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# ANALYSIS AND EVALUATION OF THE THERMOPHYSICAL PROPERTIES OF VENTILATED FAÇADE TYPOLOGIES

***Abstract***

The energy efficiency of the construction sector is denoted by the European energy and environmental policies, by international standards and national legislation. Ventilated facades can contribute towards more efficient buildings, hence this paper focuses on the evaluation of ventilated façade construction typologies and the impact of thermal radiance exposure. The selected scenarios were evaluated in terms of thermophysical analysis and laboratory measurements, and based on the results useful conclusions can be derived. Nevertheless, there is need of further investigation towards alternative configurations of the facades, such as implementing alternative ventilation configurations and patterns as well as more innovative and technical efficient construction materials.

*Keywords: thermophysical analysis, ventilated façade, construction typologies, radiance exposure*

# АНАЛИЗА И ОЦЈЕНА ТЕРМОФИЗИЧКИХ СВОЈСТАВА ТИПОЛОГИЈА ВЕНТИЛИСАНИХ ФАСАДА

***Сажетак***

Енергетску ефикасност грађевинског сектора обиљежавају европска енергетска и еколошка политика, међународни стандарди и национално законодавство. Вентилисане фасаде могу допринијети ефикаснијим зградама, стога се овај рад фокусира на оцјену типологија слојева конструкције вентилисаних фасада и утицај изложености топлотном зрачењу. Одабране ситуације су процијењене у смислу термофизичке анализе и лабораторијских мјерења и на основу резултата се могу извести корисни закључци. Ипак, постоји потреба за даље истраживање у правцу алтернативних фасадних система, као што је имплементација алтернативних вентилационих система и шаблона, као и иновативнијих и технички ефикаснијих грађевинских материјала.

*Кључне ријечи: термофизичка анализа, вентилисана фасада, типологије конструкција, изложеност зрачењу.*

# 1. INTRODUCTION

The EU's energy and environmental strategy has set clear objectives for improving energy efficiency, reducing greenhouse gas emissions and fostering the use of renewable energy sources. The first goal of 20-20-20 has practically been achieved, and there are optimistic indications that the goals for 2030 will also be achieved, whilst there is the promising vision of a carbon neutral Europe by 2050 [1]. Nearly Zero Energy Buildings (nZEBs) are a pivotal instrument in that direction and in order to rise up to this challenge one has to utilize the full array of technologies: energy efficient building envelope elements, high efficiency heating, ventilation and air-conditioning systems, renewable energy systems and of course smart technologies and automations to run all these systems, along with smart metering. The use of automation and smart system technologies, in particular, proves a challenge and, at the same time, the only answer for achieving the goals of the energy strategy for buildings in the current building stock.

Effective thermal protection of the envelope is a prerequisite for efficiency, in order to prevent unwanted heat fluxes, while also managing the internal temperature and achieving efficient HVAC operation and building energy efficiency in the usage phase. This research focuses on the operation of ventilated facade building typologies in the presence of thermal radiation.

Finally, increasing the share of Renewable Energy Sources (RES) is necessary to meet the reduced requirements and lower CO2 emissions, hence mitigating climate change. It goes without saying, that financial aid instruments are needed to help in implementing rules and regulations and achieving the goals stated, whilst taking into consideration social factors, affordability and maintenance of living standards should not be left out of sight [2].

A number of research studies [3] have been carried out on the thermophysical study of building sections in order to determine their influence on interior thermal comfort [4], performance [5], and even energy conservation [6]. In our situation, the key focus is their performance study in an in vitro experiment, employing heat radiation sources. In this line of approach, more research into the functioning of construction typologies will lead to a greater knowledge of them before they are implemented on the envelope of an existing building. Hence, the novelty of the paper is the assessment of the the impact of mechanical ventilation on the thermal response of the ventilated façade.

# 2. METHODOLOGY

The methodology focused on in vitro measurements considering the thermophysical parameters examined in a number of selected scenarios. The scenarios selected describe three ventilated facade construction typologies and the goal of the study is to evaluate their thermophysical characteristics.

In order to evaluate the thermal response of the ventilated facade typologies, a wall was constructed in the laboratory which the various elements of the sections of the ventilated façade were mounted. . The laboratory is in the Department of Civil Engineering of the Aristotle University of Thessaloniki. The laboratory in not heated or cooled, in order to have free floating temperature conditions. Thessaloniki has, according to Köppen-Geiger's climate classification, humid subtropical climate (Cfa) and semi-arid climate (BSk) [7], [8].

The under evaluation construction sections of the building envelope consist of brickwork, stone wool insulation and a variety of materials regarding the ventilated façade part (Fig. 1). The ventilated façade construction is presented in figure 1 and a short description of the sections is given on table 1. As far as it concerns the insulation, the thermal conductivity coefficient (λ) of stonewool, is 0.035 W/mK, and induced thermal resistance (R) for 5cm width of material is 1.4 $m^2K/W$. The thickness of the insulation was determined so as to achieve optimal insulation for different building elements based on different climatic conditions.

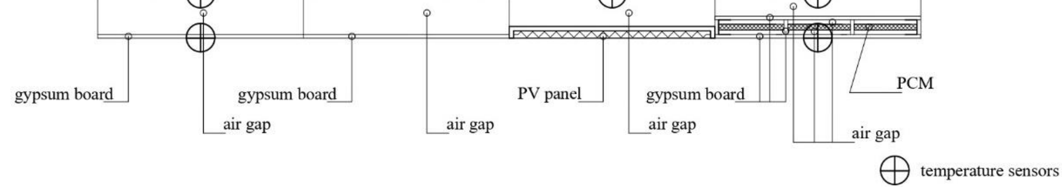


Figure 1. *Floor plan of the under evaluation ventilated façade construction.*

*Table 1. Scenarios under thermophysical evaluation.*

| Scenarios | Description |
|---|---|
| Gypsum board section | Mineral wool insulation (5cm) and gypsum board façade |
| PV section | Mineral wool insulation (5cm) and PV panel mounted on facade |
| PCM section | Mineral wool insulation (5cm) and PCM sandwich on the external part of facade |

## 3. CONSTRUCTION TYPOLOGIES' EVALUATION IN TERMS OF THERMOPHYSICAL ANALYSIS

The three different construction typologies are evaluated in terms of thermophysical analysis. Figure 2 presents the different typologies during the construction process and also the finished final configuration. Part of the experiment is using mechanical ventilation of the façade's cavity. For this purpose a cross flow fan is used (Figure 3) [9].

(a) (b)

Figure 2. *Presentation of under evaluation ventilated facade, (a) construction phase and (b) final configuration, PV mounted, radiation lamp and automation installed.*

Figure 3. *Cross flow fan under the PCM section.*

The construction sections under evaluation are typical masonries with stone wool insulation and a width of insulating material of 5cm. The ventilated façade sections lay one next to another mounted on the same wall.

Based on their layer structure as presented in Fig. 2, the thermal transmittance values for the gypsum board and PCM façade sections were determined. The calculations were performed without considering the thermal conductivity of the air space, as there are not enough data in order to calculate it according to ISO 6946-2017 [10]. Ri and Ra are not considered either, as the experiment is conducted in an indoor space and air is practically stagnant. The phase change material used is the salt based inorganic PCM SP26E created by Rubitherm [11]. In table 2, are presented the lower U value is noted on the PCM facade construction section, while the gypsum board façade has a little higher U value.

In order to conduct the thermophysical analysis two HOBO UX120 data loggers were used to capture the surface temperatures of different parts of the under evaluation construction as indicated in figure 1 [12]. Moreover, the two out of three construction sections were exposed to a thermal radiation lamp of 1200 Watt. The part of the wall covered with the gypsum board was evaluated under a four days' schedule test, while the PCM section was evaluated according to a 3 days' schedule respectively. The schedule for each section is presented in table 3 and table 4 respectively. The construction section where the PV panel is mounted was not tested, because a large number of sensors and a different process is required for this type of evaluation. So, test schedule is not defined for the PV section and its thermophysical properties are not calculated, because the section was not directly tested. Still the temperature of every section during the testing period is presented.

*Table 2. Ventilated façade layers description and thermophysical characteristics.*

| **Section** | **Layer** | **Thickness d [m]** | **Thermal Conductivity λ [W/mK]** | **U-Value [W/m2K]** |
|---|---|---|---|---|
| **Plain gypsum board façade** | Coating | 0.02 | 0.9 | *0.537* |
| | Rockwool | 0.05 | 0.035 | |
| | Masonry | 0.15 | 0.45 | |
| | Air space | 0.15 | Variable | |
| | Gypsum board | 0.0125 | 0.225 | |
| | Coating | 0.02 | 0.9 | |
| | Total | 0.4025 | - | |
| **PCM façade** | Coating | 0.02 | 0.9 | *0.508* |
| | Rockwool | 0.05 | 0.035 | |
| | Masonry | 0.15 | 0.45 | |
| | Air space | 0.1125 | Variable | |
| | Gypsum board | 0.0125 | 0.225 | |
| | Encapsulated PCM | 0.025 | 0.5 | |
| | Gypsum board | 0.0125 | 0.225 | |
| | Coating | 0.02 | 0.9 | |
| | Total | 0.4025 | - | |

*Table 3. Operational schedule of thermophysical analysis of gypsum board section.*

| Section | Day 1 | | Day 2 | | Day 3 | | Day 4 | |
|---|---|---|---|---|---|---|---|---|
| | Time | Lamp Operation | Time | Lamp Operation | Time | Lamp Operation | Time | Lamp Operation |
| Plain gypsum board facade | 12.15 | On | 12.15 | Off | 12.15 | Off | 12.15 | Off |
| | | | 20.15 | On | | | | |

*Table 4. Operational schedule of thermophysical analysis of PCM section.*

| Section | Day 1 | | Day 2 | | Day 3 | |
|---|---|---|---|---|---|---|
| | Time | Lamp Operation | Time | Lamp Operation | Time | Lamp Operation |
| PCM facade | 14.10 | On | 14.10 | On | 22.10 | Off |
| | 22.10 | Off | 22.10 | Off | | |

The operational schedule is separated into two parts: thermal charging and discharging, during which the thermal radiation lamp is turned on and off, respectively. The radiation lamp is positioned first in front of the gypsum board section according to a four-day schedule and then in front of the PCM section according to a three-day schedule. Also, the surface temperature sensors that monitor the front and back surface temperatures are moved to the corresponding section. For the gypsum board section, the adopted approach consists of a 24-hour circle of charging, then an 8-hour circle of discharging, a 16hour circle of charging and a final 24hour circle of discharging. For the PCM section an 8hour circle of charging, then a 24-hour circle of discharging, an 8-hour circle of charging and a final 24-hour circle of discharging are applied respectively. During the first cycle of charging of the PCM section the installed cross flow fan is in operation mode, while on the second cycle off charging it is powered off. Main goal of the applied schedules is the assessment of the thermal performance of the façade typologies under exposure to thermal radiation.

The conducted analysis in case of the gypsum board indicated (Figure 4) that during the 1st 24hours operation of the thermal radiation lamp, the temperature difference from for back surface and front surface reaches almost 8K with the front surface temperature ranges from 17.5°C to 18.1°C and the back surface temperature ranging from 9.5° C to 10.7° C. The surface temperature of the masonry in contact with the air space of the façade, is also presented for every section. Those surface temperatures constantly change and the temperature difference between those surface temperatures and the front surface temperature is constantly decreasing. The PV and gypsum board sections temperatures are almost reaching the front surface temperature at the end of the 24 hours (approximately 2K difference), while the PCM temperature is maintained at low levels and follows the trend of the back surface temperature line. During the second stage (8 hours on non-operation of the thermal radiation lamp) all the measured temperatures are similar varying from 10.8° C to 12.5 ° C. The 16-hour operation of the thermal radiation lamp and 24-hour non-operational day follow, with the same profile as the first 24-hour set and the first 8 hours on non-operation, respectively.

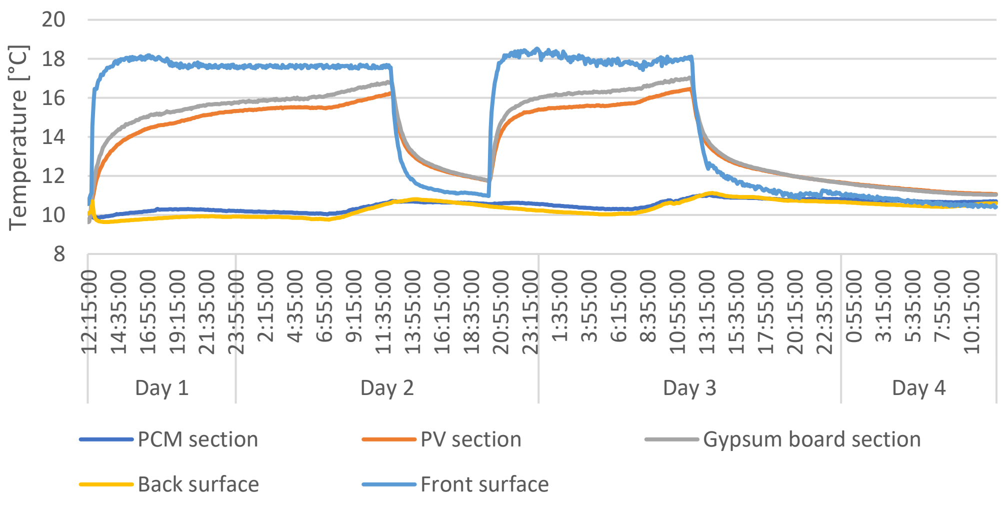


Figure 4. *Analysis of experiment on gypsum board façade section.*

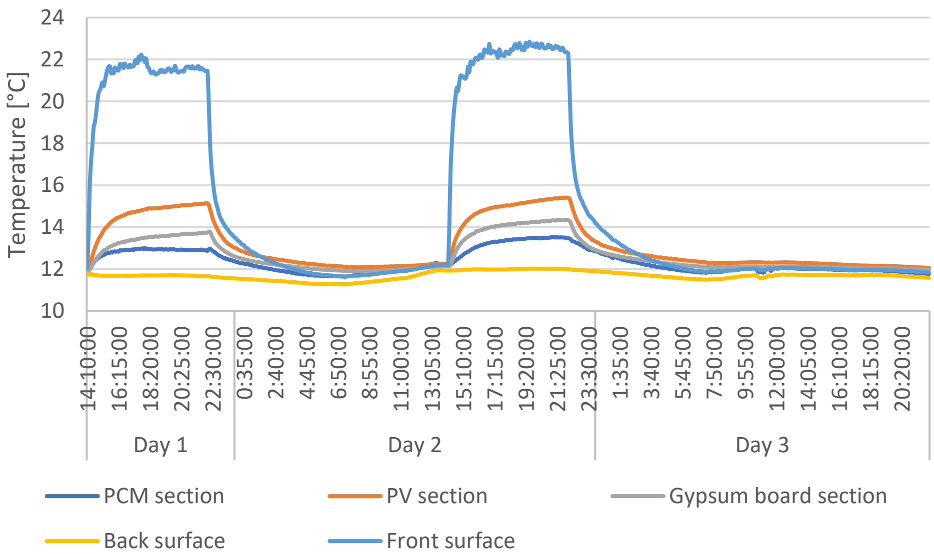


Figure 5. *Analysis of experiment on PCM façade section.*

The results of the experiment conducted on the PCM section indicate (Figure 5) that, during the 1st 8-hours operation of the thermal radiation lamp, the temperature difference between back and front surface reaches almost 10 K with the front surface temperature ranging from 21.2° C to 22.1° C and the back surface temperature ranging from 11.5° C to 12.1° C, respectively. For each segment, the surface temperature of the brickwork in contact with the air space of the façade is also shown. The difference in temperature between those surface temperatures and the front temperature is continually reducing as the surface temperatures fluctuate. The temperatures of the PV and gypsum board sections kept rising during the 8-hour period, reaching 14.9° C and 13.5° C, respectively. The temperature of the PCM part increases at the start of the 8-hour period and then nearly stays constant. The results for the other sections indicate that temperatures constantly change and the temperature difference between those surface temperatures and the front surface temperature is constantly decreasing. During the second stage (16 hours of non operation of the thermal radiation lamp) all the measured temperatures are similar varying from 11.7° C to 13.0° C. Following that is an 8-hour thermal radiation lamp operation and a 24-hour non-operational day, with the same profile as the first 8-hour set and the first 16 hours of non-operation, respectively. The results for the PCM section indicate (Figure 5) that during the 2nd 8hours operation of the thermal radiation lamp, the temperature continues to rise till 13.6° C, but still at smaller rates compared to the gypsum board and PV sections.

Comparing the results between mechanical ventilation on and mechanical ventilation off the temperature difference is relatively small. However, one can easily observe the stabilization of temperature that the mechanical ventilation offers.

## 4. CONCLUSIONS

The energy efficiency of buildings is still a major focus of EU energy and environmental policy. Furthermore, the Energy Performance of Buildings Directive's standards, in conjunction with progress toward new Nearly Zero-Energy Buildings (NZEB), establish measurable CO2 emissions and energy efficiency targets. In the thermophysical investigation of the ventilated facade sections using thermal radiation sources, all of the sections under consideration respond to the high temperatures induced by the thermal radiation, recording temperature variations of up to 10 K. The study found significant difference on the performance of the PCM versus the gypsum board façade sections. Most specifically even though there is only slight difference between the U-value of the two sections, the PCM helps keeping both the ventilated cavity and the back surface of the wall at more stable low temperatures. Based on the findings of the measurements, more research into alternate facade layouts and ventilation patterns is required, in order to identify and better quantify the increase of the energy efficiency of the buildings that can be accomplished.

The installation and evaluation of such ventilated façade typologies in real buildings will be the subject of future research. According to the results of this research, ventilated facades might help improve the performance of buildings by reducing the impact of high external temperatures in the Mediterranean area during the summer by charging the building envelope with reduced radiation and temperature loads. Those circumstances can help improve the structure's inside atmosphere, making it more pleasant and comfortable for the residents and even enhancing their productivity despite the hot Mediterranean summer. The influence of the energy profile improvement, on the other hand, should not be neglected, since combining the aforementioned typologies on a vented façade might reduce cooling loads and building energy consumption. Given the worldwide significance of the major study findings in terms of different climates, it's critical to establish the climatic factors and outdoor circumstances that influence energy consumption, environmental impact, and thermophysical characteristics of architectural typologies. Nonetheless, significant progress has been made in the construction sector, especially when we consider that, in addition to the severe economic recession, the construction sector has to deal with unexpected circumstances such as covid-19, which have an impact on the real economy and add to an already unstable economic framework. It is self-evident that, in addition to sustainability, construction should prioritize resilience by developing and implementing systems, materials, and structures that can adapt to vulnerabilities, catastrophes, and extreme events while also protecting users and providing consistency.

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