings
	Testo 176-T4	Two lines, 4-channel capacity, battery 8, temperature range -200 to + 1000°C, memory: 2 million readings
	Type K sensors (NiCr-Ni)	Thermo polar thread K (NiCr-Ni) flexible type, fiberglass, Ø 1.5 mm, temperature range -50 to + 400°C
	Testo Comsoft Basic 5	Basic software for programming and reading Testo dataloggers; presentation of the values as a graph or table and export functions
	Weather Station CAR-Sant Cugat del Valles (+41.484858 N, +2.080158 W)	<p>This equipment has meteorological sensors that can measure temperature and relative humidity, overall solar irradiance, wind speed and direction, and rainfall.</p> <p>The data provided by these sensors are recorded every 30 minutes and sent to the headquarters of the <i>Servei Metreològic de Catalunya</i> (SMC) every half hour through GPRS communications.</p>

Figure 6. The measuring equipment that was used

Thus each of the coating materials of flat roofs was evaluated on equal terms:

- Every roof was exposed to the same climate.
- All were arranged in the same solar orientation.
- All had the same thickness of coating material (about 5 centimeters).
- All were arranged on a black background (the usual color of the waterproofing membrane).
- All were collected in the same type of wooden recipient.
- All temperatures were taken with the same type of datalogger.
- All remained for the same length of time, with the exception of the conventional materials (deck 3), which were positioned two weeks after the start of the study of decks 1 and 2. Therefore, the comparative study was restricted to the period in which decks 1, 2 and 3 were set up.

4. Interpretation of results

To facilitate the interpretation of the results, a graph was drawn up showing the behavior of each deck for the months of June, July and August, and a table of the most significant results was created for each of the channel's values. Every day, both the maximum and minimum temperature peaks were recorded, which correspond to the daily fluctuation in the 24-hour cycle. This first analysis is presented below for the deck 1 (see Figures 7 & 8).

Instrument name: Caixa 1 01989517			30-08-15 19:05	
Start time: 5/6/2015 5:15:00 PM		Minimum		Maximum Mean value
End time: 27/8/2015 10:30:00 AM	Channel 1 [°C]	13.9	66.6	31.621
Measurement channels: 4	Channel 2 [°C]	14.1	60.5	27.614
Measured values: 7942	Channel 3 [°C]	14.5	64.4	31.64
C1: SN 01989517 / 012	Channel 4 [°C]	14.6	71.3	33.329

Figure 7. Table of significant values (minimum, maximum and average) from deck 1 for each of the channels, over the measurement period

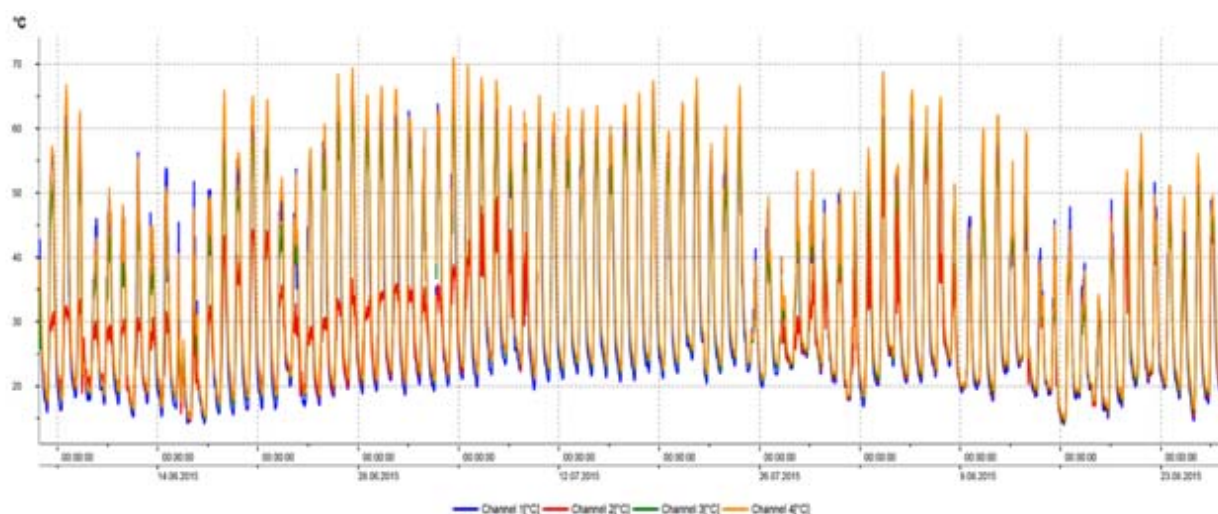


Figure 8. Graph of values from deck 1 for each of the channels, throughout the measurement period

General observations for deck 1

- Qualitatively, the results show that channel 2 (R2 amber glass) was the least heated, in terms of both average values and maximum values. The most heated was channel 4 (R4 transparent flat glass).
- Qualitatively, the results show that channel 1 (R1 varied crushed glass) was the most cooled, in terms of both average values and minimum values. The least cooled was channel 4 (R4 transparent flat glass).
- Quantitatively, by summing up all the measured temperatures for the days in the study period, we obtain:
 - Channel 1 (R1 varied crushed glass): 250947.2°C
 - Channel 2 (R2 topaz colored crushed glass): 173857.2°C
 - Channel 3 (R3 domestic crushed glass): 251098.7 °C
 - Channel 4 (R4 flat transparent glass crushed): 264501.6°C

Instrument name: Caixa 0 01989454			30-08-15 19:07	
Start time: 15/6/2015 10:30:00 AM		Minimum		Maximum Mean value
End time: 27/8/2015 8:30:00 AM	Channel 1 [°C]	13.7		62.4 30.935
Measurement channels: 4	Channel 2 [°C]	13.5		60.7 30.051
Measured values: 7001	Channel 3 [°C]	6		67 27.955
CI: SN 01989454 / 012	Channel 4 [°C]	14.5		61.9 31.79

Figure 9. Table of significant values (minimum, maximum and average) from deck 2 for each of the channels, over the measurement period

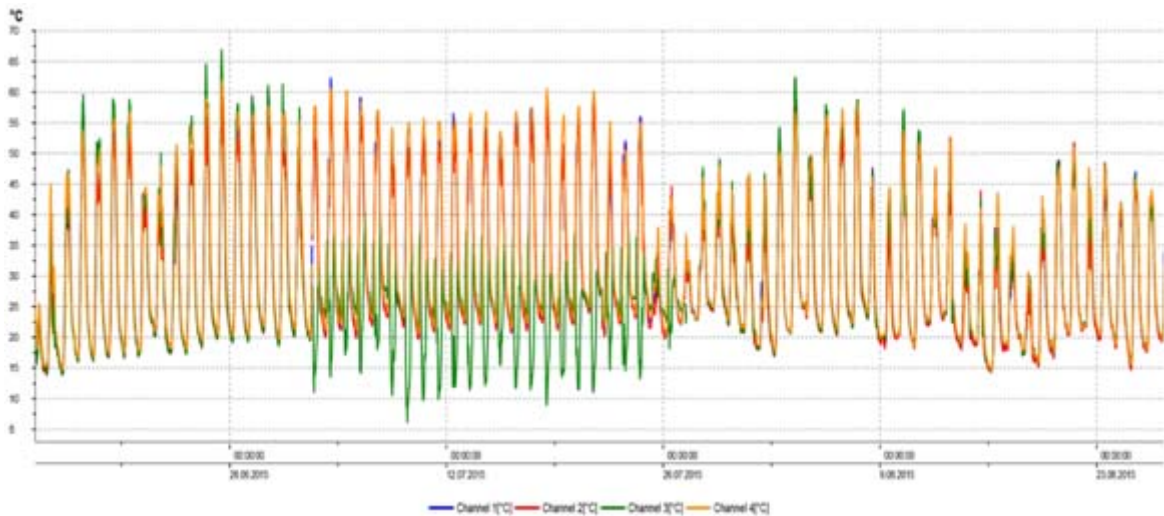


Figure 10. Graph of the values of deck 2 for each of the channels, throughout the measurement period. (Note: in part of the experiment, a probe was disconnected accidentally, which shows that channel 3, green, had downward peaks over the time range. These data were not considered.)

General observations for deck 2 (see Figures 9 and 10)

- The average lowest temperature was recorded by channel 3 (R7 gray decorative crushed glass)
- The average highest temperature was recorded by channel 4 (R8 green decorative crushed glass)
- The maximum temperature was recorded by channel 1 (R5 black decorative crushed glass)
- The minimum temperature was recorded by channel 3 (R7 gray decorative crushed glass)
- Quantitatively, by summing up all the measured temperatures for the days in the study period, we obtain:

- Channel 1 (R5 black decorative crushed glass) totaled 216511.3°C
- Channel 2 (R6 violet decorative crushed glass) totaled 210324.6°C
- Channel 3 (R7 gray decorative crushed glass) totaled 195656.5°C
- Channel 4 (R8 green decorative crushed glass) totaled 222500.8°C

Instrument name: Caixa 2		30-08-15 19:10		
Start time: 6/23/2015 12:30:00 AM		Minimum	Maximum	Mean value
End time: 8/26/2015 11:30:00 PM	Channel 1 [°C]	13	57.3	29.689
Measurement channels: 2	Channel 2 [°C]	14.5	47.7	27.25
Measured values: 6237				
SN 40705703				

Figure 11. Table of significant values (minimum, maximum and average) from deck 3 for each of the channels, over the measurement period

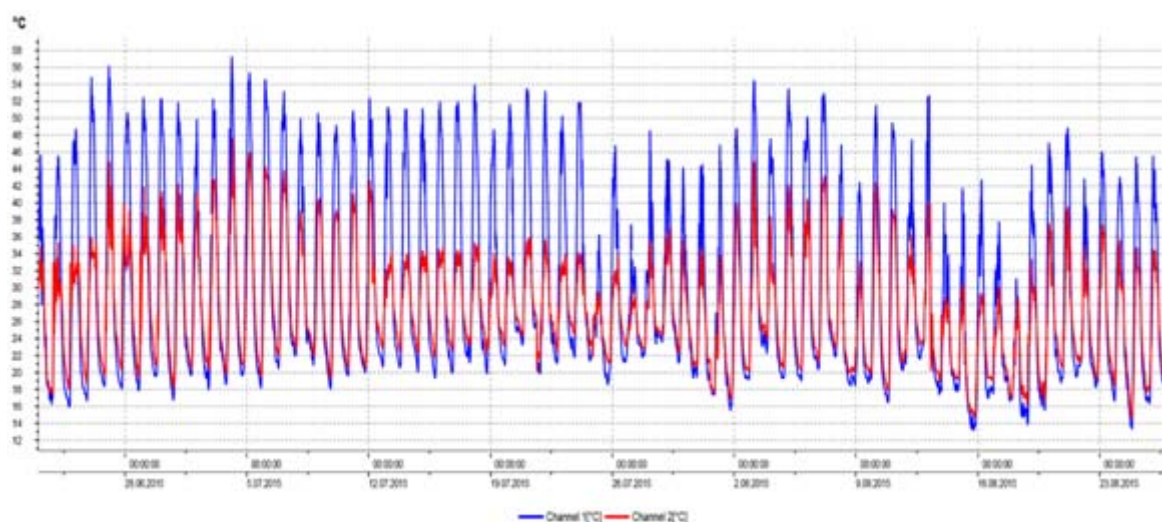


Figure 12. Graph of the values from deck 3 for each of the channels, throughout the measurement period

General observations for deck 3 (see Figures 11 and 12)

- The lowest average temperature was recorded by channel 2 (R10 white limestone gravel).
- The highest average temperature was recorded by channel 1 (R9 baked clay unglazed tile 14x28x1.3 cm)
- The maximum temperature was recorded by channel 1 (R9 baked clay unglazed tile 14x28x1.3 cm)
- The minimum temperature was also recorded by channel 1 (R9 baked clay unglazed tile 14x28x1.3 cm)
- Quantitatively, by summing up all the measured temperatures for the days in the study period, we obtain:
 - Channel 1 totalled 185108.5 °C
 - Channel 2 totalled 169902.6°C

Initial evaluation results and proposed comparison

- The crushed glass generally had accumulated thermal behavior that was not as favorable as conventional materials for roof covering.

- The minimum temperatures were similar, but the maximum temperatures were different, probably because of the greater transparency of glass to solar radiation.
- When the glass was crushed to a greater extent (particles of a smaller diameter), e.g. crushed decorative cover 2, the adverse effects of crushed glass were alleviated in the area of maximum temperatures.
- The only exception was R2 colored topaz crushed glass, from the grinding of beer bottles , whose average values were measured and were within the range of the conventional coatings.

Therefore it was decided to perform further comparisons on deck 1, by increasing the crushing level of R2 colored glass so that it was similar to that of R3 domestic glass.

Instrument name: Caixa 1 01989517			31-08-15 9:11		
Start time: 05/6/15 5:15:00 PM		Minimum		Maximum	Mean value
End time: 10/7/15 11:30:00 AM	Channel 1 [°C]	13.9		66.6	31.899
Measurement channels: 4	Channel 2 [°C]	14.4		49.6	26.749
Measured values: 3338	Channel 3 [°C]	14.8		64.4	31.853
C1: SN 01989517 / 012	Channel 4 [°C]	14.6		71.3	33.741

Figure 13. Table of the significant values (minimum, maximum and average) from deck 1 before further crushing of glass R2 (channel 2) to make the particle size similar to that of glass R3 (channel 3)

Instrument name: Caixa 1 01989517			30-08-15 19:46		
Start time: 27/7/2015 2:15:00 PM		Minimum		Maximum	Mean value
End time: 27/8/2015 10:30:00 AM	Channel 1 [°C]	13.9		62.2	29.444
Measurement channels: 4	Channel 2 [°C]	14.1		60.5	28.588
Measured values: 2962	Channel 3 [°C]	14.5		60.5	29.62
C1: SN 01989517 / 012	Channel 4 [°C]	14.7		68.9	30.963

Figure 14. Table of significant values (minimum, maximum and average) from deck 1 after further crushing of glass R2 (channel 2) to make the particle size similar to that of glass R3 (channel 3)

Second evaluation of results after the comparison (see Figures 13 and 14) and a proposed new comparison

- Channel 2 (R2 topazcrushed glass) had higher average temperatures after being recrushed, even though the test was performed in a period more distant from the equinox (the angle of solar incidence descends as we move away from the equinox). The R3 channel and other channels had lower average temperatures, in accordance with this reduction in angle of incidence.
- Minimum temperatures, which were always during the dark hours of the night, did not seem to be very sensitive to recrushed glass or to temporary separation from the equinox.
- Maximum temperatures were reduced in all channels alike, due to temporary separation from the equinox and the modification of channels 2 and 3 to make the crushed level similar.
- The beneficial effect of using the R2 sample (topazcrushed glass) seems therefore to owe more to the grain size of the crushed glass than its color and composition. As the glass is from beer bottles, the beneficial effect must be due to the curved glass and the volume of trapped air in the layer due to stacking this residue (low bulk density).

Therefore, we decided to perform a further comparison between the extreme crushed glass values, obtained in channel 2 (R2 crushed glass topaz) and channel 4 (crushed glass flat transparent) on deck 1, but with respect to environmental conditions of irradiance and wind measurements in the afore mentioned meteorological station. The study period was selected after the summer equinox week.

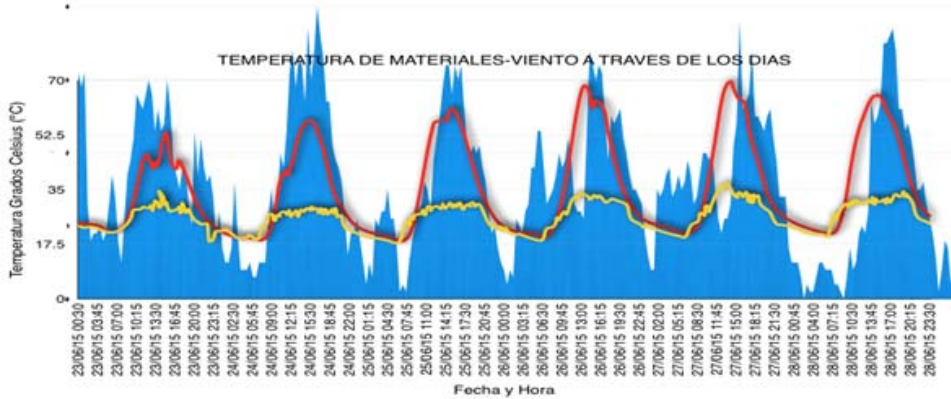


Figure 15. Graph of the temperature values from deck 1, for channels 2 and 4, superimposed on the graph of wind speed

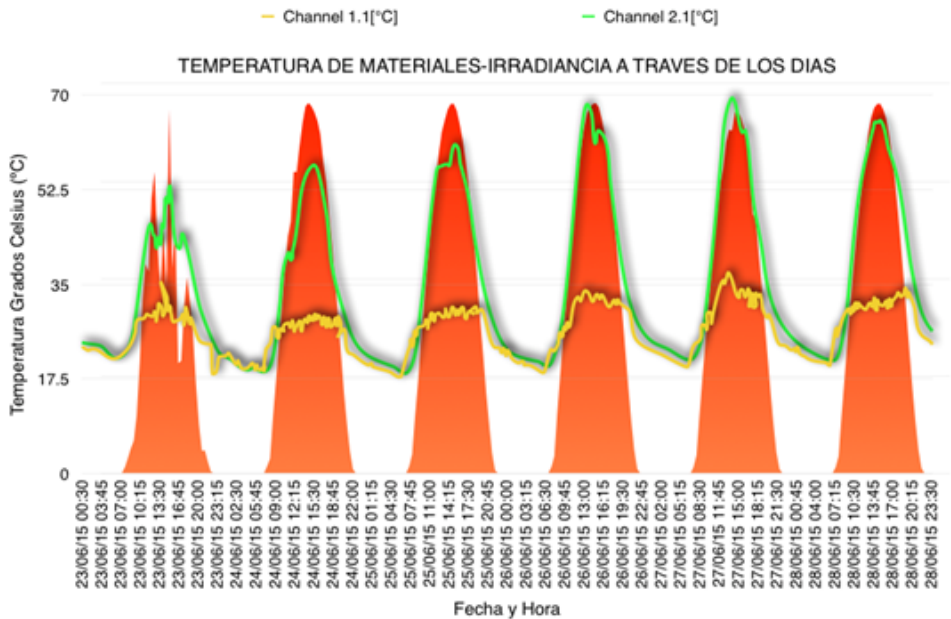


Figure 16. Graph of the temperature values from deck 1, for channels 2 and 4, superimposed on the graph of sun radiance

Further evaluation of results:

- In this weather situation, wind and maximum irradiance both occur at noon (12 am) and match the minimum values of temperature at 6 am. In other words, all channels have their maximum and minimum values at the same peak times.
- The minimum values of channels 2 and 4 practically coincide. The maximum values are clearly different.
- The wind factor seems to affect the maximum values of both channel 4 and channel 2, but only in situations of sustained wind and not in the case of gusts.

- The irradiance factor seems to be more cyclical, and thermal oscillation is mainly noted in channels 2 and 4. Channel 4 has oscillating thermal behavior according to the evolution of the inclination of the sun's rays, while channel 2 presents marked cumulative character until sunset.

5. Conclusions

- The bright nature of glass does not appear to produce a decrease in temperature under the glass coating exposed to the sun.
- Crushed glass from waste is mostly from the packaging of different types of foods. Consequently, it has convex and concave curved surfaces, and stacking generates micro air chambers that promote thermal insulation if large grain sizes are maintained.
- Crushed glass from waste is of different colors. This modifies the heating of the material that is exposed to the sun, but darker glass did not seem to produce worse results.
- A layer of crushed glass from waste has similar thermal behavior to the usual roof covering materials (calcareous gravel or tiles fired clay), if the bottles are crushed and the grain size is in accordance with the radius of curvature of the bottles.
- The use of crushed glass from waste can save money for the building industry, because this aggregate does not need to be extracted, it is easily crushed, and does not appreciably affect the thickness of the layer of insulating material situated underneath.

Acknowledgements

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