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OPTIMIZATION OF THE BUILDING ENVELOPE WITH INTEGRATED VEGETATION MODULAR ELEMENTS USING FACTORIAL DESIGN

Abstract: *The vegetation walls using in the architecture has opened new design possibilities and created new challenges for the designers, with the aim to increase the energy efficiency of the structures. The purpose of this investigation is optimization of the façade by covering of the existing architectural structure with vegetative modular elements, using factorial design. The analysis shows the impact of the side of the world or the outside temperature and the type of the model to the building internal temperaure. This paper presents a plot contour and surface plot of considered parameters (external temperature and model type) to internal building temperature. This investigation with factorial design represents a key element in solving the dependence between comfort, external view and energy balance of a structure, since through the building envelope an interaction is going on between the external environment and the internal space.*
Keywords: *green wall; architecture; energy performances; optimization; factorial design.*

1. INTRODUCTION

The covers of the up-to-date architectural structures tend to be dynamic and in an interactive relation with the environment, with maximum benefit of the technological potentials. The vegetation walls open a new field of achievements in façade covering investigation, treating the architectural structures as a potential place for production and realization of artistic creations.

The vegetation walls help the improvement of energetic characteristics of the structures, biodiversities, featured values and take part in decrease of air pollution.

Through the structure covering with vegetation walls an interaction between the environment and internal space is developing; the vegetation walls may represent a key element in solution of subordination between realization of the confortability conditions in the structure, external view and energetic harmony of the structure. Designing of such elements and using of vegetation walls is having aim of improvement and superintegration of the basic human needs for energy, considering them as a meta-systemic transition towards entirely new abilities of the architecture, society and technology (Figure 1).

Figure 1. Vegetation wall as an element of the architectural investigation

The vegetation walls created the designers' challenges for application of such compositions with an aim to increase the energy efficiency of the structures. The structure covering represents a facade element with a direct influence to the energy balance of structure, and application of vegetation walls in materialization of the structure covering promotes the energy potential of the structure. The integration of vegetation and redesign of the existing architectural structures as well as the integration in the newly designed structures may generate a considerable decrease of the energy consumption and expenditure of the resources, with simultaneous decrease of the urban warm island effect decrease and improvement of the air quality. The basic goal of the architectural vegetation walls is to enable a new form of the urban recognition of the architectural structure in the environment and to create the conditions for an efficient protection of the structures from overheating in the summer period (Figure 2).

Figure 2. Vegetation wall as a display of the multivalence in the architecture

The vegetation walls in sence of technology represent a modern version of the traditional forms of the green wall surfaces. The green facade coverings of the structures use the natural features and characteristics of the vegetation for solving the shape and energy problems and offer an up-to-date approach to the architectural designing. The vegetation walls having in its composition green surfaces covered by plants, and they have an important role during unfying the micro-climatuc parameters in relation to the local environment as well as decrease of heat passage through the facade shell in the summer period. The leaf surface of the plant covering has an important role to absorb sun radiation and by its emission of heat radiation behaves as a protective element of the facade covering. Vegetation decreased heat transfer through the south facade wall by 13.7% to 40.7%. This research tries to redefine architectural typology of façade coverings by implementing new technological solutions and by applying vegetation walls [1-5].

2. PRACTICAL MODELS

The basis for determining the parameters of the analysis and the assembly of the façade is reflected in the collection of the necessary air parameters and technical characteristics of the established model of the vegetative wall according to Sudimac, B. [6], the accurate registration of the following influencing factors: "emissivity of the surface, the air temperature, humidity, intensity and direction, solar radiation intensity and duration of sun, the intensity of the radiation environment, the radiation intensity of the celestial sphere, geometry factors, radiation, local radiation sources, the existence and duration of the rain".

In defining the types of modular elements of the vegetation walls, special attention must be at the selected factors that mostly affect to the energy performance of the element itself, and that in the further analysis may affect the characteristics of the technological and architectural model enhancements. The criteria setting of the vegetation of the wall to be analyzed are defined in relation to the existing facade layer, which is identical to the circuit part of the reference model and its orientation in space.

Figure 3. The modular system of the perforated box (M1).

For the purposes of experimental research, they are defined three practical modular models (Figure 3,4,5) for forming a wall of vegetation. Practical models are described as models M1, M2, M3.

Figure 4. A modular system with a fabric backing (M2)

Figure 5. A modular system with a unified planting element (M3).

3. FACTORIAL DESIGN OF EXPERIMENTS

Design of Experiments (DOE) is a mathematical methodology which has become one of the most popular statistical technique used in different industries and academic fields. Factorial designs are most frequently employed in engineering and manufacturing experiments. There are three different types of experimental designs: full-factorial, fractional factorial and Taguchi orthogonal arrays. Factorial design is an efficient tool for estimating the influence of individual variables and studying their interactions using the minimum number of experiments. Although the full-factorial design requires a great number of experiments or calculations, it provides very accurate results on the interaction among the factors, so conclusions are highly credible and reproducible. The advantage of factorial experiement and its main characteristic is that all levels of one factor are combined with all levels of remaining factors. The efficiency of the experiment can significantly increase in conditions of factorial experiment, if favourable type of plan is chosen [7-12].

4. EXPERIMENTAL PART

Two output parameters are monitored in the paper: Tzu - internal temperature of the wall with the green and Tb - temperature of the foliar surfaces. All three models are considered as input parameters, as well as the outside air temperature Tev (for four external walls which have the orientation to the sides of the world - east, west, north and south). Considered parameters are shown in Table 1.

Table 1. *Input and output parameters*

Model 1			
input parameter		***output parameter***	
orientation	***Tev***	***Tzu***	***Tb***
south	25.5	19.17	24.5
east	28.3	21.96	24.9
west	28.8	22.58	26.6
north	29.4	22.97	26.2
Model 2			
input parameter		***output parameter***	
orientation	***Tev***	***Tzu***	***Tb***
south	25.5	19.17	24.3
east	28.3	21.31	24.4
west	28.8	21.93	25.9
north	29.4	22.32	25.7
Model 3			
input parameter		***output parameter***	
orientation	***Tev***	***Tzu***	***Tb***
south	25.5	18.61	24.4
east	28.3	21.31	24.3
west	28.8	22.04	26.2
north	29.4	22.43	25.5

4.1. Internal temperature of the wall with greenery

In this part of investigation, it is analyzed the internal temperature of the wall with greenery set on all four sides of the world (on four walls of the observed building). The internal temperature of the wall is observed for three different models with greenery. In Table 2, the models are marked with the A letter, and the outer wall temperature with B letter. At the same time, the model is third level and the temperature is fourth level.

Table 2. *Levels for various control factors*

Control factors	**Units**	**Level**			
		I	**II**	**III**	**IV**
(A) Model	-	1	2	3	
(B) Temperature, Tev	C	25.5	28.3	28.8	29.4

Table 3 shows the orthogonal matrix L12 created according to the input and output values. Based on the estabilished matrix,it was performed the experimental measurement of the internal temperature of the wall with the green Tzu and temperature of the foliar surfacesTb, which are displayed in Table 3 below.

Table 3. *Experimental design using L12 orthogonal array*

	A	***B***	***Tzu***	***Tb***
1	1	25.5	22.03	24.5
2	1	28.3	21.31	24.9
3	1	28.8	22.58	26.6
4	1	29.4	22.97	26.2
5	2	25.5	22.05	24.3
6	2	28.3	21.31	24.4
7	2	28.8	21.93	25.9
8	2	29.4	22.32	25.7
9	3	25.5	18.61	24.4
10	3	28.3	21.31	24.3
11	3	28.8	22.04	26.2
12	3	29.4	22.43	25.5

Table 4 *Analysis of Variance for Tzu.*

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*	*Pr.(%)*
Regression	5	10.8090	10.8090	2.16179	4.50	0.047	
Linear	2	6.6436	9.3886	4.69432	9.78	0.013	
A	1	2.5313	4.3860	4.38603	9.14	0.023	18.4916
B	1	4.1123	5.0026	5.00261	10.42	0.018	30.0411
Square	2	1.1341	1.1341	0.56707	1.18	0.369	
A*A	1	0.1568	0.1568	0.15682	0.33	0.588	1.1454
B*B	1	0.9773	0.9773	0.97733	2.04	0.203	7.1393
Interaction	1	3.0313	3.0313	3.03127	6.32	0.046	
A*B	1	3.0313	3.0313	3.03127	6.32	0.046	22.144
Residual Error	6	2.8799	2.8799	0.47999			21.03821
Total	11	13.6889					

Table 5 *Analysis of Variance for Tb.*

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*	*Pr.(%)*
Regression	5	5.36397	5.36397	1.07279	2.23	0.178	
Linear	2	4.43781	4.93414	2.46707	5.13	0.050	
A	1	0.40500	0.24684	0.24684	0.51	0.501	4.909
B	1	4.03281	4.68730	4.68730	9.75	0.021	48.8874
Square	2	0.84154	0.84154	0.42077	0.88	0.464	
A*A	1	0.16667	0.16667	0.16667	0.35	0.578	2.02
B*B	1	0.67487	0.67487	0.67487	1.40	0.281	1.0256
Interaction	1	0.08461	0.08461	0.08461	0.18	0.689	
A*B	1	0.08461	0.08461	0.08461	0.18	0.689	8.181
Residual Error	6	2.88520	2.88520	0.48087			34.9756
Total	11	8.24917					

The analysis was conducted using the statistical software Minitab 16 with Response Surface Methodology (RSM) of analysis. Tables 4 and 5 represent the results of analysis of variance (ANOVA) analysis of the temperature of the wall and the temperature of the green leaf surface, respectively.

Based on the analysis and Fischers distribution of 99, 95 or 90% probability, it may be determined the influence of the impact of factors to the output, i.e. to the temperature of the wall with the greenery and the temperature of the green leaf surface. Based on the factors degree of freedom and errorsdegree of freedom for Fischersdistribution of 95% probability, in this paper F is 5.99, for both analyzes. By analyzing, the obtained value F must be greater than the value for the appropriate distribution with appropriate errors and factors degrees of freedom. It is observed that the temperature of the wall with the green (Table 4) is influenced by both considered factors, i.e. model and the outside air temperature, as well as their interactions. At Fisher's distribution, the temperature of the green leaf surface (Table 5), is influenced only by the outside air temperature.

The influence of the considered factors can be determined based on the percentage rate of each individual factors and their interactions to the output, i.e. to the temperature of the wall with the green and the temperature of the green leaf surface. Table 4 shows the analysis of the temperature of the wall with the greenery, influence of the considered factors and the effect of their interaction (in percent). The most influent factor is B, i.e. outside air temperature with the percentage of 30.04%, than interaction A*B with the rate of 22.144% and the influence

of the model with 18.4916% at the temperature of the wall with the greenery. According to the table 5, it can be concluded that the most influential factor to the temperature of the leaf area is outside air temperature with the rate of 48.88%.

A graphical representation of the results obtained by RSM analysis are given at the contour plot and a plot of the surface diagrams (Figures 5 – 8).

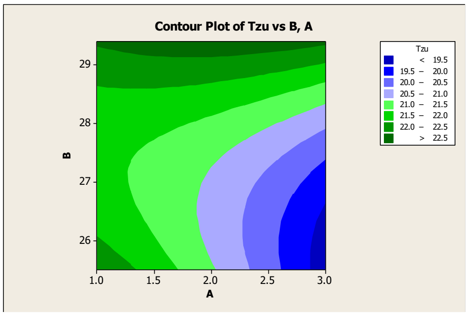

Figure 5.Contour plot for the dependence of internal temperature of the wall with greenery, models and external air temperature

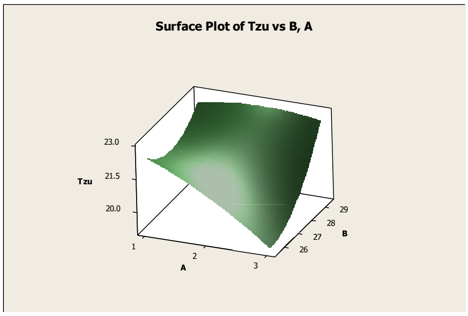

Figure 6. Surface plot for the dependence of the internal temperature of the wall with greenery, models and external air temperature

By analyzing the graphichal results (Figure 5, 6) it can be seen that the smallest inner wall temperature with greenery is achieved with the third model and with the lower values of external air temperature (about 26.5ºC). With the increasing of external air temperature, internal temperature of the wall with greeneryincreases too. Also, it can be noted that at the first model at the lowest external air temperature, internal temperature of the wall with greenery is higher, while with the increasing of the external air temperature (up to about 29.5ºC) the internal temperature of the wall with the greenery decreases.

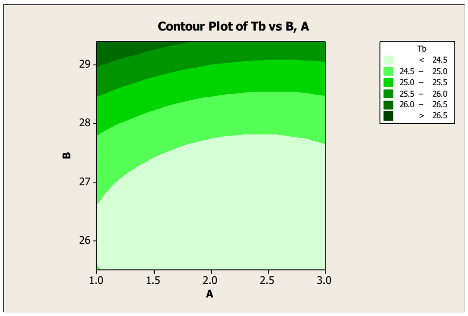

Figure 7. Contour plot for thedependence of temperature of the green leaf surface, model and external air temperature

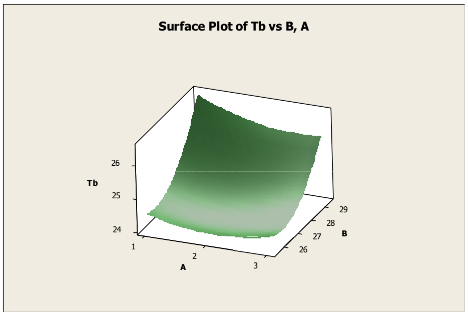

Figure8. Surface plot for te dependence oftemperature of the green leaf surface, model and external air temperature

Figures 7 and 8 shows a graphical presentation of the dependency of temperature of the green leaf surface, model and the external air temperature. It is observed that in all three considered models, temperature of the green leaf surface depends on the outdoor air temperature. Also, it can be seen that the highest temperature of the leaf surface is achieved for the first model at a temperature of 29ºC, while the lowest a temperature is achieved with the second and third model at the outside air temperature of 27ºC.

5. REGRESSION ANALYSIS

With the mathematical model it is possible to predict the internal temperature of the wall and the temperature of the green leaf surface with the considered factors [10,11]. Regression equation 1 has been developed with multi-linear regression analysis in Minitab 16 for the interior temperature of the wall with the greenery, as follows:

Tzu = 203.103 - 11.1214 A - 12.8501 B - 0.2425 A*A + 0.411745 A*B + 0.227358B*B.

The correlation between the models, external air temperature and the temperature of green leaf surface was also developed based on the multi-linear regression equation and it is given by equation 2:

Tb = 152.211 + 0.701174 A - 9.79389 B + 0.25 A*A - 0.0687919 A*B + 0.18893 B*B.

The obtained regression equations can be used to predict the value of the interior temperature of the wall and the temperature of the green leaf surface. More of coefficinets values in the developed equations is atributed to the greater influence of factors to the considered value. Figures 9 and 10 shows the normal probability plots of the internal temperature of the wall with the greenery and the temperature of the green leaf surface according to the change of model and the external air temperature.

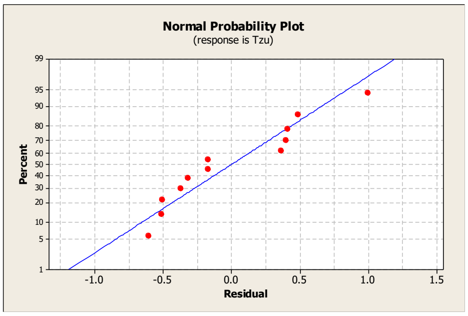

Figure 9. Normal probability plot of the residual for the internal temperature of the wall with the greenery

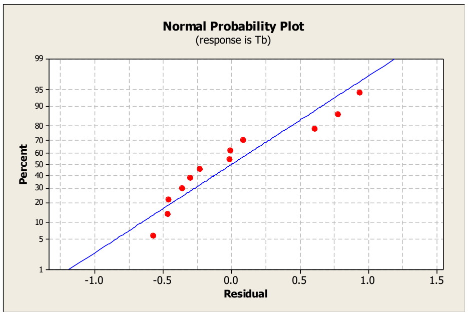

Figure 10. Normal probability plot of the residual for the temperature of the green leaf surface

5. CONCLUSION

This investigation has shown that factored experimental design can be successfully used to develop empirical equations for predicting and finding the most influential parameters to the internal temperature of the wall with the greenery and the temperature of the green leaf surface .

Based on these analysis, it can be concluded that to the inner wall temperature with the the greatest impact has the outside air temperature (30.04%), then the effect of the interaction A * B (22.144%) and the effect of the model (18.4916%). Also, the most influential parameter on the temperature of the green leaf surface is outside air temperature with the ratio of 48.88%.

In order to monitoring the parameters of the internal temperature of the wall and the temperature of the green leaf surface, it has been developed a multi-linear regression equation as a function of the parameters which have been analyzed in this paper.

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