COOL PAVEMENTS FOR CLIMATE CHANGE ADAPTATION

Cristina Ávila Freire
Responsable SGI, CHM Obras e Infraestructuras, S.A., España
José Simón Grau
Jefe de Laboratorio, CHM Obras e Infraestructuras, S.A., España
Julio López Ayerra
Responsable área mezclas bituminosas, CTCON, España

ABSTRACT

In the framework of road infrastructures, CHM has led a study that investigates construction products in order to combat the heat that is accumulated and released by urban surfaces, such as asphalt, especially in summer, seeking to minimize the "island of urban heat".

This project is the result of having developed reflective pavements (cool pavements) than have passed through the first phase at the laboratory level, manufacturing on an industrial scale and their small-scale testing to ensure proper implementation, as well as their implementation by means of a large-scale demonstrator, operating on 24.000 m^2 of pavement in the city of Murcia (LIFE HEATLAND).

This mixture has a series of benefits with respect to conventional mixtures, leading to an improvement in the urban environment and quality of life of the citizens of the implantation environment and which are mainly:

- Saving energy in air conditioning and in the consumption of public lighting.
- Saving energy consumption and raw materials.
- Improves air quality.
- Improves noise pollution.
- Improves comfort and health of pedestrians.
- Economic and environmental benefits.

To date, the demonstrator has been monitored and the following conclusions have been obtained, validating this type of pavement as a mechanism to reduce the urban heat island effect:

- Initial luminance of reflective pavement 2.5 cd / m^2 under the lamppost, 150% higher than in the conventional asphalt street.
- Solar reflectance is almost four times higher than conventional asphalt.

- Average surface temperature for reflective pavement of 7-11 ºC lower than conventional.
- Asphalted areas where tire rubber has been deposited as a result of the rolling of vehicles are heated 1-3 ºC more than clean areas.
- Environmental noise level of the area: 3 dB (A) lower.

1. MAIN INFORMATION

1.1 Introduction

Research project developed by CHM Obras e Infraestructuras, S.A., with the collaboration of CTCON, within in framework of the REPARA 2.0 project, supported by co-financed by Centre for the development of Industrial Technology (CDTI) and European Regional Development Fund (ERDF).

At first, we are going to explain what the cool pavements are and how they help to reduce the climate change. So now we are going to define key concepts which are the following.

The development of the innovative asphalt pavement with high solar reflectance arises in order to mitigate the effects of climate change and, specifically, due to the global warming that is taking place on our planet according to the latest anomaly data determined by NASA, with annual anomalous average temperature variations of between 1-2 ºC, while in summer periods this range of temperature variation is between 1-4 ºC at the national level.

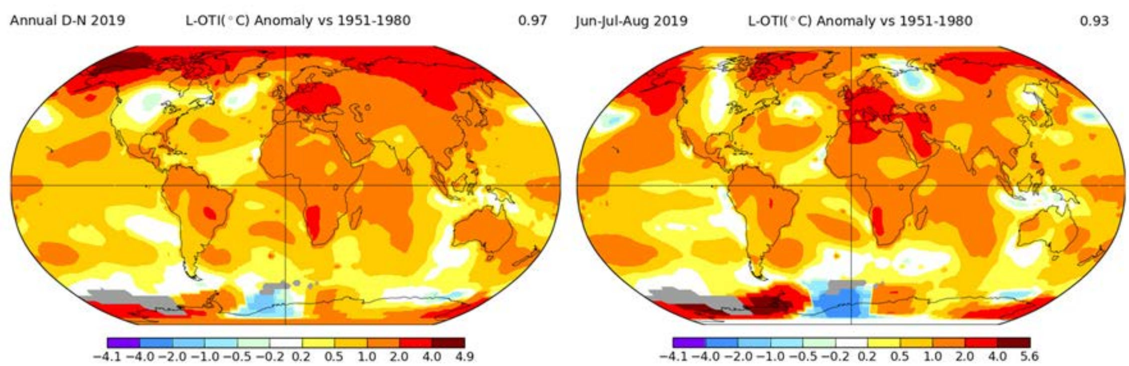

Fig. 1 – Average variation climate (2019), about Surface temperature, and variation of June-August 2019. NASA, Goddard Institute for Studies

The actions which have contributed to this climate change it is found in the last 50 years the population has start to live in urban areas instead of rural areas. See Fig. 2.

This fact has caused the proliferation of big urban zones where it is produce the phenomenon known as “Urban heat island”.

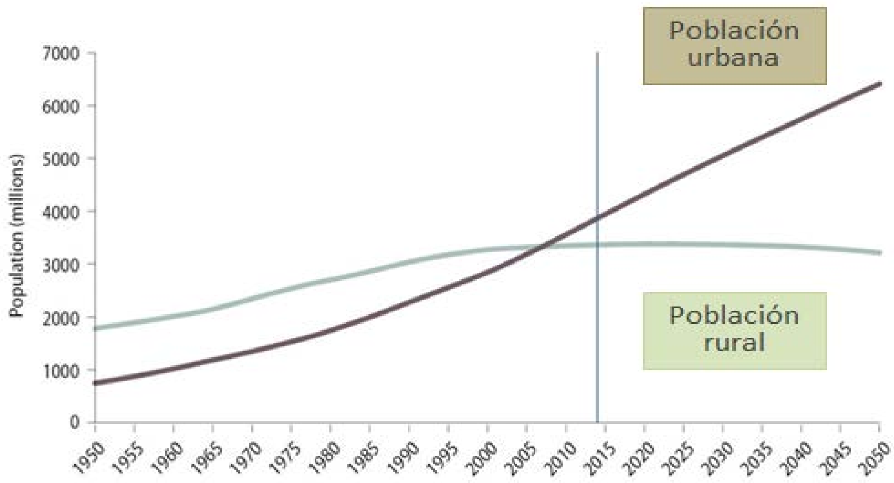

Fig. 2 – Source: data from World Bank about the basis of the Urban Perspective of the United Nations

1.2 Urban heat island (UHI)

It is the effect when an area, which has been created by the human, get a temperature hotter than the around area without modify.

This temperature difference can be seen in the following graph "referential temperature urban profile compared to rural areas", where it can be seen between urban centers and surrounding areas such as the countryside, without modifications by humans, it is got temperatures differences between 3ºC and 4ºC. See Fig. 3.

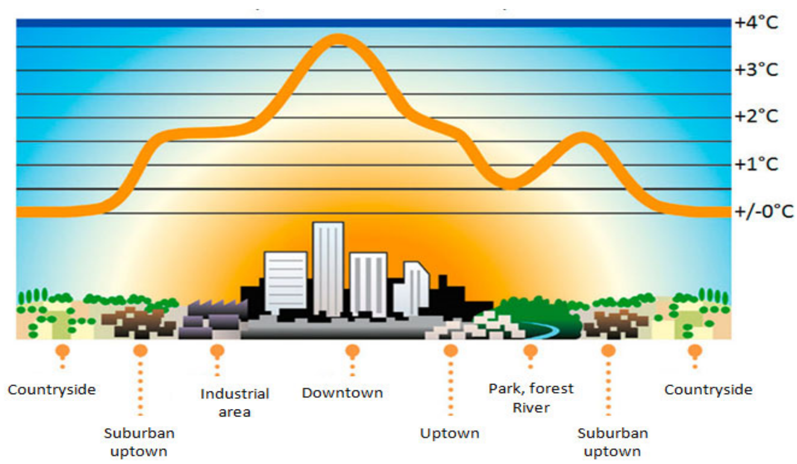

Fig. 3 – Referential temperature urban profile compared rural areas. Source: Saint-Gobain PPC. Translate, own development

Therefore, it is obtained one of the actions which cause the urban heat island effect is to change areas with vegetables materials by other materials, such as concrete or asphalt, among others.

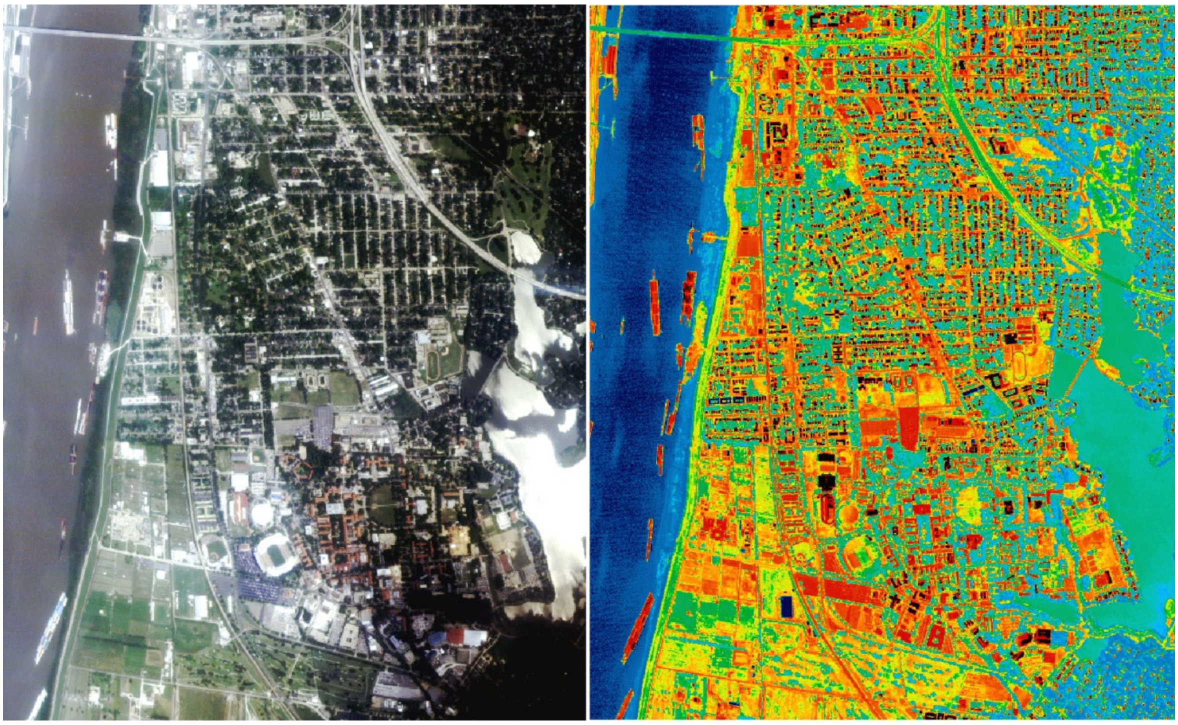

Fig. 4 – Thermography, Baton Rouge city, USA. NASA

From this and after the consulted bibliography, it has been estimated the general distribution of surfaces is identified with the distribution of the following diagram, in which the majority areas modified in the cities are constituted by pavements in general. It is had the pavements constituted around 39% of the modified surfaces in a city and these are capable of absorbing and storing energy in the form of heat, which is notoriously contributing to the aforementioned urban heat island effect. See Fig. 5.

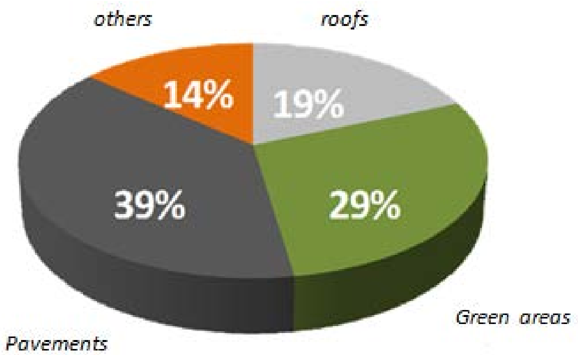

Fig. 5 – Surface distribution in urban areas.

Conventional pavements are able of absorbing up of the 90% of the incident solar energy that means they have a low solar reflectance.

1.3 Solar reflectance

It is the relation between reflected solar energy and incident solar energy. See Fig. 6.

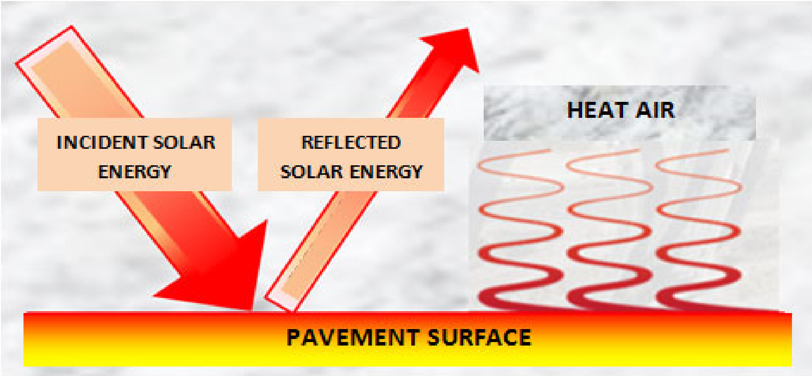

Fig. 6 – Solar reflectance. Source: own development

That the reason why, conventional pavements contribute to urban heat island effect by the following mechanism:

- Solar energy hits the pavements surface.
- Part of that energy is reflected, approximately 10%.
- The rest of the energy is absorbed as heat by the pavement, around 90%, which causes the surface to heat up, reaching surface temperature of up to 70ºC. This means, especially at night, there is a flow of hot air (convection) which increases the ambient temperature and increase the urban heat effect.

This effect gives a great Energy demand and due to the poor ventilation in the cities with respect to the existing one in the field, it is produce an overheating of urban areas.

On the other hand, solar radiation which is a thermal radiation defined as a set of electromagnetic radiation emitted by the sun which in form of waves propagates in the form of waves with lengths between 150 and 400 nanometers (nm). The radiation which reaches the Earth oscillated between 300 and 2500 nm, the rest is rejected by the atmosphere. This wavelength range it divided in three electromagnetic spectra: UV spectrum: wavelength range between 280 – 400 nm; VIS spectrum: wavelength range between 400 – 700nm; IR spectrum: wavelength range between 700 – 2500nm.

The magnitude which measures the solar radiation is called irradiance and its units are W/m2, each wavelength will have a determinate irradiance. The standard distribution of the irradiance is definite by the ASTM standard G173-03-AM 1.5G, where it is quantified the energy power which affects the Earth layer in each one of the three spectrums (UV, VIS and IR).

These values are measure at sea level, 20ºC temperature and with a determined inclination of the sun (37ºC) to the terrestrial surface. If all irradiances values of all wavelength are added, the total radiation which arrive to the Earth will be 963,8 W/m². With these incident solar results and measuring the reflected energy, one can know the reflectance percentage of a surface. See Fig. 7.

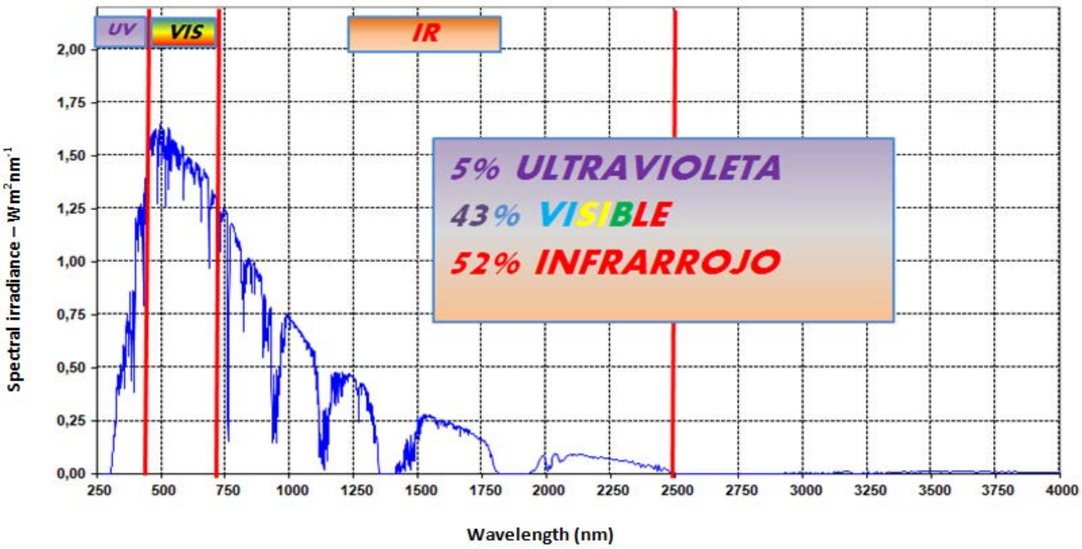

Fig. 7 – Graphic representation of solar spectrum AM 1,5 G-ASTM G173-03.

It can see, approximately the 5% of the energy which affects the Earth's surface corresponds to the ultraviolet spectrum (UV), the 43% to the visible spectrum and 52% to the infrared (IR).

The reflectance value range to zero (for surface without reflectance) from one (for surface with total reflectance). The result may give as a percentage. The absorbance is an inverse concept of reflectance. See Fig. 8.

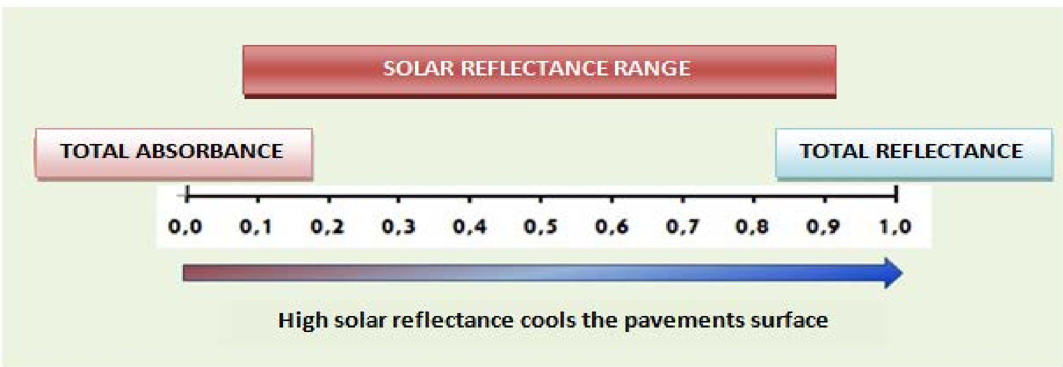

Fig. 8 – Solar reflectance range. Source: own development.

The solar spectrum is composed of UV, VIS and IR, it can determine within the total solar reflectance, the reflected part in the ultraviolet spectrum (UVR), the visible- VISR spectrum and the infrared-IR.

2. MATERIALS AND METHODS

These reflected pavements are able to reduce the surface heating, especially in cities, as a consequence the ambient temperature, so this gets a great importance in summer periods. See Fig. 9.

Fig. 9 – Cool Pavement. Source: own development

According to the LEED v4-ND Certification system sponsored by the US Green Building Council for the Development of Residential Areas, in the chapter GIB CREDIT: HEAT ISLAND REDUCTION, it is selected the measures which the horizontal surfaces of the pavements have to adopt to minimize the heat island effect in the cities.

In particular, pavements are considered reflective when the initial reflectance index is equal or greater than 33% and the reflectance index at three years is equal or greater than 28%. Therefore, based on the definition of the reflectance index, the higher the solar energy reflected, the higher the reflectance index and the lower the solar energy or the heat absorbed by the pavement surface, resulting in less heating of the ambient air, so a lower ambient temperature.

2.1 Measurement methods of solar – SR reflectance on opaque surfaces

In the process of designing the reflective pavements, two test methods have been used to measure the reflectances of the entire solar spectrum in the materials and mixtures developed. One uses a UV-VIS-IR spectrophotometer that measures reflectances in laboratory samples and in the other a pyranometer is used to measure the solar reflectances on surfaces of already constructed pavements.

2.1.1 Spectrophotometer UV-VIS-IR:

To measure the solar reflectance from flat surface it is used a UV-VIS-IR spectrophotometer with integration sphere according to ASTM E 903-12 standard. It is the ideal method for small laboratory samples, 5 x 5 cm in size. It does not serve to measure reflectances on field surfaces. The measurement range is between 300 and 2500 nm of wavelength.

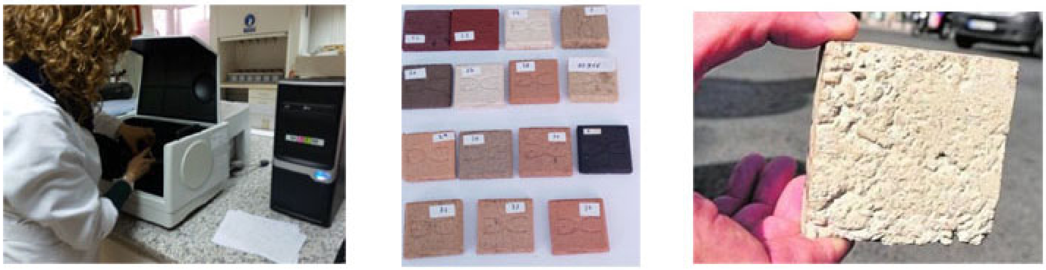

Fig. 10 – Spectrophotometer and simples used

This method of measurement allowed the characterization of the raw materials to use for establish the composition and final dosage of the asphalt pavements developed, according to the criteria of the LEED certification system mentioned above.

2.1.2 Pyranometer:

The solar reflectance is calculated from the measurement of the intensity of the solar radiation, incident and reflected by a surface, with the ASTM E1918 standard (ASTM 2006). Large areas are needed, such as circles with at least four meters in diameter and squares with four lateral meters and a low slope. It measures both the incident energy and the reflected energy in W / m².

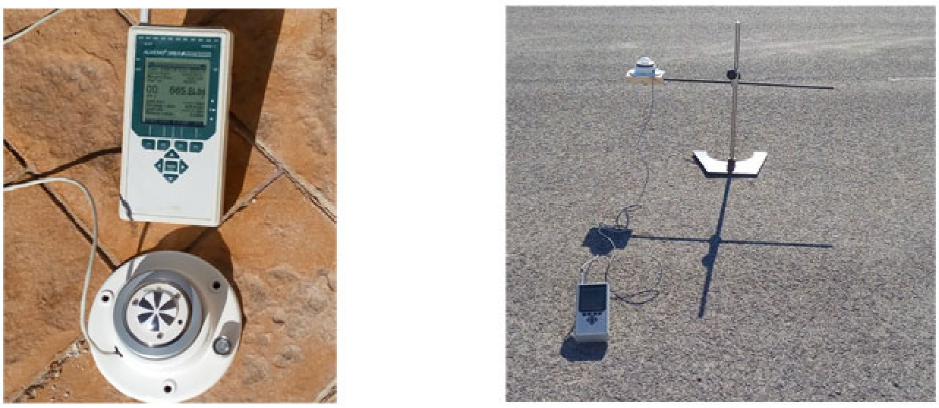

Fig. 11 – Pyranometer and field measurement

According to the defined reflective mixture, tests have been made with their corresponding measurement, which it has been obtained that initially the reflectance index is 40% compared to 7% of a conventional mixture.

Therefore, based on the initial value obtained, initially this mixture is considered reflective and it is expected that it can contribute to mitigate the urban heat island effect.

2.2 Behavior

Regarding, the variation of temperature itself, both superficial and internal, the following figure shows a reference sample of conventional mixture and another of reflective mixture, which the temperature inside of both with respect to the surface temperature varies around 3-4ºC, of which the behavior of both is similar and the data obtained are comparable.

The surface and interior temperature of the reflective mixture differs 8-10°C with respect to the conventional mixture. This temperature difference does not depend on the ambient temperature but depends on the radiation which reaches the exposed surface.

With this, the reflective mixture, when subjected to a lower temperature, will have a longer life than the conventional mixture.

In addition, the reflective mixture has been subjected to the regulatory tests in Spanish regulations (granulometry, density, hollow%, water sensitivity, Marshall deformation, rolling resistance - track test, etc.) and it is concluded that it meets the regulatory requirements, like conventional asphalt pavements.

2.3 Benefits

According to North American studies, in particular, the one realized by the investigating group Heat Island Group of the National Laboratory of Energy Lawrence Berkeley (LBNL), for pavements with reflectance index superior to 40%, the benefits are the following:

- Energy savings: in lighting system -Public light- and air conditioning system -air conditioner-.
- Natural improvement: air quality.
- Improvement quality of life: comfort and pedestrian.

It is expected a temperature reduction on surface between 10-12ºC respect to conventional mixture, probably it will be a temperature reduction of 1-2ºC so it will save 0.5KW/m2 in air conditioner, as a consequence a reduction in energy demand.

In addition, the decrease in ambient temperature causes the slowdown of photochemical reactions and, consequently, the formation of "smog" by the 5% decrease in tropospheric ozone due to tropospheric ozone in abundant quantities is considered a pollutant of the atmosphere.

Respect to change of the hue of the reflective mixtures with respect to the conventional ones, it would suppose a saving of 30% in public lighting due to the need of less power in the luminaries, which translates in a saving of energy consumption, together with the above, leads to lower levels of CO2, NOx and VOCs to cover the energy demand.

On the other hand, with the solar reflectance measurement methodology, the total solar reflectance value is obtained in %. You can also obtain the % of the reflectance of the three spectra (UV-VIS-IR) separately, this possibility of calculation is very important for the design criteria of the reflective asphalt mixtures. We look for pavements with high reflectance in the visible and infrared, and low reflectance in the UV (this will avoid any inconvenience to the users of the pavements), for this we will take into account the color and physical-chemical characteristics of the components of the mixtures.

From this, it wanted to check if the clear tone of the reflective pavement could be harmful to health due to the level of reflectance. To do this, a comparison was made of the reflectance values for the wavelengths of each spectrum in other surfaces which are harmful to health such as snow, and another with conventional pavements which are not.

It is known the ultraviolet-UV electromagnetic spectrum is harmful to health; the following figure determines the solar reflectance values and shows that the UV wavelength behavior of the reflective asphalt pavement is more similar to conventional asphalt pavement, far from the reflectance of a surface harmful to health such as snow. See Fig. 12.

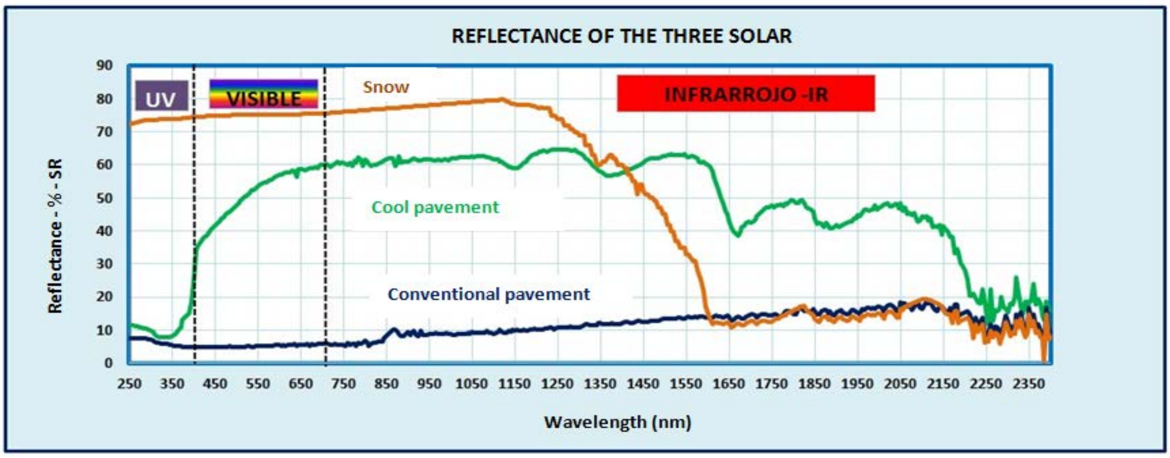

Fig. 12 – Graphic representation of the reflectance of the three solar spectra on snow surfaces, reflective and conventional asphalt pavements.

Therefore, from the design system of obtaining reflectance of the pavements separately, low reflectance of the ultraviolet-UV spectrum can be achieved, which will allow to circulate through the reflective pavements reducing the need to use sunglasses or sunscreen, in contrast to what occurs in other surfaces such as snow, due to its high reflectance of the ultraviolet-UV spectrum and that the mixture developed so far meets the expectations of being a reflective asphalt pavement that may contribute to the mitigation of change climate.

3. RESULTS

The developed technology has been studying by CHM, with CTCON collaboration, with REPARA 2.0 project. Also, a prototype LIFE HEATLAND project with the European support of the LIFE program whose general objective until 2020 is to group forces to contribute to sustainable development achieve the objectives and goals of the European 2020 Strategy and the strategies and plans of the European Union on the environment and climate. The following results are:

- 24.000 m2 of the cool pavement installed. The pavement albedo is expected to be increase from the 0.05 for conventional asphalts to 0.46 for the new technology.
- Four metering towers built-up and data acquisition system correctly working.
- Quantitative and qualitative demonstration of the effectiveness of the innovative pavement to mitigate the UHI effect. Throughout the test program, about 1.5 million data will be obtained: metering towers will register, every 30 minutes, 24 hours/day and during 2 years, the following parameters: pavement surface temperature, air temperature (at 0.5, 1.5 and 4 m height), moisture, wind speed, solar irradiance, air ozone, illumination level and noise; together with thermography, existing and new pavement samples analysis and other related information.
- To actually mitigate the UHI effect in the implementation area. It is expected to reach an air temperature decrease of 1.5ºC and a surface pavement temperature decrease of 10ºC. Energy savings of 7% for refrigeration devices and 5% for street lighting are expected.
- A mathematical model to predict the effect of the innovative pavement implementation in other urban areas.
- Quantitative demonstration of the economical balance of the new technology and its feasibility.

Fig. 13 – Work area. Demonstrator.

Fig. 14 – Monitoring tower

Fig. 15 – Location – monitoring tower.

Fig. 16 – Demonstration results about innovation pavement.

Fig. 17 – Crosswalk. Intersection between pavements.

Fig. 18 – Thermometer. Surface temperatura difference dirty-clean 4,7 ºC, conventional-cool pavement clean 13,1 ºC (14/06/2020 - 15.30 a.m.).

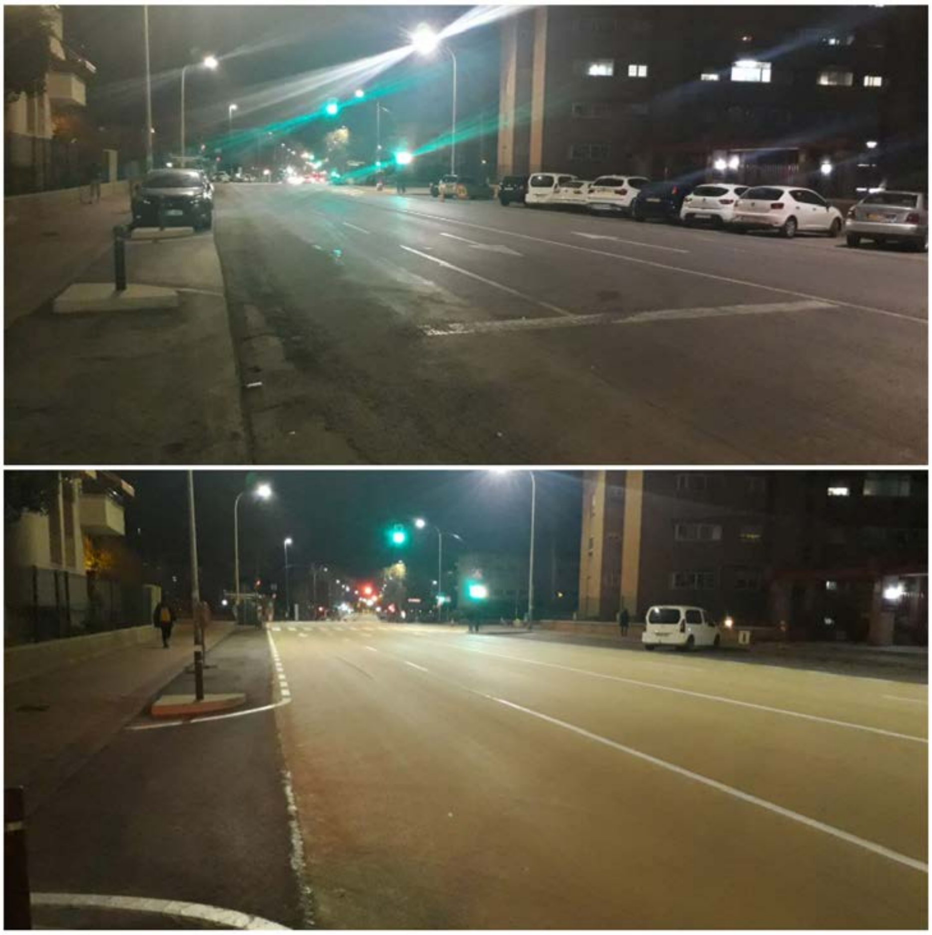

Fig. 19 – Night results, before and after cool pavement.

4. CONCLUSIONS

Until today, the demonstrator has been monitored and the following conclusions have been obtained, validating this type of pavement as a mechanism to reducing the urban heat island effect:

- Initial luminance of reflective pavement 2.5cd / m2 under the lamppost, 150% higher than the conventional asphalt street.
- Solar reflectance of 30%, almost four times higher than that of conventional asphalt.
- Average surface temperature with reflective pavement 7-11ºC lower than that of the conventional pavement surface
- Areas of the asphalt where rubber has been deposited from the tires as a result of the rolling of vehicles are heated 1-3ºC more than the clean areas.
- Lower environmental lower noise level of the area: 3 dB (A).

Fig. 20 – Demonstrator results.

4.1 Innovation

- National Patent (Spain): P201830642
- Patent Cooperation Treaty: PCT/ES2019/070432
- European Patent: 19827481.3 – PCT/ES2019/070432

ACKNOWLEDGEMENTS

- Centro para el Desarrollo Tecnológico Industrial (CDTI).
- Programme LIFE.
- CHM Obras e Infraestructuras, S.A.
- CTCON: Julio López, Gloria Motos, Francisco Moral, etc.
- Ayuntamiento de Murcia.
- XIV Congreso de Ingeniería del Transporte (CIT 2021).

REFERENCES

ALCHAPAR, N. L., & CORREA, E. N. (2016). The use of reflective materials as a strategy for urban cooling in an arid “OASIS” city. Sustainable Cities and Society, 27, 1-14.

HELEN ROSE WILSON,JOHANES HONEK Y TILMAN E. KUHN (2015), Instituto Fraunhofer Freiburg i. Br. “Índide de reflectancia solar (SRI) del hormigón”.CPI, Oct. 80-86

YANG, J., WANG, Z. H., & KALOUSH, K. E. (2015). Environmental impacts of reflective materials: Is high albedo a ‘silver bullet’for mitigating urban heat island?. Renewable and Sustainable Energy Reviews, 47, 830-843.

TAM, B. Y., GOUGH, W. A., & MOHSIN, T. (2015). The impact of urbanization and the urban heat island effect on day to day temperature variation. Urban Climate, 12, 1-10.

QIN, Y. (2015). Urban canyon albedo and its implication on the use of reflective cool pavements. Energy and Buildings, 96, 86-94.

ZHENG, M., HAN, L., WANG, F., MI, H., LI, Y., & HE, L. (2015). Comparison and analysis on heat reflective coating for asphalt pavement based on cooling effect and anti-skid performance. Construction and Building Materials, 93, 1197-1205.

STONE JR, B., VARGO, J., LIU, P., HABEEB, D., DELUCIA, A., TRAIL, M., ... & RUSSELL, A. (2014). Avoided heat-related mortality through climate adaptation strategies in three US cities. PLoS One, 9(6), e100852.

SANTAMOURIS, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. Renewable and Sustainable Energy Reviews, 26, 224-240.

SANTAMOURIS, M., GAITANI, N., SPANOU, A., SALIARI, M., GIANNOPOULOU, K., VASILAKOPOULOU, K., & KARDOMATEAS, T. (2012). Using cool paving materials to improve microclimate of urban areas–design realization and results of the flisvos project. Building and Environment, 53, 128-136.

Other references:

- https://www.coolrooftoolkit.org/
- http://www.usgbc.org/resources/leed-v4-building-design-and-construction-current-version
- http://www.emeraldcities-international.com
- http://albedomap.lbl.gov/#0
- https://www.epa.gov/heat-islands
- http://www.urbanheatislands.com/

- http://www.albedocontrol.it/Pubblicazioni/ALBEDOSAT.pdf
- https://heatisland.lbl.gov/projects/projects-cool-communities)-
- https://heatisland.lbl.gov/publications/mesoscale-climatic-simulation-surface
- http://www.model.envi-met.com/hg2e/doku.php?id=apps:albero:start
- http://ec.europa.eu/environment/integration/research/newsalert/pdf/cool_pavements_reduce_urban_heat_islands_state_of_technology_450na3_en.pdf.
- www.chm.es
- http://www.proyectorepara.com/
- https://heatlandlife.eu/