PRELIMINARY STUDIES FOR A COOL ROOFS' ENERGY RATING SYSTEM IN ITALY

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ABSTRACT

Energy saving in the building sector is one of the key issue to achieve environmental targets at national and EU levels. Even if characterised by a large number of different climatic conditions, Italy energy policies were aimed at reducing the energy consumption related to space heating in buildings, neglecting other relevant energy uses as space cooling, which has dramatically increased in the past years. The recent EU Directive for the State Members is to assess the energy quality of buildings taking into account all the relevant energy uses.

Cool roofs are an old concept merged with new technologies that play a crucial role in the energy balance of buildings especially at Mediterranean latitudes. Reducing the solar gains thanks to the roof high solar reflectance, cool roofs keep the building cooler during cooling season, reducing the cooling demand and increasing the thermal comfort; On the other hand this technology has a negative impact on the winter energy balance. It is be noted that the performance of the roof surface also depends on the thermal emissivity, that drives the radiative exchanges of the roof towards the sky and the surrounding objects. If the performance of the cool roof products is a function of the above cited quantities, the technology impact is a function of several other parameters: climatic conditions, building geometry, thermo-physical characteristics of the building envelope.

Energy rating and labelling are a quick solution to compare energy related products, as inferred from recent EU Ecodesign Directive which requires the energy labelling not only for products that consume energy but also for energy related components, as windows.

This study presents the first studies aimed at the definition of an energy rating scheme for cool roof, starting from product properties and reaching the building performances, with a focus on dwellings. The methodology is based on a wide number of energy simulations carried out with an accurate dynamic calculation tools. The variables taken into account are:

- Roof surface radiative properties;
- Reference buildings characteristics - including solar and thermal properties, geometry, orientation;
- Climatic zones: The calculations were carried out for Palermo, Rome and Perugia in order to take into account a wide variety of summer and winter conditions of the Mediterranean areas of the country.

The calculations were performed with an insulated and not-insulated building configurations. Hourly and annual heating and cooling demands were calculated, as well as effective heating and cooling degree days.

The results were used to find out simple linear regressions, expressing the energy performance of the building as a function of the roof radiative properties and, as a consequence, measuring the performance of the cool roof product. Limits and potentialities of the method are discussed.

KEYWORDS

Cool roof, energy rating, solar reflectance, thermal emissivity

1 INTRODUCTION

Improving the energy efficiency in the building sector is one of the key issues to achieve at national and EU levels, as communicated by the EU in the 2011 Energy Efficiency Plan and the 2020 Strategy, as well as in the 2011 Italian Energy Efficiency Plan. Even if characterised by a wide variety of climatic conditions, Italy energy policies were aimed at reducing the energy consumption related to space heating in buildings, neglecting other relevant energy uses as space cooling, which has dramatically increased in the past years (ENEA, 2012). Similar trends can be observed in other countries for residential and commercial buildings. What is highly relevant, in this sense, are the requirements set by the EPBD 2010/21/EU regarding the energy quality of buildings to be assessed by taking into account all the relevant energy uses.

Improving the energy performances on yearly basis requires the implementation of cooling efficient technologies in new and existing buildings. Cool roofs merge old concepts (white/light coloured construction materials) with new technologies. Reducing the solar gains thanks to the roof high solar reflectance allows to keep the building cooler during cooling season, decreasing the cooling demand and increasing the thermal comfort. The technology has great potentialities in the Mediterranean climate countries, but it is important to note that cool roofs also have a negative impact on the winter energy balance because of the reduced solar gains. Besides, it is important to emphasize that the performance of the roof surface also depends on the thermal emissivity that drives the radiative exchanges of the roof towards the sky and the surrounding objects. Several studies were carried out during the past years and showed potentialities and limits of the technology by means of numerical analyses (Synnefa, 2007, Akbari, 1997, Suehrcke, 2008, Zinzi, 2010) and monitoring in real buildings (Bozonnet, 2011, Kolokotroni, 2011, Romeo, 2011, Kolokotsa, 2011, Synnefa, 2012). The cool roof technology is now a well-established technology in need of proper tools to increase the market penetration.

Energy rating and labelling for windows are implemented, as voluntary schemes, in several countries: Australia, Denmark, Finland, Sweden, USA. A preliminary study was carried out in Italy (Maccari, 2000) and similar activities are on-going in several EU countries. This instrument resulted to be an important wheel in driving the market towards more efficient energy related products. No other building envelope materials and components have such instruments, while the energy labelling is spreading in EU of energy using products, as: light bulbs, refrigerators, washing machine, etc. The framework set by the Ecodesign Directive 2009/125/EC will drive a strong change in the coming years, with mandatory ecological requirements for energy-using and energy-related products.

The energy rating scheme for cool roof is, at last, a tool useful to facilitate the market penetration. It allows to properly inform the end users about energy efficient solutions and to set the boundaries for the implementation of EU Directives in the fourth coming years. Unlike products that directly use energy, the definition of a rating scheme for cool roof requires very in-depth analyses in order to take into account all the variables affecting the performance of the product and of the building, it will be installed on.

2 METHODOLOGY

The building energy performances depend on several parameters: Climatic conditions; building geometry and use; thermal and solar properties of the building envelope. A successful energy rating scheme should be, as a matter of fact, simple and general. The latter two values will ensure that the scheme will be easily understood and will reach a larger community of stakeholders. To achieve the above mentioned objective, the development of the energy rating method for cool materials is based on the effort to establish a direct relation between the energy performances of the building and its surface thermo-physical properties, without taking into account variables that are specifically building-dependent.

Cooling and heating energy calculations were performed in order to assess how different parameters affect the building and roof thermal response. The calculation results also

provided the data sets necessary to implement the mathematical functions and regressions, the energy rating should be based on.
The variables analysed in the study are described below.

2.1 The climatic conditions

The regulatory framework for the heating season is implemented since more than two decades (Decree *DPR 412/93*, 1993), with small adjustments through the years. The Italian territory is divided in six climatic zones as a function of the heating degree days, counted in base 20 °C. The zones range from A (degree days lower than 700) up to F (degree days higher than 3000). No legislative or technical standard still officially exist for the cooling season. Nevertheless, a relevant technical pre-normative work has been carried out (Iatauro, 2013) with the introduction of a climate severity index based on cumulative values of air temperature, specific humidity and solar irradiation during the cooling season. The index ranges from A (coolest zone in summer) to G. Even if the summer zoning is no yet implemented, the data are useful for the selection of the reference localities. Three exemplary cities were selected: Palermo, with hot summer and mild winter; Rome, mild summer and winter; Perugia, mild summer and colder winter. The reference climatic data are in table 1. The choice of Perugia as *cold* city depended on the focus given to the Mediterranean area of the country, where the cool roof technology has a major chance of market penetration, without considering the alpine and sub-alpine areas.

Table 1: Climatic parameters of the reference localities

City	Winter climatic zone	Winter degree days	Summer climatic zone	Summer climate severity index
Palermo	B	720	F	2014
Rome	D	1440	E	1758
Perugia	E	2289	B	1536

2.2 The reference buildings

The main choice for the reference buildings was to consider the single flat instead of the whole structure, since most of new and existing buildings use ambient regulation controls for the heating and cooling systems. The following typical apartments were selected:

- Flat with four external walls, typical configuration of detached houses;
- Flat with three external walls, typical configuration of small apartment blocks;
- Flat with two external walls, typical configuration of large and tower apartment blocks.

The base floor and the internal walls are adiabatic, the roof is flat. The geometrical characteristics were summarised in table 2.

Table 2: Geometric characteristics of chosen reference buildings

	2 External walls	3 External walls	4 External walls
Net floor area [m^2]	87	76.5	99.5
Gross Volume [m^3]	267.3	245.7	302.4
S/V Ratio [m^{-1}]	0.53	0.59	0.68
Internal Height [m]	2.7	2.7	2.7

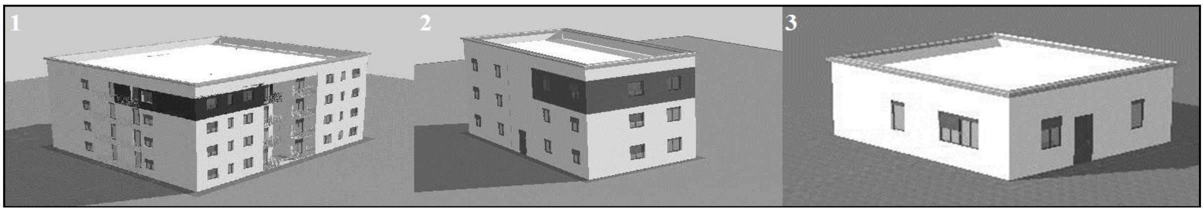

Figure 1: Apartment selected: (1) two external walls, (2) three external wall, (3) four external walls

Each building was created considering two insulation levels. The not insulated envelope was characterised by elements with the following thermal transmittances: 1.15 W/m^2K for the external vertical walls, 1.13 W/m^2K for the roof, 3.5 W/m^2K for the windows glass and 3.48 W/m^2K for the windows frame. The insulated envelope configuration, instead, presents an external walls thermal transmittance of 0.45 W/m^2K, a roof thermal transmittance of 0.47 W/m^2K, while the transmittance values for windows were set to 2.42 W/m^2K for the glass and 2.15 W/m^2K for the frame.
Other settings, common to all the three considered building models, both non-insulated and insulated, were chosen according to Italian standard reference UNI TS 11300-1 for residential structures. Internal gains were set to 4 W/m^2 with a constant occupancy density of 0.04 persons/m^2 (metabolic rate: Seated, light work). Air change value was set to 0.3 Vol/h. Net energy demands were calculated considering a temperature set-point of 20 °C during winter and a temperature set-point of 26 °C and a relative humidity set-point of 60% during summer.
The shading factor was controlled with a solar set-point. The windows shading system was modelled with a blind with low reflectivity slats activated during summer when the solar radiation is up to 150 W/m^2.

2.3 The roof surface properties

Solar reflectance (ρ_e) and thermal emissivity (ε) are surface properties of materials. The first represent the capability of material to reflect a portion of the incident solar radiation.
The second is the ability of material to emit and dissipate during the night the heat stored during the whole day.
In order to evaluate the energetic performances of cool materials, characterised by high solar reflectance and high infrared emissivity, used as roof covers, the reference buildings were studied selecting three levels of roof solar reflectance, 0.2, 0.5 and 0.8, combined with three values of thermal emissivity, 0.3, 0.6 and 0.9, obtaining nine different combinations.

3 CALCULATION RESULTS

A numerical analysis was performed using Design Builder in order to investigate the energetic performances of a cool roof application.
Design Builder is a graphical interface developed to make Energy Plus software more user-friendly. The latter is a stand-alone software for thermal simulation in a dynamic regime of building-plant systems and returns outputs in energy consumption, temperatures and heat flows. Energy Plus was developed in the laboratories of Berkeley University and Los Alamos. It has been continuously improved both in university laboratories and scientific and technical organisations such as ASHRAE that validates the calculation procedures through a special international protocol.
In essence, Design Builder combines one of the most powerful and reliable engines for calculating energy simulations with quick and easy dynamic modelling tools and also includes a simulation module for natural lighting and a powerful CFD engine calculation. Moreover it provides an easy to use OpenGL solid modeller that allows to assemble buildings models

through the positioning, the stretch and the blocks cut in three-dimensional space. Realistic three-dimensional elements determine a visual feedback of the element thickness and internal areas and volumes. Several geometric forms can be modelled as well as the optical and thermal properties of the surfaces. The templates allow to load into data projects the most common settings, activities, HVAC and lighting systems of buildings by simply selecting this features from the drop-down lists. It is also possible add or create customized templates.
More than 600 simulations were expected, taking into account: climate, building type and orientation, insulation level, roof surface properties. The first screening to reduce the number of calculations was to assess the influence of the apartment orientation. A set of simulations was performed for the eight cardinal orientations, being the apartment configured with typical values of insulation and roof properties. The orientation, whose resulted to be the closest to the average of the 8 orientation for the cooling and heating demand, was chosen as the reference, reducing to 162 the final number of simulations.
An explanatory figure is reported below to show the annual cooling, heating and global (the sum of the first two) demands as a function of the building models under study.

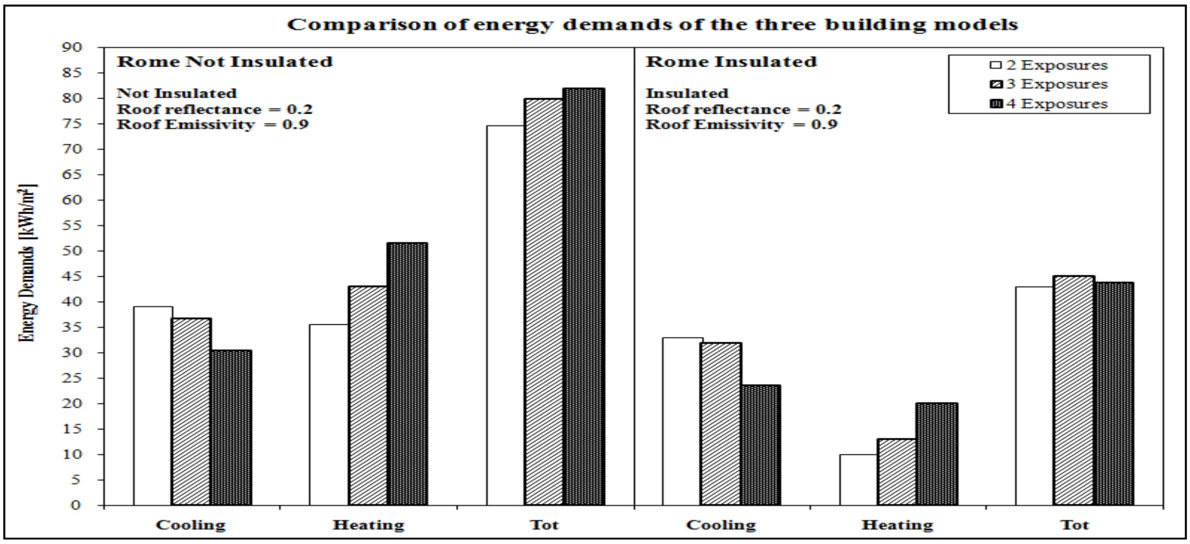

Figure 2: Annual energy demands for Rome, roof reflectance 0.2, roof emissivity 0.9

In figure 2 it is important to notice that the increase of insulation affects especially the heating demands, also by decreasing the cooling ones even if in smaller amount.
In order to assess in a more simple and general way the large number of simulation results, it was chosen to report only the average values of annual demands, summarised in table 3, obtained for the three structure types. The following figures put in evidence the impact of a cool roof application by dividing the effects due to the solar reflectance from the ones due to infrared emissivity.

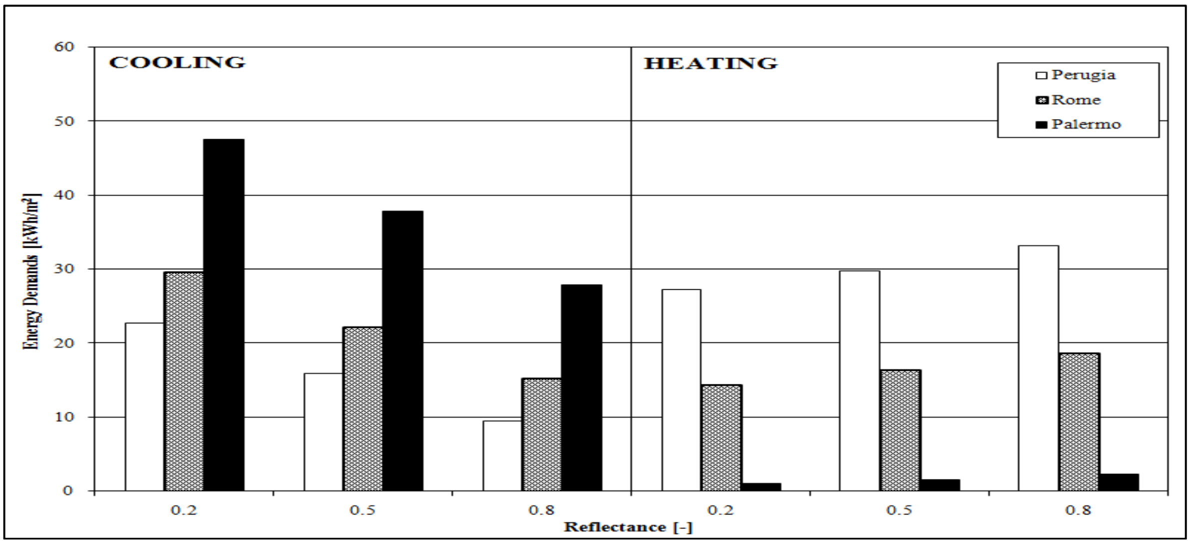

Figure 3: Insulated building: Increasing roof reflectance impact on cooling and heating demands (ε = 0.9)

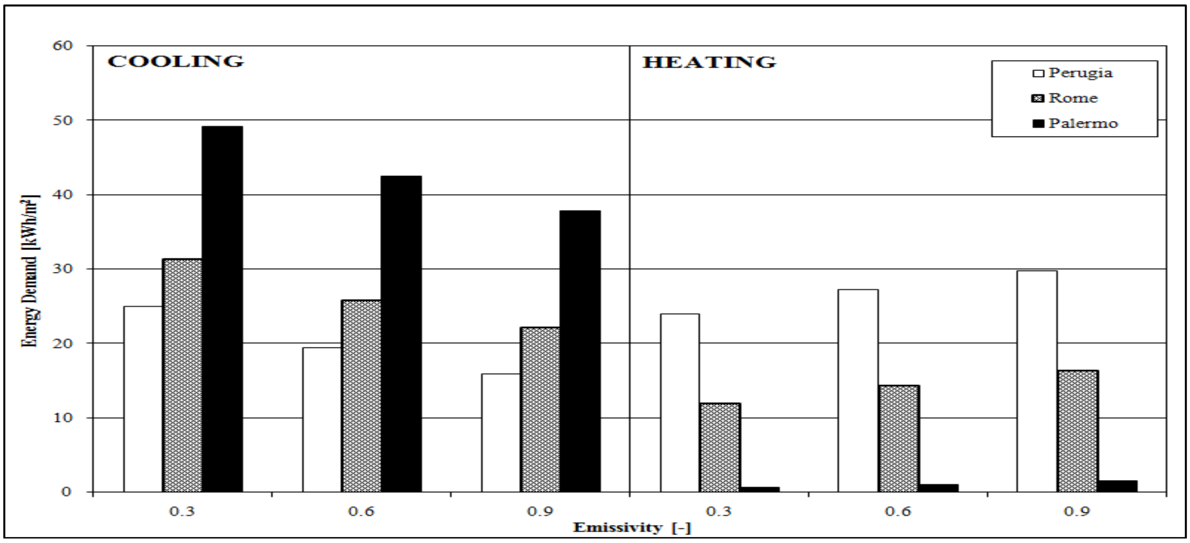

Figure 4: Insulated building: Increasing roof emissivity impact on cooling and heating loads (ρ_e = 0.5)

Figures 3 and 4, referred to the insulated building case, show how an increase both in roof reflectance and roof emissivity, can induce, during a year, a decrease in cooling demands and an increase in heating demands depending on climatic zone. The results were obtained by changing roof solar reflectance being equal emissivity set to 0.9 and by changing roof emissivity being equal solar reflectance set to 0.5.

Table 3. Design Builder results: Energy demands in kWh/m^2

			Insulated			Not Insulated		
	ρ_e	ε	Cooling	Heating	Global	Cooling	Heating	Global
Perugia	0.2	0.3	35.4	21.2	56.6	52.5	54.6	107.2
	0.5	0.3	25.0	24.0	49.0	31.0	63.1	94.1
	0.8	0.3	14.7	27.4	42.1	12.2	74.5	86.7
	0.2	0.6	27.7	24.7	52.4	37.0	64.4	101.4
	0.5	0.6	19.5	27.3	46.8	20.8	73.2	94.0
	0.8	0.6	11.4	30.8	42.2	7.9	84.1	92.0
	0.2	0.9	22.7	27.3	50.0	27.1	72.6	99.7
	0.5	0.9	16.0	29.8	45.8	14.6	81.2	95.8
	0.8	0.9	9.5	33.1	42.7	5.6	91.4	97.1
Rome	0.2	0.3	42.5	9.8	52.3	61.4	29.4	90.8

	0.5	0.3	31.4	11.9	43.3	38.7	35.7	74.5
	0.8	0.3	20.5	14.6	35.1	18.8	44.3	63.2
	0.2	0.6	34.7	12.3	47.0	45.7	37.0	82.7
	0.5	0.6	25.8	14.4	40.2	28.4	43.6	71.9
	0.8	0.6	17.2	16.9	34.1	13.5	52.2	65.7
	0.2	0.9	29.6	14.4	44.0	35.5	43.4	78.9
	0.5	0.9	22.2	16.3	38.6	21.8	50.1	71.9
	0.8	0.9	15.2	18.7	33.9	10.1	58.2	68.3
Palermo	0.2	0.3	62.8	0.4	63.1	90.0	5.2	95.2
	0.5	0.3	49.3	0.7	49.9	62.3	8.4	70.6
	0.8	0.3	35.0	1.2	36.2	35.0	13.2	48.2
	0.2	0.6	53.7	0.7	54.4	72.0	8.3	80.3
	0.5	0.6	42.5	1.1	43.6	49.3	12.1	61.4
	0.8	0.6	30.7	1.8	32.5	27.4	17.2	44.6
	0.2	0.9	47.6	1.1	48.7	59.5	11.4	70.9
	0.5	0.9	37.9	1.5	39.5	40.6	15.3	55.8
	0.8	0.9	27.9	2.3	30.2	22.6	20.5	43.1

4 DEVELOPMENT OF THE RATING ALGORYTHMS

The simulation results were used to develop the regressions, the energy rating should be based on. Observing the data it can be inferred that the heating and cooling demand affect the global demand in a different way as a function of the roof surface properties in the various climatic zones. Moreover the share of cooling and heating demand respect to the global energy demand dramatically depends on the insulation level for the three cities. Following the above considerations, a double track for the cool roof rating definition was implemented and it is presented in the next sub-chapters.
In the framework of the coming nearly-zero energy buildings and in order to skip the dependence on energy system efficiencies, the analyses are carried out considering on the net energy demand as provided by the simulations.

4.1 Climate dependent global energy rating

Three rating algorithms were implemented for the three selected climatic zones. A first analysis was carried out to check the impact of cool roof technologies on the global energy performances. The absolute values of the global energy demand in kWh/m^2 is strongly dependent on the insulation level, check table 3. The results can be also be presented as energy savings normalised respect to the maximum energy demand (calculated for emissivity 0.3 and solar reflectance 0.2) for each climatic zone.
Figure 5 reports the normalised energy savings for the two configurations and it can be inferred that trend and figures are similar for the two insulation levels, for the Rome case. Similar results were obtained for Palermo and Perugia, for the latter small differences of global energy demand were calculated for the not insulated configuration and for the roof properties but the trend was confirmed. For this reason the regressions were calculated starting from the global energy demand values obtained for the insulated configuration. This choice is also in accordance with the requirements of actual building codes in Italy.

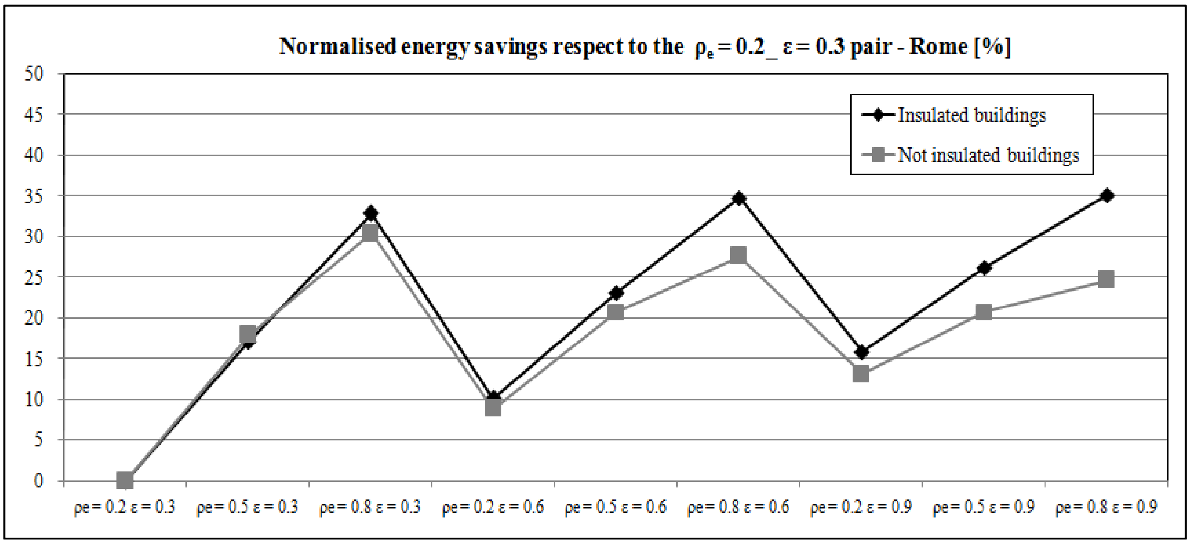

Figure 5. Comparison of the normalised global energy savings for the Rome buildings

Nine pairs of emissivity and solar reflectance values of the roof were considered in total. A linear regression for heating and one for cooling were calculated, and then combined together in a single equation for each climatic zone. Excellent r-square values were obtained, ranging from 0.964 for the heating season in Perugia to 0.995 for the cooling season in Rome. The equations for the three climatic zone are:

$$EP_{perugia} = 59.7 - 17.6\rho_e - 5.69\varepsilon \quad (1)$$

$$EP_{rome} = 56.92 - 22.4\rho_e - 8.01\varepsilon \quad (2)$$

$$EP_{palermo} = 75.8 - 39.87\rho_e - 16.68\varepsilon \quad (3)$$

4.2 Climate independent cooling energy rating

Figure 6 shows the specific cooling demand (empty red-lined boxes) for the three localities and for the insulated configuration. The results depend on the climatic zones, since significant differences can be found for the three cities and, in particular, between Palermo and the other two localities. The same results can be normalised respect to a climatic indicator as shown in figure 6, secondary Y-axis. Normalising the specific cooling demand to the Cooling Degree Days, calculated with base 10°C, a more uniform trend was obtained for the three data sets. The Degree Days are an output of the Design Builder.

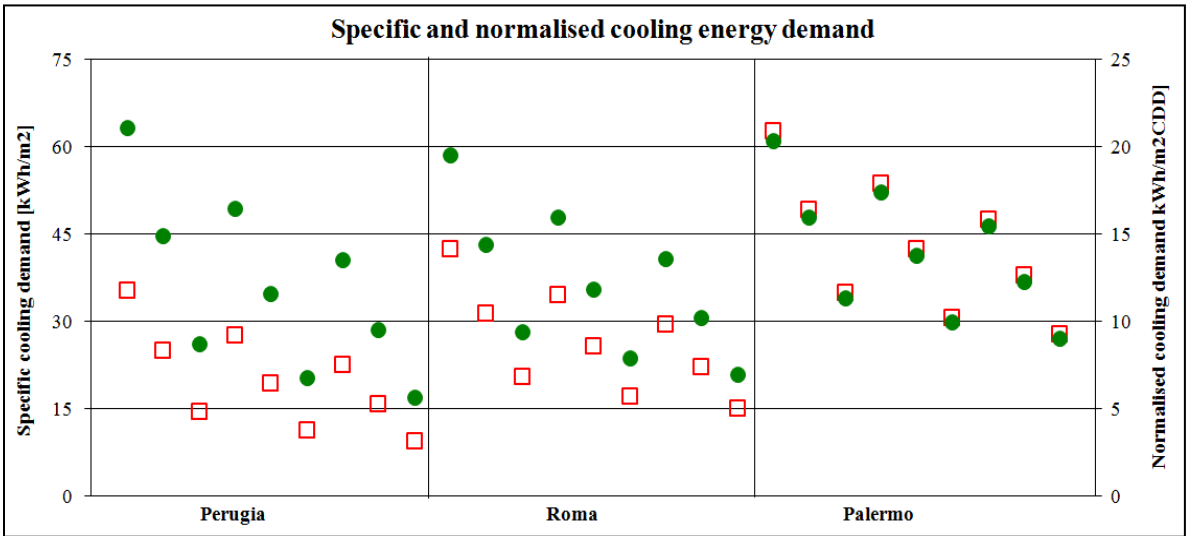

Figure 6. Effect of the cooling degree days normalisation on the climate dependence of the energy performances

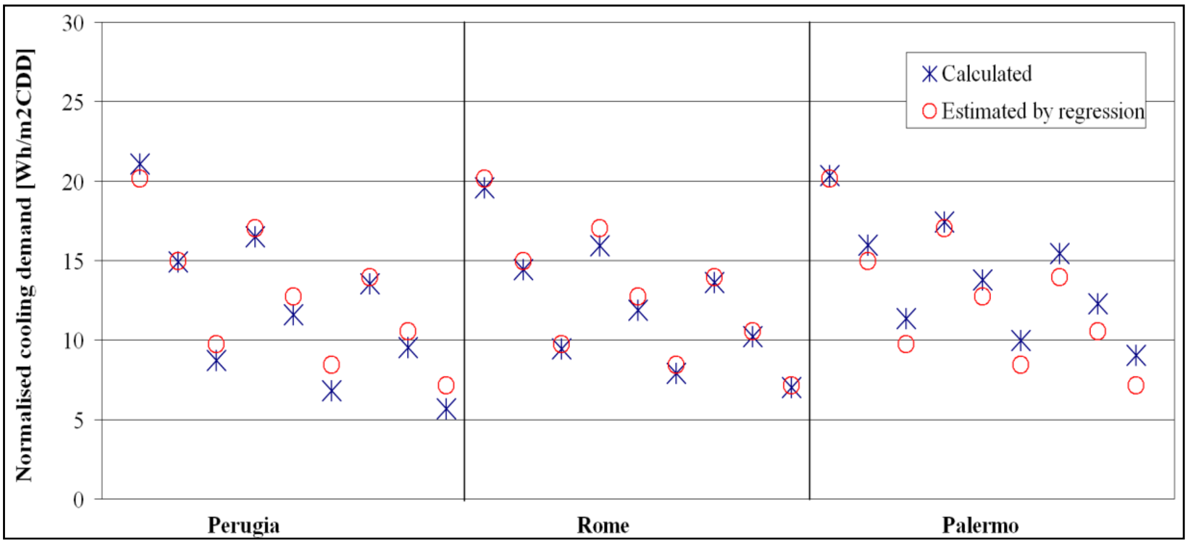

Figure 7. Comparison of the normalised cooling demand as obtained by simulations and as estimated by regression

The normalised 27 points (9 pairs of emissivity and solar reflectance values for 3 cities) were used to derive the linear regression. The indicator, expressing the performance of the cool roof product in the Italy for the cooling season (NEP_{cool}), was calculated according to the following expression:

$$NEP_{cool} = 27.32 - 20.35\rho_e - 12.35\varepsilon + 10\rho_e\varepsilon \quad (4)$$

Several regression models were tested, including different power for the reflectance and the emissivity; the best result was obtained with the above equation that include an interaction between the two physical properties. The r-square value of the regression is 0.94, which can be considered satisfactory according to the simplicity of the model. The relative error between the simulation and regression values is lower than 15% in 24 of 27 points, see figure 7. Higher discrepancies are generally found for high solar reflectance values, being lower the global energy demand.

5 CONCLUSIONS

The study demonstrated the dependence of the energy performance of residential buildings on the radiative properties of roofing products. Performances also depend on the climatic conditions and building characteristics. The insulation level was proved to be another crucial parameter affecting the amount of heating and cooling demand respect to the global energy performances.
The next step was the development of a rating system for cool roof products, starting from the results of the calculation. According to the available data two options were proposed: a climate dependent rating, assessing the performance of cool roof throughout the whole year, and an independent climate rating, actually developed for the cooling season only. The regressions are hence suitable for rating the cool roof products and define the efficiency classes in case of energy labelling.
First results of the study were promising and the research is ongoing, aimed at refining the actual algorithms as a function of more populated data sets and other more accurate normalisation procedures. The method should be next developed for other building categories were cooling demand is predominant and in dramatic increase, as office and commercial buildings

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