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Impact of a cool roof application on the energy and comfort performance in an existing non-residential building. A Sicilian case study

C. Romeo, M. Zinzi*

ENEA – Italian National Agency for New Technologies, Energy and Sustainable Economic Development Technical Unit for the Energy Efficiency, Casaccia Research Centre, Via Anguillarese, 301, 00123 S. Maria di Galeria, Rome, Italy

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ABSTRACT

The vernacular Mediterranean architecture was characterised by passive solutions able to ensure thermal comfort conditions in the built environment during the hot season. The use of light colours to redirect most of the incident solar radiation was based on these traditional solutions. Cool roofs are a mix of ancient concepts and modern technologies; their application in new and existing buildings can significantly improve the energy efficiency during the cooling season and throughout the year. The paper reports the results of a large application in an office/laboratory building belonging to a school campus in Trapani, on the west coast of Sicily. The experiment was carried out in two phases. The building was continuously monitored during the first phase from late April to late September 2009: indoor and outdoor air temperatures, relative humidity and solar radiation were acquired. The monitoring was carried out before and after the cool eco-friendly white paint application, characterised by high solar reflectance and thermal emittance. The monitored data were used to calibrate the building model input into a dynamic simulation tool, used to evaluate the building performance with a number of variants. The analysis gave interesting results on the potential of this technique for the southern European climatic conditions.

1. Introduction

Most European energy consumption takes place in cities and towns, as 73% of EU citizens live in urban areas, and this share is expected to grow to 80% by 2030 [1]. Urban density and the design of the built and natural environments of cities therefore play a crucial role in shaping consumption patterns. Climate changes and, in particular, the global warming lead to other effects at urban level: the ambient temperatures increase, more frequent heat waves and hot spells with a longer duration.

A typical effect of this new condition consists in the urban heat island (UHI) effect. It is defined as an increase in urban air temperature compared to cooler surrounding rural areas. The main cause of the urban heat island is the modification of the land surface in the urban area, where the vegetation has been replaced by built surfaces (typically paved roads and buildings surfaces), characterised by high solar absorption, high impermeability and favourable thermal properties for energy storage and heat release. Several anthropogenic activities cause an additional increase of the air temperature as: exhaust of public and private transports, exhaust of building heating systems, heat dissipated by air conditioning systems. Several studies carried out at different latitudes confirmed the existence of the phenomenon: UHI intensities up to 12 °C have been measured, while many studies carried out in urban area around the world showed that daytime and daily UHI range between 2 and 6 °C [2–8].

Urban temperature profiles affect the energy consumption in buildings. This sector accounts for approximately 40% of total final energy consumption and 36% of CO_2 emissions in Europe [9]. The electricity consumption for cooling buildings is continuously increasing in Mediterranean countries, with a new and relevant market share in residential buildings during the last decade [10].

Passive building technologies contribute to mitigate the cooling demand increase, reducing the energy consumption in cooled buildings and improving the thermal comfort in non-cooled buildings [11]. Several techniques are available to optimise the energy performance of buildings, but they will imply a re-thinking of the construction and architectural mainstream [12]. The solar radiation control is the most important passive strategy in summer. Because of the high horizontal solar radiation at Mediterranean latitudes during the cooling season, roofing systems are the envelope opaque component mainly involved in the solar control, since they can get higher than 30 °C warmer than the ambient air temperature. A wide study on the performance of urban construction materials can be found in Ref. [13].

Cool materials are a particular category of materials and components able to stay cool under the solar radiation. They are characterised by high solar reflectance values, which reduce the

* Corresponding author. Tel.: +39 06 30486256; fax: +39 06 30483930.
E-mail address: michele.zinzi@enea.it (M. Zinzi).

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solar radiation absorbed by conventional building materials and limit the surface temperature rise in the presence of high solar loads. These materials are also characterised by high infrared emittance values being able to emit to the sky during the night and dissipating the accumulated heat without transferring it indoors. Roofing systems using such materials are called cool roofs (CR). These characteristics allow the material to rise its surface temperature only few degrees above the ambient temperature, reducing the heat released from the roof to the outdoor air by convection and, as a consequence, mitigating the urban heat island effect.

Lower surface temperatures also reduce the heat transfer from the roof to the built environment reducing the cooling load of the building. Main cool roofs materials are available as tiles, asphalt shingles, metal roofs, elastomeric coatings, single-ply membranes. During this decade the interest in this cool technique arose again and it is now possible merging old concepts with new technologies (most of these already available on the market), more affordable, efficient and durable.

A comprehensive study of the cool roofs impact, on the building energy performance was conducted in several US climate zones. The citywide application of cool roofs can lower the average surface temperature, which in turn cools the outside air leading to indirect savings as urban air temperatures are reduced [14,15]. Cool roofs thereby could help to mitigate the "daytime urban heat island" by making cities cooler in summer [16]. The effect of cool roof solar reflectance has been also seen as an additional thermal insulation, with benefit for the cooling performances [17,18]. Calculation studies using dynamic codes were performed in order to assess the potential energy savings arising from the application of cool roofs at several latitudes [19,14]. A comprehensive analysis for Mediterranean residential buildings can be found in Ref. [20].

The most diffuse cool roof systems are the white coatings. Results on review and testing of such materials can be found in [21,22]. The study shows that also metal roofs, even if characterised by low emittance values, can be cool in case of high solar reflectance. Recently cool coloured materials were developed and tested. They are mainly based on spectrally selective inorganic or organics pigments characterised by a high reflectance in the infrared portion of the solar spectrum, maintaining the reflectance profile of conventional coloured materials in the visible spectrum. They are used for coatings and tiles and present a solar reflectance much higher than that of conventional coloured materials. This high reflectivity is due to pigments [23–25]. Thermochromic materials characterised a dynamic envelope able to respond to the environment inputs are still at the research stage [26].

Monitored applications of cool roofs in real buildings, replacing existing conventional roofs, demonstrated the efficacy of the technology in reducing the cooling energy demand or improving the indoor thermal conditions [27,15]. Similar studies were carried out using scale models [28,29].

This study will address the positive effects of a cool roof application in reducing the energy cooling demand and increasing the thermal comfort of a public building in the south Mediterranean area. Other critical issues, as durability and ageing of the materials, were not taken into account in this study and will be addressed in next research activities.

2. Implementation and analysis of an Italian case study

The main objective of this study is to demonstrate that cool roofs techniques are now ready and able to bring energy, comfort and environmental benefits to the European building stock. This case study is intended as an example of the cool roof capabilities in improving the indoor thermal conditions and in reducing the energy consumption in cooled buildings.

Table 1
Net area and volume of the school building.

Zone	Walls (m^2)	Windows (m^2)	Net floor area (m^2)	Net volume (m^3)
1. Staff room	93.5	24.9	112.4	370.9
2. Head mistress	9.8	9.0	41.9	138.0
3. Office rooms	34.2	17.3	97.1	320.4
4. Corridor	31.6	32.1	173.3	571.8
5. Laboratories	54.2	39.1	200.0	660.0
6. Secretary	54.1	30.7	81.9	270.3
Total	277.4	153.1	706.6	2331.4

Overheating in the summer has been repeatedly reported by the occupants, mainly due to failures of the air conditioning system: cool roof application revealed to be a solution to mitigate indoor summer discomfort conditions.

2.1. Description of the building

The building considered in this case study is a school located in the municipality of Trapani, a town on the west coast of Sicily, whose latitude is representative of building constructions characterised by a high cooling energy demand. This public building is a mixed office and laboratory structure consisting of a single floor and has an irregular rectangular shape (Fig. 1). The two main facades are north-west and south-east oriented. The ground floor is articulated in a staff room (1), the headmistress' office (2), office rooms (3), corridors and toilets (4), laboratories (5) and the secretary office (6). The roof is a flat one.

The school building has been analyzed as a multizone building. The plan distribution has been described creating the model to be investigated strictly responding to the real internal uses and occupancy profiles. The geometrical characteristics (areas and the volumes) of the six identified zones of the building are presented in Table 1. The gray area was not considered in the model. The total area and volume of the school building are shown in Table 1.

2.2. Envelope characteristics

The framework of the building is of reinforced concrete and the masonry consists of volcanic limestone blocks not insulated. The external surface finishing is of gray plaster. The windows consist of single glass glazing with aluminum frame. All transparent surfaces present internal shading devices manually handled and are also provided with external vertical concrete elements as solar obstructions which are particularly effective for east and west exposures. The roof external finishing is of gray concrete tiles. The ground floor is above an air cavity partially filled with water.

In order to take account of the correct contribution of the internal gains of the school building we considered three kinds of gains: heat gains from occupants, from appliances installed and from artificial lighting subjected to different hourly profiles in the model.

There is an installed electric heat pump system for both heating and cooling conditioning with fan coils in each zone.

2.3. Cool roof technology

The existing roofing system was a concrete tile, made darker by the soiling through the years.

The application of cool roofs technology aimed to achieve:

- energy benefits by reducing summer cooling loads obtained by increasing the thermal reflectance of the roof coating;
- environmental benefits by the mitigation of the urban heat island effect;
- comfort benefits due to acceptable indoor thermal conditions.