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EFFECTS OF RADIATION REFLECTIVE COATINGS APPLIED TO MASSIVE WALLS

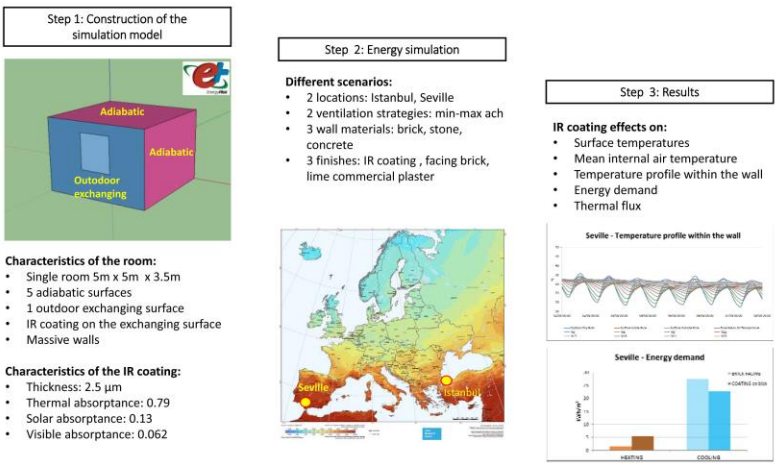

Fig 1: Steps of the infrared reflective coating analysis

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

Reflective coatings reflect the infrared incident radiation on a surface, reduce the radiation absorbed by the building surfaces and therefore decrease the cooling energy consumptions during summer. They are used mainly on the horizontal surfaces of light construction buildings to create cool roofs. Today they are also applied on the outside vertical surfaces to prevent overheating during summer. Reflective coatings change the reflective properties of the surfaces, modifying the thermal performance of the whole building envelope. It is therefore important to analyse them integrated in buildings with different users´ behaviours and construction technologies. In particular, this paper focuses on their application on existing buildings with massive walls (stone and brick masonries). We performed thermal simulations with the software EnergyPlus on a reference room located in two climates with different solar radiation values: Istanbul (TUR) and Seville (ESP). To have many scenarios, we change step by step the following parameters: (i) surface orientation; (ii) internal natural summer ventilation; (iii) internal conditions, (iv) stratigraphy and (v) materials of the exterior walls. We analyse the temperature inside the walls, the temperature of the outside and inside surface, the heat flux entering and leaving the treated surface. We calculate the energy consumptions during the whole year evaluating the coating effects on walls made by stone, brick and concrete.

Keywords: **reflective coating, inside wall temperature, surface temperature, energy consumptions**

1. Introduction

Reflective coatings are passive solutions able to reflect the infrared incident radiation on a surface. At urban level, they contribute to mitigate the effects of the heat island phenomenon reducing the surfaces temperatures. At building level, they decrease the radiation absorbed and the cooling consumptions during summer, and contemporary they improve the thermal comfort. They are used especially for the “cool roof” technologies. Synnefa, Santamouris, and Livada (2006) shown that the reflective coating can reduce the surface temperatures of a white concrete tile under hot summer conditions (4°C during day and 2°C in the night). It could be warmer than the ambient air by only 2°C during the day and cooler by 5.9°C during the night. Xiaoxing Wang et al. (2008) developed a thermal simulation model for a retail shed coated with reflective material. They demonstrated that the reflective coating significantly reduces the energy consumptions for different climates in a range of 25-38%. Synnefa, Santamouris, and Akbari (2007) shown that a cool coating with a solar reflectance of 0.65, applying on a roof, could reduce the cooling loads (8-48 kWh/m^2), the hours of discomfort (9-100%) and the maximum temperature (1.2-3.7°C), depending on the climatic conditions. Also, Pisello and Cotana (2014) demonstrate the benefit relate to a cool roof for the indoor thermal conditions in summer for the temperate climate. Whereas, this correspond to a smaller heating penalty in winter. Juodi et al. (2013) shown the contribute of an external reflective coating on net cooling savings and the penalty on net heating loss. The total saving can be seen in warmer climate, with a dominant cooling load, e.g. due to high internal load.

Berdahl (1995) considered that the white coatings with high solar reflectivity and high reflective emissivity can significantly reduce energy use for cooling, both in horizontally and vertically exposed surface.

Shen et alii (2011) present an experimental study about the impact of reflective coatings on building surface temperatures, air temperature, globe temperature, energy consumption, and thermal comfort. The results showed that, depending on location, season and orientation, exterior and interior surface temperatures can be reduced by up to 20◦C and 4.7◦C respectively using different coatings. Actually, there is no specific literature on their application in the vertical walls of massive type. For this reason, the work aims to analyse the effects of the reflective coating applied on the vertical surfaces of existing buildings with massive walls.

2. Methodology

The analysis method is structured into the following phases:

- Construction of the simulation model;
- Energy simulation of the building with different scenarios (climatic zone, surface orientation, ventilation, functions, internal conditions, wall stratigraphy);
- Comparison among the energy behaviour of reflective coating and traditional systems (lime plaster, facing bricks).

First, we built a thermodynamic simulation model of a reference room (5 x5 x3.5 m) with the software EnergyPlus 7.2. We considered five adiabatic surfaces and one vertical surface with thermal exchange with the outside, to reduce the variables affecting the simulation results. We used as outside conditions the weather data created with meteonorm.

Therefore we considered two climatic locations: Istanbul (TUR) and Seville (ESP), as representative example of high solar radiation.

We considered a commercial reflective coating applied on the outside face of the exterior wall exchanging with the outside. The properties of the coating and of all materials are listed in Tab II. As a starting point, we analyzed the effects of the coating depending on the orientation of the surface. For this first step, we considered the room located in Istanbul without windows, internal heat gains, and HVAC system, perfectly airtight and made by brick walls. We calculated the surface temperature difference with and without the reflective coating, both on south and north façades. As a second step, to have more realistic conditions, the room has been designed as a residential space, with internal heat gains, natural ventilation and one window with a surface of 2.5 m^2. The air infiltrations are equal to 0.5 ach (minimum for residential use during the occupation hours) and the natural ventilation is 5 ach, available only when indoor temperature is higher than 24°C and outside temperature is at least 1°C lower than the inside one. Also, the internal heat gains are equal to 10.2 W/m^2 (standard value for residential use). There is an ideal load heating system with a constant set point of 20°C. In this phase, we analyzed the internal nodes temperatures inside the wall and the outside surface temperatures. As a third step, we installed a cooling system inside the residential model and we calculated the thermal energy consumptions with and without the coating. Finally, using the model, we compared the performance of the reflective coating and white lime plaster, considering different stratigraphy of the walls: stone, brick and concrete (Tab II for the properties).

3. Results

3.1 *Effects on surfaces with different orientations*

The reflective coating has a higher effect on the south oriented façade than other surfaces because of the higher incident solar radiation. The peak temperature difference between exposed brick and reflective coating reaches 26.6°C on the south façade and 8.2°C on the north façade. Therefore it is more important to study the effects of the coating on a south oriented surface.

3.2 Temperature profile within the wall

To understand the effect of the reflective coating inside the wall, we simulated the nodes temperatures using the Finite Difference method implemented in EnergyPlus. The node number increases from the inside to outside of the wall (see Fig. 3).

Both during winter and summer, the reflective coating stabilizes the temperatures, avoiding mechanical stress into the structure, extending the life of the structure and preventing cracks. Fig. 1 and Fig. 2 show the temperatures inside the wall during 10 days in summer in Seville.

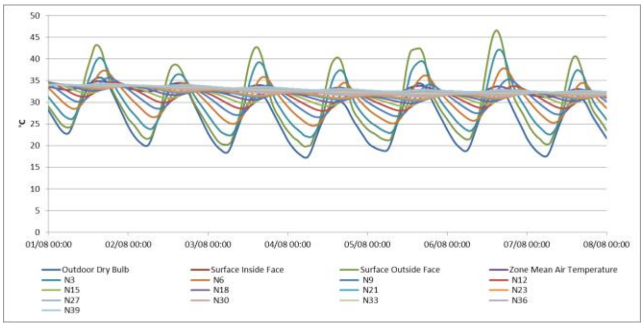

Fig. 1: Temperatures inside the wall without reflective coating (Seville, summer period, 0.5 ach)

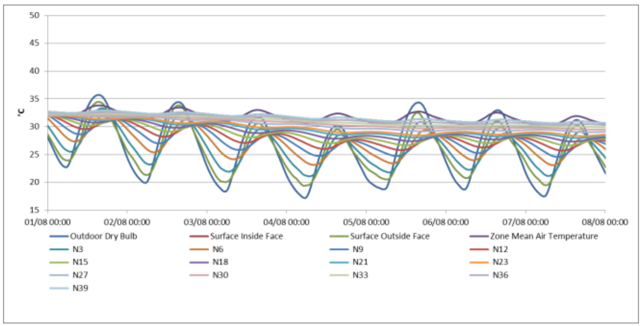

Fig. 2: Temperatures inside the wall with reflective coating (Seville, summer period, 0.5 ach)

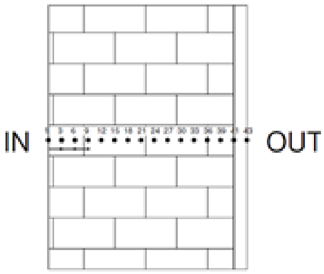

Fig. 3: Position of the nodes in the wall

3.2 Outside face temperatures

To understand the effects of the coating on the outside face temperature during the year, we analyzed a typical summer (11.08, without cooling system) and winter day (08.01). In summer, the effects are more high than in winter: it decreases the peak temperature up to 5.8°C in Istanbul and up to 8.1°C in Seville. In winter, it decreases the temperature up to 5.9°C in Istanbul and 12.4°C in Seville. This happens considering both 0.5 ach and 5ach. It means that the interior ventilation rate doesn´t influence the outside surface temperatures. On the opposite, the solar radiation highly influences the performance of the coating: the higher the radiation, the higher the reflective effects.

3.3 Cooling and heating consumptions

The effects of reflective coating on surface temperatures are linked to the energy consumptions. We modelled a cooling system inside the reference room (adding 5ach natural ventilation) and we calculated the total energy consumptions for the room with brick exposed walls and for the room with the reflective coating. Fig 4 and Fig 5 show the heating and cooling amount of energy in Seville and Istanbul.

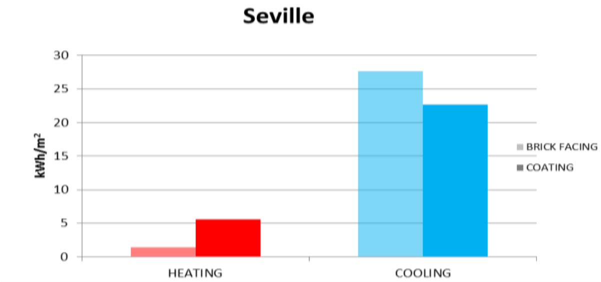

Fig 4: Thermal energy consumptions in Seville

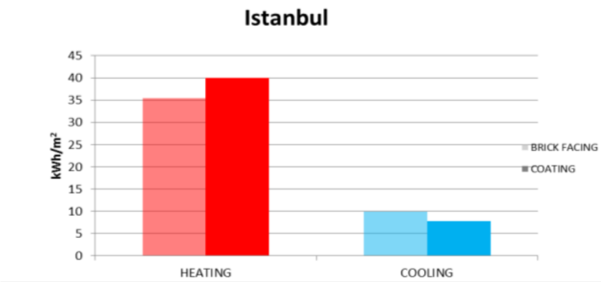

Fig 5: Thermal energy consumptions in Istanbul

The reflective coating reduces the energy demand in Seville and increases it in Istanbul. In Seville, the total energy demand decreases from 29.06 kWh/m^2 to 28.26 kWh/m^2: heating slightly increases but comfort is reached the most of the time without a heating system; cooling, the majority of the total energy demand, decreases of 5 kWh/m^2. In Istanbul the total energy demand increases from 45.35 kWh/m^2 to 47.8 kWh/m^2: heating increases of 4.6 kWh/m^2; cooling slightly decreases. The increase of the heating demand in both climates is connected to the growth of the negative thermal flux through the exterior surface of the envelope wall during winter (positive radiation is added to the surface, negative radiation is lost by the surface). Fig 6 shows the reduction of the solar radiation heat gain, convection heat losses and thermal radiation heat gain. The reduction of the losses due to the lower temperature difference between surface and external air temperatures is not enough to supply the less solar radiation gain. Reflective coating applied on vertical surfaces made by 50 cm of bricks are therefore useful to reduce energy demand only in very hot climates as Seville where a heating system is the most of the time not necessary.

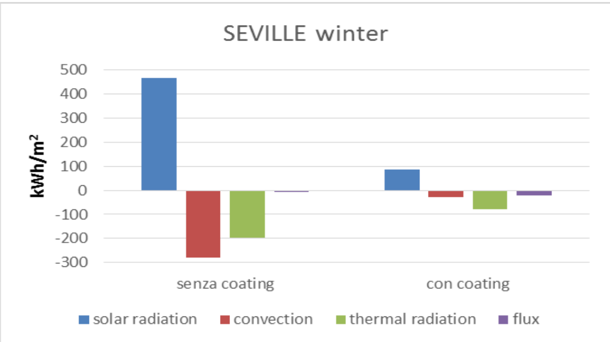

Fig 6: Thermal flux during winter in Seville

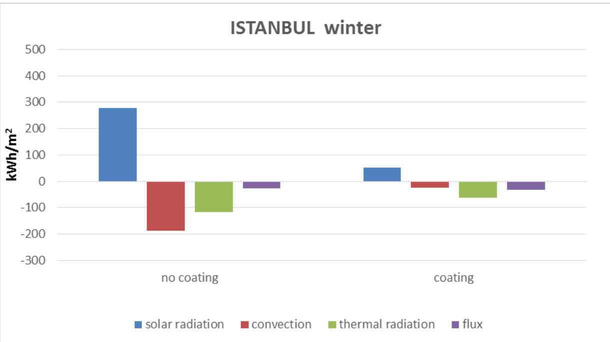

Fig 7: Thermal flux during winter in Istanbul

3.4 Thermal effect on different stratigraphy

To understand the best conditions for the application of the reflective coating, we analyzed different stratigraphy of walls. We considered a residential use of the building and 5ach of natural ventilation, no cooling system. We compared the effects of a white standard commercial plaster (see Tab II for the properties) to the effects of a reflective coating. Fig 8 shows the difference in the outside surface temperatures between the walls made by brick, concrete and stone, applying a standard white plasters and a reflective coating during a typical summer day in Seville. The masonries have a peak difference of 13.3°C and an average difference during the day (from 08:00 to 18:00) of 7.5°C. The stone and concrete walls have a similar average difference in outside surface temperatures (12°C). The decrease of outside face temperatures due to the coating is higher in brick masonries and less in other walls. This is probably connected to the different thermal effusivity of the materials. Lower values increase the effects of the coating for reducing the outside face temperature. The opposite happens to the zone mean air temperatures difference (Fig 9 and Fig 10). In Seville, the average zone air temperature (24h) during a typical summer day is reduced in brick (0.29°C), concrete (0.63°C), and stone (0.51°C) walls. In Istanbul the effects are lower (brick = 0.17°C; concrete = 0.37°C; stone =0.30°C). This is due to different thermal capacity of the materials. Lower thermal capacities increase the effects of the reflective coating for reducing the zone mean air temperature in summer.

4. Conclusion

We analysed the effects of reflective coating applied on vertical surface of massive walls. The reflective coating reduces the temperatures oscillations inside the walls avoiding mechanical stress into the structure and extending its life. Moreover, the reflective coating applied to vertical massive walls can contribute to energy saving in hot climates, increasing comfort conditions and reducing the zone air temperature.

	Conductivity (W/mK)	Thickness(m)	Specific Heat (J/kgK)	Density (kg/m^3)	Thermal absorptance	Solar absorptance	Visible absorptance	Thermal capacity (J/m^{2}K)	Thermal effusvity (Ws^{-1}/m^{2}K)
IR coating	0.83	2.5*10^-6	1000	1450	0.79	0.13	0.062	-	-
White commercial plaster	0.83	0.03	1000	1450	0.9	0.6	0.6	-	-
Brick	0.47	0.48	1600	1000	0.9	0.7	0.7	768000	867
Stone	1.3	0.48	712	2200	-	-	-	751872	1426
Concrete	1.35	0.30	1000	1800	-	-	-	540000	1559

Tab I: Temperature reduction with and without the reflective coating on different construction

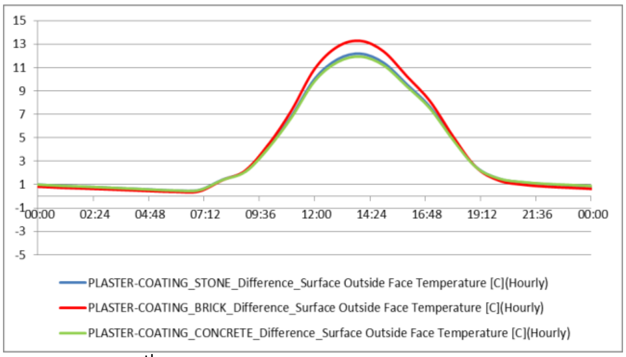

Fig 8: 10th August in Seville, outside face temperatures difference with and without reflective coatings

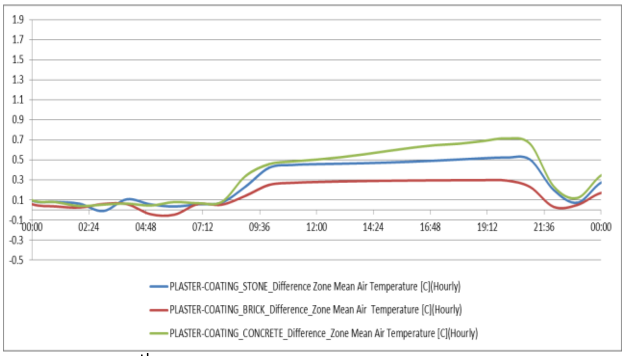

Fig 10: 10th August in Istanbul, zone mean air temperatures difference with and without reflective coatings

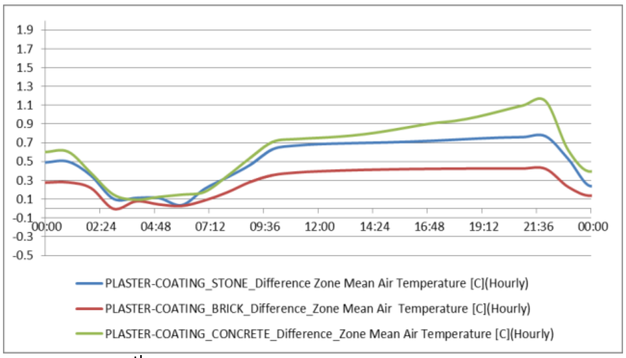

Fig 9: 10th August in Seville, zone mean air temperatures difference with and without reflective coatings

6. Acknowledgments

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	Average whole Winter		Average Whole Summer		Whole Summer maximum peak		Average Tipical Summer day (08:00-18:00)		Average Tipical Summer 24h	
	IST	**SEV**	**IST**	**SEV**	**IST**	**SEV**	**IST**	**SEV**	**IST**	**SEV**
Stone	0.13	0.94	0.56	0.79	1.50	1.81	0.41	0.64	0.30	0.51
Brick	0.1	0.66	0.3	0.45	0.79	1.18	0.25	0.37	0.28	0.29
Concrete	0.13	1.06	0.69	0.91	1.95	2.22	0.5	0.74	0.37	0.63

Tab II: Material properties

7. References

Berdahl, P. 1995. “Building Energy Efficiency and Fire Safety Aspects of Reflective Coatings”, *Energy and Buildings* 22(3): 187–191.

Joudi, A., Svedung H., Cehlin M., and Rönnelid M. 2013. “Reflective Coatings for Interior and Exterior of Buildings and Improving Thermal Performance”, *Applied Energy* 103: 562–570.

Pisello, A. L., and Cotana, F. 2014. “The Thermal Effect of an Innovative Cool Roof on Residential Buildings in Italy: Results from Two Years of Continuous Monitoring” *Energy and Buildings* 69: 154–164.

Shen, H., Hongwei, T. and Tzempelikos, A. 2011. “The Effect of Reflective Coatings on Building Surface Temperatures, Indoor Environment and Energy consumption. An Experimental Study” *Energy and Buildings* 43(2-3): 573–580.

Synnefa, A., Santamouris, M. and 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.

Synnefa, A., Santamouris, M., and Livada, I. 2006. “A Study of the Thermal Performance of Reflective Coatings for the Urban Environment.” *Solar Energy* 80(8): 968–981.

Wang, X., Kendrick C., Ogden R., and Maxted J. 2008. “Dynamic Thermal Simulation of a Retail Shed with Solar Reflective Coatings.” *Applied Thermal Engineering* 28(8-9): 1066–1073.