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DETERMINING GEOMETRICAL PARAMETERS OF EXTERNAL WALLS ON LOW-RISE RESIDENTIAL BUILDINGS WITH GABLE AND PITCHED ROOFS AND OPTIMIZATION OF ITS ECOLOGICAL PARAMETERS

Abstract: *This paper analyzes the influence of the implementation of an optimization process in the process of designing residential buildings in order to improve their performance. Optimization parameters which are interesting for this research are building orientation, window area, gable and pitched roofs and overhang. Based on acquired results, this paper gives conclusions on CO_2 emissions and discomfort of low-rise residential buildings.*

Keywords: *external walls, energy efficiency, Design Builder, optimization*

1. INTRODUCTION

Modern research in the field of residential building exploitation is directed primarily towards comfort and quality of living, energy efficiency and environmental protection. This research examines in which way it is possible to create residential buildings of such characteristics.

Researchers from around the world have under various criteria examined energy efficiency and the increase of comfort. In Teheran [1] window area and type of window glass as well as window shades effects on energy efficiency while heating the residence was researched. Research based on converging towards a zero net energy use, through the use of solar photovoltaic panels is being developed in Serbia [2]. In order to achieve a better thermal comfort in a house the type of heating is very important, [3]. It is very important that the temperature in the house gravitates towards a constant value throughout the year and that it has the lowest possible oscillations in relation to the season. Also, it is necessary to have a certain amount of fresh air in the entire house, which is attained naturally or through mechanical ventilation, [4]. All these parameters which have been explored can be viewed as variables of a multi-criterion optimization, [5]. The increase of energy efficiency is viewed as converging towards a zero net consumption, [6]. Energy consumption changes depending on weather the tenants are awake, are they sleeping or not at home. The influence on energy efficiency of a house is also affected by dividing walls, [7]. By examining various aspects of the research and optimization of low-rise buildings the most influential parameters on CO2 emission and the number of uncomfortable hours on a yearly basis can be found.

The motivation behind this research is in the real need for defining specific parameters which influence quality in exploitation of low-rise residential buildings from an energy efficiency, comfort of living and environmental standpoint.

2. PROBLEM STATEMENT

2.1 Basic assumptions

This paper examines qualitative values of energy efficiency, adverse effects on the environment, comfort (quality) of living in a thermal sense and building costs for residential buildings:

- Orientation - represents the buildings placement in relation to cardinal directions,
- Overhang length - determining the length of an overhang for achieving energy efficiency,
- Window area - area of the outer wall which is occupied by windows,
- Type of implemented roof structure -gable or pitched roof.

Building orientation represents a parameter which depends on the house's position in relation to the sun throughout the year. As the drop angle of the sun rays is lower in winter they penetrate the windows and improve heating, while in the summer period overhangs prevent their direct penetration through the windows which increases thermal comfort.

The window area is a parameter dependent on the orientation of the house and the length of overhang, as well as the type of roof structure. The first value defines the required window area in order to maximize desirable effects.

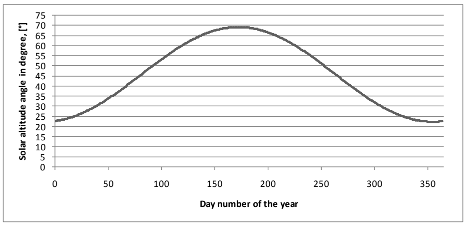

Figure 1 -Average values of sun ray drop angles for the territory of Serbia [8]

The type of implemented roof structure has a goal of determining a suitable system- gable or pitched, in order to achieve the most desirable performance.

It can be seen that all parameters are dependant of each other and that the best building is an optimal solution achieved through varying all parameters simultaneously.

The base assumption is that the desirable determining of these values for specific models will result in energy savings, more comfortable exploitation conditions and that the building will be better for its environment. It is true that the list of parameters can be appended with numerous variables, but for the purposes of this research it was interesting to see the effects of these variables on the beneficial exploitation of low-rise residential buildings.

2.2 Geometrical characteristics of the residential building

For the required analysis and verification different models have been created of low-rise residential buildings in Design Builder software. For the purposes of this research a model of the building with a gabled roof and a model of a building with a pitched roof were created. Calculations of energy expending, influence of these buildings on the environment (CO_2 emissions), comfort of exploitation of these buildings as well as achieved thermal comfort. An optimization by CO_2 emission criteria and discomfort was performed based on which conclusions were made for creating a house suitable for creating a house suitable for real-world exploitation conditions.

Geometrical characteristics of the house are shown in figure 2.

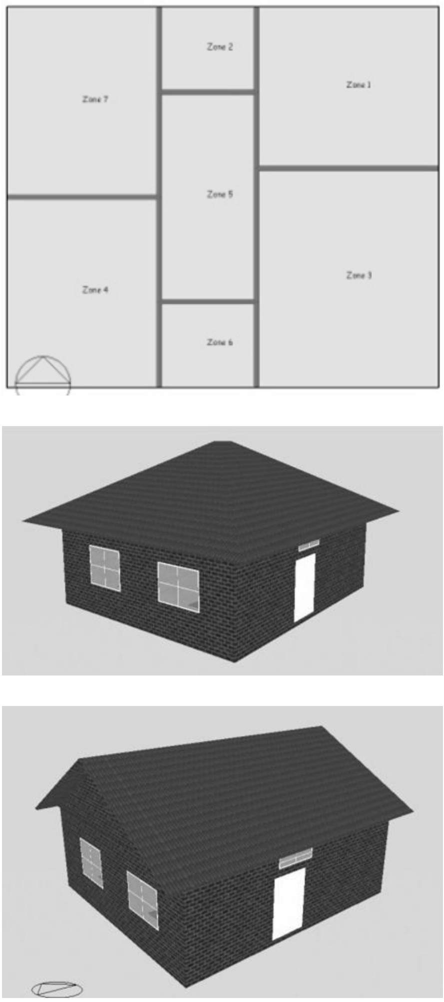

Figure2 -Geometrical characteristics of the analyzed residential building

For the analysis, for models with gable and pitched roofs the building area and room layout are identical, as well as all materials and systems (installations) built into the house. The only difference is roof structure in order to determine the more desirable one for exploitation.

The total area of the models shown in figure 2 is $60m^2$. The chosen system of heating are radiators combined with natural ventilation, heated on propane. Weather conditions for the simulation are taken for the area of Belgrade, Serbia. The number of tenants is two and all appliances are implemented as per the suggested needs of a two member family. The starting orientation is north-south, where the entrance is oriented towards the south.

3. UTILIZED METHODS

For the calculation, optimization and verification of results Design Builder software has been used. The software offers the possibility of adjusting all parameters in order to have this object completely simulate real conditions and its real exploitation. For the calculation of energy use, CO_2 emissions, thermal comfort, achieved temperatures and all other parameters of the calculation are done in Energy Plus which is supported by Design Builder.

A multi-criteria Pareto optimization has been performed. Optimization criteria are CO_2 emissions and discomfort. Therefore the goal is to minimize the harmful influence of the residential building on the environment, by which emissions are lowered, since there is a direct link between energy efficiency and CO_2 emissions. Aside from this the goal is to have the discomfort values at a minimum. Variables of this optimization are the area which windows occupy on the walls, building orientation (cardinal direction) in relation to the starting position and size of the overhang. The method that Design Builder uses is the genetic algorithm.

Upon the completion of the optimization conclusions were drawn based on which the optimal model has been created. For this model CO_2 emission, comfort of use and energy use results have been displayed compared. Based on the results a final model has been created with the best possible characteristics and their analysis has been completed. The results of this model are also presented in this paper.

4. RESULTS

For the purposes of this research a large number of timely simulations have been performed, however in the paper only the most influential have been presented.

CO_2 emission and discomfort values prior to the optimization process for residential buildings with a gable and pitched roof are presented in table1.

Table 1 – Calculated CO_2 emission and discomfort values for designing objects with gable and pitched roof before the optimization process.

Variable name	Values
Gable –CO_2emission	*6569 kg*
Pitched – CO_2 emission	*6393 kg*
Gable – discomfort	*2486 h/year*
Pitched – discomfort	*2548 h/year*

Depending on the initial values it is possible to see favorable characteristics for houses with a pitched roof, in regard to CO_2 emissions while in regard to comfort the results are almost equal. This needs to be verified after a completed optimization.

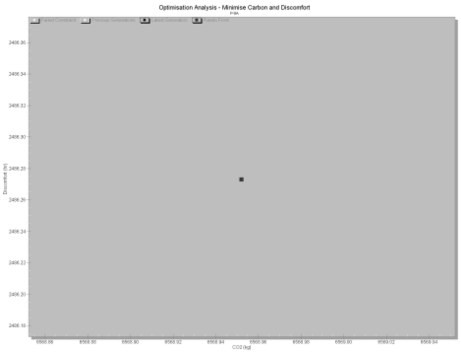

Figure3 -Optimization results for the residential building with a gable roof

For the optimization shown in figure 3 the derived optimal values for CO_2 emissions is in the range from 6569 to 6685 kg, while discomfort ranges from 2486 to 2506 hr. This means that the most favorable characteristics of the house lie in a very small range and that the chosen optimization variables do not have a great effect on them. The chosen possible combination derived from the optimization process is 6569 kg of CO_2 emissions and 2486 hr for discomfort. For these values the window size should be decreased to 28%, the orientation is at 43^o counterclockwise relative to the starting position, and the coefficient which determines the overhang (roof shading coefficient) has a value of 3.578.

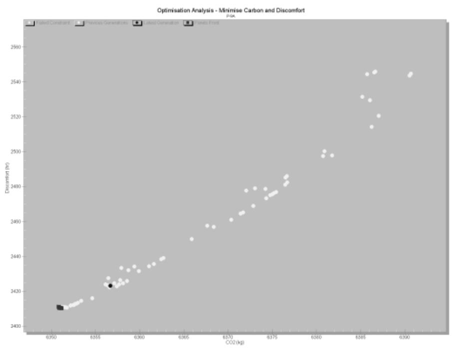

Figure4 -Optimization results for the residential building with a pitched roof

For the optimization shown in figure 4 the resulting optimal value of CO_2 emissions in ranging from 6351 to 6393 kg, while discomfort ranges from 2410 to 2548 hr. The chose possible combination resulting from the optimization process is 6351 kg for CO_2 emissions and 2410 hr for discomfort. For these values the window size should be increased to 67.50%, the orientation is at 88^o counterclockwise relative to the starting position, and the coefficient which determines the overhang (roof shading coefficient) has a value of 3.734.

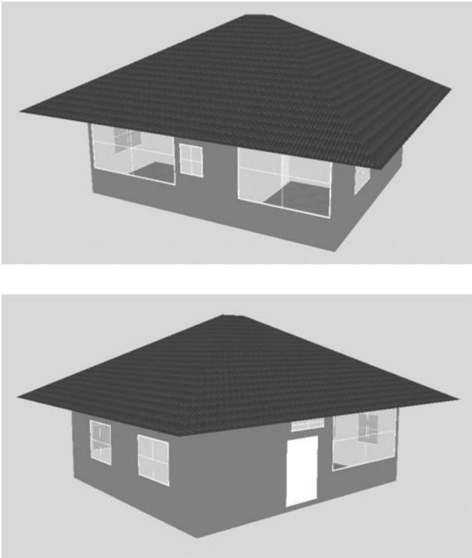

Figure5 -Visualization of the model with optimal characteristics

Values resulting from the final created model (the optimal solution) are obviously favorable to the initial values. CO_2 emission values for this model are 6351 kg while the values of discomfort are 2410 h/year. The cost of all of these solutions for a low-rise residential building vary very little, because of this these values were not presented in the paper.

5. CONCLUSION

The base conclusion is stating that there is a realistic possibility of maximizing favorable effects while minimizing negative ones in building and exploitation of low-rise residential buildings.

From a cost aspect the prices of the primarily designed and optimal models of the house are similar, therefore this aspect can be disregarded for the purposes of this research.

Residential buildings resulting from the optimization process have better CO_2 emission characteristics from the initial gabled roof model by 3.4%, and 0.6% from the house with the pitched roof.

Residential buildings resulting from the optimization process have better discomfort characteristics from the initial gabled roof model by 3.2% and from the house with the pitched roof by 5.7%.

From an energy efficiency point of view the building resulting from the optimization process has a decrease of energy consumption proportional to the decrease in CO_2 emissions.

It can be realized that the increase of the low-rise buildings performances through the implementation of the optimization process in its design process is possible. Partial improvements in performance are not drastic, but the overall characteristics of the building are improved largely. This approach improves the comfort of exploitation of the building and to the conservation of the environment.

REFERENCES:

[1] Ebrahimpour, A., Maerefat, M., "Application of advanced glazing and overhangs in residential buildings"*Energy Conversion and Management* 52(2011) 212-219.

[2] Bojić, M., Nikolić, N., Nikolić, D., Skerlić, J., Miletić, I., "Toward a positive-net-energy residential building in Serbian conditions"*Applied Energy* 88(2011) 2407-2419.

[3] Bojić, M., Despotović, M., "Influence of duration of thermal comfort provision on heating behavior of buildings"*Energy Conversion and Management* 48(2007) 2416-2423.

[4] Bojić, M., Kostić, S., "Application of COMIS software for ventilation study in a typical building in Serbia"*Building and Environment*41(2006) 12–20.

[5] Zhang, Y., Tindale, A., Garcia, A. O., Korolija, I., Tresidder, E. G., Passarelli, M., Gale, P., "How to integrate optimization into building design practice: lessons learnt from a design optimization competition"*13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28, Conference proceedings*, (2013) 1860-1868.
[6] Baetens, R., De Coninck, R., Van Roy, J., Verbruggen, B., Driesen J., Helsenm L., Saelens, D., "Assessing electrical bottlenecks at feeder level for residential net zero-energy buildings by integrated system simulation"*Applied Energy* 96 (2012) 74-83.
[7] Bojić, M., Despotović, M., Malešević, J., Soković, D., "Evaluation of the impact of internal partitions on energy conservation for residential buildings in Serbia" *Building and enviorment*, 42(2007) 1644-1653.
[8] Kostić, N.,Blagojević, M., Marjanovic, V., Djordjevic,Z.,Bojic, M., "Determination of solar angles for suitable positioning of solar systems for particular times of the year"*7. International Quality Conference (7th IQC), Center for Quality, Faculty of Engineering, University of Kragujevac*,(May 2013) 249-254.

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