THERMAL EXTRAS OF VEGETATION WALLS IN BELGRADE CLIMATIC CONDITIONS

by

Budimir S. SUDIMAC[a*], Aleksandar S. ANDJELKOVIĆ[b], and Sanja S. DUBLJEVIĆ[b]

[a] Faculty of Architecture, University of Belgrade, Belgrade, Serbia
[b] Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

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The goal of this research is to analyse the possibility of using vegetation walls in order to improve the thermal characteristics of office buildings in Belgrade's climatic conditions. The study analyses the possibility of integrating vegetation modules into the façades of office buildings. The paper shows the potential of vegetation technologies in the realisation of façade coverings of architectural buildings with a goal to reduce heat gained during summer time. The use of vegetation walls in architecture has opened up new planning possibilities and created planning conditions for reducing the energy necessary for cooling office buildings. Considering that interaction between the outer environment and inner solving the dependency between comfort, outer look and building's energy balance. This paper is presenting the possibility of using sustainable technologies for solving the problem of overheating in Belgrade's climatic conditions. The research considers the possibilities of using vertically greening systems in planning façade coverings, with an analysis of their thermal characteristics for climatic conditions in Belgrade.

Key words: *vegetation wall, technology, design, energy performance*

Introduction

The aim of this research was found in the practical approach for solving the energy problems of contemporary buildings. The research reviews the possibilities and influence of vegetation walls, fig. 1, on reducing heat gains in office buildings in Belgrade's climatic conditions. The use of vegetation in buildings as an element for reducing the necessary energy for cooling in the summer period is a new approach in solving thermal problems of objects. Several researches have shown that the use of such systems on the façade have a positive effect on the reduction on the building's energy demand. Olivieri *et al*. [1] examined the shading effect of vegetation layer on a concrete building in Mediterranean climate, with the existence of plants, and the external surface temperature of the south facing wall was reduced by 6.5% and the indoor air temperature by 4.1°C. The results of the extensive field experiments led by Nojima and Suzuki [2] in Tokyo also indicated the lower temperature of external wall surfaces as well as the reduction of conduction heat gain by plant cover. Vegetation decreased heat transfer through the south façading wall by 3.7% to 14.7% [3]. Integrating vegetation into the redesign of existing buildings, as well as integrating them into newly-planned buildings, can generate significant reduction of heat gain, while at the same time reduce the effect of urban heat island [4]. The façades of buildings are in a

* Corresponding author, e-mail: sudimac@arh.bg.ac.rs

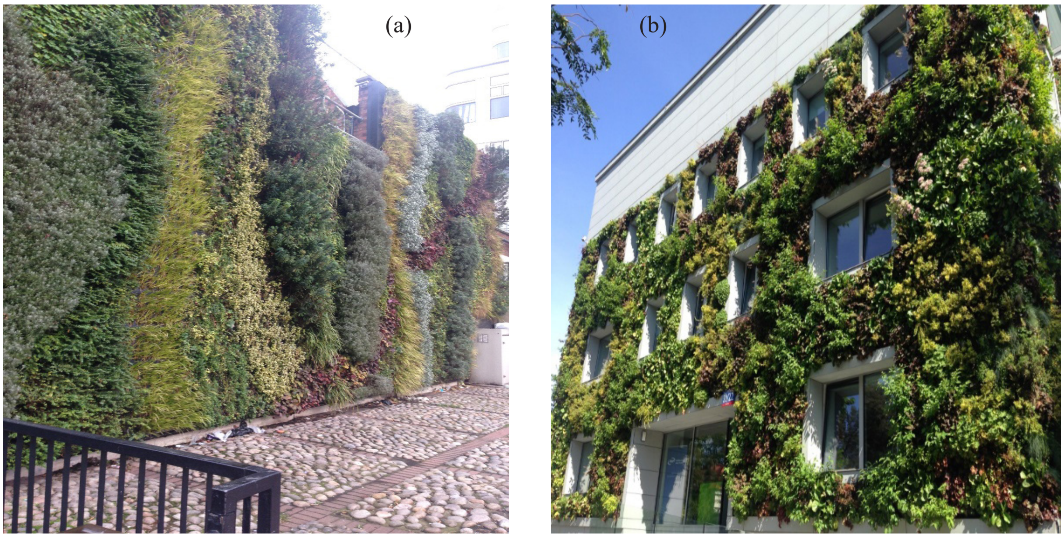

Figure 1. Example of a vegetation wall on a business building; (a) London, (b) Warsaw
(photos taken by authors)

dynamic and interactive relationship with the environment, with maximum use of technological potential. Also, the need for developing vegetation walls comes from the need for a more intensive contact between the user and natural environment. Certain research regarding the reduction of heat gain in cases when vegetation walls have been implemented show reductions of wall's area temperature in the range of 5-40 ºC. Researches find the causes for this reduction of surface and ambient temperature in evapotranspiration and shadows created by the leaf area during the summer time. The reduction of surface temperatures leads to the reduction of overall energy necessary for cooling the air inside the building. The wall's vegetable structure protects the entire wall from excessive UV radiation and atmospheric precipitation.

By definition, vegetation walls are architectural façade elements which are free-standing or applied to the load bearing part of the façade covering, and partly or entirely covered in vegetation [5]. Their aim is to give architectural buildings a new character in the relation to their surroundings, and to create conditions for a more efficient protection of buildings against overheating in the summertime. The basic element of the green walls is a bionic leaf.

Experimental facility

Experimental model

The analysis presented in this paper is experimental and mathematical. Both are aimed to show the energy potential of vegetation walls, fig. 2, in Belgrade's climatic conditions. The paper's methodology is presented by analysing Belgrade's climatic characteristics, experimental measurements of the model, software simulation analysis of the existing heat gains in office buildings during the summer, possibility of integrating vegetation walls into an office building, and by analysing the reduction of heat gains in a building after the application of a vegetation wall. The thermal response of the green walls was determined experimentally at the outdoor experimental test site by measuring the temperature and flow conditions in the microclimatic layer of the bionic façade, which consists of bionic leaves [6]. A simulation study was undertaken to assess the effects of vegetation walls on the thermal performance of a building. A thermal model of climbing plants was formulated using Revit Energy Analysis

Figure 2. Display of green plant of the module; (a) display of Module green wall, (b) display of Module without plant (photos taken by authors)

environmental simulation software and was validated against the data obtained by experimental measurements. This model was applied to a further simulation study and the results showed that plant cover improved indoor thermal comfort in summer, and reduced heat gains and losses through the wall structure. The results were relevantly analyzed [7]. The practical research was done on an experimental model of vegetation wall, which was used to measure surface temperatures in July and August. Based on the results of these measurements, the heat transfer coefficient through the experimental module was measured [8]. For the needs of this research, an experimental model of vegetation wall was made in order to measure results which will be evaluated in the mathematical model of improving thermal characteristics of office buildings. Vegetation walls do not accumulate heat like walls made of conventional materials [9].

The work on the experimental model and its testing included the following procedures: Formulating the geometry and size of the model, designing and making the model while defining the necessary construction elements and materialising the model, experimentally forming the composition of vegetation wall, collecting and analysing climatic data in time intervals in which practical measurement was done on the vegetation wall model, measurement of surface temperature of the existing façade wall, with and without applying vegetation [10].

Validation of vegetation model

Belgrade has a moderately continental climate. Winters are cold, and summers are dry and warm. Average air temperature in Belgrade is 11.9 °C. There are 2096 sunny hours annually, on average (making it 45.48 per cent of potential – possible insolation). Belgrade's climatic area is characterised by an insolation period of around 10 hours a day, in July and August, while cloudiness in greatest in December and January, when insolation is long 2 to 2.3 hours on average. Average value of direct sunlight is 80 W/m^2. By examining the climatic parameters data of the Hydrometeorological Service of the Republic of Serbia, we conclude that January is the coldest month, with an average temperature of 0.1 °C, and the warmest month of year is July, with an average temperature of 23 °C, fig. 3.

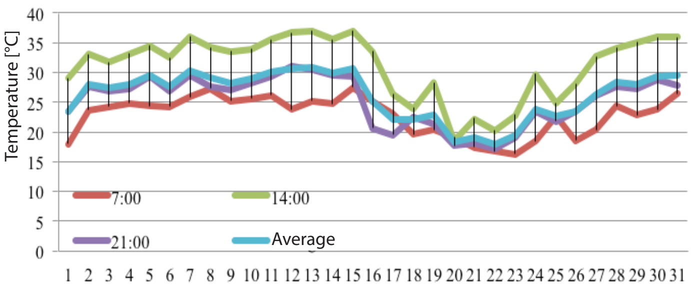

Figure 3. Graphic review of comparative values of the measured air temperatures in Belgrade in the month of July 2016
(*for color image see journal web site*)

It is easy to establish that there is a significant difference in temperature during the coldest and the warmest month. Belgrade's climate is characterised by a number of drought periods, which relate to at least five days without precipitation, or with minimal precipitation. The most drought days are in July, August, and September. A compact model was chosen for the purpose of practical measurements and analysis of the results. For the purpose of experimental research, a model for forming vegetation wall in Belgrade's climatic conditions was designed as a box model with circular perforation of the frontal part of the element, fig. 3. The model is 60 × 60 cm in size. It is made of waterproof plywood, 1cm thick. This model is ideal for planting small-root vegetation. The box is 10 cm wide, containing 8 cm of glass wool. This manner of forming the module presents the most optimal way of planting. Practically understanding and determining certain performances of the chosen models, their characteristics and supposed potentials are researched based on: formulating the geometry and size of the model, designing and making the model while defining the necessary construction elements and materialising the model, and experimentally forming the composition of vegetation wall. Evaporative exchange of air between vegetation and outer air influences the heat flow in the façade covering, but it was not measured in this experiment [11]. Data gathering was performed daily, in the course of eight weeks, three times a day. Surface temperatures on control wall and wall with vegetation were measured with Kimo TM 210 device, fig. 4.

Due to its mobility, vegetation wall was moved with regard to its orientation according to the sides of the world, lasting two weeks each. For the purpose of this research, surface temperatures on the green wall and the heat transfer coefficient were measured. Measurements

Figure 4. Measurement of contact temperatures by the device Kimo TM 210 (photos taken by authors)

were conducted at 7:00, 14:00, and 21:00 hours. The vegetation wall is equipped with an automatic watering system. Watering was done twice a day, lasting five minutes, with an addition of mineral fertiliser solution. We can conclude from the table that the highest measured temperature in this period, 28,8 °C, was measured on July 23rd, 2015, at 14:00, and the lowest measured temperature, 25,5 °C, was measured on

August 23rd , 2015, at 7:00 a. m. The average temperature measured in July was 26,76 °C, and on August 26, 10 °C. The highest measured air humidity in the same period, according to the measurements of the Hydrometeorological Service in Belgrade, was on August 17th, 2015, and it was 93% at 21:00, and the lowest was 21%, measured on August 11, 2015, at 14:00. The highest air humidity in July was 62%, measured on July 9th, 2015, and the lowest was 33%, measured on July 25th, 2015. In August, the highest air humidity was measured on August 20th, 2015, with the value of 86%, and the lowest was 32%, measured on August 11st, 2015. Speaking about the insolation length in the measurement periods in Belgrade, we can perceive its evenness in July and August. Average daily insolation in Belgrade was around nine hours. The longest measured insolation period in Belgrade for July and August was recorded on of July 3rd, 2015, lasting 13.7 hours, and the shortest period was measured on the July 31st, lasting 0.5 hours. For the given period, the wind was blowing with a decreased intensity and changeable direction. The highest measured wind speed in July was recorded on of July 23rd , 2015, at 7:00, with the speed of 6.7 m/s, and the lowest value was recorded on July 2nd and 14th, at 21:00 hours, with the speed on 0.0 m/s.

In August, the highest wind speed of 6.7 m/s was measured on August 2nd, at 7:00 hours, and the lowest was measured on August 30th, at 7:00, with the value of 0.0 m/s. Through the comparative analysis of the outer local climatic conditions and factors influencing the amount of heat received by the façade covering, we can conclude that those values, for the given period, are within the boundary values for Belgrade's climatic area. The outer temperature was taken as the average temperature for the period in which the vegetation wall was exposed to solar radiation.

The absolute temperatures of the set elements are given as average values. Through analysis, we can perceive an increase of outer air temperature, considering the unequal timing of the outer temperature measurements, with regard to the sides of the world. Apart from measuring the surface temperature of set of elements of the experimental model with contact and contactless thermometers, the model was recorded with a thermographic camera FLIR e 40.

By analysing the results, the difference in temperatures between the parts of the façade covering treated with vegetation and those without vegetation is obvious. The temperature difference in marked areas is 10.7 °C. During the southern orientation, the average outer temperature was 25.5 °C. The measured temperature of the outer wall, in the part without vegetation, was 24.0 °C, and in the part of the wall covered in vegetation, the surface temperature was 22.03 °C. One can perceive that the surface temperature of the façade wall is lower by 1.7 °C, or 8.33%, compared to the part of the façade wall not treated with greenery, fig. 5.

Table 1. Tabular display of measured temperature values according to the criteria given

Temperature	South	East	West	North
Tea	25.5	28.3	28.8	25.5
Tew	24.0	26.5	27.1	27.5
Tpw	22.0	24.7	25.3	25.9
Difference	1.97	1.80	1.74	1.55
%	8.33	6.63	6.456	5.64

Tea – external air temperature
Tew – external temperature of the wall without plant
Tpw – external temperature of the wall with plant

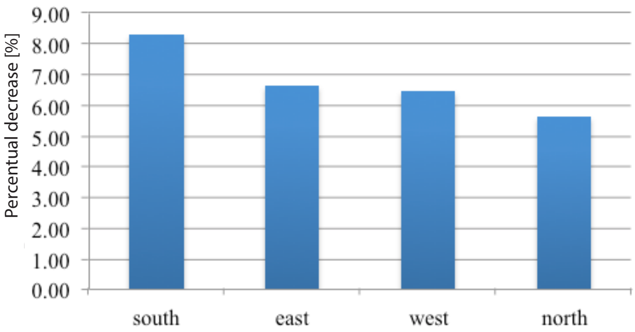

Figure 5. Graphical display of the percentual decrease of the contact temperatures of the façade wall with vegetation in relation to the wall without vegetation

When we observe the eastern wall orientation, the average air temperature was 28.3 °C, and the measured surface temperature of the wall without vegetation was 26.5 °C, and of the vegetation wall was 24.7 °C. The difference in temperatures equals 1.8 °C, or 6.63%. The western wall orientation was treated at the average air temperature of 28.8 °C, and the measured surface temperature of the wall without vegetation was 27.1 °C, and 25.35 °C for the vegetation wall. The difference in temperatures is 1.75 °C, or 5.64%. During the northern wall orientation, the average air temperature was 29.4 °C, and the measured surface temperature of the wall without vegetation was 27.5 °C, and of the vegetation wall was 26.8 °C. The difference in temperatures is 0.7 °C, or 5.64%.

The experimental model showed the higher difference in temperatures when applied to the southern and eastern side of the building. Based on these results, we can conclude that the examined model fully meets the supposed energy potentials of vegetation wall for Belgrade's climatic conditions. Based on the practical measurements, an energy balance of heat flow was determined through the model. In greened buildings, it differs in the evapotranspiration heat flow, through which plants emit almost all absorbed solar radiation [12]. Although evaporation has an important role in reducing the surface temperature of the wall, it has not been measured in the experimental model because of its small surface area. The mathematical model does not show the effect of evaporation due to its inability of a comparative analysis of the experimental and mathematical model.

Applied simulation on a residential building

The thermal analysis of the façade covering, *i. e.* the analysis of heat passage through the building's façade, aims at presenting the numerical values of overheating the building's internal space in summer on the mathematical model, based on which we can analyse the contributions of applying vegetation walls to reducing the amount of heat gains in our climatic conditions. The presented temperature variability in the experimental model acquired its numerical validity in the computer simulation of the mathematical model. The department store building in Vareška Street in Belgrade was chosen as a referential model for this research. This building was chosen because it meets the criteria of energy optimisation with its position, geometry, and functional characteristics. The façade is orthogonal, prefabricated, with a geometric division of sections. The building is used as office space. The immediate vicinity of the building does not have constructed structures which would influence this optimisation. Inner project temperature for the summer period is 26 °C. Airing/number of air changes is 0.5 per hour. Vegetation walls are applied to all four façades of the existing building, in the level of the first and second floor. The existing rulebook on energy efficiency does not include heat gains in the summer period, so the parameters of a summer project day are not defined, but the summer project day consists of hourly outer air temperature values, in the period of 24 hours. For Belgrade, the outer summer project temperature is 33 °C. In order to calculate the heat load, it is necessary to take into account the temperature variability of the outer air, over hourly values for the summer project day, together with the intensity of the solar radiance which reaches the surface of the building's covering. Solar radiance intensity is variable during the day, and directly influences the heat transmission through the building's covering. For the purpose of calculating heat gains of the office building, the software programme for calculating heat gains HanDobgub v.5.0 was used. The transfer function method of calculation was done in two steps: calculating heat gains through the elements of the covering, through walls, roof, wherein dominates the heat passage. Heat transfer originates from outer air heated to a relatively high temperature and solar radiation, whose influences are joined in the air temperature [13]. Heat transfer [14] is done by convecting the air inside the room, either directly from the inner surfaces, or indirectly, when the matter of heat transfer by radiation and the effects of accumulation are concerned.

Heat load from the heat passage through the building's elements is calculated with temperature differences, and the loads from the heat passage through the windows, due to the small accumulation coefficient, are defined based on temperature differences between the project inner and defined outer temperatures [15-18]. The calculation included heat gains from inner heat sources, people, lighting and devices. The *U*-value (thermal transmittance) through the modular vegetation module of measured value is U = 0.667 W/m^{2}K, tab. 2. Calculating the heat load was done according to the formula:

Table 2. Tabular display of measured values of the coefficient of heat transition through the vegetation wall

	V1 [Wm^{-2}K^{-1}] *U*-value	V2 [°C] Temp.	V3 [°C] Temp.	V4 [°C] Temp.
Minimum	0.37	22.7	22.0	11.0
Maximum	0.78	23.5	22.4	11.0
Average	0.65	23.2	22.2	11.0
Standard deviation	0.05	0.1	0.1	0.0
MKT	–	0.0	0.0	0.0

$$Q = U \times A \times CLTD[\mathrm{W}] \tag{1}$$

$$CLTD = (CLTDtab + M) \times U + (25.5 - tu) + (tsm - 29.4)\ [°\mathrm{C}] \tag{2}$$

The existing façade covering consists of lime-cement mortar, solid brick, stone wool, air layer, and aquapanel [19-22]. According to this calculation, the thermal transmittance coefficient U = 0.776 W/m^2 K does nor meet the conditions of maximally allowed the thermal transmittance coefficient, equalling U = 0.4 W/m^2 K. The calculation of total gains for the building was done for the months of June and July, in intervals 12:00, 14:00, and 18:00, the same time when temperature measurements were done on the experimental model and when the thermal transmittance coefficient through vegetation wall was calculated. The calculation takes the following as the initial data: outer air temperature 26°C, building height 12 m, building's area 7274.68 m^2, and the building's volume 87296.16 m^3. With the comparative analysis of the achieved heat gains in the building for the months of July and August, we noticed that numerous heat gains in the building were higher in the month of August than in July. The highest recorded heat gains were in August, advanced model at 18:00, amounting to 257.32 kW, and the lowest calculated heat gains were in July, advanced model at 12:00, amounting to 239.14 kW. The chosen model of the department store was analysed in the software Revit Energy Analysis, fig. 6, in order to check the energy performances of the building.

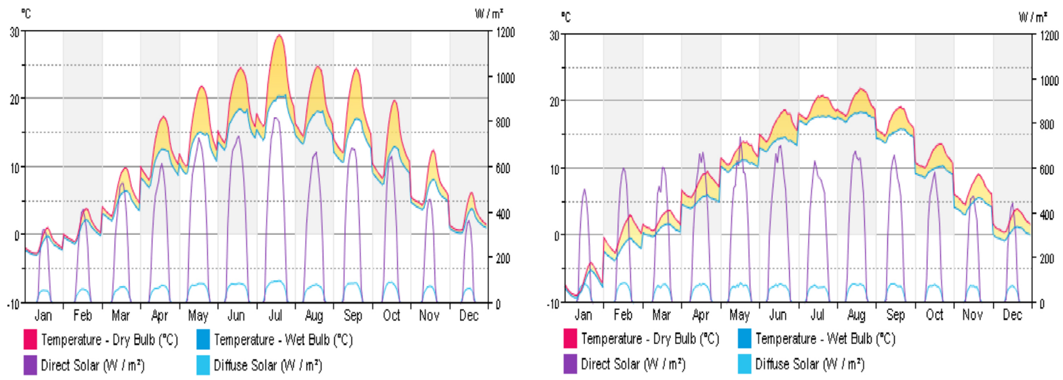

Figure 6. The status of Diurnal Weather Averages in the analysis introduced in the soft-ware Revit Energy Analysis; (a) existing status, (b) improved status

Numerical simulation was done based on climatic characteristics of Belgrade's climatic area, according to the data on materials used for the construction of the building. Two models were made, the existing state and the improved state. The simulation of the existing state and the building's energy optimisation through the application of vegetation walls was done on an annual level. The results were analysed in intervals of 12:00, 14:00, and 19:00.

The results were compared in the function of reducing the energy used for cooling in the summer period. The simulations were done according to the constant transmission coefficients. According to the analysis of the results, vegetation walls significantly influenced the reduction of heat gains in the analysed building in Belgrade's climatic conditions. The comparative analysis, tab. 3, shows that the building has the highest heat gains in the month of August, at 19:00, with the value of 313.27 kW, and that, by analysing the improved state, the largest improvement in per cents is 17.86%, achieved in this period. The building has the lowest optimisation in percentage in the month of August at 14:00, with the value of 8.05%. Taking the average percentage, by applying vegetation walls onto buildings coverings in Belgrade's climatic conditions, we would get an optimisation of 12%.

Table 3. The tabular display of the comparative values of the calculated heat gains for the hypothetic model in the Belgrade's climatic conditions

	Existing status [kW]	Improved status [kW]	Difference [kW]	Percentage of improvement
July	266.69	238.57	28.12	10.54
August	313.27	257.32	55.95	17.86

Conclusions

Vegetation walls covered in vegetation layer play an important part in balancing micro-climatic parameter compared to local surroundings, and in reducing heat passage through the façade coverings in the summertime [23]. In the terms of energy, vegetation walls should represent a type of isolation material, which should slow down the heat transfer between outer and inner parts of the façade covering, thus mitigate the influence of temperature differences, acting as a temperature regulator. In the summer period, the outer air temperature is higher than room temperature, which should be suitable for the conditions of comfort. In the summer period, the time of direct solar radiations is higher, so a large amount of energy gets into the rooms, thus influence comfort. It is necessary to reduce the excess heat to an enjoyable level, so optimal living and working conditions could be created in the rooms.

The integration of vegetation and architectural buildings establishes a new hybrid relation in architecture, thus create a multidisciplinary approach to planning façade coverings.

Vegetation wall have been treated throughout the entire research as passive systems in energy efficient architectural buildings. Comparative analysis of the results of experimental and mathematical models shows the consistency of the research results. This analysis was done with the aim of establishing certain methodology in researching vegetation walls. Defining outer significant factors for both models enabled consistent results. Temperature measurements done on the experimental models enabled adequate entry data for modelling the mathematical model. The variables from the mathematical model simulation scenario reflect the research and analysis of the experimental models. In both cases, we concluded that vegetation walls enable energy optimisation of buildings on which they are applied.

The leaf area of the vegetation layer has the role of absorbing solar radiation and, through its emission of heat radiation, acts as a protective element of the façade covering from overheating. As a consequence of this natural characteristic of the vegetation covering, thus, the evaporative cooling of air in the vegetation covering occurs. Experimental and mathematical research show that the implementation of vegetation walls in architectural buildings in Belgrade's climatic conditions enables the reduction of heat gains in the summer period, in the range of 6-12%. The heat flux of façade is reduced because of greening. Our research has confirmed the conclusions set out in the introduction [24-26].

Research of vegetation walls and their energy potentials in our climatic conditions through the experimental and mathematical model were done with the aim of giving recommendations for designing vegetable walls in Belgrade's climatic conditions. The choice of the greening systems plays a key role in the optimisation process, because, through its performances, it enables higher or lower percentile contribution of the chosen model in the process of improving the façade covering. Unlike conventional façade materials, vegetation walls do not absorb the received solar radiation.

Solar radiation descending on the leaf area of the vegetation walls is partly reflected, part is used for photosynthesis, part is used in the process of evapotranspiration and a smaller part reaches the load bearing part of the façade covering. The distribution of temperature values, seen on the thermograms of experimental models, is also read on the simulation of the mathematical model. The assumption is that vegetation and modular construction on the load bearing part of the wall construction would affect the reduction of environmental outcomes on the contact surfaces of the façade covering. In order to formulate certain conclusions of researching the mathematical model – office building in Vareška Street in Belgrade – the evaluation of the results was done based on the percentile reduction of heat gains in the building, which present the basis for solving and planning acclimatise systems. The thermal performances of the chosen façade composition were improved, but not even this composition satisfies the minimal standards of thermal characteristics for Belgrade's climatic conditions.

Nomenclature

A – wall surface, [m^2]
$CLTD$ – corrected table value
$CLTD_{tab}$ – table value
K – correction for other wall colours
M – correction for other months
tsm – mean daily temperature (for our climatic conditions 28.4 °C), [°C]
tu – inner project temperature, [°C]
U – thermal transmittance through walls or roof, [Wm^{-2}K^{-1}]

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