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ANALYSIS AND ASSESSMENT OF BUILDING ENVELOPE WITH INTEGRATED VEGETATION MODULAR ELEMENT FOR A SUSTAINABLE FUTURE

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Abstract: The vegetation walls, which are using in the architecture, have opened new design possibilities and created new challenges for designers, with the aim to increase energy efficiency of the structures.Main goal of the vegetation walls architecture is to enable the building a new type of urban recognition in the environment and to create conditions for more efficient protection of objects from thermal overheating in the summer period.The aim of this research is optimization of the façade by covering existing architectural structure with vegetative modular elements, using factorial design. The application of this technique provide the extensive use of vegetation walls in the architecture of existing and new objects.The analysis shows the impact of the side of the world or the outside temperature and the type of vegetative modular element to the thermal power between the vegetation layer and the wrapper of the building, as well as to the building internal temperature. This paper presents a plot contour and surface plot of considered parameters (external temperature, Leaf Area Index and coefficient of heat transfer) to the thermal power and internal building temperature. Investigation with Taguchi design represents a key element in solving the dependence between comfort conditions in the object, external visage and energy balance of the object. Design and use of vegetation walls is aimed at improving and super-integrating the basic human energy needs, viewing them as a metasystem transition to the completely new possibilities of architecture, society and technology.

Key words: green wall; architecture; energy performances; optimization; Taguchi design;

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1 INTRODUCTION

The research was based on previous analyzes of the urban man's need for new forms of modern urban design and the possibility of active use of vegetation in the design of architectural elements. Vegetation walls contribute to the improvement of energy characteristics of buildings, biodiversity, design values and contribute to reducing air pollution.Since the interaction between the external environment and the interior space takes place through the building envelope, vegetation walls can be a key element in solving the dependence between achieving the comfort conditions in the building, the outer appearance and the energy balance of the building.The design of these elements and the use of vegetation walls aims at improving and superintegrating the basic human energy needs by observing them as a metasystem transition to the completely new possibilities of architecture, society and technology [1-8].

2 PRACTICAL MODEL

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. [9], 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".

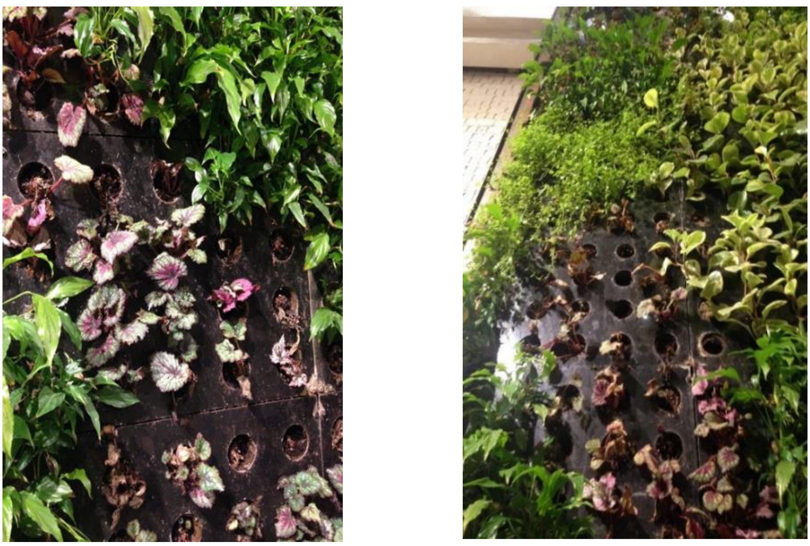

Figure 1. *Example of a vegetation wall using a modular system with a perforated box*

When defining the types of modular elements of the vegetation wall, selected factors were selected 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 very criteria for setting the vegetation wall being analyzed are defined in relation to the existing facade coating, whose circuit is identical to the reference model and its orientation in the space.

For the purpose of practical measurements and analyzes of the obtained results, a compact object was selected, without facade openings, with the installation of a vegetation wall on the eastern, southern and western sides of the building, in the Belgrade climatic conditions.

3 DESIGN OF EXPERIMENTS

Within the experiment was monitored by thermal power which is obtained between the vegetation layer and the building envelope. Thermal power is calculated for the modular system with perforated boxes. The outside air temperature is measured on all three walls of the building. The heat transfer coefficient h has values of 8, 10 and 12 W / m2K and Leaf Area Index factors are (0.2 = very rarely, 0.8 = medium, and 1.5 = dense). The value of the solar absorption coefficient of the plant α_b is 0.37. Factors that influence the thermal power values as well as their levels are shown in Table 1.

Table 1. *Levels for various control factors*

Control factors	Units	Level I	Level II	Level III
Tev	^{o}C	25.5	28.8	29.4
h	W/m^2K	8	10	12
LAI	m^2/m^2	0.2	0.8	1.5

For the experimental design it has been used orthogonal array L32 (Table 2) obtained by applying Taguchi mixed level design. The Minitab 16 statistical tool was used to form an orthogonal matrix. In the paper, the S / N ratio "the smaller the better" was used for thermal power analysis [10-17].

The equation for calculating S/N ratio for Taguchi characteristic “the less the better” is as follows:

$$S / N = -10\log\frac{1}{n}\left(\sum y^2\right) \quad (1)$$

where S/N is the signal-to-noise ratio, n is the repetition number of each trial and y_i is the result of the *i*-th experiment for each trial. S/N ratio for each level of influencing parameters is calculated on the basis of S/N analysis. Statistical analysis of variable is used to consider parameters statistically worth. Optimal combination of parameters can be predicted.

Experimental results for thermal power are obtained by using orthogonal array L27 for different factors’ combinations and they are given in Table 2. In Table 2 there are also given values of S/N ratio thermal power.

Table 2. *Experimental design using L32 orthogonal array*

	Tev, K	h	LAI	Q, W/m^2	S/N ratio
1	25.5	8	0.2	251.398	-48.0072
2	25.5	8	0.8	256.198	-48.1715
3	25.5	8	1.5	261.798	-48.3593
4	25.5	10	0.2	251.798	-48.0210
5	25.5	10	0.8	257.798	-48.2256
6	25.5	10	1.5	264.798	-48.4583
7	25.5	12	0.2	252.198	-48.0348
8	25.5	12	0.8	259.398	-48.2793
9	25.5	12	1.5	267.798	-48.5561
10	28.8	8	0.2	253.315	-48.0732
11	28.8	8	0.8	263.875	-48.4280
12	28.8	8	1.5	276.195	-48.8243
13	28.8	10	0.2	254.195	-48.1033
14	28.8	10	0.8	267.395	-48.5431
15	28.8	10	1.5	282.795	-49.0294
16	28.8	12	0.2	255.075	-48.1334
17	28.8	12	0.8	270.915	-48.6567
18	28.8	12	1.5	289.395	-49.2298
19	29.4	8	0.2	254.543	-48.1152
20	29.4	8	0.8	269.903	-48.6242
21	29.4	8	1.5	287.823	-49.1825
22	29.4	10	0.2	255.823	-48.1588
23	29.4	10	0.8	275.023	-48.7874
24	29.4	10	1.5	297.423	-49.4675
25	29.4	12	0.2	257.103	-48.2021
26	29.4	12	0.8	280.143	-48.9476
27	29.4	12	1.5	307.023	-49.7434

4 RESULTS AND DISCUSSION

4.1 S/N Ratio Analysis

The influence of control parameters such as external air temperature, transfer coefficient and Leaf Area Index (LAI) was confirmed by the S / N ratio analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter. Impacts of the control parameters on the thermal power Q are shown in Table 3.

Based on the ranking, it can be noticed that the Leaf Area Index is the dominant parameter that influences Q then the external air temperatures (Tev) and finally the coefficient of heat transfer (h).

Table 3. *Response Table for Signal to Noise Ratios for Smaller is better*

Level	Tev	h	LAI
1	-48.23	-48.42	-48.09
2	-48.56	-48.53	-48.52
3	-48.80	-48.64	-48.98
Delta	0.57	0.22	0.89
Rank	2	3	1

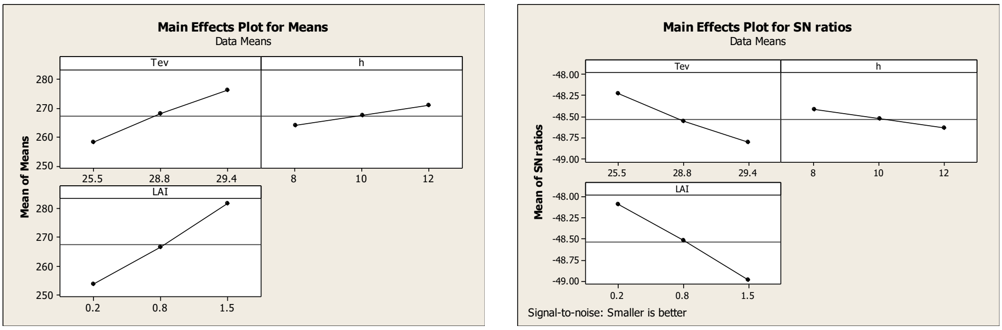

Figure 2. *Main effect plots for a) Means for the Q and b) S/N ratio for the Q*

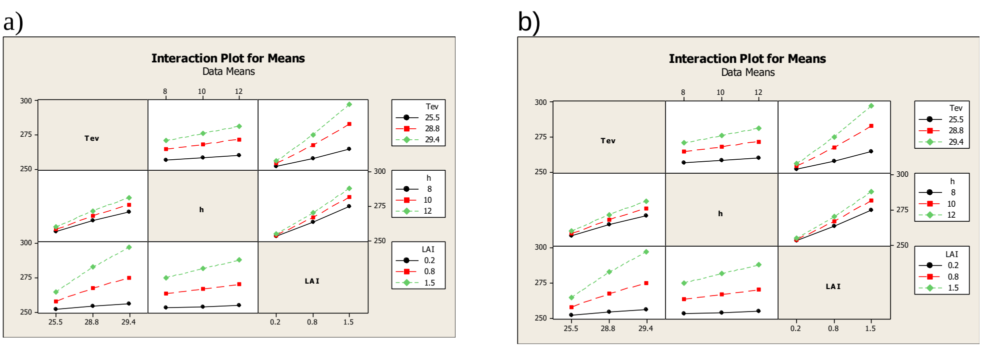

Figure 3. *Main effect Interaction plots for a) Means for the Q and b) S/N ratio for the Q*

Figure 2 shows a graph of the main effects of the influence of the various testing parameters on the thermal power. In the main effect plot, if the line for a particular parameter is near horizontal, then the parameter has no significant effect. In contrast, a parameter for which the line has the highest inclination has the most significant effect. In this case, the Leaf Area Index has the greatest influence on the thermal power, then the external air temperatures (Tev), and the smallest transfer coefficient (h).

Mutual influence interactions in the heating power is shown in Figure 2.

4.2 Analysis of variance results for the Q

The experimental results were analyzed using the (ANOVA) analysis used to examine the influence of the parameters under consideration, the outside air temperature, the heat transfer coefficient, the Leaf Area Index (LAI) on the thermal power of Q. By performing analysis of variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent variable. Table 4 the ANOVA results for specific wear rate for four factors and interactions of those factors. This analysis is carried out for a significance level of α=0.05, i.e. for a confidence level of 95%. Sources with a P-value less than 0.05 were considered to have a statistically significant contribution to the performance measures. In Table 4 the last column shows the percentage contribution (Pr) of each parameter on the total variation indicating their degree of influence on the result.

Table 4. *Analysis of Variance for S/N ratios for* ***Q***

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr
Tev	2	1.46282	1.46282	0.73141	499.68	0.000	26.17
h	2	0.22175	0.22175	0.11088	75.75	0.000	3.97
LAI	2	3.55953	3.55953	1.77977	1215.89	0.000	63.68
Tev*h	4	0.03424	0.03424	0.00856	5.85	0.017	0.31
Tev*LAI	4	0.56918	0.56918	0.14229	97.21	0.000	5.09
h*LAI	4	0.08146	0.08146	0.02036	13.91	0.001	0.73
Residual Error	8	0.01171	0.01171	0.00146			0.05
Total	26	5.94068					100

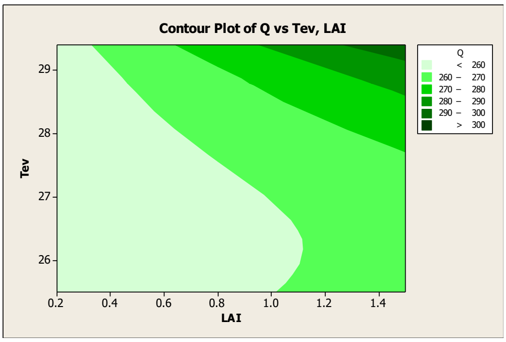

Figure 4. *Surface plot for dependence between thermal power Q rate of the Leaf Area Indexa (LAI) and external temperature (Tev)*

Table 4 shows that Leaf Area Index has the greatest impact on thermal power (63.68%). The lower thermal influence of Q has an outside temperature (26.17%). The smallest influence has a heat transfer coefficient (3.97%). The interaction concerns the greatest impact of Tev * LAI interaction (5.09%). The influence of other interactions is less than 1% and can be ignored. Since the inteaction has the greatest influence on thermal power, Tev * LAI interaction has shown in Figure 4 is the Surface plot for the dependence between the thermal power Q rate of the Leaf Area Index (LAI) and the external temperature (Tev).

4.3 Multiple regression model

Multiple linear regression model has been developed using statistical software "MINITAB 16". This model gives the ratio between parameters and respons by setting linear equation for the observed data. Regression equation generated this way establishes the connection between significant parameters obtained by ANOVA analysis, i.e. external air temperature, heat transfer coefficient and Leaf Area Index (LAI). Regression equation developed for S/N ratio of toplotna snaga Q is as follows:

$$Q = 118 + 4.07\ Tev + 1.78\ h + 21.3\ LAI$$

$$S = 6.27467 \quad R\text{-}Sq = 84.7\% \quad R\text{-}Sq(adj) = 82.7\% \qquad (2)$$

The equation (2) shows that the thermal power increases with an increase in the external air temperature, the coefficient of heat transfer and the Leaf Area Index.

Figure 5 gives comparison between the actual test results and the predicted values, which were obtained by the linear regression model.

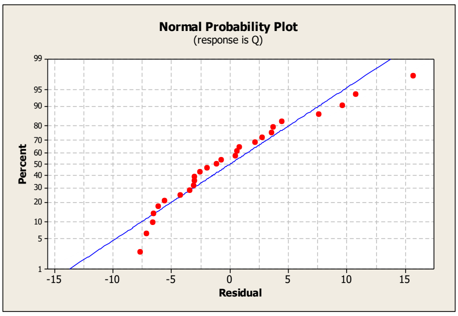

Figure 5. *Comparison of the linear regression model with experimental results for the thermal power Q*

5 CONCLUSION

This investigation has shown that Taguchi experimental design can be used to analyze the effect of parameters on increasing thermal power by applying the appropriate model as explained in this paper. This analysis can be concluded:

- The application of a modular system with a perforated box and vegetation positively influences the increase in the thermal power of the building,
- Leaf Area Index has the greatest influence on thermal power (63.68%). The outside temperature is lower (26.17%), while the smallest influence has a heat transfer coefficient (3.97%). When interactions into question the greatest effect is the Tev * LAI interaction (5.09%). The influence of other interactions is much smaller and can be ignored.
- Minitab 16 software was successfully used to form a linear regression model of heat dependence model from the input parameters with a high degree of regression.

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