Technical advances in the EU-Cool Roof project.

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Abstract

Cool materials keep the roof cool under the sun by reflecting the solar radiation away from the building and radiating the stored heat away during night time. The potential of the technology is very promising at EU level and, in particular, in the Mediterranean area. EU supports the Cool Roofs Project, where important technical actions are developed. The technical and scientific activities include: development of the first EU cool materials database; implementation of five case studies with different building typologies equipped with different cool materials; development and validation of a dedicated toolkit; production of the cool materials handbook. The paper summarises the most significant results achieved in the project.

1. Introduction

Two important phenomena recently emerged at building and urban level: the increase of peak demand and energy consumption for cooling, as well as the increase of the urban heat island effect in intensity and frequency. These issues fall within the general concern of climate change and have many implications at different levels: energy and land use, thermal comfort, public health, environmental hazards.

Few data frame the problems: according to OECD/IEA [1, 2], the energy consumption in the civil sector, including residential and tertiary, accounts for 50% for the electricity consumption. This value increases to more than 60% in the OECD (including western Europe, USA, Canada, Japan) countries. The total electricity consumption increased by 2.3% in 2005 in respect to the year before, but the percentage raised to 3.7% in building applications. The variation was 5.6% in dwellings and 1.6% in tertiary buildings. The latter point is interesting: an impressive power consumption increase in dwellings, naturally cooled until few years ago. The temperature rise as well as new comfort expectation are driving this change, even in moderate climates. The trend might have dramatic environmental impacts when this comfort expectation models will be adopted in emerging and highly populated areas of the planet.

The phenomenon depend on the temperature rise, which finds the strongest intensity in large urban areas characterised by the urban heat island (UHI), defined as the air temperature rise in densely built environments in respect to their countryside surroundings. Many studies carried in the past years stressed the effect of the urban heat island [3, 4,5]. They demonstrated that UHI is an environmental, energy, comfort and health problem, affecting the cities population. The energy issue is demonstrated by many measurement campaigns showing daytime average temperature differences between 2 and 5 degrees in built environment in respect to rural area. Peaks between 6 and 10 degrees are registered under particular conditions. UHI takes place at many latitudes and affects the energy demand, the peak consumption and the thermal comfort of buildings and people.

The vegetation plays an important role cooling the air by evapo-transpiration, but this result cannot be fulfilled in densely built areas, where concrete, asphalt and other construction materials replace trees, plants and lawns. The properties of construction materials, and cool materials in particular, are one of the possible solutions to fight the above mentioned energy and environmental hazards.

2. Cool roof: a short introduction

The cool roof, or the use of light colours for the building envelops, is an ancient concept, still witnessed by shining examples. One of these is the vernacular Mediterranean architecture, characterized by passive solutions able to ensure thermal comfort conditions in the built environment during the hot season. Among several solutions are massive structures, solar protection, natural ventilation, the use of light colours helped avoiding the building overheating. The coast of the Mediterranean, from Spain to Greece, to the south rim of the basin, testify to these design rules. This cultural heritage almost disappeared, delegating the comfort conditions to artificial systems or inducing unsustainable thermal conditions in not cooled buildings.

Cool materials and cool roofs are a mix of ancient concepts and modern technologies, characterised by two surface properties:

- Solar reflectance, defined as the fraction of the incident solar energy which is reflected by a material surface. The property expresses the material attitude at rejecting the solar radiation, avoiding its temperature rise and the thermal load inducted to the building structure and the built environment. The solar reflectance is sometimes considered as a synonym of albedo. This is partly true, since the reflectance is a characteristic of a material, while albedo indicates the total reflectance of a specific system, for example an entire town.
- Thermal emittance, defined as the ratio of the radiant heat flux emitted by a material surface to that emitted by a black body at the same temperature. It expresses the attitude of a material to radiate away the heat absorbed and stored within the structure.

If conventional construction materials are characterised by high thermal emittance, they generally have high solar absorptance and low reflectance. This is the reason why they get hot under the solar radiation, with surface temperature that can get up to 40°C hotter than the correspondent air temperature, while white cool roof get only few degrees warmer than air during daytime and several degree cooler at night. Any kind of roofing systems can become cool, using innovative solutions that make it durable, efficient and reliable.

Due to the growing interest of the technology and to the above described environment framework, the EU Commission funded the project PROMOTION OF COOL ROOFS IN THE EU, implemented within the IEE (Intelligent Energy for Europe) – SAVE Programme. The project will finish in February 2011 and the main achievements can be found at the project website: www.coolrrofs-eu.eu.

The project support the promotion of the technology through four main axes: technical, market, policy and end user. Moreover one of the major tasks of the project is the foundation of the Cool Roof Council, the organisation that will drive the cool roof market, joining the efforts of the participants that will include: universities and research centres, industries, policy makers and end users representatives.

The paper presents the most relevant results and achievements obtained by Work Package 3 – Technical Aspects of Cool Roofs, according to the project tasks. Two important phenomena recently emerged at building and urban level: the increase of peak demand and energy consumption for cooling, as well as the increase of the urban heat island effect in intensity and frequency. These issues fall within the general concern of climate change and have many implications at different levels: energy and land use, thermal comfort, public health and environmental hazards.

3. The database

Objective of the database is to present cool roof products and technologies available on the EU market. The cool roof market was practically unknown at the time the project started. Several, mainly small, companies worked in the sector but the feedback was essentially local. The database is the chance to fix the state of the art of such products but also to increase attention on this market with significant potentialities. The database will be available as a spreadsheet file at the end of the project. This first version is available as a text file for the public in the dedicated section of the website. Task of the project was to define the structure and the contents of the database. Following, the main data required for the product inclusion are listed:

- Name of the product
- Type of product
- Roof application
- Material substrate
- Solar reflectance
- Infrared emittance
- Maximum surface temperature
- Solar reflectance index

The first information is related to the generalities of the product, include the producers and the place of origin. The second set is related to the construction characteristics of the product, including the type of cool roof, the roof substrate and characteristics suitable for the product itself. The last data are related to the thermo physical properties of the material (solar reflectance and thermal emittance) and derived properties (maximum temperature surface and solar reflectance index), which expresses the capability of the material to stay cool under the sun.

In addition, task of the project was tostart populating the database through an experimental campaign, run by the National & Kapodistrian University of Athens - Group of Building Environmental Studies (NKUA) and Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA). The following equipments were used:

- Spectral reflectance measurements were performed at ENEA with a Perkin Elmer Lambda 950 spectrophotometer.
- Spectral reflectance measurements were performed at NKUA with a Varian Carry 5000 spectrophotometer.
- Broad band infrared emittance measurements were performed with a Devices and Services AE emissometer at NKUA laboratory.

The first version of the database includes more than 100 products, including coatings, membranes, mortars and tiles. Light colours are predominant for evident reasons: 22 white, 13 green, 16 yellow/ochre, 6 beige, even if a wide range of chromatic solutions was tested. Also dark cool coloured materials (reference) were tested. Cool coloured material are characterised by an increase reflectance in the near infrared range, which leads to higher solar reflectance values respect to a conventional product of the same colour. More 10 brown and black cool paints were submitted and included in the database. Without going into the details of the results, figure 1 presents two product types: white coatings and cool materials with titanium dioxide. The left figure show how white materials can have different solar reflectance, mainly depending on the spectral response in the near-infrared, even if also significant differences were measured in the visible spectrum as well. The right figure presents cool materials of different colours treated with titanium dioxide in order to achieve a double function: increase the solar reflectance and produce a photo-catalytic product.

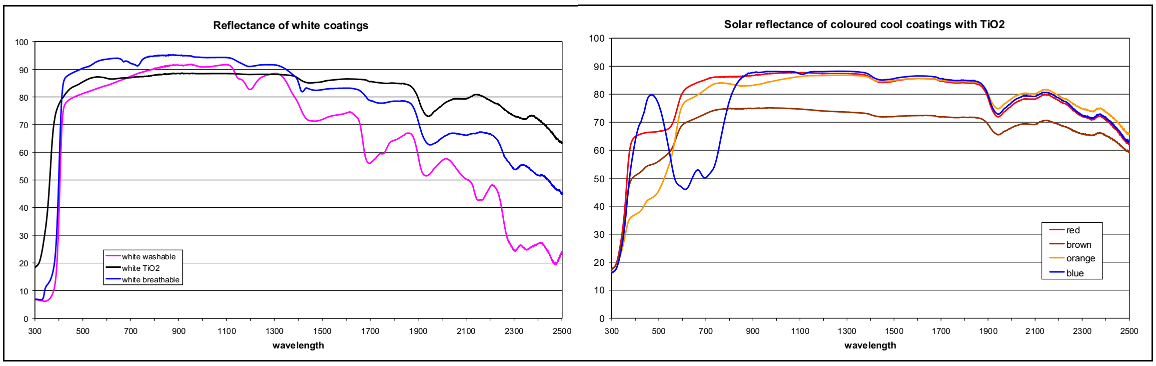

Figure 1 Spectral reflectance of white materials

3. The case studies

The case studies were one of the most important tasks of the project, since the intention was to demonstrate how the technology works in real buildings, improving the thermal comfort conditions in not-cooled buildings and improving the cooling energy performance in cooled buildings. Five buildings were selected to pursue this objective:

- School building in Kaisariani, Greece;
- Laboratory building in Iraklion, Greece;
- Public dwelling, in Poitiers, France;
- Public building in Trapani, Italy;
- Office building in London, United Kingdom

The case studies were implemented in two phase: 1) experimental monitoring of the selected buildings under real use and conditions, before and after the cool roof applications; 2) numerical analysis of the same buildings to collect more general results and knowledge about the cool roof performances. This was required since the experimental results of the building, before and after the cool roof application, could not be directly compared because of the variables affecting the building behaviour, i.e. climatic conditions, building use, occupation profiles, energy system management, etc. A numerical analysis of the building was, hence, needed to overcome this problem and provide more general results.

3.1. The procedure

The monitoring was carried out for several months and the most relevant indoor and outdoor physical data were acquired. Climatic data, if not measured on site, were collected using nearby measurement stations. The building characteristics and details were obtained by: original design tools; building inspection; on site measurements of the envelope components and related calculation; national or European reference data.

A common methodology was implemented to transfer monitoring results into the numerical analysis. The procedure was based on the calibration of the model by comparing the calculated versus measured indoor air temperatures. The admissible error, defined as the ratio of the absolute daily mean temperature difference between the measured and calculated values on the measured daily mean temperature (|Tmeas-Tcalc|/Tmeas), was set to 10%. A tuning of the model was performed until the error fell into the fixed bands for the whole calibration days. Once the model was calibrated, it was possible to compare the performance of building after and before the cool roof application. A number of building variants were carried out on the standard buildings in order to compare different low energy techniques.

Figure 2 Cool roof applications

3.1. The results

The complete report of the case studies can be found on the public section of the project website; following few exemplary results are presented. Figure 2 shows three photos during the cool roof applications. The left photo presents the Kaisariani school roofing; the photo in the middle show the different roof products (cool and conventional) on the top of La Rochelle dwellings in France; the right end picture shows the roof after the cool roof application in the office building in London. The latter is the only case study where a non-white coating was used, this product has a high solar reflectance (0.7) slightly lower in respect to the white coatings (around 80% or more). Figures 3 shows the different roof response to the solar radiation by means of thermographic images in the Kaisariani school. A 12°C difference was measured, significant considering that the images were not acquired during the peak conditions. The different surface temperature levels for a conventional and a cool roof are plotted together with the air temperature in figure 4. The results refer to the Trapani building. The graph shows that the conventional roof gets up to 25°C hotter than the air, while the white coating is never warmer than 5°C, this allows the roof to cool its temperature several degrees below the air temperature.

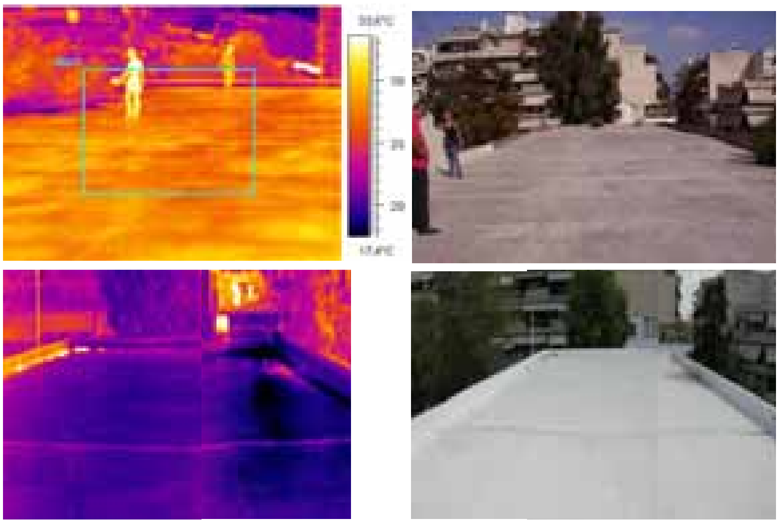

Figure 3 Cool roof thermography in the Kaisariani school..

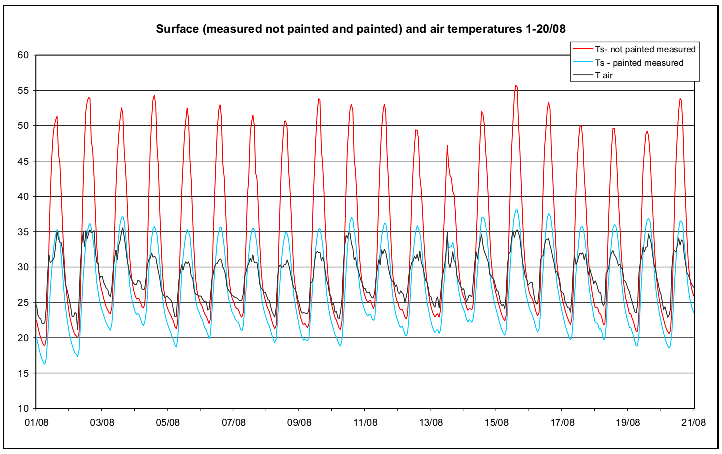

Figure 4 Outdoor air and the roof surface temperatures painted and not painted in Trapani building

The calibration work was satisfactory for all the case studies and this allowed to perform detailed numerical analysis to assess the impact of the cool roofs versus the conventional roofs, taking into account several variants such as: insulation levels, alternative cooling techniques, building use (typically cooled or not cooled buildings). As an example, figure 5 reports the cooling and energy savings, as well as the heating penalties for the laboratory in Iraklion. The climatic conditions are favourable, with a small heating demand. Nevertheless, it can be seen that the cool roof is the best performing technology among the selected. The maximum cooling benefit was found in Trapani, with saving of 54% attributed to the cool roof application. The analysis of all the calculated data demonstrated that apart from the cooling consumption savings, also the heating penalties have to be considered. The latter can overcome the former especially in not insulated buildings in several

European climates. Noticeable thermal improvements were calculated in not cooled buildings, especially with the decrease of indoor temperature peaks.

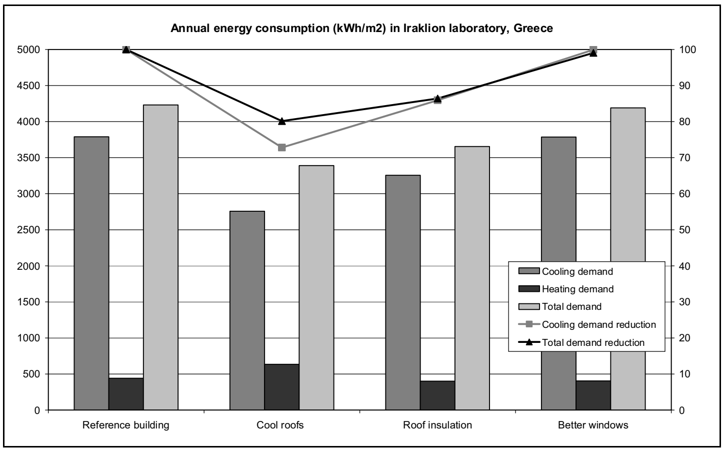

Figure 5 Calculation results of the Iraklion laboratory building in Greece

4. The toolkit

The toolkit is a web based instrument for the evaluation of the energy performance for cool roofs' application in the EU region. The main specifications requested by the specific toolkit were to be user friendly, accessible and as accurate as possible. Annual cooling and heating loads are calculated based on degree day method and then were regulated to include internal gains. The concept of the tool takes origin by similar US studies [6], but was refined on the basis of typical EU based requirements.The toolkit works using polynomial equations, function of the below reported inputs. A regression, carried out by means of a high number of dynamic simulation, allowed the determination of the coefficients, which the polynomial equations are based on. The toolkit is suitable for cool low slope roof applications. The input parameters are the following:

- Country and city selector: Most European countries are included. If a city is not listed then the nearest one in terms of latitude, i.e. of similar climatic conditions, may be selected.
- R-value (thermal heat resistance): This value refers to the existing roof. It generally falls between 0.80 and 5. The higher the R-value, the greater a product's resistance to heat flow and the better its insulating value. Even though the calculator accepts low R-values, values less than 0.25 may produce erroneous estimates. The estimator works best in the following range of values: $0.9<R<7$
- Solar reflectance (SR) and infrared emitance (IE): These values refer to the proposed roof. The values may vary: $5<SR<95$; $5<IE<95$
- Energy systems efficiencies and operational costs.

The outputs of the toolkit are:

- Heating and Cooling Degree Days for the specific area.
- Heating and Cooling Loads per surface area of roof for a black roof considering that a black roof has solar reflectance equal to 5%.
- Heating and Cooling Loads per surface area of roof for a cool roof.
- Cost savings.

5. The technical handbook

The handbook brings together the main results of the technical aspects of the project as well as proposals for the incorporation of Cool Roofs benefits and facts into EU policies. The handbook gives an overview of Cool Roofs characteristics and technical aspects including relative merits in comparison to other strategies. It continues with the description of Cool Roof materials in Europe and presents the EU Cool Roof materials database developed. It presents results from the pilot actions carried out in five buildings and describes the developed tool-kit for Europe which can be used for the assessment of Cool Roofs in the various EU regions.

6. Conclusions

The Cool Roof project is dedicating lot of effort to the technical aspects of the technology. The database advises the building and roofing sector of the available EU products. The case studies demonstrate the potential of the technology. The tool-kit and the handbook are important instruments in support of all the stakeholders, technical or not, for a better understanding of cool roof technology and the associated potential energy and economic savings.

Acknowledgments

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Intelligent Energy Europe

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