EXPERIMENTAL STUDY ON REDUCING TEMPERATURE USING MODULAR SYSTEM FOR VEGETATION WALLS MADE OF PERLITE CONCRETE

by

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Original scientific paper
https://doi.org/10.2298/TSCI170612227S

The aim of this research is to examine and analyse the thermal characteristics of the façade modular element. The possibility of optimization of the façade coating with vegetation is examined experimentally in this research, with the aim of improving the thermal characteristics of the façade wall. This element is made of perlite concrete in which the greenery is implanted. The scope of the research is experimental and theoretical testing the possibility for optimizing the façade coating with vegetation. The energy specificities of modular vegetation elements and their contribution to the improvement of the thermal properties of the façade wall are analysed in the experimental part of the research, the elements of vegetation are treated as the elements which influence the decrease in surface temperature of the façade coating. The modular elements in this research are placed on a reference wall surface facing the South. The methodology presented in this paper is based on the study of climate characteristics in city of Belgrade, experimental measurements of test models, and comparative analysis with the reference wall. During the experiment, the data on the external climate parameters and the coefficient of heat transfer through the wall were continuously measured. Conducted measurements and analyses show the vegetation influence on the reduction in surface temperature of the outer wall and the heat passage through the façade coating. The experiment used a modular model and several plant species. It is noticeable that vegetative walls with green areas covered by plant shells play an important role in the harmonization of the parameters of the microclimate in relation to the local environment.

Key words: *living wall, green façade, vegetation, energy efficient, vegetation*

Introduction

Nowadays, a large number of studies and research can be found in which the use of vegetation walls in architecture is analysed. In these researches, the technology of vegetation walls and their application from the functional, design, aesthetic, energy, and economic aspect were treated. This research was done as part of a complex process of analysing green cell technology development, treating them as passive energy saving systems. Vegetation walls are part of the façade wall structure, fig. 1. They consist of a supporting structure of a vegetation wall, a substrate for planting greenery and the greenery itself. The aims of the vegetation walls architecture is to enable a new form of aesthetic recognition for architecture and con-

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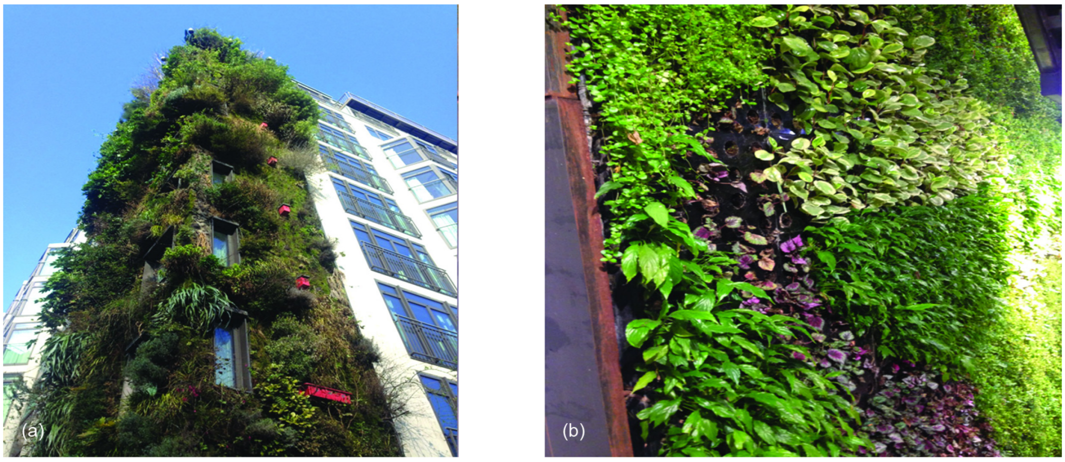

Figure 1. Vegetation walls are part of the façade wall structure (photos by authors)

tribute to sustainable development of mankind. The dynamism of the form, which is achieved by the vegetation wall, is expressed through a recognizable structure of materialization. Vegetation walls are façade wrappers that offer new solutions in the process of energy optimization of the wall. In façade coatings they have a role of protection against solar radiation (direct, diffused, and reflective) as well as convection heat transfer. A higher number of studies have shown that vegetation walls may significantly reduce the surface temperature of the wall coating and, consequently, to improve the thermal properties of the façade. Reduction of the wall surface temperature behind the greenhouse in the Di and Wong [1] research ranged from 1.9 °C to 8.3 °C, depending on the density of the leaf surface and the type of vegetation. The results of the Pereza *et al.* [2] research show that using vegetation reduces the amount of heat transfer through the envelope of the building, thereby reducing the amount of energy necessary for cooling and space heating. In his research, Hasan [3] shows that the vegetation walls considerably decrease the total value of heat transfer resistance in the façade walls.

Analysing the impact of green walls on the replacement of the necessary energy in the facilities, Perini *et al.* [4] proves in his work that the cooling capacity in the building can be reduced by 62.03 kWh per person, which means that this would reduce the need for cooling energy by 26%. Manso *et al.* [5] proves in its work that vegetative walls improve the heat comfort of the interior space and contribute to reducing the outside temperature of the wall surfaces by 15° C, which leads to a reduction in thermal gain to in the summer period. According to the survey of Susorova *et al.* [6], the application of vegetation in the envelopes of architectural objects reduces the external surface temperature of the wall by 0.7-13.1 °C, while in the same research, the heat flux through the external wall decreases by 2-33 W/m^2, depending on the orientation on the wall, the leaf surface index and the coefficient of radiation. This research is based on the experimental model and theoretical assumptions used to estimate the effect of vegetation on the thermal performance of a building. Since the interaction between the outside environment and the interior space takes place through the building envelope, vegetation walls are an element in solving the external appearance and energy balance of the building. Vegetation walls open a new field of research of façade coatings, treating architectural objects as a potential place for the creation and realization of artistic creations. Evaluation of potential benefits of vegetative walls can stimulate its use in urban environments.

Green walls are treated as shading elements, which in the summer period can change the microclimate values in their surroundings.

This effect is directly related to the plant species used, the density of the leaf cover (LAI), the evapotranspiration factor and the modular substrate of the vegetation wall. The energy potential of a particular shell of an architectural object is determined by the structure of the cover itself, the location climatic conditions and the mode of use of the object. The total solar radiation that falls on the leaf surface of the vegetation wall is distributed: the part is reflected, the part is used for photosynthesis of plants, the part is used in the evapotranspiration process, while the smaller part comes to the façade wall [7].

Experimental facility

Experimental model – system design

In order to determine the thermal performance of the vegetation wall, its physical model was first established. When defining the type of modular elements of the vegetation wall, selected factors have been treated which mostly influence the energy performance of the element itself, which in the further analysis can influence the technological characteristics and designing improvements of the model. The modular system of vegetation walls implies the application of controlled planting and maintenance systems for plant species in panels containing soil for plants as well as an autonomous maintenance system. The design concept of the modular model was designed to create the conditions for a sustainable system for green walls. The process itself involves: formulating the geometry and the size of the modular element, defining the structure and modelling, materializing the model, and forming a vegetation wall assembly. For this experiment, a vegetation wall type SB1 was formed. It consists of: a supporting part made of perlite of concrete (position 1), styrofoam (position 2), substrate (position 3), and plant seedlings, fig. 2(a). Modules of 30 × 60 cm were created. and placed on metal brackets. Each panel contains three fruit pockets, fig. 2. The modules are made of perlite concrete. Perlite concrete belongs to a group of lightweight concrete which consolidates good thermal insulation properties and load capacity, *i. e.* low heat conductivity coefficient.

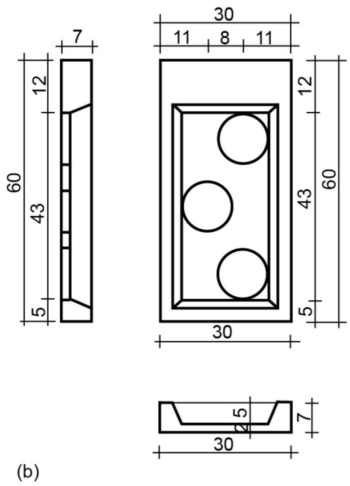

Figure 2. (a) 3-D presentation of the model, (b) dimensions [cm] of the modular model (photos by autors)

For the purposes of the research, the coefficient of thermal conductivity of the modular element was also tested. The density of cured concrete in the dry state is ρ_0 = 458 kg/m^3. The weight of the element prior to plant sowing was 5436 kg, and the weight of the planted element was 6320 kg., fig. 3. The rhythm of circular openings for planting plant breeds is symmetrical. A module made of this material has an increased water absorption capacity, so the whole system is able to absorb a certain amount of water that plants can use in the irrigation process.

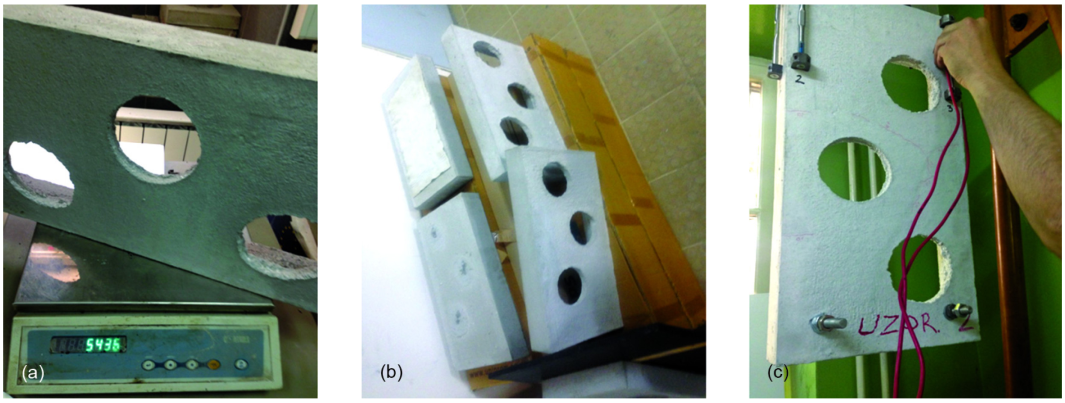

Figure 3. (a) Weight measurement, (b) finished models, (c) finishing the planting pocket (photos by authors)

The greens are planted in a substrate representing a mixture of 90% light peat (granulation 00-20 mm, 00-30 mm) and 10% black peat (granulation 00-20 mm, 00-30 mm). Three models of vegetation walls with plants from different types of plants were examined. These are experimental models: SB1 with plant *Geranium macrorrhiuum*, SB2 planted with *Cordifolia stock* and SB3 with planting *Nitida lemon*. The plants used are with oblong, pointed leaves, bent at the tip. The leaves are simple, arranged alternately, with several colours and shades on the petals. The requirement was to use the plants which need wet soil and grow very fast. In the course of growth, the plants were fed with liquid fertilizer for leafy shrubs every two weeks. The soil is obtained by mixing 3/4 of forest soil with 1/4 of garden soil. For model experiments, the described model and plants with different value of the coefficient of leaf surface were used. Leat area index is the ratio of total leaf upper side area and the area of the soil where it grows. Typical values are between 0 for bare soil and 8 m^2/m^2 in a dense forest; grass surfaces possess equal to 1 m^2/m^2 [8]. The plants used have a good cover effect. The structure of leaves is different. The development of this system is based on the assumption of minimizing environmental impacts, enabling the replacement of a single module in order to improve the thermal performance of the facility.

Methods

The basis for analysing and determining the parameters of the façade assembly is reflected in the collection of adequate climate parameters. The measurements were made in Belgrade in the year 2016, fig. 4. The methodology presented in this paper is based on the analysis of the climate characteristics of the Belgrade climate area, experimental measurements of the test model and comparative analysis with the reference wall. During the experi-

Figure 4. Measuring contact temperatures (photos by authors)

ment, the data on the external climate parameters and the coefficient of heat transfer through the wall were continuously measured. In addition to these parameters, in order to examine the influence of plant species on the temperature parameters of the wall, the wall temperature was measured in relation to different plant species. The climatic characteristics of the dive, geographical influence and microclimate characteristics are the main factors for the successful cultivation of certain plant species. In Belgrade climatic conditions, the problem of plant maintenance is due to late spring frosts and frosts that occur in the early autumn, when the vegetation is still underway. We can treat the climate of Belgrade as a city climate that differs from the climate in the environment due to increased construction and urbanization of the area. A large ammount of different aerosols reduces radiation and the length of the Sun's radiation. Belgrade is at 44° 48' north latitude and 20°28' east longitude, with an average altitude of 132 m. Climatic characteristics can be treated as part of a moderate continental climate with an average annual mean temperature of 11.9 °C. The Belgrade climate region has the largest insolation period of about 10 hours a day in July and August, while the highest cloudiness in December and January when the insolation length in average 2 to 2.3 hours. It can be concluded that the intensity of direct solar radiation in the central parts of the city is lower compared to the suburban zones due to the cloudiness of the air and the level of urbanization. Three experimental modules SB1, SB2, and SB3 with different plant breeds were mounted in a test experimental vegetation wall, and the measurement values were continuously collected and processed. Test models are placed on the reference wall, South oriented.

The installation has no shading throughout the day. The dimensions of the experimental walls are 2.4 m × 2.4 m, using 32 modules. The reference wall is 35 cm thick, made of brick. During the experiment, an automatic irrigation system was activated. Wall modules are irrigated for 1 minute at a time interval of 3 hours. The distribution of water was horizontal and moderate. The temperature values are measured for each of the walls separately. Measurements of the temperature performance of façade coatings were done on the south side, during the daytime, from 7:00 to 19:00 hours, every 60 seconds.

Weather conditions are analysed based on the weather station, the PCE-FWS 20 wireless model, installed near the reference wall, fig. 5. The results of local meteorological data such as the outside temperature, relative humidity, precipitation and insolation were measured automatically and collected every 15 minutes, which is shown in the paper in the

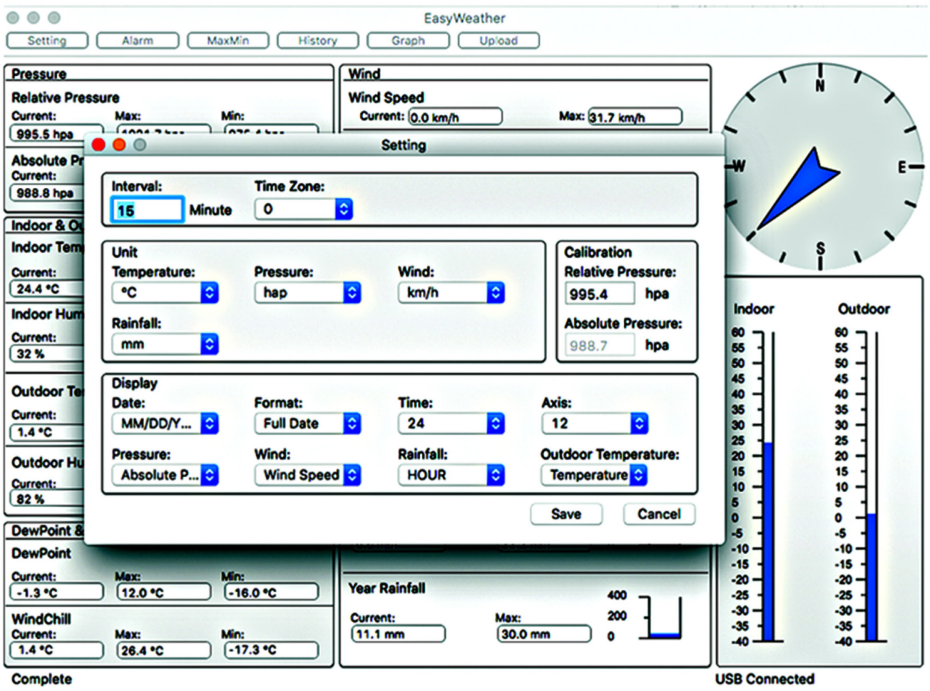

Figure 5. Outer climatic conditions PCE-FWS 20

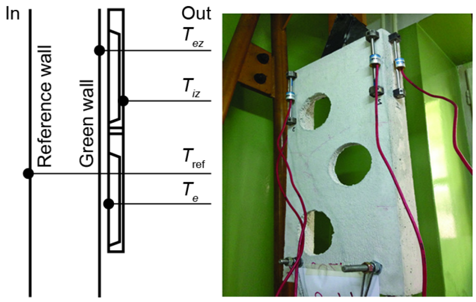

Figure 6. Surface probes positioning

form of graphic presentation. The temperature measurement in several measuring points within the green wall was measured every 2 minutes and collected in the Kimo TM 210 datalogger. Temperature sensors measured the temperature of the inner surface [°C] of the reference wall, T_{ref}, the outside temperature of the reference wall, T_{ez}, the surface temperature vegetation module, T_{iz}, surface temperature of the reference wall in contact with the vegetation module, T_e. Measuring equipment is shown in fig. 6. The coefficient of the reference wall heat transfer is determined by calculation and this value was compared to the measuring values. Operating principle: thermometer: thermocouple, according to the Seebeck effect, when two wires composed of different metals are joined at both ends, an electric circuit is formed. The voltage increases with temperature. Thermometer: Pt100 probe. Pt100 is a resistance with a positive temperature coefficient which varies according to the temperature. The higher the temperature is, the more the value of the resistance increases.

Analysis and discussion

Measurements and comparative analyses within experimental models show the uniformity of the results obtained. Measurements and analyses showed that the temperature on the surface of a wall with vegetation, T_{iz}, is considerably lower compared to the reference wall without vegetation. These data indicate that vegetation modules influence the reduction of the wall surface temperature. Based on the results obtained, it can be noticed that the different types of plants, *i. e.* the difference in their leaf surface, greatly influence the thermal behaviour of experimental models.

The main aim of the research was testing and analysing the influence of vegetation on the reduction of temperature and heat transfer coefficients for the reference wall for a typical summer day. Measurements of the thermal performance of the façade coating were done on the south side, during the daytime, from 7:00 to 19:00, fig. 7. The analysis of a typical summer day results shows that the maximum daily outdoor air temperature was 24.1 °C, measured at 17.40 hours, while the minimum temperature was 13.1 °C, measured at 7.00 hours, fig. 8. The mean outside air temperature for south-oriented experimental wall was 20.45 °C. Solar radiation shows a maximum value of 995.6 W/m^2, measured at 13.06 hours. Air humidity varies in the range of 46% to 97%. The mean average temperature measured in July was 26.76 °C, and in August it was 26.10 °C. When it comes to the mean value of the length of insolation in measuring periods in Belgrade, its balance is observed for the months of July and August. The maximum value of air humidity was measured in the early morning hours and the minimum humidity was measured at 17.38 hours. The mean values of the measured temperatures were taken in the analysis.

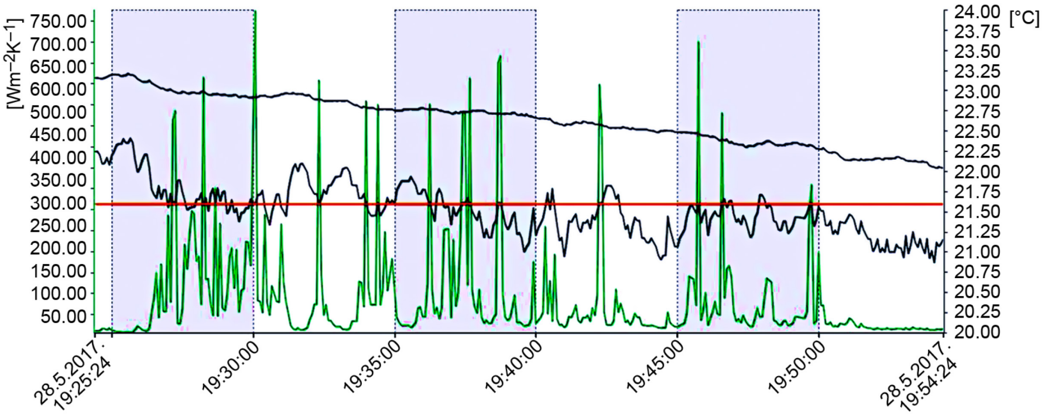

Figure 7. Graphic display of values of the thermal transfer coefficient in vegetation wall, measured with Kimo TM 210 device

The measured mean outside temperature of the surface of the reference wall in the part without vegetation was 22.38 °C, and in the part where the wall was covered with vegetation, the measured wall temperature was 20.9 °C (SB1), 19.45 °C (SB2), and 19.12 °C (SB3). It can be noticed that the temperature of the reference façade wall is higher compared to the part of the façade wall where the vegetation was installed for 1.47 °C or 6.57%. This was set for SB1 model. For SB2 model the difference in temperature was 2.93 °C or 13.10%, and for SB3 it was 3.26 °C or 14.58%, figs. 9 and 10. Given the measured daily surface temperature of the reference wall, the difference between the measured surface temperature of the experimental walls is about 3 °C. This shows us the conformity of the obtained results with the results of other experimental investigations, which showed a decrease in the temperature surfaces of the façade coatings. Maximum temperature of the vegetation module was reached between 14 00 and 16 00 hours.

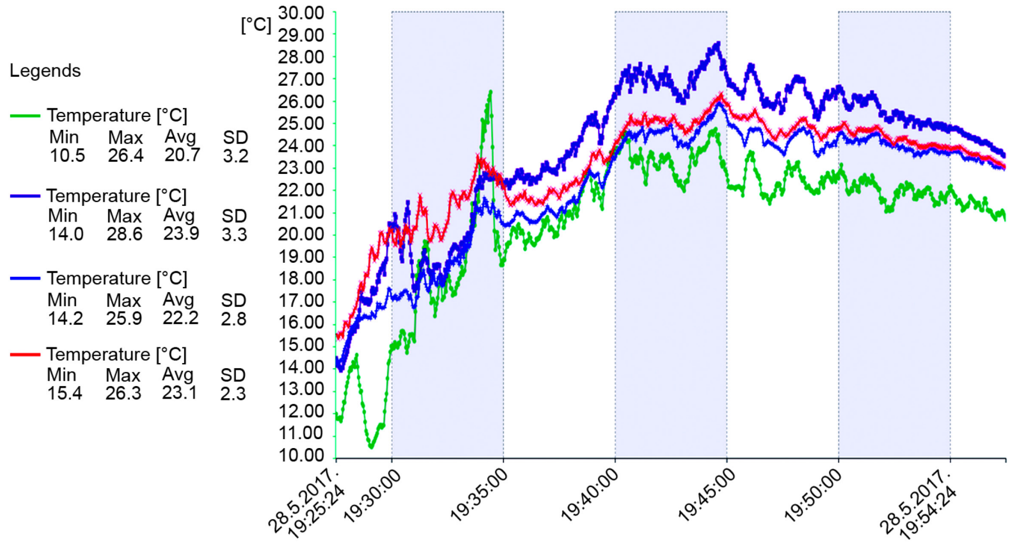

Figure 8. Graphic display of measured temperature values in vegetation wall, done with a measuring device Kimo TM 210

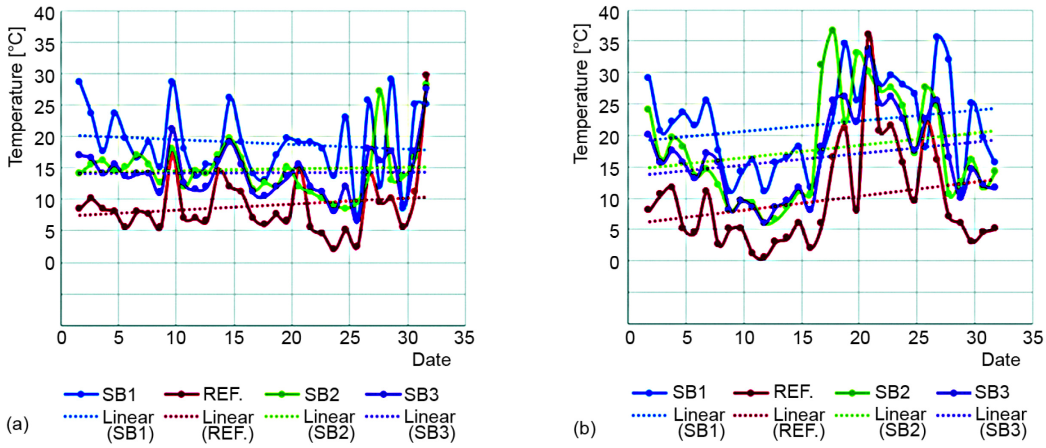

Figure 9. Graphic display of measured surface temperature (SB1, SB2, SB3, REF.); (a) July, (b) August (*for color image see journal web site*)

The green wall in this experiment slowly releases the accumulated heat from the reference wall. Obviously, the surface temperature of the vegetation module exposed to sunlight during the evening is reduced under the influence of vegetation. Temperature decreases in different temperature ranges. It can be noticed that irrigation has an influence on the temperature of the vegetation module [9, 10]. The analysis sowing that the plant plantation with thick leaves (high index of leaf surface) is more successful in reducing the temperature of the façade surface, and therefore the thermal flux through the façade.

The reference wall has a measured heat transfer coefficient U = 0.482 W/m^{2}K, fig. 8. According to the current Energy Efficiency Rulebook of the Republic of Serbia, this value is higher than the maximum allowed value for the walls in new buildings which is

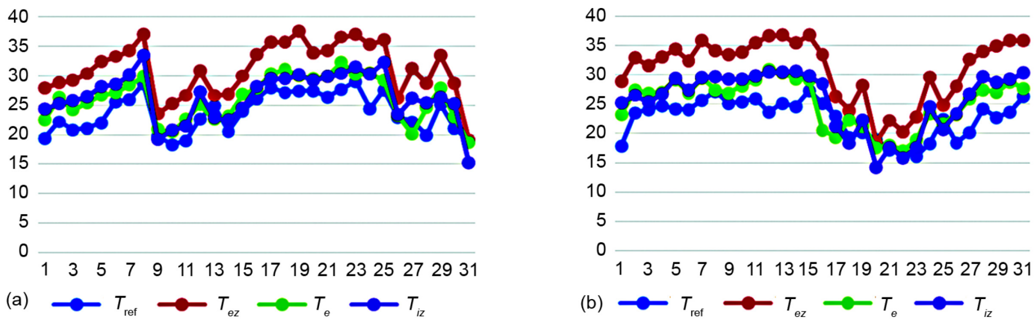

Figure 10. Graphic display of measured temperature (SB3) values according to the set criteria; (a) July, (b) August (*for color image see journal web site*)

Up = 0.3 W/m^{2}K. The measured result of the wall heat transfer coefficient consisting of the reference wall and the added experimental vegetation wall is U = 0.354 W/m^{2}K for model SB1, U = 0.321 W/m^{2}K for model SB2, and U = 0.319 W/m^{2}K for the SB3 model, tab. 1. It was noted that with the increase in the index of leaf surfaces, the temperature of the façade behind the vegetation and the heat transfer coefficient through the wall significantly decreased, because the leaf surface with thick leaves oriented normally to the Sun's radiation is the most efficient case of reducing direct solar radiation on the wall. Increasing the LAI coefficient results in a decrease in the U value.

Table 1. Tabular display of measured *U*

Model	Ref	SB1	SB2	SB3
U value [Wm^{-2}K^{-1}]	0.482	0.354	0.321	0.319

It means that the vegetation walls are a good and practical solution in the reconstruction of the existing buildings with a heat transfer coefficient higher than the allowed values stated in the mentioned rulebook. Also, green walls can be used in new buildings with the aim of improving their thermal properties. It is primarily related to the reduction of the thermal island effects, as well as the improvement of the complete architectonic of the building and space.

Conclusions

The analyses made in this experimental study show the thermal behaviour of the vegetative modular system compared to the reference wall. Their comparison was done by measuring the surface temperatures and the coefficient of heat passage through the wall. The comparison was conducted on three vegetation wall models with different types of plant species and leat surface coefficient (LAI). A comparison was made by evaluating the experimental data collected during the measurement in the summer period.

Reference wall was analysed as well as the influence of the three vegetation wall models on its performances in the same conditions of microclimate. The models of vegetation wall modules were the same, only three different plant species were used, appropriate for usage in Belgrade climate area. Measuring equipment was used to measure the values of the coefficient mentioned and thermal properties during the summer period in the conditions of moderate continental climate. Then, the reference wall heat transfer coefficient is calculated using the existing calculation method. Comparing the heat transfer coefficient calculation values with the obtained measurement values, it can be concluded that the heat transfer coefficient is reduced by 6-12% in relation to the reference wall value (without the addition of vegetation). During the experimental measurements, 9% reduction in surface temperature of the outer wall can be noticed.

It can be concluded that in hot sunny days, the application of vegetation walls on the existing brick façade reduces the surface temperature of the wall by 2.8-5.4 °C, and therefore reduces the coefficient of heat conductivity of the wall for $U = 0.163$ W/m^{2}K. This increases the thermal comfort of the building and reduces the energy demand for cooling. This reduction of parameters is conditioned by the orientation of the wall, the index of the leaf surface, the choice of the modular element and the plant breeding [11].

Unlike conventional material for façade materialization, vegetation walls do not absorb the received solar radiation. Since the value of the coefficient of heat transfer of the façade wall with the added vegetation wall has been reduced, it can be concluded that the experimental measurements yielded the expected results [12, 13]. The selection of the system of greening plays a key role in the optimization process, because it allows its performance to increase or decrease the percentage contribution of the selected module in the process of optimizing the façade coating [14].

Based on these results, it can be concluded that the analysed model fully meets the assumed energy potentials of the vegetation walls. This experimental study explores the thermal behaviour of vertical greenery in a modular system made of perlite concrete. Its behaviour was compared to the measured values on the reference wall.

Measurements during the summer showed the reduction in temperature on the surface of the vegetation walls. Unlike conventional materials for façade materialization, vegetation walls absorb much more absorbed solar radiation. In further research and work on vegetation walls, it is recommended that, from the point of view of energy optimization of objects point of view, the relations of energy optimization of the object and the required surface of the vegetation wall are analysed so that the whole process would have an economic justification [15]. This question has not been addressed in this research. Finally, the model developed and applied here can be used to quantify the reduction of conductive heat load and its contribution to total energy consumption for the design of space in buildings with plant façades. In addition, this model of a vegetation façade can be used to form guidelines for the design of buildings with vegetative walls in different climatic conditions.

The analysed vegetation wall models met the expected results and they could be used in practice for modular façade creation depending on the decoration, that is, greenery shape the designer decided to use. The advantage of the analysed vegetation module is the application of the thermal concrete of low density with the porous inner structure which also contributes to the reference wall thermal properties improvement. It increases the heat transfer resistance during the summer mode. Vegetation walls made of these modules are easier to mount and they are suitable for new and old building façades. Their application in old buildings can lead to the reduction in heat transfer coefficient within the limits demanded by the Energy Efficiency Rulebook of the Republic of Serbia. Also, the application of the vegetation walls and the analysis of the modules used can be conducted on the buildings characteristic for the city micro-locations highlighted as heat islands. Green façades have a favourable influence on CO_2 emission reduction. Therefore, in addition to the decorative function, their application leads to electricity consumption reduction in air-conditioning systems during the summer mode. Measurements during the summer period showed a considerable reduction in temperature on the surface of the vegetation walls.

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Paper submitted: June 12, 2017
Paper revised: March 20, 2018
Paper accepted: April 16, 2018