THERMAL BALANCE OF VENTILATED FAÇADES IN WINTER AND SUMMER: GREEN VS. CLADDING

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Abstract
The application of vegetation to building structures is becoming an increasingly hot topic for mitigating the negative effects of summer overheating. The benefits are particularly significant in the summer months, extending also into the colder months of the year. Few papers are devoted to analysing the effects during the winter months. This paper demonstrates the results of comparing facades with vegetated walls and wood cladding in winter and summer. The measured results indicated that a vegetated façade effectively cools the surrounding space during the summer months and retains heat throughout the winter months.

Keywords
Living wall, wooden cladding, temperature, winter, summer

1 INTRODUCTION

The façade of a building has two important functions: it is a representative element of the visual image of the building when viewed from the exterior and acts as a covering element of the interior, therefore its importance extends beyond its structural role, impacting the space inside and around the building. With the challenges of climate change and energy requirements, designers have started to develop new approaches to improve the quality of the environment in urban areas. One of these approaches is the implementation of vertical gardens, otherwise known as vegetated façades. Vegetated façades have started to occupy a prominent place in recent years [1]. Vegetated walls have more potential than vegetated roofs since in urban centres the scale of façade greening exceeds several times that of the building plan [2].

Vegetation can be considered as an additional construction material to increase the functionality of façades. Given the recent developments in the field of vegetated façade technology, it is important to identify and classify existing systems according to their construction techniques and main characteristics [2]. In general, vegetated façades (VGS – Vegetated green systems) can be divided into two main systems: green façades (GF) and living wall systems (LWS). Direct green facades involve direct attachment of plants to the wall offering the advantage of not requiring a support system. In contrast indirect green facades include a support structure for the vegetation in the form of various ropes or nets. Continuous LWS are based on the application of lightweight and permeable screens into which plants are inserted individually. Modular LWS are elements with a specific dimension that contain a growing medium in which plants can grow [3]. A further division is based on how the vegetation connects to the building itself. The classification of vegetated facades is presented in Fig. 1.

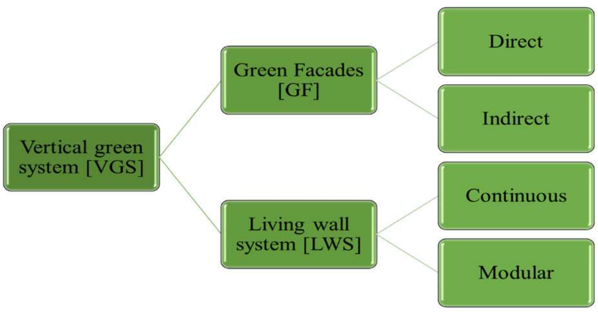

Fig. 1 Division of vegetated façades.

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The use of vegetation has a significant impact on the thermal performance of buildings and also on urban climate change, both in winter and summer conditions. Plants absorb a significant amount of solar radiation for their growth and biological functions, and act as a solar barrier to prevent extensive absorption of solar radiation into the building envelope structure [4]. As the global population becomes increasingly urbanized, many vegetated areas have been replaced with hard surfaces. Dark building materials and pavements absorb large amounts of solar radiation during the day and release longwave radiation during the night, increasing the average temperature in city centres [5]. This phenomenon is generally known as the urban heat island effect (UHI) [6].

The heating and cooling of buildings accounts for up to 40% of the global building energy consumption [7]. It is the building envelope that performs a major role in the overall energy consumption of buildings by controlling the interaction between the indoor and outdoor environment. The façade is the largest element of the building thermal envelope and thus makes a significant contribution to the management of building energy consumption. Vegetated façades can regulate temperatures by blocking and absorbing solar radiation, providing cooling through evapotranspiration, improving heat conduction, and reducing wind speeds in direct contact with the building envelope itself. As a result, vegetated façades are considered a simple, cost-effective passive strategy to adapt to climate change, regulate urban air temperature and mitigate the effects of UHI [8]. It also plays a significant role in reducing heat leakage from the building during winter months due to the additional layer that affects the air cavity temperature pattern in the case of LWS [9]. It is the assessment of seasonality on the temperature regime of the façade between different surface treatments that is the focus of this paper.

The Department of Civil Engineering and Urbanism at the Faculty of Civil Engineering of the University of Žilina, engages in research on envelope analysis regarding thermal and humidity regimes. This article compares the thermal regime between a façade with the use of the LWS vegetation wall system and a façade with the use of wooden cladding. Several articles have discussed the issue of vegetated façade comparison; however, the analysis was mainly focused on the summer period, through the benefits of evapotranspiration cooling from living vegetated façade structures [6], [10], [11]. Other articles are devoted to assessing the difference between different types of vegetated facades. A comprehensive review and analysis of published data is reviewed in [3]. The scope of this paper is the observation of the behaviour of the temperature regime in the immediate vicinity of a double-skin ventilated façade with living structures (LWS) and non-living structures (wood cladding).

2 METHODOLOGY

A research pavilion for studying building envelope structures was constructed in 2011 at the Department of Civil Engineering and Urbanism at the Faculty of Civil Engineering of the University of Žilina (DCEUF, FCE, UNIZA). This research facility consists of three rooms, two of which are used to closely observe the thermal-moisture behaviour of different samples of the timber-columned structure of the building envelope. These rooms differ not only in thermal insulation materials and surface materials but also in their orientation. While one research room is oriented to the south with a slight 15° rotation to the west, the second room is oriented to the east with a slight 15° rotation to the south. The third room is dedicated to window structures research. This room is adjacent to the south-facing room with a westward rotation (Fig. 2). The structures under scrutiny are embedded into the exterior walls to expose them to natural external conditions. The research focuses on long-term measurements of temperature and humidity in the different compositions of the timber mullion construction and on the thermal and optical properties of selected types of fenestrations exposed to real exterior conditions [12].

Fig. 2 View of the timber post and window samples from the exterior side (south sample on the left, window structures on the south side in the middle, east sample on the right).

In 2021 the research pavilion expanded with the introduction of the first experimental vegetation façade of the Living wall system (LWS), which was made on the eastern wall of the laboratory with a slight 15° southward rotation. The vegetation façade sample is located below the timber columned envelope sample (Fig. 3). The

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vegetation façade is constructed as a double skin construction with a ventilated air cavity. The vegetation layer consists of a slab of recycled material from textile waste from the automobile industry, in which vegetation is pre-grown. The thickness of this innovative vegetation board is 50 mm. The façade segment itself is made in three different variants. Two samples have an air cavity thickness of 50 mm (Variant 1 and Variant 2), and the third sample has a cavity thickness of 70 mm (Variant 3). As this is a prototype of such a design, one of the research focuses was the optimization of the irrigation system or a technological solution. The investigated vegetation façade sample underwent a change in technological design and three changes in the irrigation method. The vegetation wall was improved with drip irrigation. However, to determine the impact of irrigation, especially in the summer months, it is still possible to irrigate the different variants separately (independently of each other), as published in a previous paper. During the winter months, the irrigation system is suspended. The reason for this is increased air humidity and freezing temperatures, which would complicate the method of irrigation and would have a detrimental effect on the vegetation sample.

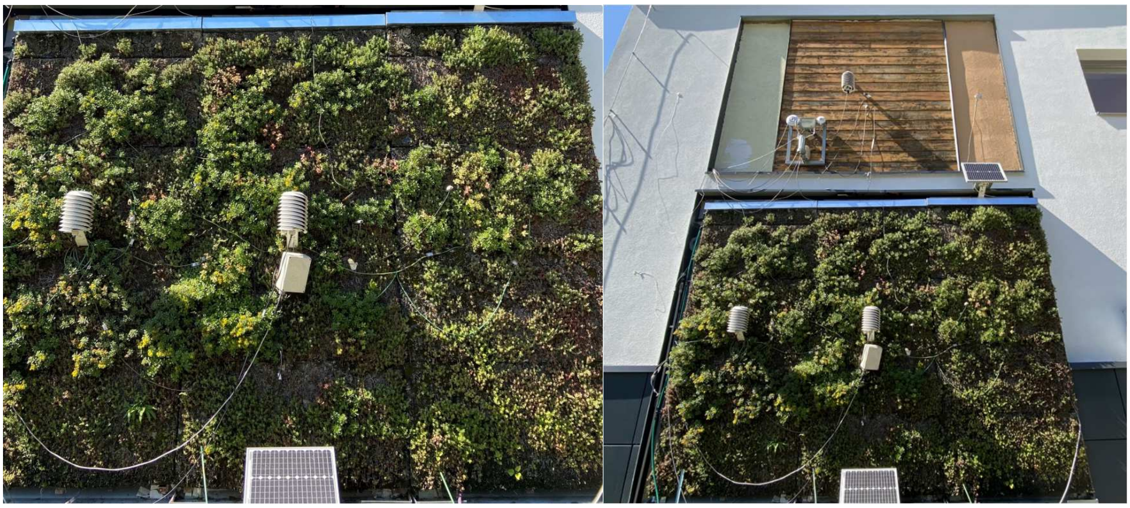

Fig. 3 View of the vegetated façade sample (left) and location in relation to the timber columned structure sample (right).

Temperature sensors and humidity sensors are strategically placed in the individual layers of the samples, both vegetated façades and timber columns. The temperature and relative humidity in the immediate surroundings in front of the façade are also observed. The sensors are located in radiation shields which protect them from direct sunlight [13]. As can be seen in Fig. 2, in the case of a wooden columned structure, the middle three segments are designed with ventilated wooden cladding. For these specimens, the results of the behaviour of the ventilated façade with living components (vegetated wall) and non-living components (wooden cladding) in the thermal-moisture regime are demonstrated. Both samples are oriented on the same side and exposed to the same weather conditions. Climatic data is obtained from a fixed weather station located on the roof of the pavilion laboratory recording data at a one-minute interval. The weather station records: outside air temperature, outside air relative humidity, atmospheric pressure, wind direction and speed, gust wind speed, precipitation, direct and diffuse solar radiation. There is also a mobile weather station located on the façade with wood cladding, which also records outdoor climate data that directly affects the addressed samples. The intensity of solar radiation has a significant role in influencing the orientation of the sample. It is the intensity of direct solar radiation that has an impact on the increase in surface temperatures on the samples, which will affect the total amount of heat energy that is transported through the structure in the form of increased heat flux. Fig. 4 demonstrates the solar radiation pattern and intensity as a function of orientation during a clear sunny day.

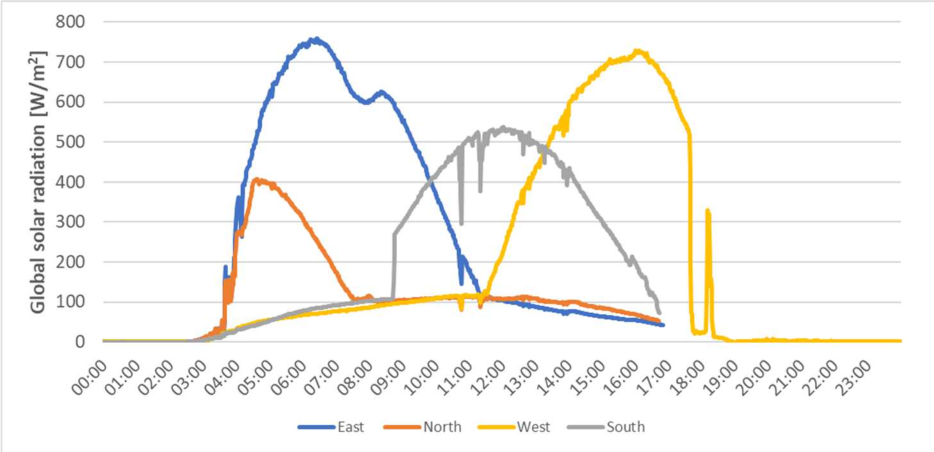

Fig. 4 Global solar radiation during the day as a function of orientation.

Fig. 5 shows a schematic view of the investigated samples including a cross-section and the marked location of the sensors. Within the pavilion research, it is possible to measure the temperature waveform of different types of commonly used building envelopes. The structures have compositions finished with: light plaster, dark plaster, timber cladding, dark cladding and a vegetated wall. The vegetated wall and timber cladding constructions also have a ventilated air cavity in which the temperature and air relative humidity are also measured. All sensors used are powered by data loggers located indoors with one-minute recording intervals for vegetation walls and 15-minute recording intervals for wood cladding. These values were solved by averaging the values in a 15-minute step.

For the purpose of our research, sensors were used to measure the temperature at the surface and behind the air cavity on the insulation sheeting. The research focused on the difference in temperature regimes between the vegetated wall façade (Variant 2) and the wood cladding, where the results of the behaviour of the living structures in comparison with the non-living structures of the envelope due to seasonality were demonstrated. The sensors from which the results were derived are highlighted in Fig. 5 where the temperature at the surface (TWC) and the temperature at the foil behind the air cavity (TWF) in the case of wood cladding are shown. Similarly, the temperature at the surface (TG2) and the temperature on the foil behind the air cavity (TF2) in the case of a vegetated wall are presented. The outdoor air temperature and solar radiation intensity data were taken from the fixed weather station (Fig. 6, Fig. 7).

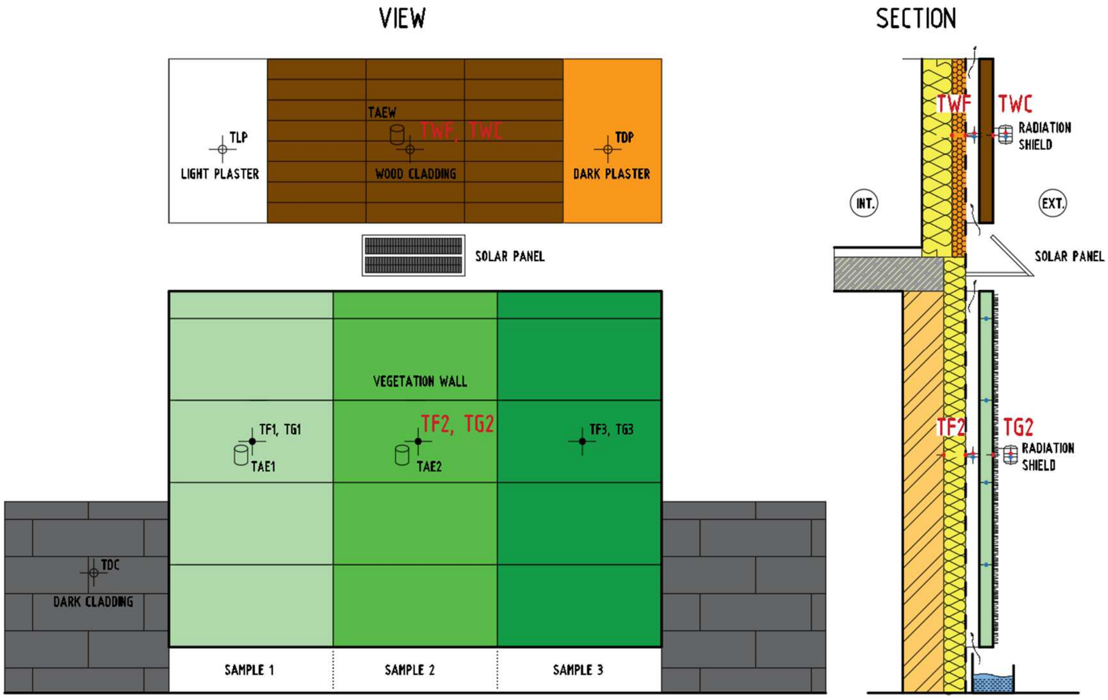

Fig. 5 Schematic view and section of the samples considered.

The measurements focused on the impact of seasonality. For the selected period considered, a time with a representative pattern of air temperature and solar radiation intensity in summer and winter was chosen. The year 2022 was used for the measurement results, where the month of January was selected as the winter period and the month of July was selected as the summer period. From the monthly graph, for both the winter period (Fig. 6), and summer period (Fig. 7), of temperature and solar radiation intensity progression, a period of three consecutive days was selected.

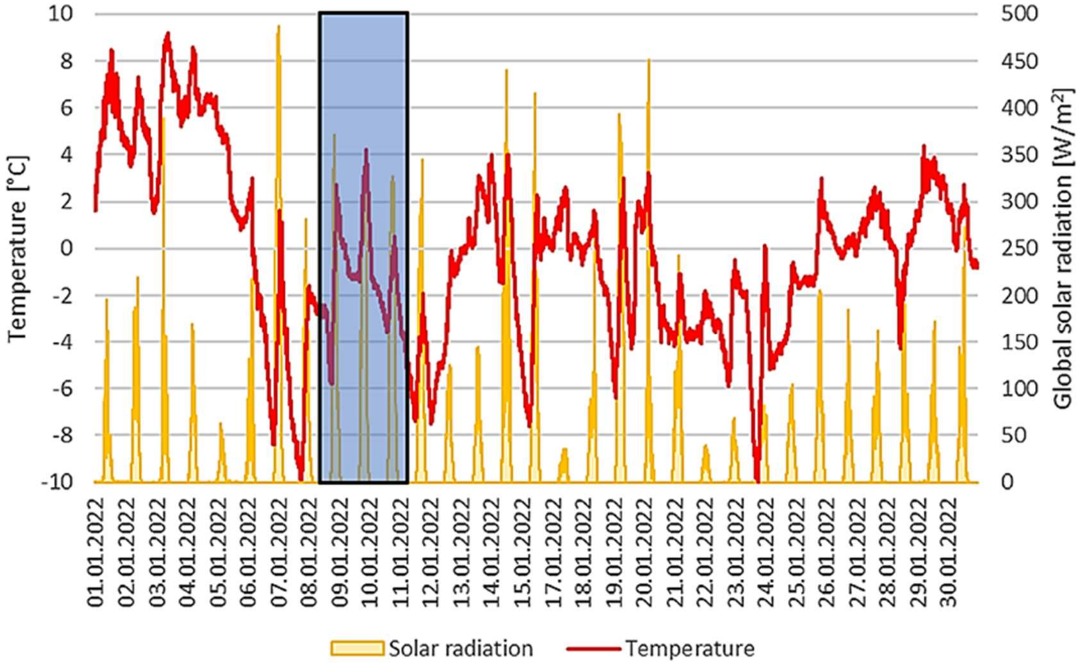

Fig. 6 Temperature and solar radiation intensity for the winter period (January 2022) with days considered: 09.01.2022 – 11.01.2022.

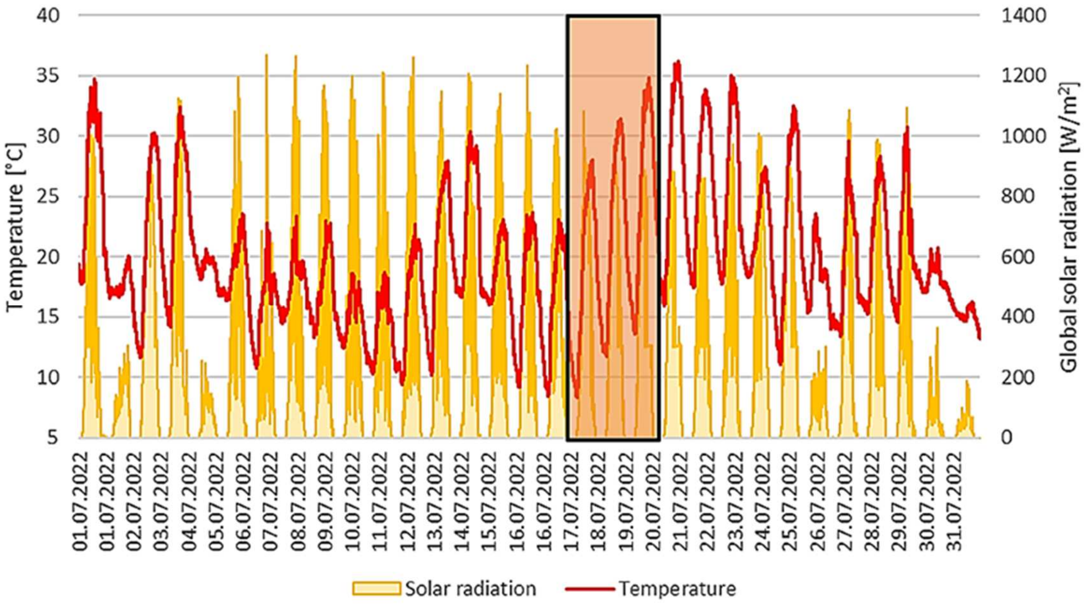

Fig. 7 Temperature and solar radiation intensity for the summer period (July 2022) with days considered: 18.07.2022 – 20.07.2022.

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3 RESULTS

During the winter period, there was no irrigation for the vegetation samples, as discussed in Chapter 2. However, as has been shown by previous experimental measurements, the vegetation facade needs the presence of water and regular irrigation to be viable. Not only does this have a significant effect on the actual survival of the plants and living structures of the facade, but due to the presence of water and moisture in the growing medium, evaporation occurs, which has a significant effect on the thermal-moisture microclimate in its immediately surrounding area. The irrigation of the vegetation wall in the summer period, observed was provided by an electric pump with timed adjustment. The irrigation was carried out with the intention of the necessary presence of water, not because of deliberate cooling of the vegetation wall. The water pump setting was 3-minute intervals at 4:00, 6:00, 8:00, 10:00, and 12:00 UTC (Coordinated Universal Time). Irrigation alone did not have a significant impact on the temperature change of the sensors in the samples.

The following graphs show the results of the thermal regime of the envelope with the vegetated wall compared to the wooden cladding. The first two graphs focus on the temperature regime during winter. Fig. 8 shows the temperatures on the surface of the vegetation wall and the wooden cladding, and also the air temperature pattern and the solar radiation intensity. Fig. 9 represents the temperatures on the insurance film behind the ventilated air cavity.

The next two graphs focus on development during the summer period. Fig. 10 presents once more the temperatures on the surface of the vegetation wall, and the wooden cladding, and also the air temperature and the solar radiation intensity. Fig. 11 presents the temperatures on the insurance film behind the ventilated air cavity. The temperature label represents the outside air temperature.

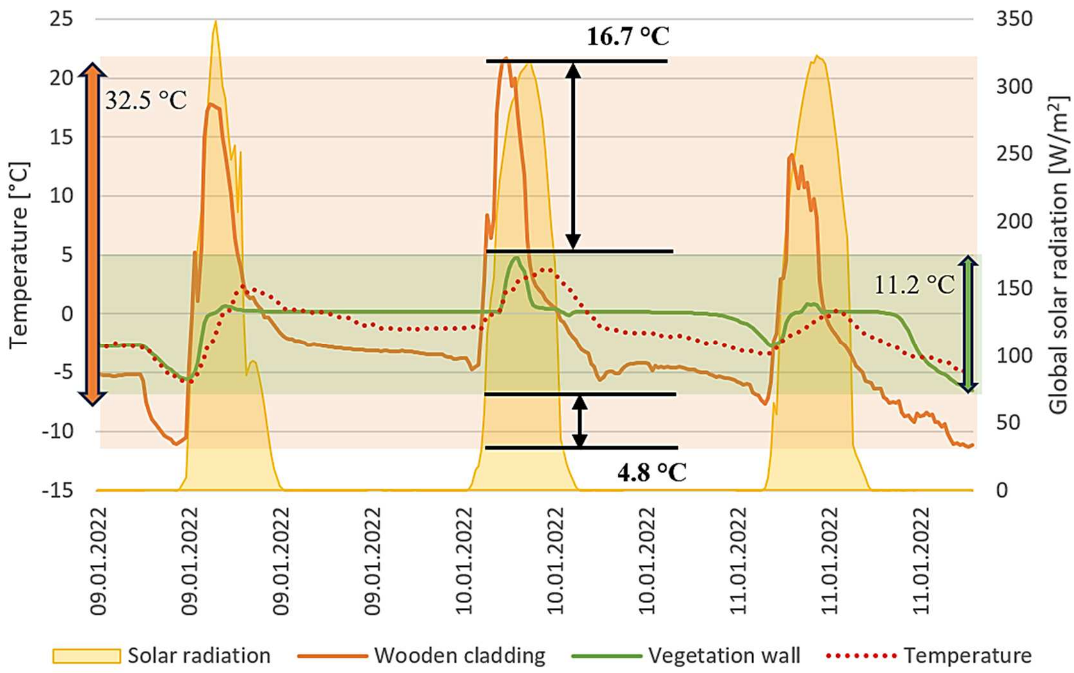

Fig. 8 Surface temperature comparison between vegetation wall and wood cladding for selected winter seasons.

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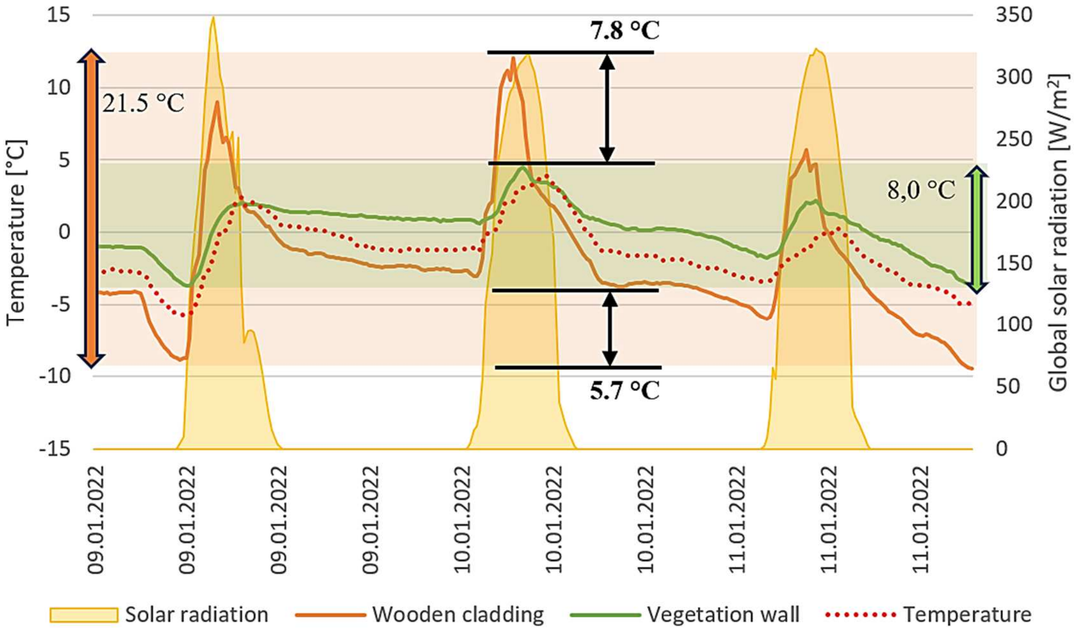

Fig. 9 Comparison of the temperature on the diffusion film between the vegetation wall and the wood cladding for a selected winter period.

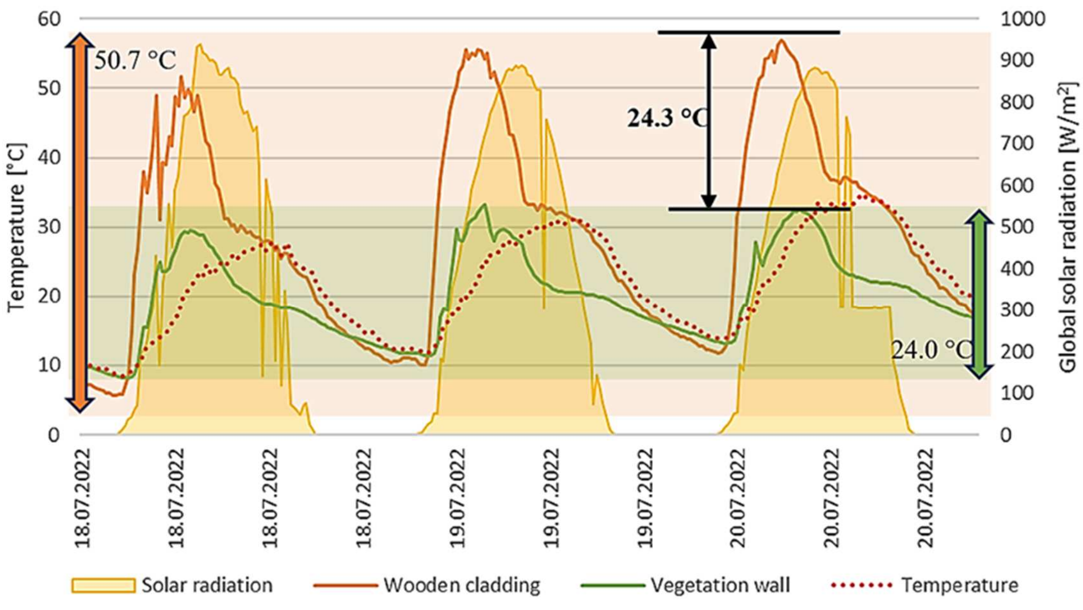

Fig. 10 Surface temperature comparison between vegetation wall and wood cladding for selected summer period.

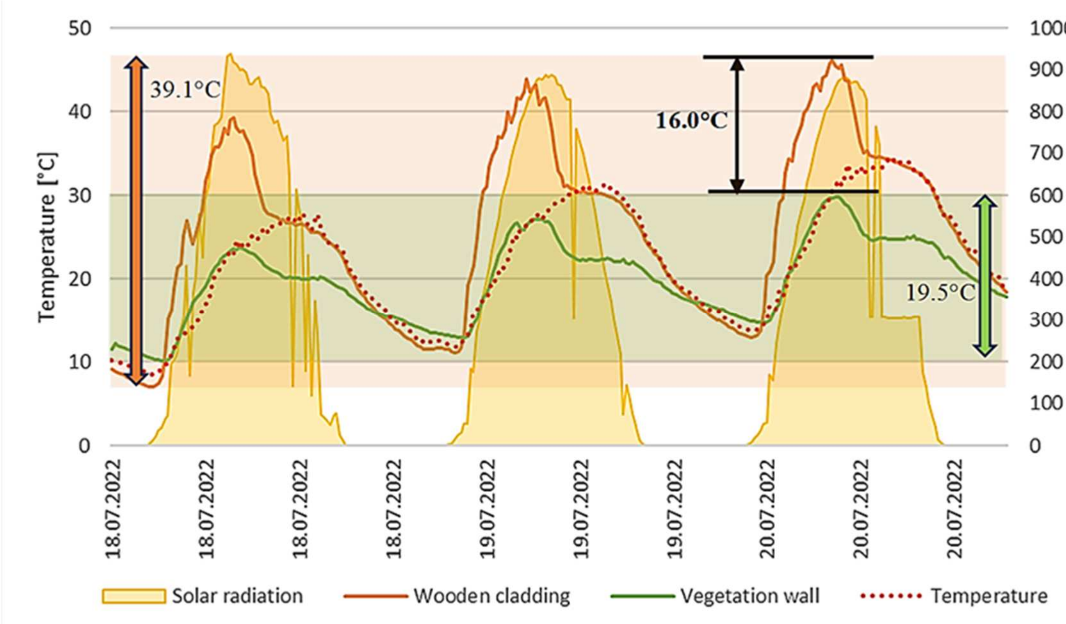

Fig. 11 Comparison of the temperature on the diffusion film between the vegetation wall and the wood cladding for the selected summer period.

4 DISCUSSION

The data obtained from the IN-SITU experimental measurements, used in the graphs in Figures 8–11, show the significant benefits of a façade incorporating a vegetated wall over the more conventional timber cladding. The graphs in Fig. 8 and Fig. 9 present the behaviour of the temperature regime of the façade in winter. The graphs in Fig. 10 and Fig. 11 present the behaviour during the summer period.

Fig. 8, which demonstrates the comparison of surface temperatures during winter, illustrates a significant difference in the thermal oscillation. The difference reaches up to 21.3 °C. This figure clearly illustrates that it is the pattern of direct solar radiation that has a dominant influence on the surface temperature increase and not so much the air temperature. While the air temperature reaches a maximum of 5 °C, the temperature on the wooden surface reaches almost 22 °C. Surface albedo (colour – absorption of sunlight) also plays an important role. It is important to mention the progression during night hours. The temperature of the wood cladding is lower than the outside air temperature, the temperature of the vegetation wall almost always maintains a higher temperature than the air temperature.

Fig. 9 presents the surface temperature profile on the diffusion film behind the air layer. It can be noticed from the graph that the oscillation of the surface temperature is reduced from 21.5 °C to 8 °C which is almost a threefold reduction. It should be pointed out that the temperature behind the vegetation wall is consistently higher than the outside air temperature. In addition, there is no excessive surface cooling, which reduces the amount of heat flux that is transported through the structure to the exterior. There is a significant difference in the maximum temperatures when the surface is overheated and when it is undercooled.

During the summer period, we can notice an increase in surface temperatures due to the effect of solar radiation, especially on the wood cladding, as interpreted by the graph in Fig. 10. The difference between the maximum surface temperature on the wooden cladding and the vegetation wall is up to 24.3 °C. It should be noted that the vegetation wall was not permanently irrigated but received plenty of irrigation for necessary survival. From the graph, the fact that the maximum surface temperature on the vegetation wall is at the level of air temperature can be noted.

The graph in Fig. 11 presents the temperatures at the diffusion film in the summer period. Again, there is a significant reduction in the thermal oscillation in favour of the vegetation wall. The thermal oscillation is even lower than that of the outside air. It can be noticed that the temperature behind the vegetation wall is consistently lower than the outside air temperature during the day, and higher during the night. This fact prevents the building envelope from overheating during the day and undercooling at night.

The results in this paper demonstrate the damping of thermal oscillations in favour of the vegetated façade in both summer and winter. A significant reduction of temperature oscillations occurs at the surface itself, and also behind the air cavity at the surface of the heat-exchange envelope of the building. As could be seen, the thermal oscillation at the surface during the winter period for wood cladding was 32.5 °C, while for the vegetation wall, the value was 11.2 °C. Behind the air cavity, the oscillation was 21.5 °C for wooden cladding and 8 °C for the vegetation wall. During the summer period, a significantly increased thermal fluctuation occurs. The surface temperature for the wood cladding reaches almost 51 °C, while for the vegetation wall, it reaches 24 °C. The temperatures behind the air cavity for wooden cladding have a fluctuation of more than 39 °C and behind the vegetation wall barely 20 °C.

5 CONCLUSION

The numerous publications emphasizing the benefits of vegetation structures, particularly in the summer months, have consistently highlighted the proven positive effects of these structures, primarily attributed to evaporative cooling from living constructions in the presence of sufficient water content in the growing medium. This paper has extended this understanding by demonstrating the behaviour and impact of vegetation structures during the winter season. The results were proved in favour the advantages of a vegetated façade. The vegetation wall effectively cools the air close to the building envelope during summer and thus does not overheat the structure, on the contrary it keeps the temperature higher in winter, thus reducing the temperature difference in the building envelope therefore preventing heat transfer out of the building. The presence of living constructions significantly influences the microclimate in the immediate vicinity of the building. This is mainly due to the hydro-accumulation and thermoregulatory capacity of the growing medium and the presence of living vegetation, which can dampen the abrupt temperature fluctuations that occur during the day. Often, the hard, non-living materials used in the building envelope do not have cooling capabilities leading to significant temperature extremes during the day, which can be two to three times higher than those observed with a vegetation wall.

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