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NUMERICAL INVESTIGATION ON THERMAL EFFICIENCY OF INNOVATIVE SOLUTIONS USED FOR EXTERIOR WALL REHABILITATION

BY

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Abstract. Rehabilitation of residential buildings that do not comply with present efficiency requirements represents one of the strategies for reducing energy consumptions in EU countries. Therefore, ventilated façades systems are increasingly being used for retrofitting the existing building stock due to their advantages compared to compact walls. These constructive systems, if properly designed and built, can lead to energy savings and to an increase of the durability of the exterior walls. The architectural variations of the exterior layer are many, with a large number of materials that can be used (wood, brick, ceramic and metallic elements, composites, etc.). Nowadays, variations to the classical solutions are becoming more and more common. In this paper, the thermal efficiency of one of these solutions has been investigated numerically and some of the results are presented hereby.

Key words: ventilated façades; numerical model; rehabilitation; thermal efficiency; energy consumption.

1. Introduction

The building façade is an important architectural element that accounts for a large percentage of the total cost for a given construction. Moreover, the

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exterior walls have a large impact on the overall heat loss because of their significant area. Therefore, the façade design, construction and maintenance are of the most importance when designing the next generation of energy efficient buildings.

In the last decades it has become a current practice to have the building enclosure built from multiple layers. The ventilated façade represents a special case of these structures, with two different materials being separated by an air layer. This particular system is efficient in the warm season because air movement can transport heat to the exterior, thus reducing the thermal load to the building. Some authors consider that heat fluxes reduction of up to 50% can be obtained for high values of solar radiation intensity (Patania *et al*., 2010; Ciampi *et al*., 2003; Mesado *et al*., 2010; Eicker *et al*., 2008). These systems are considered to be disadvantageous in the cold season, especially when solar radiation increases the convective flow in the cavity and, consequently, the quantity of heat that is transported to the exterior. Nevertheless, some studies show that wall ventilation has no effect on heat exchange in the cold season (Naboni, 2007).

The design of ventilated façades in the temperate climate of our country must consider both the cold winters and warm summers. Night radiation also plays an important role on the thermal performance of the façades (Aelenei & Henriques, 2004; Künzel, 2002; Romila, 2012). The parameters that are considered to have the largest influence of the ventilated façades thermal efficiency are the channel geometry and exterior layer's physical properties.

The thermal efficiency can be investigated numerically by computational models. One such model, that is capable of predicting with good accuracy the heat fluxes through the supporting wall of the ventilated system for a wide range of parameters (sun radiation intensity, exterior and interior air temperatures, properties of materials, channel geometry) has been presented by Romila *et al*. (2012). The proposed model is based on the conservation of conductive, convective and radiative fluxes on the surfaces of the constitutive elements. The obtained results were in good agreement with similar ones described in the scientific literature.

2. Innovative Solutions for Exterior Wall Rehabilitation

Metallic elements offer a wide variety of possibilities for the making of the exterior layer of ventilated façades. The metallic coating is usually made of copper, aluminium, zinc, lead or steel or an alloy of these materials. The panels are made from corrugated or plane metals sheets with thicknesses of several millimetres.

Ventilated façades made of metallic elements have been used for the thermo-physical rehabilitation of several students' halls in Tudor Vladimirescu campus of the "Gh. Asachi" Technical University of Iaşi (Fig. 1).

Fig. 1 – Ventilated facades made of corrugated metal sheets used for the thermal rehabilitation of students' halls in "Tudor Vladimirescu" campus, Iaşi.

In an INCO-Copernicus project, a team of researchers from the Faculty of Constructions and Building Services of Iaşi has proposed a innovative solution for the rehabilitation of a student hall in the same campus. The hall is a typical building made of large concrete panels, characterized by low values of thermal protection. The solutions of thermal rehabilitation consisted in: supplementary insulation of the exterior wall, adding an extra glass sheet on the windows, supplementary insulation at the terrace roof and base floor, building installation replacement and the disposal on the longitudinal façades of bow-windows on the 50% of the classical windows area (Fig. 2).

Fig. 2 – Thermal rehabilitation of the T14 student hall.

The constructive system used for the exterior wall retrofitting was considered to be an upgrade to the classical ETICS solution (External Thermal Insulation Composite Systems). Therefore, Polyalpan panels were mounted on the façade to the exterior (Fig. 3).

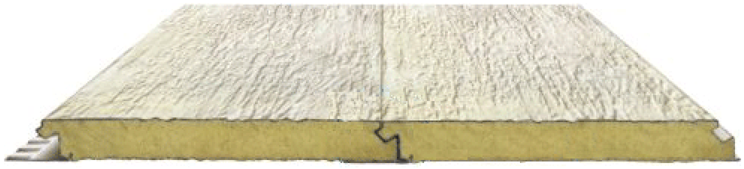


Fig. 3 – Polyalpan panels used for the thermal rehabilitation of students' hall in "Tudor Vladimirescu" campus, Iaşi.

The choice for this kind of system was motivated from several reasons: the panels form a tight layer that protects the wall from temperature and humidity variations and it shields the polystyrene layer from mechanical shocks. The most important features of the panels are related to the thermal efficiency reasons: low emissivity of aluminium foils on both faces of the panels, an extra insulation layer between the faces made of polyurethane foam and small inlet/outlet openings area.

The panels were mounted on the entire height of the building (12 m) on 2.4 cm thick wooden battens that have been previously been treated for fire protection and humidity decay. The cross-section of the rehabilitated wall is presented in Fig. 4.

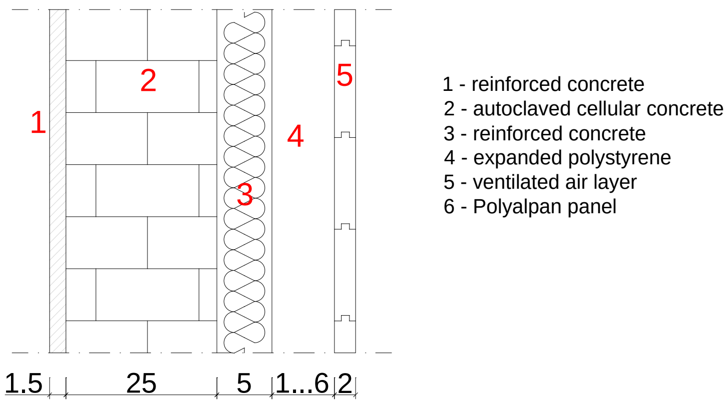


Fig. 4 – Cross section of the rehabilitated wall (some dimensions are not scaled).

The physical properties of the constitutive materials are presented in Table 1.

Table 1
Physical Properties of the Constitutive Materials

Layer	Conductivity W/m.K	Emissivity	Solar absorption coefficient
Polyalpan panels	0.03	0.05	0.93
Expanded polystyrene	0.04	–	–
Reinforced concrete	2.03	0.9	–
Autoclaved cellular concrete	0.24	–	–

3. Numerical Modelling Results

The numerical model was used to calculate the effect of ventilation on heat fluxes through the exterior walls. The obtained heat fluxes, q_v , [W/m^2], where compared with the ones that would have been obtained if the ETICS solution was applied, q_{wall} , [W/m^2]. The results are afterwards outlined using the ratio between the obtained values.

Thermal efficiency of the system was investigated for a wide range of exterior air temperatures and solar radiation intensities, in both seasons, considering the climatic conditions for the city of Iaşi.

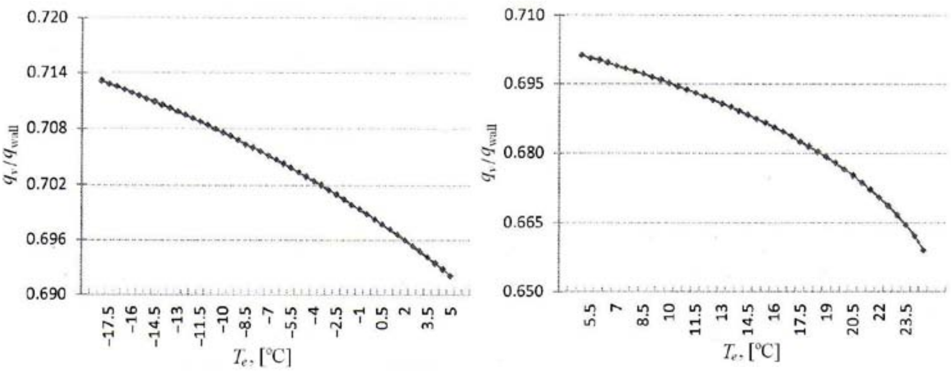
The exterior and interior air temperatures for both summer and winter conditions are taken from the Romanian design code and they are presented in Table 2.

Table 2
Conventional Temperatures According to Romanian Codes

Case	Exterior temperature, [°C]	Interior temperature, [°C]
Summer	+28	+25
Winter	–18	+20

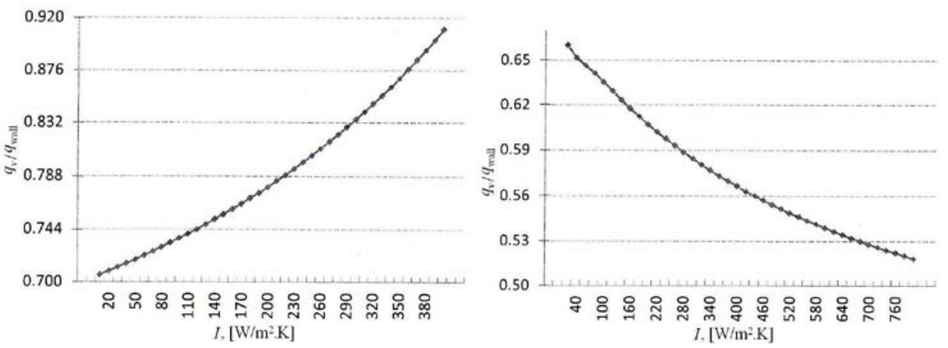
The ratio's q_v/q_{wall} variation *versus* of the exterior wall temperature shows that the heat fluxes, for the case of the retrofitted wall with Polyalpan panels, are with 30% smaller in winter and with 35% in summer, showing a good thermal efficiency of this system (Fig. 5). Lower temperature differences between the inside and outside air will increase the system thermal efficiency due to a decrease in air circulation inside the channel. This phenomenon can be explained by the fact that the air becomes still, the heat is transported mainly through conduction, thus the air and panel thermal resistance can be added to the wall's total resistance.

The solar radiation has an important effect on the efficiency of the ventilated systems. In the cold season, the increase of the solar radiation intensity will lower the heat gains so that the differences between the compared fluxes are less than 20% for solar intensities greater than 200 W/m^2. However, this type of ventilated façade offers a net heat gain in winter for the entire considered interval due to some particular features: a very small surface of the inlet/outlet openings (0.0006 m^2/m) and a very big ventilation volume that will oppose the buoyancy forces. In summer, the energy reduction increases from 35%, in the case of no solar radiation, to approximately 50%, for high values of the solar intensities. In Fig. 6 is presented the variation of the ratio q_v/q_{wall} function of the solar radiation intensity.



a *b*

Fig. 5 – The ratio between the heat fluxes for the rehabilitated façade with Polyalpan panels against the ETICS solution *versus* the exterior air temperature in: *a* – winter; *b* – summer



a *b*

Fig. 6 – The ratio between the heat fluxes for the rehabilitated façade with Polyalpan panels against the ETICS solution *versus* of the solar radiation intensity in: *a* – winter; *b* – summer

The difference between the heat fluxes obtained in both summer and winter period can be transformed in supplementary thermal resistance. Fig. 7 presents this supplementary thermal resistance, R_v^+, [m^2.K/W], brought by the panel and the air layer function of the interior–exterior air temperature difference, without the solar radiation effect.

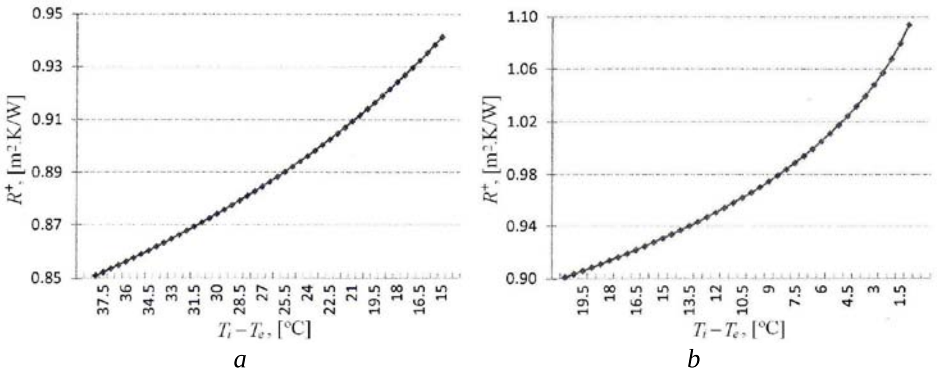


Fig. 7 – The supplementary thermal resistance *versus* the temperature difference between the interior and exterior air in: *a* – winter; *b* – summer.

The average supplementary thermal protection brought by the air layer and the panel was of 0.85...0.95 m^2.K/W in winter and 0.90...1.10 m^2.K/W in summer. These values show a very good thermal protection of this constructive system compared to the classical ETICS solution.

If we compare these values with the individual thermal resistance of both the unventilated air layer (R_{air} = 0.18 m^2.K/W) and Polyalpan panel (R_{panel} = 1.54 m^2.K/W), we can observe that channel ventilation is equivalent to a loss of approximately 0.70 m^2.K/W thermal resistance to the entire systems. Nevertheless, wall ventilation in summer will considerably decrease the heat fluxes towards the interior of the buildings. This reduction can be equivalent with an increase of the total thermal resistance of the exterior wall.

4. Conclusions

The proposed numerical model is considered to be an acceptable tool to carry out a parametric study in order to investigate the thermal efficiency for a given construction system.

The thermal rehabilitation of the exterior walls of a students' hall with Polyalpan panels was proven to lead to the reduction of heat fluxes with almost 50% in the warm season, due the big thermal resistance of the panels. The system has also some other characteristics that improve the thermal performance: small inlet/outlet surfaces, low emissivity of the faces of the panel and the big height of the air volume.

The supplementary thermal resistance of the ventilated system was about 0.90 m^2.K/W in the cold season and 1.00 m^2.K/W in the warm season, thus proving the system's efficiency. The constructive system offers an extra thermal protection in winter, for solar radiation intensities greater than 200 W/m^2. Other ventilated systems show a disadvantageous behaviour over this value because the sun radiation increases the air flow in the channel and therefore, the heat losses.

In conclusion, we can assert that this particular solution of ventilated façade system is very efficient in obtaining energy losses through the building envelope.

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INVESTIGAREA PRIN METODE NUMERICE A EFICIENȚEI TERMICE A SOLUȚIILOR INOVATIVE UTILIZATE PENTRU REABILITAREA TERMOFIZICĂ A PEREȚILOR EXTERIORI

(Rezumat)

Reabilitarea clădirilor rezidențiale care nu satisfac exigențele actuale de calitate reprezintă una din strategiile principale propuse în Uniunea Europeană, de reducere a consumului de energie. Prin urmare, fațadele ventilate sunt din ce în ce mai utilizate pentru reabilitarea termofizică a stocului de clădiri existent datorită avantajelor comparative față de sistemul de perete compact. Aceste sisteme constructive, proiectate şi construite corect, pot conduce la economii de energie şi la creşterea durabilității pereților exteriori. Variațiile arhitecturale ale stratului exterior sunt mari, cu un număr mare de materiale care pot fi utilizate: lemn, cărămidă, elemente metalice şi ceramice, materiale compozite etc. La ora actuală, variații ale sistemelor clasice de fațade ventilate sunt din ce în ce mai utilizate. Eficiența termică a unui astfel de sistem constructiv a fost investigată prin metode numerice, iar rezultatele sunt prezentate în acest articol.