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ENERGY PERFORMANCE OF SEMI-DETACHED RESIDENTIAL BUILDINGS: A COMPARISON OF SINGLE-STOREY AND TWO-STOREY CONCEPTUAL DESIGNS

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Abstract: This paper analyses the energy performance of a semi-detached residential building by comparing single-storey (ground level) and two-storey configurations. For both configurations, 3D geometric models were created in SketchUp, and energy models were subsequently developed in EnergyPlus. A total of 24 simulations were performed over the heating season, considering three thermal insulation scenarios and four building orientations (0°, 90°, 180°, and 270°). The insulation scenarios included a fully insulated building (Scenario 1), a partially insulated building without roof insulation (Scenario 2), and an uninsulated building (Scenario 3). The results were compared in terms of building configuration, thermal insulation level, and orientation. Comparison of the results across configurations showed that the difference between the two-storey and single-storey configuration is not identical for all orientations and thermal insulation scenarios. In Scenario 1, the differences range from 1.38% to 6.13%; in Scenario 2, from 0.43% to 5.03%; and in Scenario 3, from 0.86% to 2.22%. Furthermore, the two-storey configuration achieved lower heating requirements at an orientation of 90° across all three cases, whereas the single-storey configuration recorded its lowest heating requirements at 0° orientation.

Key words: energy performance, EnergyPlus, semi-detached residential building, single-storey configuration, two-storey configuration

1 INTRODUCTION

The building sector accounts for a significant share of global energy consumption, making the improvement of building energy efficiency an important step towards reducing global energy demand. Improving the building envelope is among the most common approaches to reducing energy consumption. Solaković and Mujan [1]

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investigated energy retrofit measures for an existing ice arena using OpenStudio, demonstrating the potential of improving envelope properties and other building systems to reduce energy consumption. Similarly, Popović et al. [2] analysed different energy retrofit measures for an educational building in Kragujevac using EnergyPlus, including thermal insulation, window replacement, and heating and ventilation system improvements.

In Serbia, residential buildings offer considerable potential for energy savings, particularly through improvements in building design and the thermal performance of the building envelope. Velemir Radović et al. [3] reviewed the energy efficiency of buildings in Serbia, highlighting the importance of residential building typology, construction characteristics, and energy efficiency measures. The energy performance of a building depends on several factors, including the thermal properties of its envelope, geometry, orientation, climatic conditions, and operating characteristics. Skerlić et al. [4] analysed the influence of insulation thickness on heating energy consumption for a residential building in Kragujevac. Their results confirmed that improving the thermal insulation of the building envelope reduces the energy required for heating. Furthermore, Rodrigues et al. [5] investigated the influence of thermal transmittance on the heating and cooling energy demand of residential buildings under present and future climatic conditions and demonstrated that thermal properties of the building envelope depend on local climatic conditions.

On the other hand, as stated by Velemir Radović et al. in [3], apart from thermal insulation, building design also influences building energy performance. Song et al. [6] investigated the relationship between urban morphology, climatic parameters, and heating energy consumption, identifying building height and shape factor among the important influencing parameters. Xie et al. [7] investigated university dormitory blocks and identified relationships between building morphology, energy consumption, and solar energy potential. Similarly, Liu et al. [8] analysed the influence of residential block configurations on building energy consumption and solar potential, emphasizing the importance of building shape and spatial arrangement. At the residential building scale, Kurniawan et al. [9] compared different residential building shapes and window-to-wall ratios using EnergyPlus, demonstrating that architectural design choices influence energy requirements and indoor environmental performance. Additionally, Wang et al. [10] examined different residential configurations and demonstrated that building morphology affects heating and cooling energy consumption, with building shape factor playing an important role.

These findings highlight the importance of considering building geometry during the early design stage. This was confirmed by Elgohary et al. [11], who developed a form-finding approach to improve building energy performance through architectural design. Additionally, Al Hindasi et al. [12] investigated different building geometries and orientations using EnergyPlus. The study showed that compact building forms generally achieve lower energy consumption and are less sensitive to changes in orientation than more complex configurations.

Al Hindasi et al. in [12] introduced another influential parameter on building energy performance - building orientation. Habibi [13] investigated the effect of orientation on heating and cooling loads, demonstrating that its influence depends on climatic conditions and building characteristics. Furthermore, Nikolić et al. [14] examined the influence of shading caused by adjacent buildings on the heating energy demand of a non-residential building, showing that reduced solar exposure can significantly affect predicted heating requirements.

As the reviewed studies demonstrate, the thermal insulation, building geometry, and its orientation can significantly influence the energy performance of the

building. Therefore, the aim of this study is to analyse and compare the energy performance of two conceptual configurations of two-unit residential buildings. The first configuration consists of two single-storey apartments connected by a common wall, while the second represents a two-storey building with apartments separated by an intermediate floor. Three levels of thermal insulation and four building orientations (0°, 90°, 180°, and 270°) are considered. The analysis is conducted using EnergyPlus, resulting in 24 simulation scenarios. The obtained results are compared to evaluate the influence of building configuration, thermal insulation, and orientation on heating energy requirements under the climatic conditions of Kragujevac, Serbia.

2 METHODOLOGY

The methodology applied in this study is based on dynamic building energy simulations conducted using EnergyPlus. Two conceptual configurations of a residential building containing two apartments were developed and compared in terms of their heating energy requirements. The configurations were developed based on the technical documentation of an existing single-storey residential building (Figure 1).

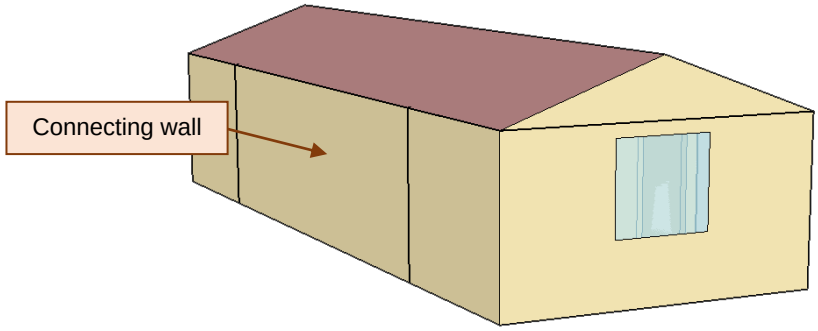

Figure 1. *Existing single-storey residential building with the wall designated for horizontal connection*

The first configuration (Case A) consists of a two-storey building with two vertically arranged apartments separated by an intermediate floor, while the second configuration (Case B) represents two horizontally arranged apartments connected through the wall indicated in Figure 1. Both configurations were developed using the same basic apartment layout to enable a comparison of their energy performance. Each apartment consists of a living room with a kitchen, two bedrooms, and a bathroom. These rooms were represented as separate thermal zones in the energy models. Both configurations also include an unheated attic space above the residential area. Three-dimensional geometric models for both configurations were developed in SketchUp, and displayed in Figures 2 (Case A) and 3 (Case B). Furthermore, the analysis considered three scenarios of thermal insulation and four building orientations. Scenario 1 represents the fully insulated building based on values prescribed by the Regulation on the Conditions, Content, and Process of Issuing Certificates of Energy Efficiency of Buildings of the Republic of Serbia [15], Scenario 2 represents a partially insulated building, where the insulation layers were removed from the roof construction, and Scenario 3 represents an uninsulated building, in which there are no insulation layers.

The heat transfer coefficients for all envelope elements, across all three scenarios are displayed in Table 1. The orientations are set to values of 0° (south), 90°, 180° and 270°. The EnergyPlus simulations were performed for each combination of building configuration, insulation scenario, and orientation, resulting in total of 24 simulation scenarios.

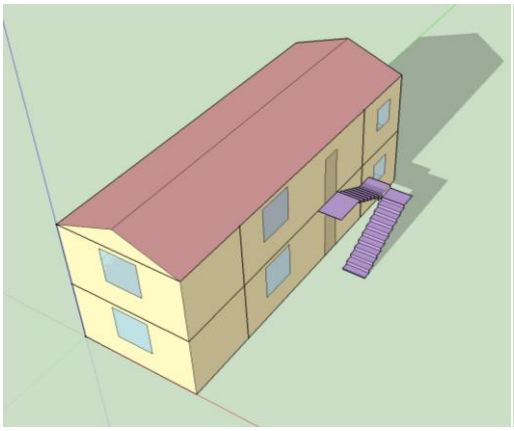

Figure 1. *Isometric view of the Case A model, 0° orientation*

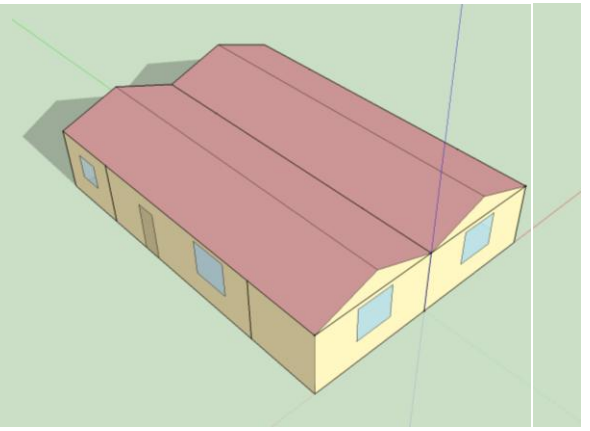

Figure 2. *Isometric view of the Case B model, 0° orientation*

The simulations were performed using weather data for Kragujevac (44.03° N, 20.93° E). The heating season was defined from October 15 to April 15. Indoor temperature setpoints were adopted according to room usage. During the heating period, from 06:00 to 22:00, the temperature was maintained at 20 °C in living rooms and bedrooms and 24 °C in bathrooms. During the remaining period, from 22:00 to 06:00, the setpoint was reduced to 16 °C. Temperature control was implemented using thermostats and corresponding operating schedules. Air infiltration was defined separately for each thermal zone, with air change rates of 0.5 h^{-1} for bedrooms, 1.5 h^{-1} for living rooms with kitchens and bathrooms, and 1.0 h^{-1} for the unheated attic.

Table 1. Heat transfer coefficient values across all three insulation scenarios

Type of construction	*Heat transfer coefficient, U [W/m²K]*		
	Scenario 1	*Scenario 2*	*Scenario 3*
exterior wall	*0.269*	*0.269*	*1.470*
interior wall	*1.363*	*1.363*	*1.363*
roof	*0.292*	*3.020*	*3.020*
floor	*0.295*	*0.295*	*1.897*
bathroom floor	*0.3*	*0.3*	*2.233*
exterior door	*1.387*	*1.387*	*1.387*
ceiling below attic	*0.285*	*0.285*	*2.11*
ceiling below heated area	*2.46*	*2.46*	*2.46*
ceiling below heated bathroom	*3.13*	*3.13*	*3.13*
exterior window	*1.493*	*1.493*	*1.493*

3 RESULTS AND DISCUSSION

The results of all 24 EnergyPlus simulations are presented in Tables 2-4, while Table 5 provides a percentage comparison of the seasonal heating energy requirements between building configurations A and B for all three thermal insulation scenarios and four building orientations.

Table 2. *Total seasonal heating requirements by building configuration and orientation for Scenario 1*

Scenario 1, Case A			
0°	*90°*	*180°*	*270°*
13,748.22 kWh	*13,185.25 kWh*	*14,273.65 kWh*	*14,545.75 kWh*
Scenario 1, Case B			
0°	*90°*	*180°*	*270°*
13,423.99 kWh	*13,637.23 kWh*	*14,079.57 kWh*	*13,705.60 kWh*

Table 3. *Total seasonal heating requirements by building configuration and orientation for Scenario 2*

Scenario 2, Case A			
0°	*90°*	*180°*	*270°*
14,019.22 kWh	*13,458.72 kWh*	*14,544.73 kWh*	*14,816.87 kWh*
Scenario 2, Case B			
0°	*90°*	*180°*	*270°*
13,959.13 kWh	*14,172.24 kWh*	*14,615.19 kWh*	*14,241.08 kWh*

Table 4. *Total seasonal heating requirements by building configuration and orientation for Scenario 3*

Scenario 3, Case A			
0°	*90°*	*180°*	*270°*
24,724.72 kWh	*24,145.10 kWh*	*25,072.87 kWh*	*24,941.01 kWh*
Scenario 3, Case B			
0°	*90°*	*180°*	*270°*
24,250.16 kWh	*24,355.08 kWh*	*24,633.77 kWh*	*24,398.95 kWh*

Table 5. *Percentage difference in total seasonal heating requirements between two-storey and single-storey configurations*

Orientation:	*0°*	*90°*	*180°*	*270°*
Scenario 1	*2.42%*	*-3.31%*	*1.38%*	*6.13%*
Scenario 2	*0.43%*	*-5.03%*	*-0.48%*	*4.04%*
Scenario 3	*1.96%*	*-0.86%*	*1.78%*	*2.22%*

In Scenario 1, the two-storey configuration achieved the lowest total seasonal heating requirements at an orientation of 90°, amounting to 13,185.25 kWh, while the highest heating requirements were recorded at an orientation of 270°, reaching 14,545.75 kWh. For the single-storey configuration, the lowest heating requirements were obtained at an orientation of 0°, amounting to 13,423.99 kWh, whereas the highest value was recorded at 180°, reaching 14,079.57 kWh. Comparing the two-storey and single-storey configurations in Scenario 1, the two-storey configuration exhibited 324.23 kWh (2.42%) higher heating requirements at an orientation of 0°. At 90°, the

opposite trend was observed, with the two-storey configuration exhibiting 451.98 kWh (3.31%) lower heating requirements than the single-storey configuration. At 180°, the two-storey configuration exhibited 194.08 kWh (1.38%) higher heating requirements, while the largest difference was observed at 270°, amounting to 840.15 kWh (6.13%).

In Scenario 2, the two-storey configuration achieved the lowest total heating requirements at an orientation of 90°, amounting to 13,458.72 kWh, while the highest heating requirements were recorded at an orientation of 270°, reaching 14,816.87 kWh. For the single-storey configuration, the lowest heating requirements were obtained at an orientation of 0°, amounting to 13,959.13 kWh, whereas the highest value was recorded at 180°, reaching 14,615.19 kWh. Comparing the two-storey and single-storey configurations at the same orientations, the two-storey configuration exhibited 60.09 kWh (0.43%) higher heating requirements at 0°. At an orientation of 90°, the two-storey configuration exhibited 713.52 kWh (5.03%) lower heating requirements than the single-storey configuration. At 180°, the two-storey configuration exhibited 70.46 kWh (0.48%) lower heating requirements, while at 270°, its heating requirements were 575.79 kWh (4.04%) higher.

In Scenario 3, the two-storey configuration achieved the lowest total heating requirements at an orientation of 90°, amounting to 24,145.10 kWh, while the highest heating requirements were recorded at an orientation of 180°, reaching 25,072.87 kWh. For the single-storey configuration, the lowest heating requirements were obtained at an orientation of 0°, amounting to 24,250.16 kWh, whereas the highest value was recorded at 180°, reaching 24,633.77 kWh. Comparing the two-storey and single-storey configurations at the same orientations, the two-storey configuration exhibited 474.56 kWh (1.96%) higher heating requirements at 0°. At an orientation of 90°, the two-storey configuration exhibited 209.98 kWh (0.86%) lower heating requirements than the single-storey configuration. At 180°, the two-storey configuration exhibited 439.10 kWh (1.78%) higher heating requirements, while at 270°, its heating requirements were 542.06 kWh (2.22%) higher.

The observed differences between building configurations and orientations across all three scenarios may be attributed to variations in the exposure of external and glazed surfaces to solar radiation. Changes in building orientation affect solar heat gains through windows, potentially influencing the total seasonal heating requirements. This may partly explain why the two-storey configuration achieved its lowest heating requirements at 90°, while the single-storey configuration performed best at 0°.

4 CONCLUSION

This study analysed and compared the energy performance of two conceptual configurations of a two-unit residential building: a single-storey and a two-storey configuration. Three-dimensional geometric models of both configurations were developed in SketchUp, followed by the development of energy models in EnergyPlus. Three thermal insulation scenarios and four building orientations (0°, 90°, 180°, and 270°) were investigated, resulting in a total of 24 simulations. The analysis focused on the total heating requirements during the heating season and their variation depending on building configuration, thermal insulation level, and orientation. The results showed that the lowest heating requirements were achieved in Scenario 1, while the highest values were obtained in Scenario 3. Considering all three thermal insulation scenarios and four building orientations, the lowest seasonal heating requirements for the two-storey configuration were recorded in Scenario 1 at an orientation of 90°, amounting to 13,185.25 kWh. Similarly, the single-storey configuration achieved its lowest heating requirements in Scenario 1, but at an orientation of 0°, amounting to 13,423.99 kWh. In

contrast, the highest heating requirements for both configurations were recorded in Scenario 3 at an orientation of 180°, reaching 25,072.87 kWh for the two-storey configuration and 24,633.77 kWh for the single-storey configuration. The results indicate that the differences in seasonal heating requirements between the two configurations depend on building orientation and thermal insulation level. The maximum absolute differences were 6.13% in Scenario 1, 5.03% in Scenario 2, and 2.22% in Scenario 3, occurring at orientations of 270°, 90°, and 270°, respectively. At these orientations, the two-storey configuration exhibited higher heating requirements in Scenarios 1 and 3, while lower requirements were observed in Scenario 2. Furthermore, the two-storey configuration achieved its lowest heating requirements at an orientation of 90° in all three scenarios, whereas the single-storey configuration consistently performed best at 0°. These variations may be partly attributed to changes in the exposure of glazed surfaces to solar radiation resulting from different building orientations. Overall, Scenario 1 represents the most favourable scenario in terms of total heating requirements, as all designed building envelope elements are thermally insulated. Compared with Scenario 3, heating requirements were considerably lower, demonstrating the importance of thermal insulation in external walls, intermediate floor constructions, roofs, and floors. Scenario 2 produced results between Scenarios 1 and 3, indicating that removing roof insulation increases heating requirements. Apart from energy performance, the two configurations also differ in their structural characteristics. The two-storey configuration offers the advantage of distributing the total floor area across two levels, resulting in smaller ground-contact floor and roof areas compared with the single-storey configuration. On the other hand, the two-storey configuration includes an intermediate floor construction and a more complex spatial arrangement, while the single-storey configuration has a simpler construction and provides access to all rooms on the same level.

Based on the simulation results, thermal insulation was identified as the dominant factor influencing seasonal heating requirements, while building configuration and orientation also played important roles. Although the two-storey configuration has a smaller roof and ground-contact floor area, the results demonstrated that it does not necessarily achieve lower heating requirements than the single-storey configuration. Instead, the relative energy performance of the two configurations depends on building orientation and thermal insulation level. These findings highlight the importance of considering thermal insulation, building geometry, and orientation together during the design process, rather than assuming that a more compact building configuration will inherently result in better energy performance.

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