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The insulating paint with nanoparticles as a high-performance solution for the thermal and energy efficiency of buildings in hot areas

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Abstract – The optimization of energy consumption has emerged as a prominent topic, drawing continuous attention from researchers across various disciplines, including the field of construction. In today's climatic and economic conditions, designers face a significant challenge in providing thermal comfort to building users through passive solutions, while simultaneously reducing energy usage and mitigating environmental impacts. The building facade, acting as a heat exchange surface between the interior environment and external climate, relies on several factors to perform efficiently. This research aims to investigate the thermal and energy performance of building facades in hot regions, specifically focusing on the application of insulating paint embedded with reflective nanoparticles. The study adopts an experimental approach, utilizing test cells to measure surface and ambient temperatures through thermal cameras, infrared thermometers, and thermo-hygrometers. Additionally, a numerical study employing the dynamic thermal simulation software "TRNSYS 17" complements the research, enabling an assessment of how facade surface properties influence the thermal behavior and energy efficiency of buildings throughout the year. The findings of the study reveal a positive impact of facade surface properties on the building's thermal performance and energy efficiency. The implementation of insulating paint with reflective nanoparticles emerges as a durable and effective solution, ensuring user well-being in hot regions while simultaneously reducing energy consumption for heating and air conditioning, and preserving the natural environment.

Keywords – Insulating Paint; Nanoparticles; Thermal Comfort; Energy Efficiency; Experimentation; Hot Areas.

I. INTRODUCTION

The rationalization of the energy waste has become a universal issue in all sectors especially the construction sector. The building sector accounts for 40 to 45 % of the total primary energy consumption and is one of the energy-intensive industries in the world [1-4]. This large quantity was mainly used to improve the thermal conditions of the occupants [5, 6] by using great ingenuity and integration of multiple devices [7, 8] making reducing this number a major challenge for designers [9]. The indoor thermal surroundings is influenced by many parameters that have an effect on the energy performance of the building like materials and opaque surfaces [10]. Hence, the necessity to search out economical suggests that to attenuate energy consumption [11].

In Algeria, the energy consumption of the building sector represents a percentage of 43 % of the final consumption [12] as shown in Fig. 1.

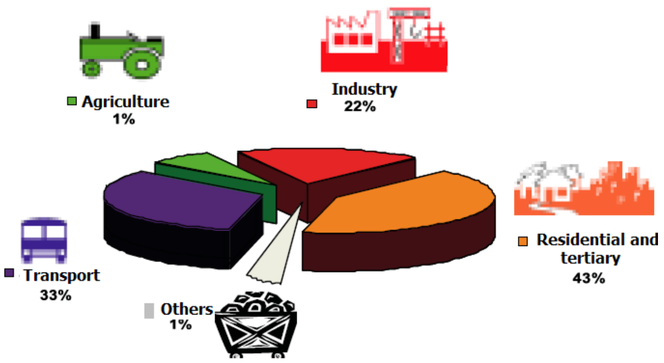

Fig. 1 Algeria's final energy consumption by sector [10]

Buildings are significantly massive consumers of energy because of the uncontrollable exploitation of heating and cooling.

The building envelope most exposed to solar radiation generates phenomena of absorption and reflection that modify per the surface characteristics of materials and surface characteristics [13]. The color (light or dark) and the texture of a surface (smooth or rough) are two very important characteristics that influence the absorption of the elements of the facades and the thermal functioning of the walls [14, 15]. Which subsequently influences the thermal behavior of the construction and the thermal comfort of users. These two parameters are considered as passive methods area thought of as good solutions to optimize the energy performance of buildings whereas improving the interior thermal condition [16].

Many researchers take into account cool materials as a good solution to stop heat accumulation on the surface of the facade and scale back the quantity of heat-transferred inwards [16, 17]. These materials will cut back the surface temperature right down to 15 °C [18].

The objective of this research is to study the influence of surface properties of the facade on the thermal comfort and energy performance of buildings in a hot and arid environmental condition.

II. Materials and Method

This research is based on the different methods of investigation, experimental approach and a numerical study.

A. *The study context*

The context of the study focuses on hot and arid areas taking the city of Biskra as a case study (southern Algerian city at a latitude of 34° 48' North, a longitude of 5° 44' East and an altitude 86 meters). Figure 2 shows the climatic characteristics (the monthly radiation and the monthly temperatures during a year) of the city of Biskra generated by "Meteorom V.7.2.1" meteorological data software [19].

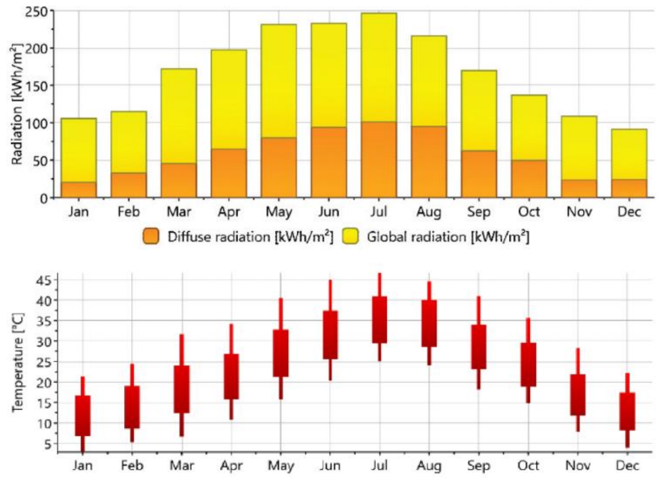

Fig. 2 Algeria's final energy consumption by sector [10]

It is seen that there are very large thermal amplitudes between the maximum and minimum temperature during the same month with a large hot period. We noticed that the radiation values are high throughout the year particularly during the summer.

B. *Presentation of test cells*

The objective of this research is to study the impact of surface properties of the facade on the thermal comfort and energy efficiency of buildings in a hot and arid climatic context. In our case, tow test cells were created in order to study the impact of solar reflectivity and the thermal emittance of the surface of the facades on the external and internal surface temperatures, as well as the ambient temperature exploitation cool (insulating) paint with nanoparticles.

The Figure 3 illustrates the two test cells realized with a rectangular shape (80x90 cm) and a height of (90 cm). The walls are hollow bricks of (10 cm) with a cement coating of (1 cm), a screed of (2 cm) and a solid slab of (7 cm).

The first cell (C1) was used as a reference cell (control). The second (C2) was covered by an insulating (cool) paint with nanoparticles (having a high solar reflection and a very high thermal emittance) to test the impact of these two parameters on the thermal behavior of the facade.

Fig. 3 The two studied test cells

The used insulating paint contains nanoparticles (20 µm micrometer semi-hollow silica micro-beads, titanium oxide, water and acrylic silicone). These cool paints produce a high infrared reflection factor compared to normal paints of a similar color with a surface temperature difference of more than 10 °C [20]. according to a research by Hernández-Pérez [10], cold colors are able to reduce the surface temperature down from 5 to 13 °C compared to a similar normal color.

The Figure 4 illustrates the instrument used for taking measurements (Testo 865 thermal camera).

Fig. 4 The instrument used for taking measurements

C. *The numerical study*

The dynamic thermal simulation software "TRNSYS V17" was used for the numerical study. It is a program mainly intended for building actors, as its strengths have been demonstrated by several studies [21].

We have created three numerical models ($Mab_{0.2}$, $Mab_{0.5}$, and $Mab_{0.8}$). The Figure 5 shows the geometry of the simulated models and the material composition of the facades.

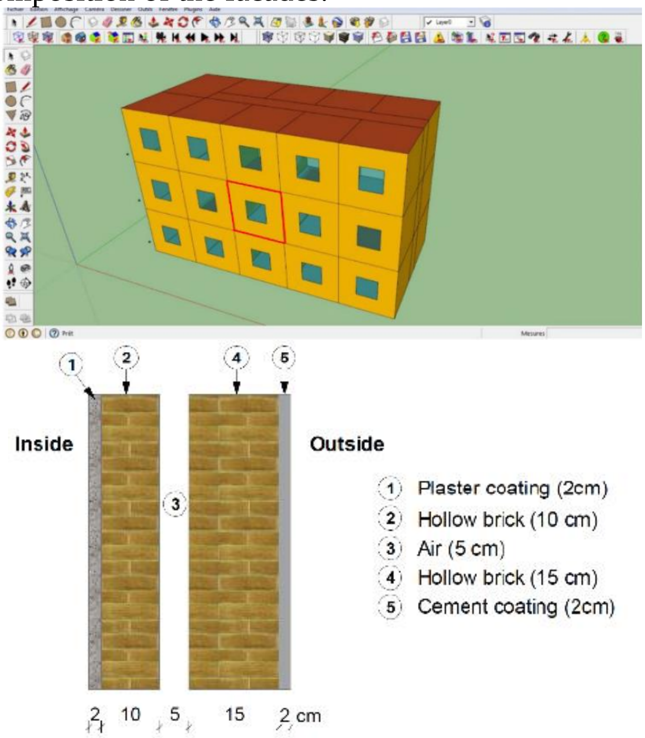

Fig. 5 The geometry of simulated models and their material composition

The material composition of the simulated walls is similar to the composition of the used walls in this region. The Table 1 illustrates the thermal characteristics of the used materials.

Table 1. The thermal characteristics of the materials of the simulated models

	Thermal conductivity λ (W/m.k)	**Specific heat C (KJ/kg.k)**	**Density D (Kg/m3)**	**Thickness (cm)**
Hollow brick	0,48	1080	900	10-15
Plaster coating	0,35	936	1150	02
Cement coating	1,40	1080	2200	02
Air	0,047	1000	1	05
Reinforced concrete	1,75	1080	2500	10
Hollow-core slab	1,20	1000	1300	16

These three models are similar only in terms of exterior surface properties of facades with low, average and high absorption. The "type 56" is used for numerical simulation by taking into account different thermal factors

III. Results And DISCUSSION

The results of the experimental study are illustrated in figure 6 which represents the photos taken by the thermal camera of the envelope of the test cells (C1 and C2).

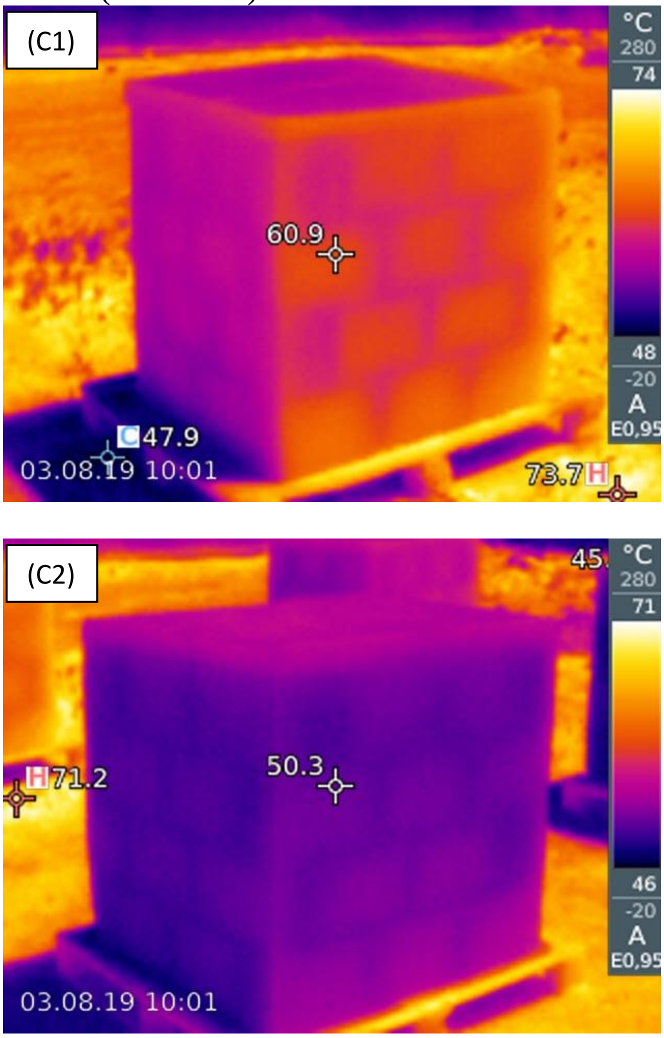

Fig. 6 Photos taken by the thermal camera of the test cell envelope

Note that the external surface temperature measured in the first cell (C1) is 60.9°C. It is very high and even exceeds the external climatic conditions (the outside temperature). On the other hand, the external surface temperature measured in the second cell (C2) is 50.3°C. The difference recorded between the two test cells is 10.6°C. Therefore, the use of insulating paint makes it possible to reduce the external surface temperature by up to 17.6%, which directly influences the thermal functioning of the construction by reducing the internal surface temperature and the ambient temperature under the influence nanoparticles of the paint used. Therefore, the reflection factor of the surfaces of the facades plays a very important role in the thermal functioning of the constructions.

The results obtained by the numerical simulation are represented in figure 7, which represents the ambient temperatures in the three test cells throughout the year.

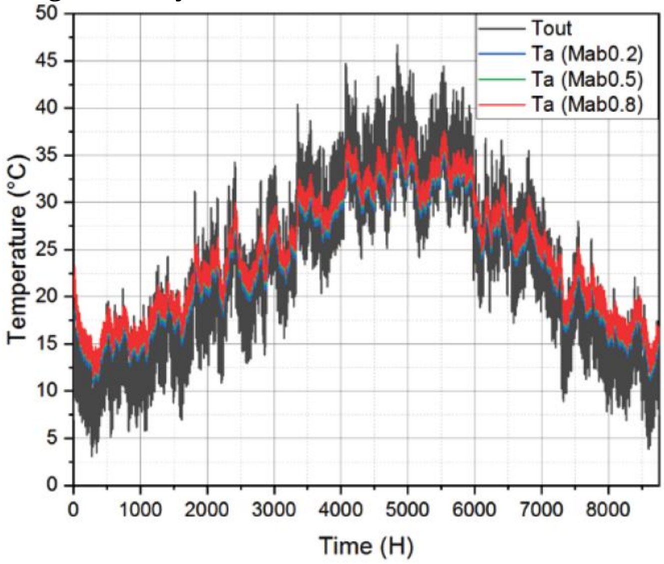

Fig. 7 Simulated ambient temperature graph for one year in the three test cells

We note that the close temperature of the model ($Mab_{0.8}$) is extremely high throughout the year particularly throughout the warm period, that explains the role of the good absorption of surfaces on the rise of ambient temperature. Contrariwise, the ambient temperature of the model ($Mab_{0.2}$) is extremely low throughout the year compared to the primary model given the low absorption of its surfaces. The reduction in surface absorption (from $Mab_{0.8}$ to $Mab_{0.2}$) has allowed us to attenuate the ambient temperature down 3.32 % in summer. Note that there is a possibility to optimize these values through a parametric simulation.

IV. CONCLUSION

This research represents the main results of a research based on an experimental work by taking measurements on test cells on a reduced scale with a thermal camera as well as dynamic thermal simulations by the "TRNSYS" software. The objective of this research is to study the impact of surface properties of the facade on the thermal comfort and energy efficiency of buildings in a hot and arid climatic context (in the city of Biskra). The results were very positive; demonstrating the positive impact of the cool paint is the surface characteristics of the facade of the buildings. The application of the cool paint on the facade of buildings in hot and arid areas makes it possible to minimize the external surface temperature by up to 17.6%. Which directly influences the reduction of internal surface temperatures and subsequently the reduction of ambient temperatures up to 3.32% to ensure the thermal comfort of users while minimizing the energy consumption used by air conditioning equipment and preserving the environment. The advantages of this paint makes its use recommended in hot and arid areas.

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