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Behavior of a hollowed-wood ventilated façade during temperature changes

Деревянный фасад с вентилируемыми каналами для тропического климата

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Ключевые слова: вентилируемый фасад; вентилируемые каналы; энергоэффективность; теплофизические характеристики; ограждающая конструкция

Abstract. The Ventilated Façade System is a reasonably new technique, which was developed in Europe with the need of cost savings from the energy for cooling and heating of constructions. This system, established in the 1960's, was an acknowledged as a constructive innovation both for esthetics and functional aims. Therefore, its use has spread not just during buildings' retrofit but also in new constructions. Despite this fact, the applicability of wood with a hollow through it for ventilated façades remain quite unknown, as mainly of these façades are built with conventional materials such as concrete, lightweight concrete, brick, ceramic, wood panels and glasses. Due to that circumstance, this paper will simulate the behavior of a wood-hollowed when submitted to temperature variations (from 10 ºC to 30 ºC), in a small-scale (1:10). During the trials, the hollowed-wood sample was set in two directions: horizontal and vertical. In addition, trials were carried out with/without insulation material, and with cyclic and non-cyclic temperature variations. The result shows that hollowed-wood presents better behavior when accompanied with thermal insulation materials, reducing the rate, on which the temperature changes inside it. In addition, different orientations of the sample lead to slight difference comportment as well as the increase of the size of the hole in the wood.

Аннотация. Вентилируемая фасадная система-это достаточно новая техника, которая была разработана в Европе с целью экономии затрат энергии на охлаждение и нагрев конструкций. Поэтому его применение распространилось не только во время реконструкции зданий, но и в новых постройках. Несмотря на этот факт, применимость древесины с вертикальным вентилируемым каналом остается довольно неизвестным, по сравнению с наиболее распространенными материалами как бетон, облегченный бетон, кирпич, деревянные панели, стекла и т.д. В данной статье представлен натурный эксперимент поведения деревянного фасада с вентилируемыми каналами при разных колебаниях температур (от 10 ºC до 30 ºC). Образец представлен в малом масштабе (1:10). Во время испытаний образец древесины с вентилируемыми каналами устанавливался в двух направлениях: горизонтальном и вертикальном. Кроме того, испытания проводились с/без изоляционного материала, а также с циклическими и нециклическими температурными колебаниями. Результат показывает, что пустотелая древесина представляет собой более лучшее поведение в сочетании с теплоизоляционными материалами, уменьшает скорость изменения температуры внутри вентилируемого канала. Различное расположение (горизонтальная/вертикальная) приводит к небольшим различиям температурного распределения.

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1. Introduction

The building's segment – i.e. the residential buildings and service sector- is the major consumer of energy and producer of CO in the European Union and is responsible for about 40 % of greenhouse emissions and total final energy consumption as presented in Figure 1 [1].

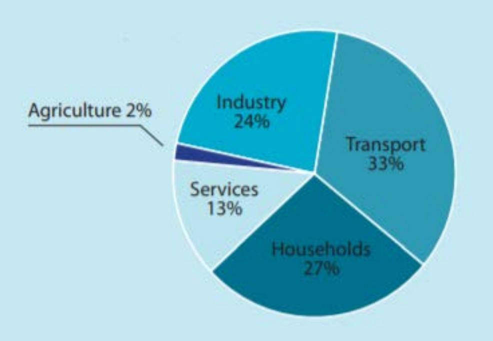

Figure 1. Distribution of energy consumption in Europe by sectors [1]

A similar scenario can be seen in United States, as, according to [2], the combined electricity demand in the residential and commercial sectors made up over 70 % of total electricity demand in 2013, with each sector using approximately the same amount of electricity. Also in Russia, as around 95 % of the buildings of the total housing stock in the country do not meet modern energy efficiency requirements for energy efficiency. Even more, as the physical state of some building façades is also often defective [3].

The residential sector has significant potential for cost-effective energy savings, which, if performed, would drive to a number of benefits, as reduced energy needs, minimize import dependency and climate effects, lower energy bills, raise of job offers and the encouragement of local development [4].

Moreover, a large parcel of European constructions was built before the 1960's – around 40 % – by the time there were basically no requirements for energy efficiency and only a minimum part has undergone any energy retrofits. Hence, it is noticeable that the oldest part of the building stock contributes expressively to the high-energy consumption in the housing sector leading to a large potential of energy saving. According to this context, the European Commission has highlighted the need for increasing the construction energy efficiency for both the new and the existing buildings. Among the most popular responses for this request, it is the improvement of the building thermal insulation. Furthermore, over the last years, ventilated façade systems have gained much attention [5].

Ventilated building façades are an external envelope technique with significant benefits over traditional, single skin façades. These benefits cover almost all building physics topics, from moisture to thermal efficiency, noise, fire resistance and structural efficiency [6].

According to [7], due to it is a non-destructive, quick and clean solution, ventilated façades have been widely used in retrofitting works especially in residential buildings around Europe. Some coating materials might receive a titanium dioxide-based product in order to makes it difficult to get dirt on the surface and simplifies cleaning. In addition, there are coatings which can receive anti-graffiti treatment, which is a problem in big cities around the world. Figure 2 shows a typical ventilated façade and its air convection.

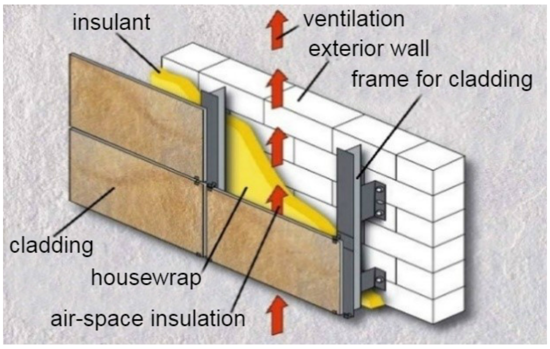

Figure 2. Traditional Ventilated Façade Scheme [12]

However, some precautions should be taken into consideration while applying this technique in the constructions. There are some minimum requirements that must be valued, such as hygrothermal performance, energy efficiency, sound proof and fire resistance.

Diverse studies were carried out in order to evaluate the efficiency of ventilated façades in edifications and application of new technologies. In [8], a wide range of solutions lead to solving energy saving problems when using ventilated façade. In addition, [9] and [10] analyze, respectively, problems related to hinged ventilated façades and structural design importance on its behavior. Work [11] studies advantages of the applicability of new technologies in standard ventilated façades.

According to [5], the maximum U-value allowed differs not just from country to country but also if a new construction is under progress or if it is a retrofit. Also, some other criteria as type of building (residential, tertiary, i.e.) or indoor temperature can lead to a different maximum U-Value allowed. Therefore, for new residential buildings, Ireland established, for example, a maximum U-Value of 0.21 W/(m²K), while in Latvia U-value may drop slightly below 0.20 W/m²K, but not below 0.15 W/(m²K). For moisture-related some general recommendations and descriptive requirements regarding avoidance of surface condensation and mold formation are provided per country.

The recommended fire resistance criteria (fire propagation time) should be at least 120 min [5]. Nevertheless, at most national building regulations the required length of time against fire is below or equivalent to 60 min. In most countries across Europe, for extensive façade, testing requirements are not mandatory by national regulations.

Energy Performance requirements applies when the ventilated façade system has to work in mutual cooperation with other energy conservation measures in order to reach ta particularly strict energy performance standard [13].

However, as long as this paper analyzed, during laboratory trials, a natural ventilated façade the criteria of energy performance was ignored.

During the previous years, many authors have studied different approaches for sustainable ventilated façades. In [14], was evaluated the use of wood-based materials (wood, cardboard and cork) as ventilated façade. Authors considered the system satisfactory in thermal and acoustic parameters and emphasized the short time of construction. Still, the cost and time for processing and assembling it in industries require further studies.

However, [15] states that the use of timber with bonded joints in ventilated façades represents a viable option in comparison with aluminium structure i.e. Nevertheless, the installation procedure needs to be followed very strictly as the adhesion of wood plastic is very unstable.

Another concept investigated related to the use of wood/trees refers to biofaçade by [16], where its application had a better thermal performance during the daytime due to its shading, photosynthesis and evapo-transpiration, contributing for reducing the indoor temperature of the studied object. On the other hand, during the night the results did not represent any gain and even obstruct heat dissipation. Moreover, different types of climbing families give different results, as the geometrical properties will influence the air velocity and room temperature.

In [17], Nore and Thue developed studies about the relation of moisture content with wood claddings and the influence of ventilation gap design in Norway, making recommendations about the openings of wood claddings. The air gap openings should be fully open when the wooden cladding will be exposed to heavy wind driven rain loads. In a dry climate, where the wall will be mostly dry, the results indicate that a design with the air gap openings closed will give the driest wood cladding.

In addition to [17–18], states that, to obtain properties that allowed it to withstand to weathering conditions it has to be properly modified in order to be able to be applied and to remain unchanged even in adverse climatic conditions without requiring great maintenance. The modification process submits the raw wood at elevated temperatures that most of the moisture will evaporate, increasing the wood resistance (up to 30 %), in a process called Thermowood.

Therefore, as long as almost all the studies about the use of wood in ventilated façade leads to the applicability of wood panels, this paper focus on laboratory experiments for verifying the feasibility of using woods with hollows as a ventilated façade in a climate which the temperature varies from 10 ºC to 30 ºC (subtropical climate). The trials carried out had two different approaches: with the hollows set on the vertical orientation and on the horizontal orientation. Moreover, it will be evaluated the heat losses during the air convection through the hollows made in the wood.

2. Methods

The experiment has been conducted in an isothermal chamber "CHALLENGE 250" with an approximated volume of 20 liters and dimensions of 0.60 x 0.75 x 0.52 m (W x H x L). The standard sensors «Dallas DS18B20» carried the measurement of instantaneous temperature. This sensor is also designed to measure the temperature of liquids, and temperature measurement in a humid environment. The sensor is enclosed in a metal flask measuring 6x50 mm. It is equipped with a sealed lead cable 1 meter length. The cable consists of 3 wires: red (VCC), blue (DATA), black (GND) [22].

The wood-hollowed sample has the following dimensions:

- L = 14 cm;
- W = 3 cm;
- H = 21 cm;
- Diameter of the holes: 1.0–1.5 cm.

The sketch of the sample with rock wool and reinforced concrete is presented on the Figure 3.

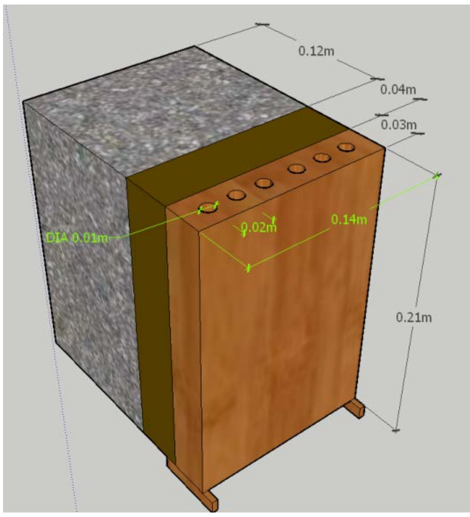

Figure 4. Sketch of the wood sample with rock wool glued and reinforced concrete attached on it

The temperature of the sensor were collected every 3 minutes, both for periodic (cyclic) and non-periodic (non-cyclic) regime. It was placed sensors inside the material, between layers and, even, one outside, in the outer surface, in order to double check the temperature of the chamber and the precision of the sensor, avoiding potential mistakes during the measurements.

The laboratory trials were carried out during the months of October and November of 2017 and different approaches were tested as shown in the scheme below in the figure 4.

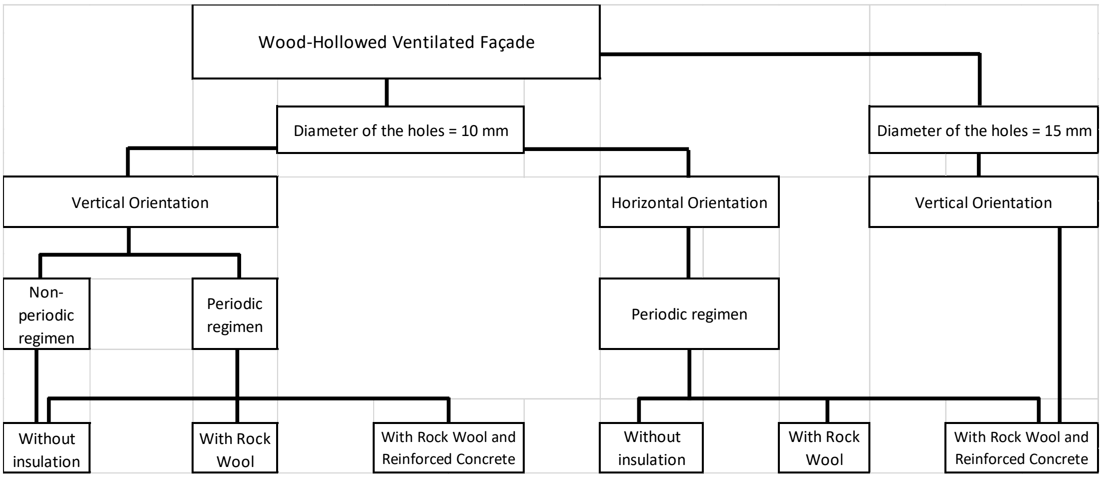

Figure 4. Scheme of the laboratory tests

During the non-cyclic regimen, the temperature of the chamber was set at zero degrees Celsius and was heated up to thirty degrees Celsius, heating to 10 ºC and to 20 ºC (30 minutes on each).

For the periodic regimen, the temperature varied from 10 ºC to 30 ºC, typical from a subtropical highland climate, which is the location of the city of Curitiba – Brazil, and one the motivations for this paper.

The picture below show the sample during the trials with different configurations of layers.

Figure 5. Different configurations during the trials: (a) without insulation and vertical orientation (d=10mm); (b) with insulation and concrete and vertical orientation (d=15mm); (c) with insulation and concrete and horizontal orientation (d=10mm)

As the Figure 5 shows, in the top of the chamber two pieces of Styrofoam (expanded polystyrene) were glued in order to simulate a disturbed movement of air inside the chamber, being more similar of what happens in an outdoor area.

The sensors were placed in the following positions:

- Sensor 1: Top of the wood;
- Sensor 2: Inside (h = 10 cm) the middle left hollow (front view) made in the wood (Figure 5b);
- Sensor 3: Inside (h = 10 cm) the middle right hollow (front view) made in the wood (Figure 5b);
- Sensor 4: Outer part of the wood;
- Sensor 5: Bottom of the wood;
- Sensor 6: Between the rock wool layer and the wood-hollowed ventilated façade;
- Sensor 7: Between the rock wool layer and the reinforced concrete layer;

The following materials were used in the samples during the experiments:

- Pine Wood – Dimensions 210 x 140 x 30 mm;
- RockWool Insulation – Dimensions 210 x 140 x 40 mm;
- Reinforced concrete block (Cement B20, steel diameter: 14 mm);

It is important to mention that the wood sample was made in a scale of 1:10. The dimensions were based in the giant bamboo tree called Guadua Angustifolia, widely spread in the forests of South America.

3. Results and Discussion

The graphics obtained from the experiments are showed below and three analysis are made related to the behaviour of the wood hollowed ventilated façade:

- Comparison between the vertical orientation without insulation layer, with insulation layer and with insulation layer + reinforced concrete on its configuration;
- Evaluation between horizontal and vertical orientation (both with insulation + reinforced concrete);
- Comparison according to the different diameters adopted (d = 10 and 15 mm).

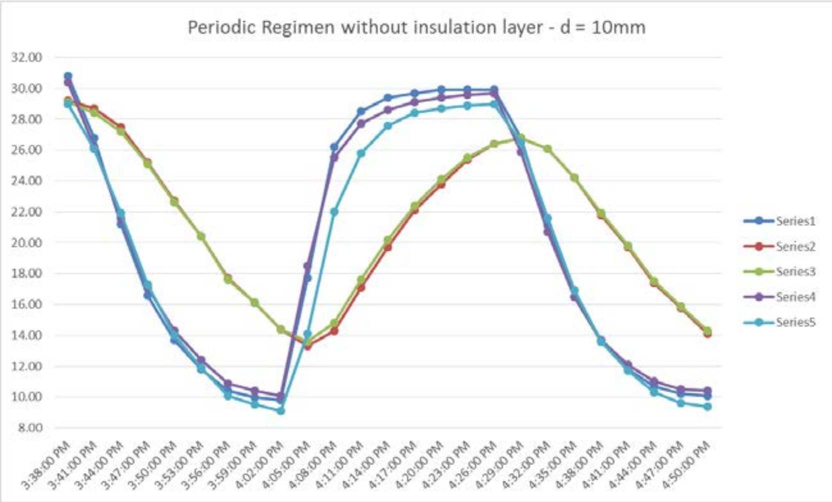

Figure 6. Periodic Regimen without insulation layer and vertical orientation – d = 10mm

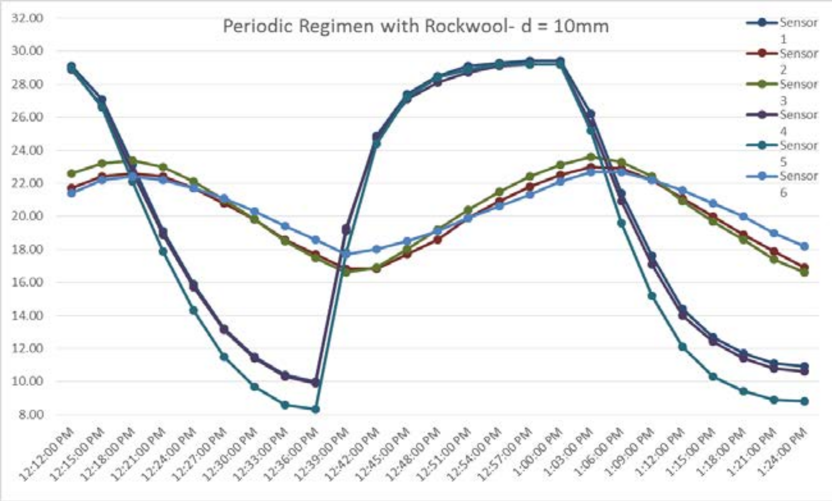

Figure 7. Periodic Regimen with Rockwool and vertical orientation – d=10cm

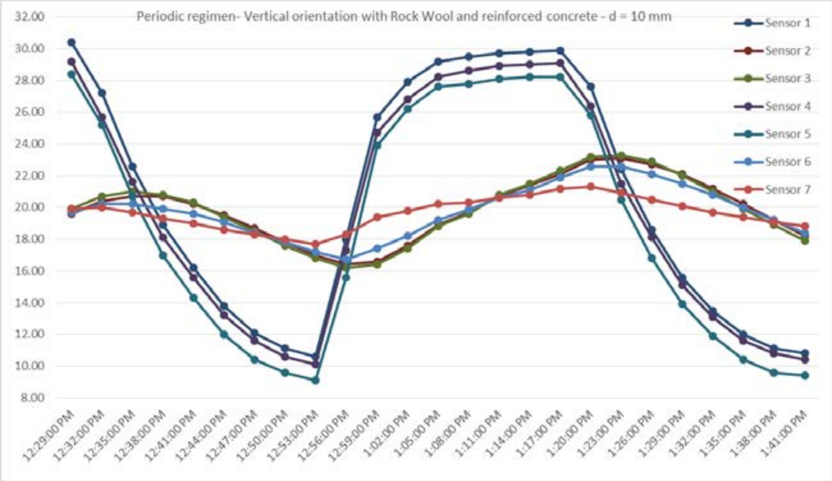

Figure 8. Periodic Regimen with Rock Wool and reinforced concrete, vertical orientation – d=10 mm

Analyzing the Figures 6–8, leads to the conclusion that the use of Rockwool, as insulation material, reduces the speed on which the temperature changes inside the ventilated façade. While the temperature varies in an average rate of 0.62 ºC/min (sensor 2) and 0.60 ºC/min (sensor 3) without the insulation layer, with the insulation glued to the ventilated façade, the temperature changes in a velocity of 0.24 ºC/min (sensor 2) and 0.28 ºC/min (sensor 3). Therefore, with the reinforced concrete added in the configuration, the ratio reduces even more: 0.20 ºC/min (sensor 2) and 0.23 ºC/min (sensor 3).

Another result that should be highlighted is the fact that, in all the configurations above (Figure 6–8), the sensor 1 (located in the top of the sample) read higher temperatures than sensor 5 (located in the bottom of the sample).

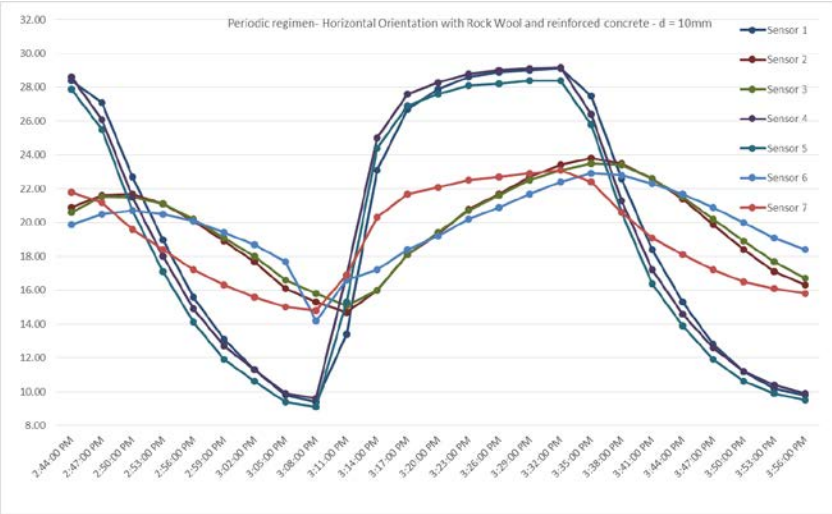

Figure 9. Periodic Regimen with Rock Wool and reinforced concrete, horizontal orientation – d=10 mm

The horizontal and vertical orientation presented similar results when comparing the temperature measured in the boundaries of the wood-hollowed sample in both sensors 1 and 5. The sensors 2 and 3 presented more discrepancies, as the vertical orientation has a temperature, which changes in an average rate for both sensors of 0.22 ºC/min and in the horizontal position in a rate of 0.33 ºC/min.

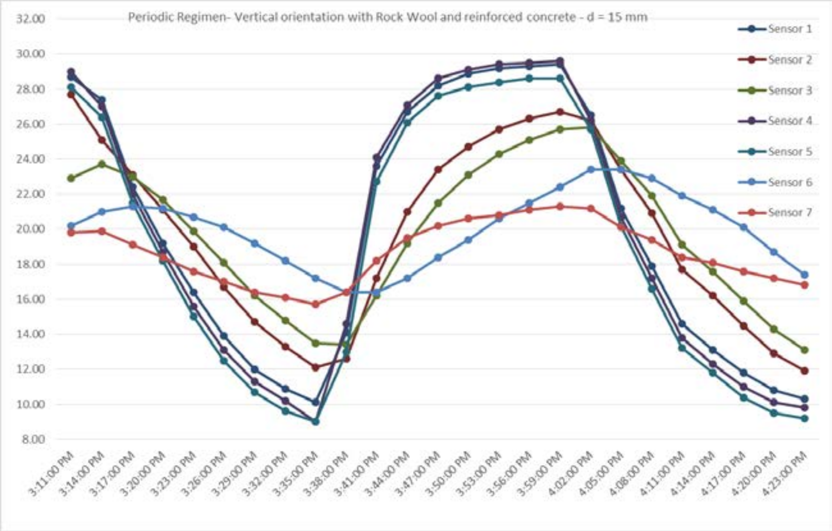

Figure 10. Periodic Regimen with Rock Wool and reinforced concrete, vertical orientation – d=15 mm

Due to the increase of 50 % of the diameter in the holes performed in the wood, the temperature inside the ventilated diverse considerably more when comparing with the same configuration but with 10 mm of diameter. While in the 10 mm diameter-wood-hollowed ventilated façade, the temperature changes, as mentioned above, has a rate of 0.22 ºC/min, with diameters of 15 mm, the rate sky rises to 0.60 ºC/min average. The sensor 6 read some small differences between both experiments, as the bigger diameter sample oscillated more the temperature than the 10 mm diameter.

Moreover, some topics should be take into consideration and are important for guaranteeing the safeness and the energy efficiency of the building. Firstly, the installation of the insulation layer, wooden ventilated façade and others should be appropriate in order to reach the maximum performance avoiding the presence of thermal bridges, through leaks or the use of improperly material in the construction, as highlighted per [19].

By the end, as wood is not a fireproof material, the need of treating it against fire is undeniable. According to [20], [21] there are a wide range of coating materials that can be used in order to improve the fire properties of the materials and meet the requirements already mentioned. Amongst those materials can be cited: epoxy, water-based materials, latex and intumescent coating. Finally yet importantly, according to [17], it is significant to evaluate the use of wood claddings for each building design as the measured moisture content in the wood claddings demonstrate the influence of ventilation gap design [23].

4. Conclusion

As conclusion, the wood-hollowed ventilated façade presents some benefits since working together with an insulation material layer. As wood has a good thermal resistance and thermal stability, the variation rate of temperature inside the wood is not elevated, when installed together with Rock Wool. Furthermore, the use of bigger holes provided a greater temperature exchange between air and wood. When comparing horizontal and vertical orientations is important to evaluate the commonly wind direction in the location which the project will be settled, as the results can be distinguished as mentioned in the results. Therefore, the use of this solution for ventilated façades are viable, but should be attentively evaluated according to the temperatures, thermal amplitude, wind flow direction and humidity.

However, the size of the sample (1:10), due to space limitation, is considered not big enough for guaranteeing the success of its use in real cases. Due to this fact, it is recommended for further analysis, to enlarge the sample.

5. Acknowledgement

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