ON THE ANALYSIS OF COOL ROOFS FOR COOLING SYSTEM EFFICIENCY

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ABSTRACT

Cool roof is a well-documented passive cooling strategy for buildings in several climate conditions. The mechanism consists of the reduction of the heat load entering the roof, which is characterized by high solar reflectance and high thermal emittance. The purpose of this paper is to study the coupled effect produced by such a technology. First, the passive cooling contribution is quantified, then, the "active" contribution is investigated. This latter effect consists of the cool roof capability to decrease the suction air temperature of heat pump external units, when these units are located over the same roof. This "cooling" benefit produce an extra-increase of the energy performance of the heat pump in cooling mode, given that it produces the decrease of the temperature lift between the source and the output. In order to study this twofold effect, an industrial building with an office area located in Rome, Italy, was continuously monitored in summer 2012. The thermal behavior of the roof, of the indoor environment, and the energy requirement for cooling were evaluated. The main results showed that the cool roof allows to decrease the roof overheating up to 20°C. The office indoor air temperature was lowered, even if the same set-point temperature was kept constant during the whole campaign. The energy requirement for cooling decreased by about 34% during the working time of the office. In order to investigate the "active" contribution, suction air temperature was monitored and a new simple analytical model is proposed in order to estimate the cool roof effect in reducing the air overheating over the roof and, therefore, the temperature lift to be smothered with the cooling system.

KEYWORDS

Cool roof; Energy saving in buildings; roof albedo; passive cooling; office building; energy efficiency.

1 INTRODUCTION

Cool roofs are those roofs that are able to reflect solar radiation and emit heat, keeping the roof cooler than a traditional roof even when subject to high solar radiation [1]. In cool roof applications, the incident solar radiation is reflected by roof, and the absorbed radiation entering the roof is consequently decreased. This passive phenomenon implies lower heat load penetrating the roof and into the thermal zones of the building, with the following reduction of energy requirement for cooling. Cool roof performance represents the object of many important studies concerning cool coating application over the roof of residential and non-residential buildings, which behavior is analyzed through experimental and numerical analysis [2].

Haberl and Cho, in their literature review about the effect of cool roofs on building energy saving for cooling [3], showed that the achievable energy saving amount is about 20% in residential and commercial buildings. They reported a cooling energy saving average range of 2-44% , and the reduction of the cooling peak of 3-35%. Cool roof performance is influenced by several parameters such as the ceiling insulation level, the attic configuration, climate conditions, occupancy schedules and inter-building phenomena in general. The effect of cool roofs in determining cooling load and thermal comfort conditions was investigated by Synnefa et al. in [4] for residential buildings. The study consisted of an integrated experimental and numerical assessment aimed at estimating the effect of cool colored materials for envelopes in 27 cities around the world. They investigated cool roof potentialities in different climatological conditions, such as: (i) Mediterranean area, (ii) humid continental area, (iii) subtropical arid area, and (iv) desert. They considered the same building layout for modeling the case study prototype and its technical-architectural features. Therefore, they estimated the cooling energy savings, together with the potential wintertime penalties. The main findings show that the increase in roof solar reflectance by 0.65 is able to reduce: (i) cooling loads of 8-48 kWh/m^2, (ii) discomfort hours by 9-100%, and (iii) peak temperature by 1.2°C to 3.7°C. The main variables to consider, when performing cool roof assessment, are climate and roof insulation level. Winter potential penalties (0.2-17 kWh/m^2) are in general lower than summer benefits (9-48 kWh/m2) and they could be worsen by high-transmittance level of the roof. In fact, the roof reflectance increase could potentially increase the heating energy demand. Several numerical and experimental studies have shown that this winter penalty is basically far less incisive than the cooling benefit, producing an overall year-round energy saving in both mild and moderate climate regions [5].

Important studies also took into account cool roof effect in determining indoor thermal comfort conditions, especially for free floating buildings, where the cool roof, as passive solution, is able to produce an operative temperature average decrease of 2.3°C in Sicily [6].

A successful European project specifically concerned the investigation around this technique. Thanks to the findings of this project [7], huge research effort was dedicated to this theme. Many cool roof applications were analyzed through experiments and numerical analyses also in those European countries which are not characterized by southern Mediterranean climate, such as London area and Andalusia, Spain. For instance, Kolokotroni et al. in [8] investigated the effect of a cool roof coating applied on the roof of a naturally ventilated office building in London. The cool roof application represented an effective building passive retrofit solution even in temperate climates, where the optimum reflectance value is around 0.6-0.7. Sprawling the boundary of this technique at larger scale, Boixo et al. in [9] focused on the potential energy saving achievable by cool roof implementation at regional scale. The case study consisting of Andalusia region allowed to quantify an overall energy saving of around 295,000 kWh per year. In fact, important cool roof effects were also carried out through larger scale studies, in particular considering the effect of high reflective surfaces in improving urban climate condition [10]. In order to be able to apply such a technique to existing buildings located in urban area, new less impacting materials and roof elements were developed, where infra-red reflectance is optimized, but visible aspect is maintained as traditional roof covering or tiles for example [11]. Therefore, cool roof strategy could become an effective and feasible solution even in urban historic centers and for existing buildings in general [12].

2 ACTIVE AND PASSIVE BENEFITS OF COOL ROOFS

As already described, cool roof as passive strategy aimed at reducing building energy requirement for cooling have already been widely investigated, in several climate conditions, building operations and architectures [13]. The potential further benefit produced by cool roofs arises from the observation that in several Italian commercial and industrial buildings, the external units of the heat pumps, commonly used for cooling, are located over the roof, especially if they have flat configuration. This positioning determines the energy efficiency of such a technology because the roof is exposed to the solar radiation all day long and during the overall year. Therefore, the thermal characteristics of the roof, and the consequent thermal environment of the air adjacent to the roof, are of primary importance in determining heat pump energy efficiency. In fact, the performance of heat pumps for cooling is affected by several factors [14], such as: (i) climate (cooling demand and maximum peak loads); (ii) temperature of the cooling source and distribution system; (iii) auxiliary energy consumption;

(iv) technical standard of the heat pump; (v) sizing of the heat pump in relation to the cooling demand and the operating characteristics; (vi) control system. Additionally, it is known that the coefficient of performance of heat pumps in cooling mode increases as outdoor temperature decreases, because it is strictly related to the temperature lift between the source and the output [14].

In this work, the cool roof effect in decreasing the suction air temperature of heat pumps with external units located over the roof is investigated, by assuming that all the other characteristics affecting heat pump efficiency do not vary due to cool roof application, except for (ii). To this aim, the suction air temperature of the cooling system is monitored before and after the cool roof installation over the case study building. Then, the passive cooling benefits are evaluated when combined with the "active" benefits in increasing cooling energy efficiency.

3 METHODOLOGY

3.1 Main steps of the research work

This research concerns the analysis of the results of an experimental campaign carried out during summer 2012 in Rome, Italy. The step-by-step methodology is described below.

- <u>Choice of the building</u>. Typical Italian industrial building is chosen, where an open office area, located in the mezzanine adjacent to the roof, is monitored for the purpose of the study. The roof is represented by a non-insulated roof with precast reinforced concrete structure. The external units of the heat pumps are located over the roof of the office, which is characterized by the application of the innovative cool roof coating.
- <u>Continuous monitoring</u>. The indoor-outdoor thermal-energy monitoring began on July 2012 and it ended on October 2013. The scenario B as "before" and the scenario A as "after" the cool roof application are monitored.
- <u>In-field albedo and thermography measurement</u>. Two kinds of measurements are carried out during the experiment, in order to measure the in-field albedo of the studied roof and evaluate the superficial temperature of the monitored roof [15].
- <u>Evaluation of the passive cooling cool roof effect</u>. The analysis of the roof thermal behavior and of the indoor thermal behavior is carried out, in order to quantify the passive cooling benefit produced by the cool coating.
- <u>Evaluation of the active cool roof effect</u>. The energy consumption of the heat pump system of the open office area is investigated. Additionally, a new simple procedure investigating the relationship between the outdoor temperature and the suction air temperature of the external units of the heat pump located over the monitored roof is proposed, with the purpose to estimate cool roof benefits produced by the decrease of suction air temperature in summer.

3.2 Analysis of the active cool roof effect

The evaluation of the cooling efficiency is performed by taking into account the capability of the cool coating to reduce the temperature of the suction air of the external unit of the heat pump, located over the roof of the monitored office. A 12-day period for each scenario is chosen in order to have similar climate conditions to compare scenario B and A. August 9th-20th is chosen for scenario B, and August 23rd-September 3rd for scenario A. The average day is elaborated for each scenario, by calculating the average value of all the data collected during these 12 days, every 5 minutes. Therefore, the temperature T(t) of each scenario is calculated, for each instant t, as follows (1):

$$T_B(t) = \frac{\sum_{i=1}^{n} T_{B,i}(t)}{n} \qquad T_A(t) = \frac{\sum_{i=1}^{n} T_{A,i}(t)}{n} \tag{1}$$

Where n=12 is the number of days for each scenario; $T_{B,i}$ and $T_{A,i}$ are the temperature values at each instant t, in each day i, for scenario B and A, respectively.

The daily overheating of the suction air temperature, with respect to the reference outdoor dry bulb temperature, is analysed through sinusoidal wave equations, in order to evaluate the cool roof contribution in reducing the wave amplitude A^* and the non-zero central amplitude T^* of the daily wave. Therefore, the 24-hour behavior of scenario B is described as follows for suction air temperature $T_{s,B}(t)$ and outdoor temperature $T_{o,B}(t)$ (2):

$$\begin{cases} T_{s,B}(t) = T^*_{s,B} + A^*_{s,B} \cdot \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \\ T_{o,B}(t) = T^*_{o,B} + A^*_{o,B} \cdot \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \end{cases} \quad 0 \le t < 24 \tag{2}$$

Eq. (3) describes the thermal behavior of suction air $T_{s,A}(t)$ and outdoor $T_{o,A}(t)$ temperature for scenario A:

$$\begin{cases} T_{s,A}(t) = T^*_{s,A} + A^*_{s,A} \cdot \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \\ T_{o,A}(t) = T^*_{o,A} + A^*_{o,A} \cdot \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \end{cases} \quad 0 \le t < 24 \tag{3}$$

Where:

- $T^*_{s,B}$ and $T^*_{s,A}$, $T^*_{o,B}$ and $T^*_{o,A}$ are the non-zero center amplitudes of the suction air/outdoor temperature sine wave, optimized to minimize in least square sense the error between real data and the sine curve for scenario B and A, respectively;
- $A^*_{s,B}$ and $A^*_{s,A}$, $A^*_{o,B}$ and $A^*_{o,A}$, are the amplitude values of the sinusoidal curves, which are manually tuned and optimized in such a way to minimize in least square sense the error between real data and the sine curve, in scenario B and A, respectively;
- φ^* is the phase values of the sinusoidal curves, manually tuned and optimized to minimize in least square sense the error between real data and the sine curve;
- T is the period of the oscillation, which corresponds to 24 hours.

The analysis of the amplitude T* and the non-zero center amplitude A* of the sine wave equation, allows to evaluate the contribution produced by cool roof in terms of overheating of the suction air with respect to the outdoor air temperature. This same overheating is calculated through the difference between the $T_s(t)$ and $T_{o,B}(t)$, in (4-5) for scenario B and A, respectively:

$$\Delta T_B(t) = T_{s,B}(t) - T_{o,B}(t) = \left(T^*_{s,B} - T^*_{o,B}\right) + \left(A^*_{s,B} - A^*_{o,B}\right) \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \quad 0 \le t < 24 \tag{4}$$

$$\Delta T_A(t) = T_{s,A}(t) - T_{o,A}(t) = \left(T^*_{s,A} - T^*_{o,A}\right) + \left(A^*_{s,A} - A^*_{o,A}\right) \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \quad 0 \le t < 24 \tag{5}$$

Given that the “active” cool roof effect could be described as the capability to decrease the difference of the amplitudes and of the non-zero center amplitudes, these parameters are synthetically defined as $\overline{T}$ and $\overline{A}$. Therefore, eq. (4-5) could be rewritten as follows (6-7), for scenario B and A, respectively:

$$\Delta T_B(t) = \overline{T}_B + \overline{A}_B \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \quad 0 \le t < 24 \tag{6}$$

$$\Delta T_A(t) = \overline{T}_A + \overline{A}_A \sin\left(\frac{2\pi}{T} t + \varphi^*\right) \quad 0 \le t < 24 \tag{7}$$

4 EXPERIMENTAL CAMPAIGN

4.1 Case study

The chosen case study consists of an industrial building located in Rome, Italy. The industrial production area occupies the ground floor of the building, around 1000 m^2 of ground surface, and an open office area occupies the mezzanine. This thermal zone is monitored and the cool roof twofold effect is investigated.

The case study industrial building was constructed in 1969 (Figure 1). The monitored office is represented by a rectangular 60 m^2 mezzanine, which longer side (10 m long) is coincident with the South-East façade of the building. The structural system of the case study consists of a precast reinforced concrete columns and beams; the opaque façade elements are concrete non-insulated panels. The roof structure consists of canal beams integrated with sloped glass panels. The structure is not provided with any insulation panel, such as all the industrial buildings constructed before the building energy efficiency regulation, forced in Italy in 1976 [16].The office basically consists of three rooms, where the main zone is monitored and where the heat pump system is located. The nominal cooling capacities of the system is 3604-5569-7034 W, while the nominal heating capacity is 3809-5862-7327 W.

Fig. 1 View of the façade and the open office of the case study building.

The thermal zone occupancy is from 8:00 a.m. to 5:00 p.m. from Monday to Friday, national holidays excluded. The monitored office is typically occupied by 6 sales-people, each one working on his desk position. According to the occupants, the cooling plants are kept at the same constant temperature set-point, in the weekends and nights as well, for the entire duration of the campaign described in this paper.

4.2 In-field thermal-energy monitoring

The thermal-energy monitoring of the open office is carried out both before and after the cool roof implementation, i.e. during what is named scenario B (before) and scenario A (after). The B scenario began on July 25th, 2012 and it ended on August 20th. The scenario A began on August 23rd, after the cool roof application (August 20th -22nd) and it ended on September 28th. Roof thermography and albedo in-field measurement are operated on August 8th and September 6th, for scenario B and A, respectively.

The monitoring setup is composed by a series of temperature probes and energy meters collecting data every 5 minutes, and connected to a data-logger station, and then to a web-based platform. The temperature probes are positioned as follows: (i) in the middle of the thermal zone (indoor air temperature), (ii) on the roof external surface, (iii) on the roof internal surface, (iv) in correspondence to the position of the suction air flux of the external unit of the heat pump, as indicated by the technology producer (Figure 2). As already mentioned, on two selected days, spot thermography and albedo measurements are performed.

Thermography is operated at three different times during each day (at about 10:00 a.m., 12:30 p.m., 3:00 p.m.) both before and after the cool roof implementation.

Figure 2(a-e): Monitoring system: (a) external surface temperature probe, (b) internal surface temperature probe, (c) indoor air temperature probe, (d-e) albedo in-field measurement before and after cool roof application.

A FLIR i3 infrared camera is used to analyze both the internal and external envelope surfaces of the building, with a <0.15°C precision and -20ºC÷250ºC temperature range. The albedo is measured by a double pyranometer DPA 568 produced by LSI-Lastem, where the first pyranometer is upward oriented and the second one is downward oriented. Both these instruments are able to measure the radiation every 20 seconds, and to report the values of average, minimum, maximum, and standard deviation every 10 minutes (Figure 2) [15].

5 RESULTS AND DISCUSSION

5.1 In-field preliminary measurements

The optical-thermal performance of the chosen cool roof coating is characterized by in-field albedo measurement through albedometer facility. The global radiation data collected every 10 minutes shows that, by selecting the 12:00 – 2:00 p.m. time interval, in order to avoid mutual shading disturbing phenomena produced by the shape of the roof, the albedo of the scenario B is 0.07 (bitumen covering) while the albedo of the scenario A is 0.75 [15]. Thermography images show that the cool roof benefit consists of the reduction of the internal and external surface temperature of the roof, and also the reduction of the thermal dissimilarities between temperature of the beam and of the concrete shingle [14].

5.2 Cool roof effect on roof thermal behavior

Figure 3 reports the temperature values of roof external surface T_{surf} and outdoor temperature T_{out}, monitored in August 9th-12th and August 23rd-26th for scenario B and A, respectively. The periods are chosen for the similar weather and temperature conditions to compare the two considered scenarios. The effect of the cool coating is evident in decreasing the daily thermal peak of 10-15°C. Nevertheless, during the night, the surface temperature does not highlight any evident difference between the two configurations.

Figure 4 describes roof external surface temperature versus the outdoor temperature, taking into account the overall 12 days of monitoring for both scenarios. By reporting the tendency line for each series of data, which is able to describe the trend (R^2>0.8), the cool roof contribution is evident at high temperature in particular. In fact, when outdoor temperature is higher than 30°C, the solar radiation is supposed to be an important contribution such as during sunny daily hours, and cool roof is able to decrease T_{surf} up to 20°C in the monitored period. Consistently with the previous consideration, the night behavior, when T_o is around 20-25°C, the roof surface temperature is not much affected by cool roof implementation.

5.3 Cool roof effect on indoor thermal behavior

Figure 5 reports the comparison between the indoor air temperature of the open office area and the outdoor temperature measured during the same days of the previous analysis. It is evident that the cool roof, despite the slightly hotter conditions registered in scenario A, is able to cool the indoor office area, even if the set-point temperature of the cooling system is kept at 23°C by the occupants during the whole period. In particular, given the cool roof capability to reduce the heat gain entering the roof in scenario A, the indoor air temperature in the afternoon is even lower than during morning, and the difference between the two considered scenarios is around 2-4°C from 2:00 pm to 10:00pm. The same phenomenon is confirmed by occupants' perception. In fact, they asked to increase the set-point temperature because of their freezing perception, after the cool roof application.

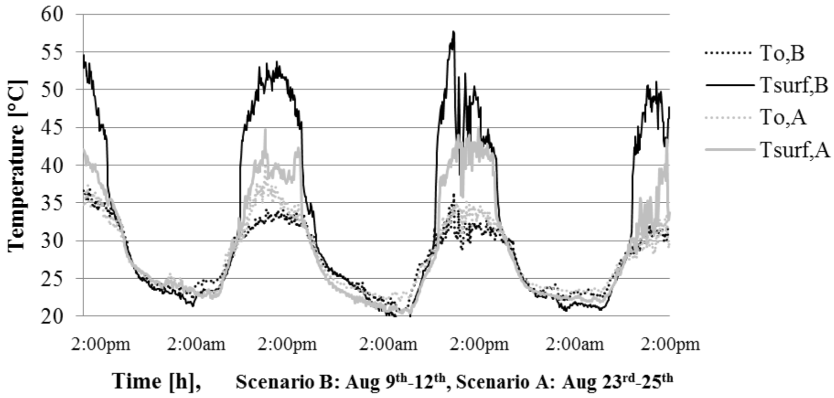

Figure 3: Superficial temperature of the roof T_{surf} with respect to outdoor temperature T_{out} for scenario B and A.

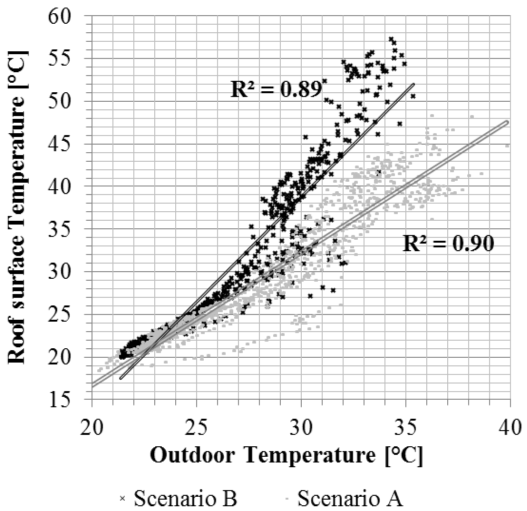

Figure 4: External surface temperature of the roof vs. outdoor temperature for scenario B and A.

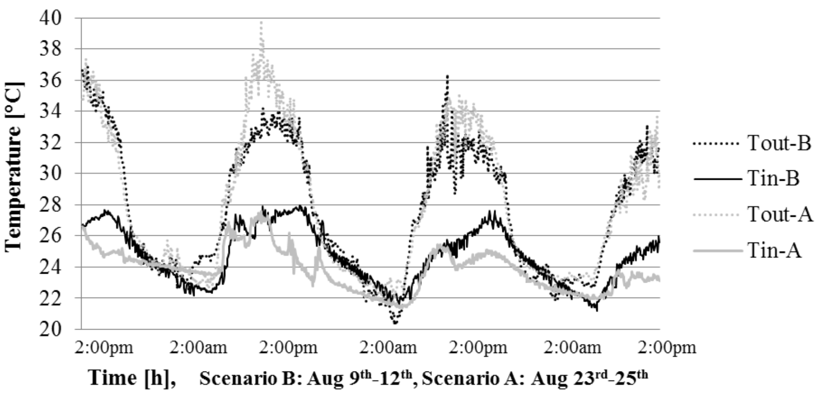

Figure 5: Indoor air temperature T_{in} with respect to outdoor temperature T_{out} for scenario B and A.

5.4 Cool roof effect on suction air temperature

As previously mentioned, the suction air temperature mainly affects the efficiency of the heat pump systems, given that it determines the temperature lift between the source and the output.

In order to evaluate the cool roof effect of this parameter, a temperature probe is installed in the proper position close to the external unit of the heat pump located over the roof, and the air temperature of this position is monitored. Section 3.1 describes the methodology proposed to investigate such an effect. The main purpose of defining a simple curve to describe the potential overheating reduction produced by cool roof, is to provide a sort of preliminary estimation that could be useful to evaluate the increase of the Energy Efficiency Ratio (EER) of the heat pumps when their external units are located in "colder" environment produced by cool roof application. This benefit, that here is defined as "active" cool roof effect, has to be added to the passive cooling contribution produced by the same cool roof application.
Figure 6 reports the daily profiles of measured suction temperatures $T_{s,B(meas)}$ and $T_{s,A(meas)}$, measured outdoor temperatures $T_{o,B(meas)}$ and $T_{o,A(meas)}$ for scenario B and A, respectively. Additionally, the sine wave equations of the same parameters are represented, as described in (2-3). Table 1 reports the descriptive parameters of the sine wave equations, calculated to minimize the error in least square sense. Therefore, the cool roof "active" effect consists of the reduction of the amplitude difference between T_s and T_o by 1.2°C, i.e. from 0.7°C to -0.5°C. Additionally, cool roof application is able to decrease the non-zero center amplitude T_s^* with respect to T_0^* by 0.4°C, when scenario B is characterized by higher T_s^* with respect to T_0^* by 0.5°C.
Figure 7 reports the difference between suction air temperature and air temperature for both the scenarios, described in eq. (6-7) and Table 2 reports the descriptive parameters of the sine waves equations (6-7). Figure 8 highlights how the cool roof effect is able to decrease the overheating of the suction air temperature, in particular during the hottest hours of the day, when the overheating decreases from 1.2°C (scenario B) to -0.9°C (scenario A). Additionally, the difference between the two non-zero center amplitudes of the overheating wave $\overline{T_B} - \overline{T_A}$ is 0.9°. The cool roof is also able to decrease the overall amplitude of the sine wave ($\overline{A_B} - \overline{A_B}$), by 1.2°C, which represent the two key parameters of the analysis of the "active" affect.

Table 1: Descripting parameter of the sine wave function of eq. (5-6).

Parameters	Scenario B	Scenario A
T_s^*	29.0°C	25.2°C
T_o^*	28.5°C	25.6°C
A_s^*	5.9°C	4.7°C
A_o^*	5.2°C	5.2°C
φ^*	0.5π rad	0.5π rad

Table 2: Descripting parameter of the sine wave function of eq. (7-8).

Parameters	Scenario B	Scenario A
$\overline{T} = T_s^* - T_o^*$	0.5°C	-0.4°C
$\overline{A} = A_s^* - A_o^*$	0.7°C	-0.5°C

5.5 Energy consumption

The energy consumption of the monitored heat pump of the open office area is collected twice a day, at the beginning and at the end of the working time, for the entire duration of the campaign. The results of two climatically similar weeks are compared in Figure 8. The graph reports the values collected at 8:00am and at 5:00pm, in order to investigate the cool roof contribution in decreasing energy requirement for cooling during the night and during the day, respectively.

The overall cool roof benefit corresponds to 34% of energy saving during the day and to 47% of the energy saving during the night, calculated by comparing scenario B with scenario A and then, calculating the average value of the week. This important reduction in energy requirement for cooling is therefore produced by the passive cool roof cooling effect, coupled with the described active effect.

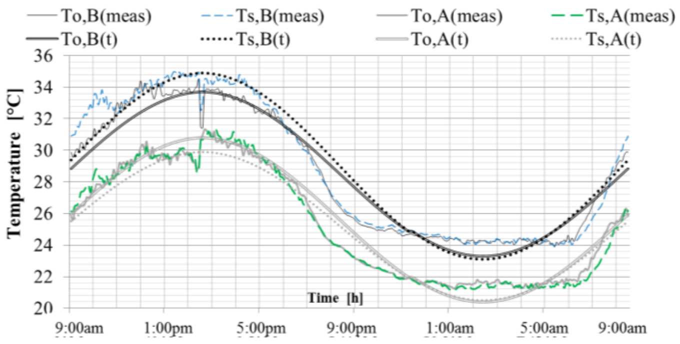

Figure 6: Daily (measured and simulated) profiles of T_s with respect to T_o in B and A scenarios.

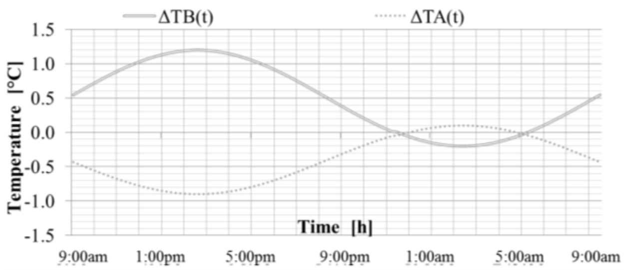

Figure 7: Daily overheating (simulated) profiles in B and A scenarios.

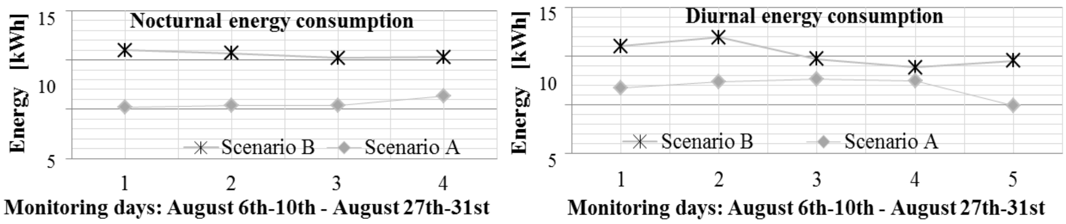

Figure 8: Daily overheating (simulated) profiles in B and A scenarios.

6 CONCLUSIONS

This study describes the twofold effect of the cool roof application on a case study industrial-office building in Italy. First, cool roof passive cooling contribution is investigated, then, specific attention is paid in order to evaluate its "active" contribution. This latter aspect consists of the cool roof capability to decrease the air temperature of the ambient over the roof, when the external units of the heat pumps in cooling mode are located. This contribution is able to decrease the suction air temperature, and then also the temperature lift between the source and the output air. For this reason, the energy efficiency of the heat pump during the cooling season increases.

The selected building is a non-insulated 1000 m^2 industrial building where the office, 60 m^2 area, occupies the mezzanine. The in-field albedo increased from 7% to 75%. The thermography showed cool roof capability to homogenize the temperature of the roof, and to lower the internal surface temperature of about 10°C. The indoor-outdoor continuous monitoring carried out during summer 2012, showed that the cool roof was able to decrease the heat gain entering the roof and the indoor air temperature of the office area by 2-4°C, even if the set-point temperature of the cooling system was kept constant for the period of the study. A comparison between two similar weather periods is operated, in order to quantify the benefit in terms of electricity saving for cooling. It corresponded to 34% during the daily work shifts of the monitored period. Finally, a new procedure was proposed to evaluate the decrease of the suction air temperature after cool roof application. The main results showed that the cool roof is able to annul the suction air overheating with respect to the outdoor air temperature.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] Akbari, H., Levinson R., Rainer L. (2005) Monitoring the energy-use effects of cool roofs on California commercial buildings. *Energy and Buildings*, 37, 1007-1016.

[2] Borge-Diez, D., Colmenar-Santos A., Pérez-Molina C., Castro-Gil M.. Passive climatization using a cool roof and natural ventilation for internally displaced persons in hot climates: Case study for Haiti. *Building and environment*, 59, 116-126.

[3] Haberl, J.S., Cho S. (2004). Literature review of uncertainty of analysis methods (Cool Roofs) Report to the Texas Commission on Environmental Quality. Texas A&M.

[4] Synnefa, A., Saliari M., Santamouris M. (2012). Experimental and numerical assessment of the impact of increased roof reflectance on a school building in Athens. *Energy and buildings*, 55, 7-15.

[5] Pisello, A.L., Rossi, F., Cotana, F. (2012). On the impact of cool roofs in Italian residential buildings: experimental assessment of summer and winter performance. DOI: 10.1615/ICHMT.2012.SEBUA-12.220.

[6] Romeo, C., Zinzi, M. (2011) Impact of a cool roof application on the energy and comfort performance in an existing non-residential building. A Sicilian case study. *Energy and buildings*. DOI:10.1016/j.enbuild.2011.07.023.

[7] Synnefa, A., Santamouris, M. (2012). Advances on technical, policy and market aspects of cool roof technology in Europe: The Cool Roofs project. Energy and buildings. *Energy and Buildings*, 55, 35-41.

[8] Kolokotroni, M., Gowreesunker, B.L., Giridharan, R. (2011). Cool roof technology in London: An experimental and modelling study. Energy and buildings. DOI: 10.1016/j.enbuild.2011.07.011.

[9] Boixo, S., Diaz-Vicente, M., Colmenar, A., Castro M.A. (2012). Potential energy savings from cool roofs in Spain and Andalusia. *Energy*, 38, 425-438.

[10] Santamouris, M., Synnefa, A., Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, 85, 3085-3102.

[11] Santamouris, M., Synnefa, A., Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, 85 (12), 3085-3102.

[12] Pisello, A.L., Cotana, F., Nicolini, A., Brinchi, L. (2013). Development of Clay Tile Coatings for Steep-Sloped Cool Roofs. *Energies*, 6, 3637-3653.

[13] Synnefa, A., Santamouris, M., Akbari, H. (2007). Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. *Energy and Buildings*, 39 (11), 1167-1174.

[14] Liu, X., Ni, L., Lau, S.-K., Li, H. (2013). Performance analysis of a multi-functional heat pump system in cooling mode, *Applied Thermal Engineering*, 59 (1-2), 253-266.

[15] Pisello, A.L., Thiemann, A., Santamouris, M., Cotana, F. (2013). Analysis of a Cool Roof System for Reducing Cooling Loads and Improving Cooling System Efficiency. Proceedings of CLIMA2013 International Conf. Prague. 16-18 June.

[16] Pisello, A.L., Cotana, F. (2013). Pisello, A.L.; Cotana, F. The thermal effect of an innovative cool roof on residential buildings in Italy: Results from two years of continuous monitoring. Submitted for publication in Energy and Building on May 2nd, 2013.