USE OF COOL ROOF TO REDUCE THE ENERGY DEMAND AND CONSUMPTION OF COMMERCIAL BUILDINGS AT MEDITERRANEAN LATITUDES

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Keywords: Reflective coatings, energy efficiency, new materials

Summary

Bright colours for the building envelope are a trademark of vernacular Mediterranean architecture, important to reduce the cooling loads and ensure thermal comfort conditions in the built environment. The modern architecture often does not take into account these concepts with increase of cooling loads and discomfort for occupants. Old design concepts merged with new technologies can improve the energy performance of buildings in the Mediterranean area. High reflective coatings can be very useful but the must have some characteristics: high reflectance, easy to clean, high durability in maintaining the original colour and resist to ageing phenomena. Once the latter properties are assessed, it is useful quantifying the energy benefits that cool roofs bring to the energy performance of the building. This papers summarises an extended study performed with TRSNSYS, a dynamic simulation tool. The energy performance of an office building (heating and cooling) were calculated as a function of: the solar reflectance of the roof, the locality (Milan, Rome, Naples, Palermo), the insulation level of the envelope and the number of floors. Hundreds of simulation were performed and the analysis of the results allows to find out the energy and environmental benefits achievable with cool roofs in mild climates.

1. Introduction

The use of bright colours for painting the building envelope of buildings is a trademark of vernacular Mediterranean architecture. This effective solution among others reduced the cooling loads and ensured thermal comfort conditions in the built environment. The modern architecture often does not take into account these concepts and it is daily experimented the increase of cooling loads in residential and commercial buildings, and the thermal discomfort for occupants. Old design concepts merged with new technologies can improve the energy performance of buildings in the Mediterranean area and reduce the increasing heat island effect in large urban areas.

The influence of solar gains through the opaque components of building is nowadays practically neglected, without taking into account the consequences of this approach. High reflective coatings and paintings for the envelope, especially the roof exposed to strong solar radiation during the cooling season, can be useful to reduce cooling loads and consumptions but some characteristics are required: high reflectance over the solar spectrum, easy to clean, high durability in maintaining the original colour and resisting to ageing phenomena.

Commercial buildings, generally used only during working hours, tend to be more sensitive than residential buildings to summer conditions, when peak thermal loads occur while the building is occupied during daytime. This is particularly true in warm climates, such as those in Southern Italy and Mediterranean countries.

Reflective coating also improve the quality of outdoor urban spaces more and more affected by the phenomenon know as “heat island effect”. This is the increase of air temperatures in cities respect to the surrounding countryside due to the high construction density, the limited green area, waste of public and private transport, waste of air conditioning systems and others cause. Monitoring campaigns found that the temperature of suburban areas can be 1-1.5 degrees higher respect to the country side, and the difference rises up to 2.5 degrees in city centres. Green area and high albedo of cities, using construction materials that reflects instead of absorbing the solar radiation, can improve the climate conditions in urban areas.

2. Construction materials under the solar radiation

The solar radiation impinging an object can be transmitted, reflected or absorbed. The sum of the three coefficients (ratio of transmittance, reflectance and absorptance on the incident radiation) is 1. For opaque objects the transmittance is obviously 0. The three coefficients depends on the wavelength, but they are usually expressed with a single number: the integer of the function weighted with the solar spectrum, defined as the range falling between 280 and 2500 nanometres. An elevate absorptance of the solar radiation, typical of construction materials and components used nowadays, implies that such energy is trapped within the material, with consequent warm up of the envelope components. The consequence is an heat transfer to the built environment that, depending on the thermal mass of the structure, insulation of the envelope components, climatic conditions and building geometry, can be relevant.

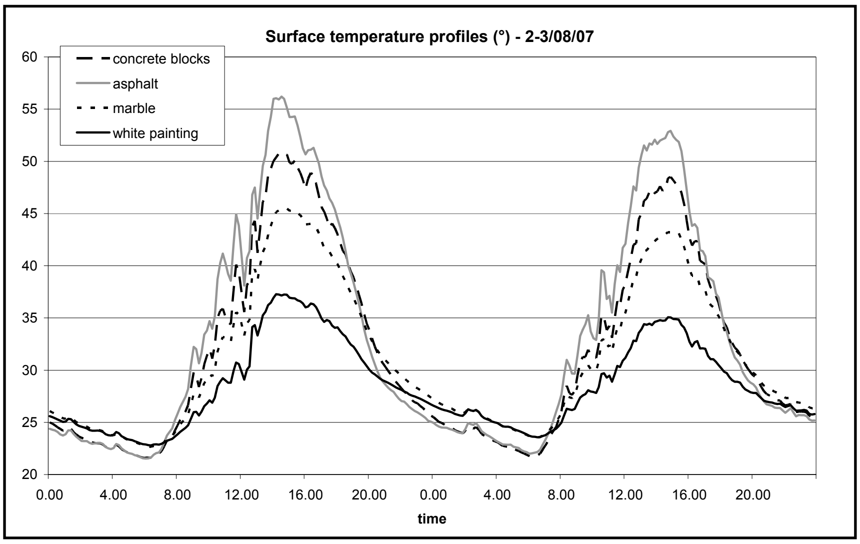

Figure 1: Construction materials under the solar radiation

A monitoring campaign was carried out on construction materials. As an example the surface temperature of concrete blocks, asphalt, marble and a white painting monitored in Rome the 2nd and 3rd of August 2006, is presented in Figure 1.The solar reflectance of the above materials is respectively: 29, 10, 39 and 86%. The consequence is a temperature difference between the white coating and the other materials up to 20° during day time, with the critical situation in the afternoon, when the combined effect of the absorbed radiation and the warming up of the air temperature keeps the surface materials very high with the negative consequence on urban comfort and energy consumption.

Even id not analysed in this paper, also the thermal emissivity of the material surfaces can affect the component and building performances, in fact radiative exchanges between the sky and the envelope. To be noted the different profiles of the material temperature at night time: the white painting cools down slower than the others. The effect is probably due to a reduced emissivity of this materials respect to the usual construction materials, generally between 0.8 and 0.9.

3. Methodology

Several products can be used for roofs in order to reduce this energy load to the buildings, they are regardless applied or appositely developed. All of them are characterised by an high solar reflectance. Field test of cool roofs were run in California and Florida, cooling load reductions ranging from 10 to 40% were monitored in homes and two single story medical offices increasing the solar reflectance of the roof from. This paper presents a parametric study aimed at demonstrating the energy benefits in terms of primary energy when the reflectance of the building roof is strongly increased. Reducing solar gains implies both, the reduction of the cooling demand as well as the increase of the heating demand. It is hence correct, in terms of annual energy balance, using the primary energy as indicator.

TRNSYS 16, a well known and tested simulation code, was used to carry on this parametric study based on the definition of a reference office building and on the following sensible parameters:

- Location
- Solar reflectance of the roof
- Number of floor of the building
- Insulation level
- Orientation

3.1 Definition of the climatic zones

The simulation work was mainly concentrated on the Mediterranean area, were the summer climatic conditions make more severe the energy consumption, more over, almost always all electric. Preliminary calculations were also performed for Milan, but abandoned because of the poor energy advantages deriving from cool roofs in commercial buildings in northern Italy.

The localities chosen for the study are:

Rome Climatic zone D (in Italy from A the hottest to F), 1440 heating degree days

Naples Climatic zone C, 1034 heating degree days

Olbia (Sardinia) Climatic zone C, 1142 heating degree days

Palermo Climatic zone B, 796 heating degree days

The main climatic parameters are presented in Table 1.

Table 1 Climatic data of the selected localities

	ROMA		NAPLES		OLBIA		PALERMO	
MONTH	t (°)	J (MJ/m2)	t (°)	J (MJ/m2)	t (°)	J (MJ/m2)	t (°)	J (MJ/m2)
JAN	7.2	7.1	10.3	7.3	9.6	7.5	11.2	8.4
FEB	8.4	9.8	10.7	10.2	10.2	10.4	11.7	11.5
MAR	10.5	14.2	12.4	14.1	11.2	14.8	13.7	15.4
APR	13.0	17.7	15.8	18.1	13.0	18.2	16.3	19.1
MAY	17.2	21.8	19.9	21.9	16.8	22.0	20.4	22.7
JUN	21.1	23.6	23.0	23.9	21.3	24.0	24.7	24.2
JUL	23.9	23.6	26.1	23.7	24.4	24.1	27.7	24.4
AUG	24.1	20.6	26.1	20.9	24.8	21.0	27.7	21.4
SEP	21.0	15.8	23.3	16.2	21.6	16.2	24.6	16.9
OCT	16.5	11.4	19.4	11.7	17.1	11.9	20.2	12.9
NOV	11.5	7.6	15.4	7.8	13.0	7.9	16.1	8.8
DEC	8.1	5.6	11.3	6.1	10.3	6.3	12.6	7.3
	t mean	J tot	t mean	J tot	t mean	J tot	t mean	J tot
YEAR	15.2	5449	17.8	5543	16.1	5616	18.9	5880

3.2 Definition of the reference building and operative conditions

A reference building was defined with the objective of having results whose validity was as general as possible. The attention was focused on a 3 floors building in the ENEA Research Centre Casaccia. The building plan has a linear development, this shape can be *iterated* for more complex geometries as inferred from figure 2. The layout of the building is: two rooms with opposite orientation and corridor in between, details are in Figure 2. The internal walls and floors are considered as adiabatic. The net floor height is 2.9 meters. The room has a row window of 3.77 m^2, corresponding to the 31% of the façade surface.

The building portion was divided into three zones: north orientation, south orientation, corridor. The simulation were performed considering the cases of 1, 2 and 3 floors. The rooms have fenestration with 0.75 as g-value and a fixed reduction of 0.4 is taken into account because of shading systems. Table 2 summarises the main thermo-physical properties of the building envelope components. To be noted that 3 insulation levels are defined, the mean values are selected according to the actual national standards by climatic zone, the high and low values represents a parametric variation identical for all the climatic zones. The operative parameters are presented in Table 3

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Table 2 Thermal properties of the building envelope

	U (W/m^2°K)				
Component	B	C	D	Well insulated	Poorly insulated
wall	0.64	0.56	0.50	0.35	1.00
roof/ ground costr.	0.60	0.55	0.46	0.30	0.90
window	2.94	2.94	2.94	2.94	2.94

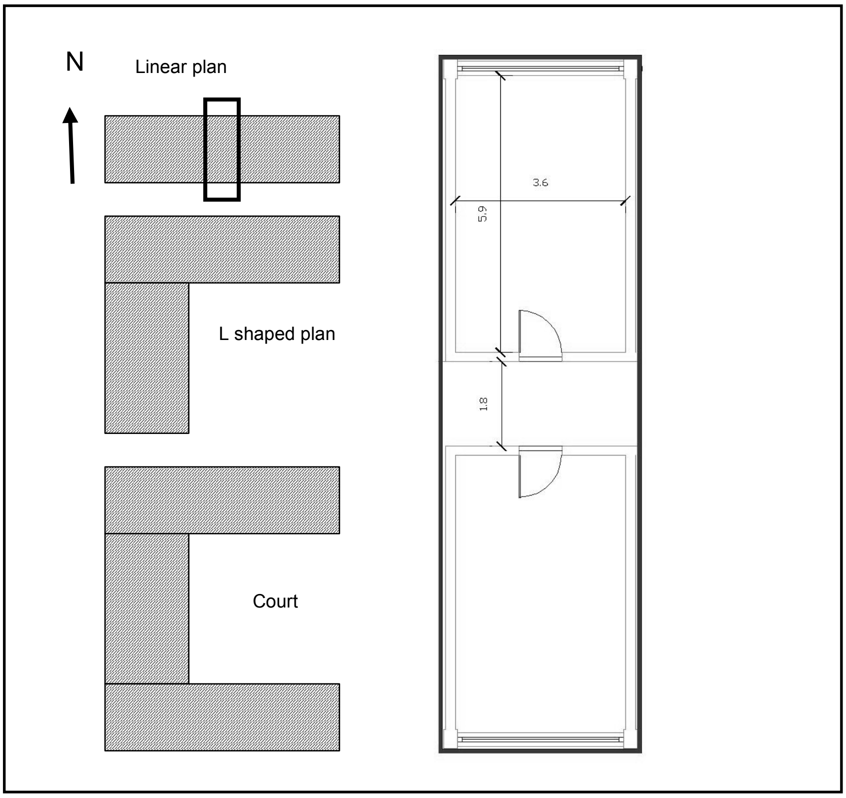

Figure 2: Building geometry and layout

Table 3 Operative conditions of the building

Operative parameters	Unit	Set-point
Temperature – heating set point	(°)	20
Temperature – cooling set point	(°)	25
Humidity – cooling set point	(%)	50
Infiltration + ventilation	(1/volume)	1
Heating efficiency	(-)	0.85
Energy system and occupancy schedule	(-)	08.00-18.00 – week end off
Artificial lighting	(W/m2)	5
Appliances	(W/room	250
People	(W/m2)	120
COP of chiller	(-)	2.5
Electricity transformation	(-)	0.36

The set point values are typical of the Italian situation. According to the energy system design in Italy, the heating consumption refers to the sensible heat only, meanwhile the latent contribution is considered in summertime. Infiltration and natural ventilation were grouped in this model, and they were assigned rate was one volume per hour. This values is little high and tends including eventual night free cooling. In most common situation this set point leads to a small underestimation of the cooling demand and overestimation of heating demand.

4. Results

The main results are following presented as histogram graphs and following discussed. According to the aim of this study, all the figures have the solar reflectance as X-axis and the energy demand/consumption on the Y-axis. The solar reflectance range from 0.2 to 0.8, respectively typical of dark surfaces and white surfaces. The energy demand and consumption are expressed in megajoule per year.

One of the first steps of the simulation work was to check if this technology was applicable independently from the latitude and the climatic conditions. A set of simulation was run for the one floor building located in Milan, belonging to the Italian climatic zone E. These results are summarised in Figure 3. The energy demand is predominant and the effect of the roof reflectance causes an 8% increase of the heating demand passing from 0.2 to 0.8. The cooling loads are reduced of 26%, but in terms of energy consumption the overall reduction is less than 4% between the two extreme reflectance values. The results were not significant for this technology application and it was decided to focus on warmer climates.

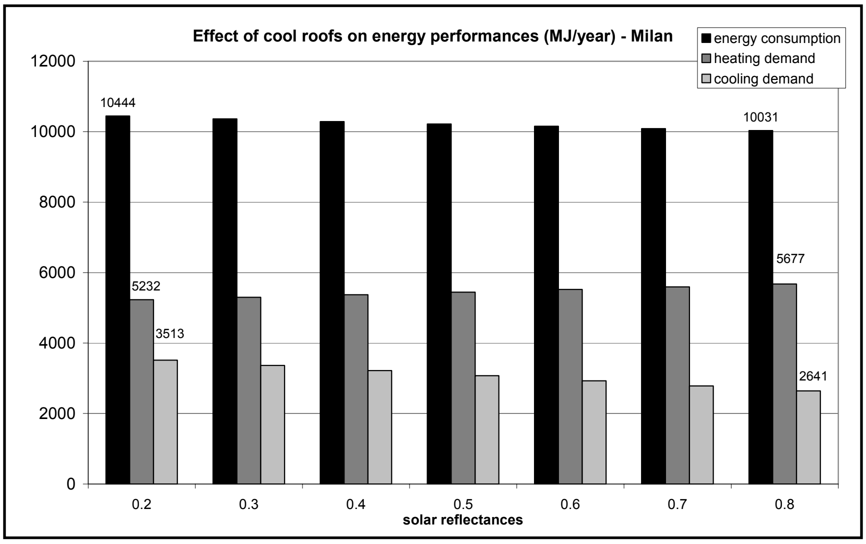

Figure 3: Effect of roof reflectance on one floor building in Milan

Also the orientation was in a first stage taken into account. Preliminary simulations were run with the two facades facing on the three orientations (considering the building symmetry): north/south, east/-west, south-west/north-east. The consumption of the building increases of respectively 20 and 12% for the E/W and SO/NE orientation respect to the S/N for the roof reflectance 0.2 (less than 2% more for the reflectance 0.8). The energy savings within the same orientation remain anyway close, see Figure 4. Because of these findings it was decided to continue the parametric study on one orientation only, in particular on the north/south orientation having the best performances.

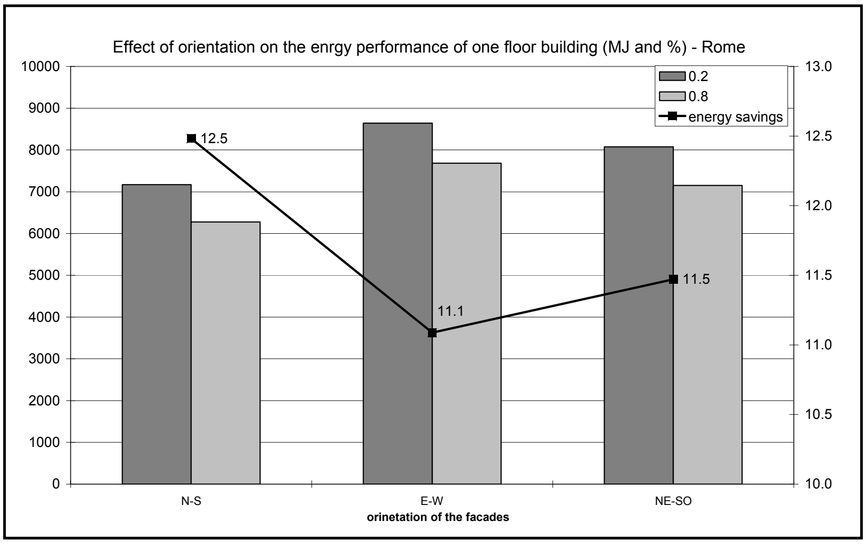

Figure 4: Effect of orientation on one floor building in Rome

The core of the simulation work consists in a parametric study as a function of 4 solar reflectance coefficients (0.2, 0.4, 0.6, 0.8). The results are grouped as a function of the number of floors and commented according to the energy consumption differences between the two extreme solar reflectance values of the roof. Good linear interpolation are calculated, even if the procedure is not presented here, hence it is possible calculating the energy consumption for whatever solar reflectance of the construction materials on the roof and estimate the advantages of reflective coatings.

Figure 5 summarises the result for the single floor geometry. Rome is characterised by intermediate climatic conditions, comparable heating and cooling demand. The effect of the cool roof is an energy saving up to 10% for mean and poor insulated buildings. Slight advantages are obtained for better insulation levels, this depends on the heating demand reduction by far compensated by the increase of the cooling demand, typical situation of too insulated and tight building at Mediterranean latitudes. The effect of insulation level play an important role since the lowest is the insulation, the higher is the energy consumption. The best performing solution is the highest insulation and solar reflectance. Olbia and Naples are characterized by similar results. Yearly energy savings vary between 14 and 11% for mean and poor insulation, and remain around 10% for better insulation. It is important noting that reducing the solar gains of the building, the energy consumption tends to the same value for mean to well insulated buildings or, as in Olbia, a too insulted envelope makes the energy consumption higher. The best configuration in Naples is the highest insulation and solar reflectance, while in Olbia a mean insulation is better performing. The latter conditions apply in Palermo, whatever are the roof solar properties. Energy savings can be up to 21% under these climatic conditions and the insulation of the envelope is not effective, in fact close results are obtained for low to medium insulation level. The best performance are here obtained for the lowest insulation and the highest sola reflectance.

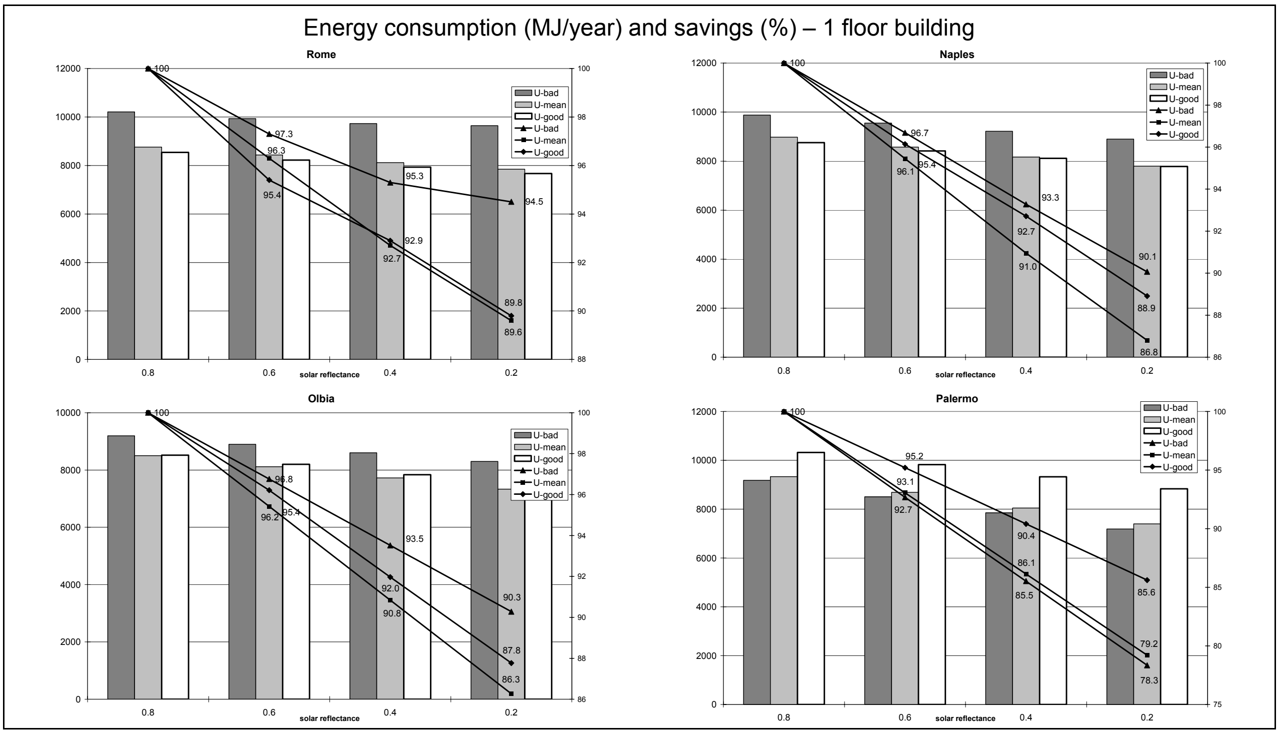

Figure 5: Energy consumption of the 1 floor building

Figure 6 summarises the result for the two floor geometry. The first general issue to outline is that the heating demand does not change (the order is few units percent) respect to the single floor, while a consistent increase of the cooling demand (between 200 to 370%) is calculated. It is important, as consequence, reducing the cooling demand as a general strategy, even if the percentage influence of the cool roof decrease respect to the previous conditions.

The main outcomes of this building configuration are the reduction of the energy consumptions between 7 and 12% as a function of the roof reflectance in Rome, Naples and Olbia. The mean insulation level is the best performing in these localities, even if the influence of the insulation tends to zero for high reflectance values in Olbia. Palermo results outlines the consistency of this technology, in fact the energy savings are around 15% from average to poor insulation of the envelope. High U-values and reflectance values for roof ensure the best energy performance over the year.

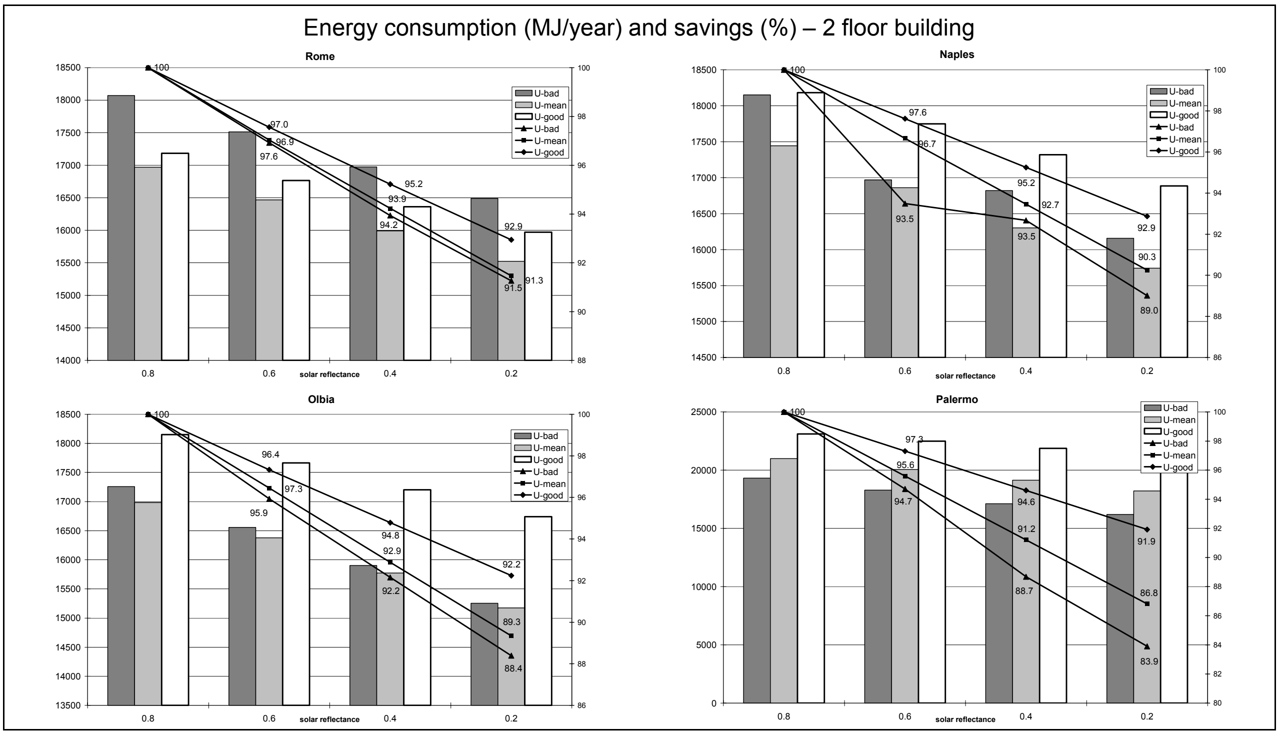

Figure 6: Energy consumption of the 2 floor building

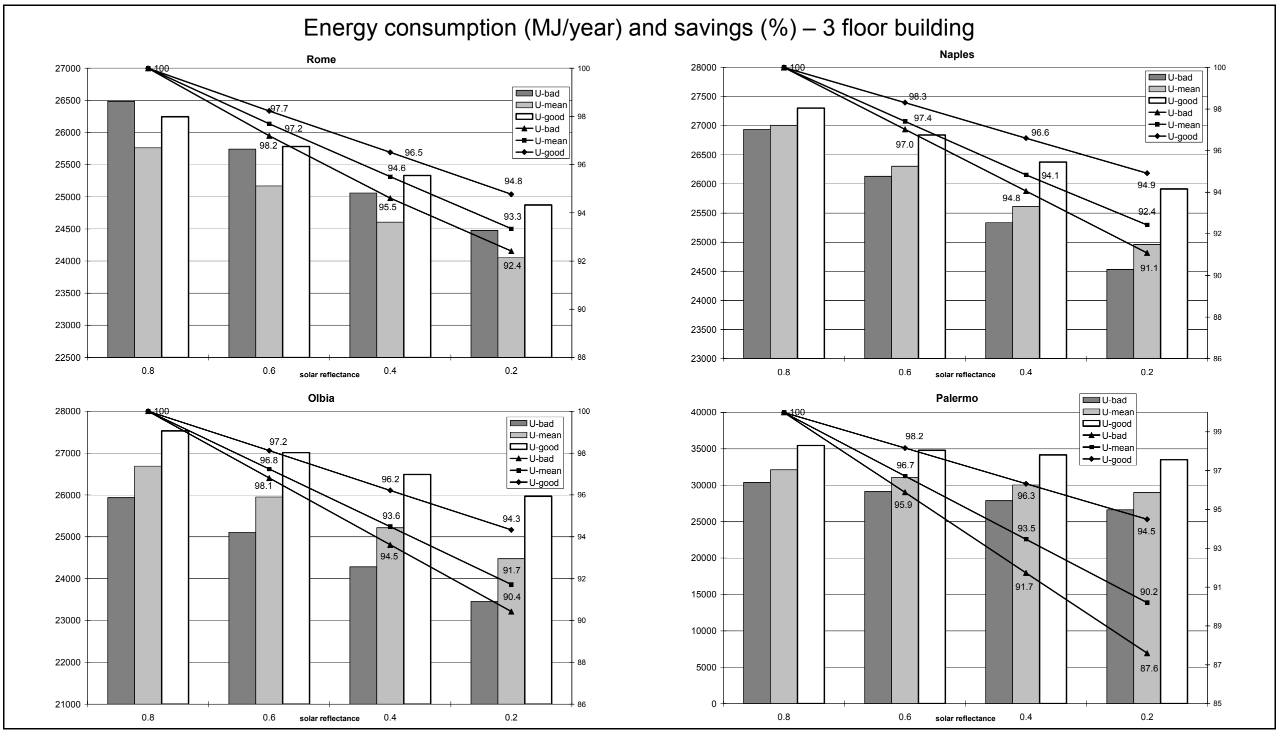

Figure 7: Energy consumption of the 1 floor building

Figure 7 summarises the result for the three floor geometry. As in the previous configuration, the heating and cooling demands have completely different shapes. The heating demand registers a modest increment, never higher than 50% with a triplication of the cooled/heated volume, while the cooling demand has a dramatic increase (up to 700%) is calculated. It is important, again, reducing the cooling demand, while strategies aiming at reducing the heating consumption might be not effective.

The main outcomes of this building configuration are the reduction of the energy consumptions between 6 and 9% as a function of the roof reflectance in Rome, Naples and Olbia. The mean insulation level is the best performing in Rome only, while in all the other localities the lower is the insulation level, the better is the energy performance, this applies for al the roof reflectance. Energy savings of 10-12% can be obtained in Palermo using reflective coatings.

4. Results

The energy balance of commercial buildings, considering the typical use patterns, is affected by several parameters and accurate analyses are needed to find out the best strategies to optimise the envelope and building energy performances. Usual construction materials generally have high absorptivity across the whole solar spectrum and get hot under the solar radiation. The extensive parametric study here presented stressed how the solar properties of roofs affect the global energy performances of office buildings at Mediterranean latitudes.

The most important findings are:

- The cooling demand and consumption should lead the energy measures during the design and refurbishment phases of commercial buildings.
- High reflectance coatings and paintings for roofs improve the yearly energy balance, in colder climate as Milan too. The advantages are, as expected proportional to the climatic conditions.
- The energy performances of the building are affected by the orientation, but this applies only in a small percentage for the relative savings due to the cool roofs.
- The insulation level is critical for commercial buildings and in general it is not true that the energy performance is always improved by lower U–values of building components. It found that moderate, or even less, insulation level optimises the energy performances at Mediterranean latitudes.

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