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INFLUENCE OF WINDOW ROLLER BLINDS ON ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS IN SERBIA

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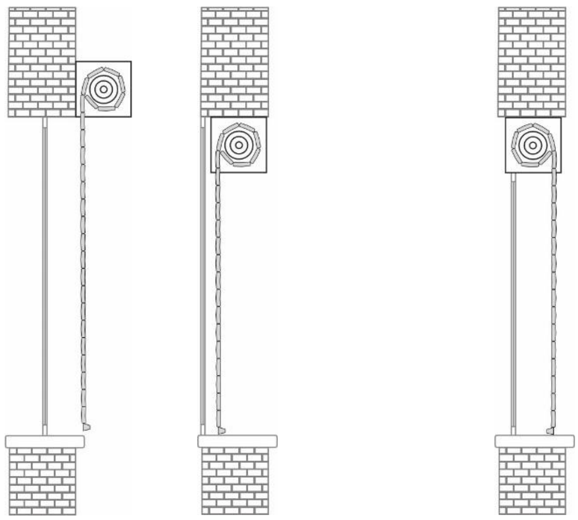
Abstract: Roller blinds are devices that are retracted and wrapped in a box above the window opening and are used to protect against the solar radiation. Those are the well-known devices with distinct advantages over the fixed external dimming elements. The influence of external blinds on the internal thermal environment in climatic conditions in the Republic of Serbia, the city of Kragujevac, was considered in this research. An external blind was installed in the test room and its influence on the internal temperature was compared with the internal temperature of the room without the blind. Real-time monitoring was carried out in February and August 2023. The results presented in this paper show that the blind reduces the temperature in summer by 3.57ºC and increases it in winter by 1.76ºC. The cooling load can be reduced by about 20%, and the heat load by about 15%.
Keywords: exterior window blinds, heat load, cooling load, lighting, energy efficiency

1. INTRODUCTION

Solar radiation that passes through the windows of buildings can have a significant impact on the thermal comfort in the interior rooms. Indeed, when the sun shines through the window, the interior heats up, which has a negative effect on the cooling load during the summer. On the other hand, the sunlight of the room has a positive effect on the heat load in winter. In addition, the scarce daylight conditions the use of artificial lighting, while on the other hand, excessive and uncontrolled daylight can lead to problems related to glare. All this leads to the conclusion that the use of curtains on windows plays an important role in the energy efficiency of residential and commercial buildings.

Roller blinds are devices for protection against solar radiation that are formed from horizontal slats (laths) that are being wound on a shaft located in the housing above the window opening. They provide the sunlight control and reduce heat gain by blocking the solar radiation from the outside. In the lowered position, the blind increases thermal resistance, due to the blind itself and the additional air layer closed between the window and the lowered blind. In addition to this role, blinds also protect against the atmospheric conditions (rain, wind, hail), noise, unwanted views and burglars. Additionally, one of the functions to which the special attention is paid as well, is aesthetics. Depending on the method of installation, blinds can be external or internal, Figure 1.



(a) (b)

Fig. 1. Schematic presentation of the external blind
according to the method of installation: a) external and b) internal

With external blinds, Figure 1(a), the shutter mechanism is fixed to the exterior of the building or window, with access to the housing and all the components from the outside. They are most often installed on existing windows as a retrofit. Internal roller blinds, Figure 1(b), are an integral part of the window, they are placed in a box located above the window frame with internal access to all the components. Blinds can have a manual or motorized system for raising and lowering the blind. The manual system consists of a belt that is pulled, which turns the shaft on which the slatted blinds are wound. Motorized blinds have an electric motor that turns the shaft and can be automated. The moldings that form the blind are usually extruded aluminum slats filled with polyurethane foam or hollow profile PVC slats. The thermal capacity of the blind is determined by the thickness of the slat and the density of the polyurethane insulating foam. The profile, width and curvature of the slat determine the rolling ability of the blind, and therefore the size of the roller housing.

Window shades are one of the most critical elements that affect the energy performance of buildings. All the literature on blinds is oriented towards the evaluation of the reduction of electricity consumption for lighting, for saving energy for cooling or heating, and for thermal and visual comfort in a closed space.

Tzempelikos and Athienitis (2007) presented an analysis of the simultaneous influence of the glazing area, properties and control of the blinds on the cooling of the building as well as the need for lighting. They considered a typical Montreal office with automated exterior blinds through the effect of window-to-wall ratio on visual and thermal performance and the use of electrical lighting. The simulation results show that a significant reduction in the need for cooling and lighting in office spaces could be achieved, depending on climate conditions and orientation. Palmero-Marrero and Oliveira (2010) studied the influence of blinds on the energy performance of a building, the energy needs of which were analyzed both in the cooling and heating seasons, for different positions of windows and blinds, in the climatic conditions of Mexico, Cairo, Lisbon, Madrid and London. The results of simulations, done using TRNSYS and EES software, show that the application of blinds can lead to significant energy savings, compared to a building without them. Al-Tamimi and Fadzil (2011) investigated the feasibility of using the curtains to reduce temperature in high-rise residential buildings in the hot and humid climate of Malaysia. They used simulation to investigate the ideal external blinds that can contribute to control the indoor temperature due to solar radiation and thus improve the energy use. Kim G. et al. (2012) have investigated different conventional blinds and designed an external solar radiation protection device in terms of energy consumption for cooling and heating, the practical application of which for external sun protection is shown based on energy simulation, obtained by a computer modelling of an apartment located in a building in South Korea. Yazicioglu (2013) has calculated and compared the energy characteristics of the two window systems in traditional Istanbul houses, one with the wooden shutters, and the other a blind with aluminum slats. The value of the thermal conductivity coefficient (U-value) of the window system with an aluminum blind is twice as low as that of the window system with a wooden shutter, showing that more energy is lost with the latter. Atzeri et al. (2014) have simulated different office configurations in Rome, using the EnergiPlus 8 software, to compare the curtain characteristics in terms of thermal and visual comfort and overall primary energy consumption. Although the use of blinds always improves thermal comfort, their results pointed that the energy consumption can increase depending on the position of the blinds, the orientation of the window and the type of glazing. Kim, S.H. et al. (2015) investigated the cooling and heating energy consumption of commercial buildings in South Korea, which used the horizontal solar shading devices or venetian blinds, as well as optimal solar shading devices based on surfaces and orientations. Lee et al. (2015) conducted a climate index development study using the local weather data to understand the influence of local climate in the early design phase and to validate the selection of sun protection devices. Kim M. et al (2015) investigated cooling load reduction in commercial buildings to confirm the impact of solar shading devices. Their results have shown a reduction of the cooling load by 35% due to the application of curtains. Fitton et al. (2017) considered the influence of window coverings, such as curtains and internal blinds, on reducing the heat loss in a whole house with single-glazed windows, in the case of heterogeneous heat distribution throughout the house. A comparison was made to a house with homogeneous heat distribution, which is assumed in laboratory tests and modelling. Aklhatib et al. (2023) have investigated the benefits of the simultaneous use of multiple control parameters to control the operation of shutters to maximize the energy savings and optimize occupant comfort in buildings in three different cities: Dublin, Berlin and Madrid. Hu et al. (2023) investigated the impact of blinds as an energy saving strategy on energy consumption in a subtropical climate, on the west and south facing windows. Their results have shown that with west-facing windows, the application of blinds resulted in 10% less energy consumption for air conditioning and 90% less energy consumption for lighting, while for the south-facing windows, the sunlight can completely supplement the lighting.

The majority of previous research has been conducted on window shades, which are expensive or complicated to install, either on new or existing windows. The aim of the research presented in this paper was to analyze the effectiveness of simple, external roller blinds, which is cheap, easy to mount on existing windows and is most often used on windows in buildings in the Republic of Serbia. The characteristics of the blinds in terms of energy efficiency were evaluated based on the value of the heat load through the window with and without blinds for the coldest and warmest months of the year.

2. PROBLEM FORMULATION

The heat load through the window Q_{to} calculated as the sum of the heat loads due to the heat transfer $Q_{to,tr}$ and due to the solar radiation $Q_{to,sol}$, ASHRAE Handbook: Fundamentals (2001):

$$Q_{to} = Q_{to,tr} + Q_{to,sol} . \tag{1}$$

Considering that the windows are made of thin glass surfaces and have a low resistance to heat conduction, it is considered that there is no accumulation of heat in the windows and that the passage of heat through the windows is instantaneous. Therefore, the heat load from heat transfer through the window $Q_{to,tr}$ is calculated for the observed time moment with the current temperature difference of the outside and inside air:

$$Q_{to,tr} = U_w \cdot A \cdot (T_{out} - T_{in}), \tag{2}$$

where: U_w is the heat transfer coefficient of the window, T_{out} is the external air temperature, T_{in} is the air temperature in the room, and A is the total area of the window. When calculating the heat losses in winter, in addition to stationary heat transfer conditions, one-dimensional heat transfer is assumed, as well, i.e., the heat flux is considered to be directed in the direction of the maximum temperature gradient. It is also assumed that all the physical quantities are constant, i.e., they do not depend on temperature, and that the material is homogeneous.

The heat transfer coefficient of the window U_w can be calculated if the heat transfer coefficients of individual window elements are known, based on EN ISO 13790:

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + l_g \cdot \psi_g}{A_g + A_f}, \tag{3}$$

where: U_g, U_f, are the coefficients of heat transfer of glass and frame, respectively, A_g, Af are the surfaces of glass and frame, respectively, l_g is the volume of glass surface and ψ_g is the linear coefficient of the heat transfer (temperature correction factor for thermal bridges between frames and glass). The calculated values of U_g, U_f, and ψ_g are given in tables 3.4.1.4, 3.4.1.5, 3.4.1.6, 3.4.1.7 and 3.4.1.8, of the Rulebook on energy efficiency of buildings, Official Gazette of the RS, no. 61/2011.

The heat load the from solar radiation through the window $Q_{to,sol}$ is calculated as (EN ISO 13790):

$$Q_{to,sol} = F_{sh} \cdot g_{gl} \cdot (1 - F_f) \cdot A \cdot I_{sol} \cdot \tau_{sol} , \tag{4}$$

where: $F_{sh} = F_{hor} \cdot F_{ov} \cdot F_{fin}$ is the room shading factor, where F_{hor}, F_{ov}, and F_{fin} are the correction factors for 45° north latitude according to tables 6.6, 6.7 and 6.8, g_{gl} is the solar radiation transmittance factor depending on the type of glass, table 6.10, F_f is the frame factor, and A is the window area, $I_{sol} \cdot \tau_{sol}$ is the mean sum of solar radiation, table 6.9. All cited tables are from the Rulebook on energy efficiency of buildings, Official Gazette of RS, no. 61/2011.

The heat transfer coefficient of a window with the shutter down can be calculated based on the following equation, according to EN ISO 10077-1:2006:

$$U_{ws} = \frac{1}{1/U_w + \Delta R}, \tag{5}$$

where ΔR is the additional thermal resistance due to the air layer between the lowered blind and the window itself.

3. RESULTS AND DISCUSSION

The rooms used for testing are two bedrooms, located next to each other on the fifth floor of a thirteen-story building. The rooms are identical in size of about 12 square meters and have one double-glazed window with air filling. The frame material is wood. The glass is low emissivity, and the window receives direct sunlight during the morning. Both rooms are located on the east side of the building. In the test room, there is an external blind with PVC slats on the window. In the control room, there is no blind or any other protection from the sun on the window. The window area in both rooms is 2.4 m^2. The testing was done in February 2023 (from 01/02/2023 to 28/02/2023) and August 2023 (01/08/2023 to 28/08/2023) because these are the coldest and warmest months of the year on the territory of the city of Kragujevac, Serbia. The temperature was measured using a DS18B20 digital sensor, and an Arduino Uno module was used to collect and process data as a part of the temperature measurement. In the test room, the blind was closed between 08:00 and 12:00 in the morning.

Figure 2 shows the outdoor temperatures for the months of February and August 2023. The data was taken from the website of the Republic Hydrometeorological Institute of Serbia.

Figure 3 shows the temperatures obtained by measurements in the test room (room with lowered blinds) and the control room (room without blinds) for the months of February and August.

a)

b)

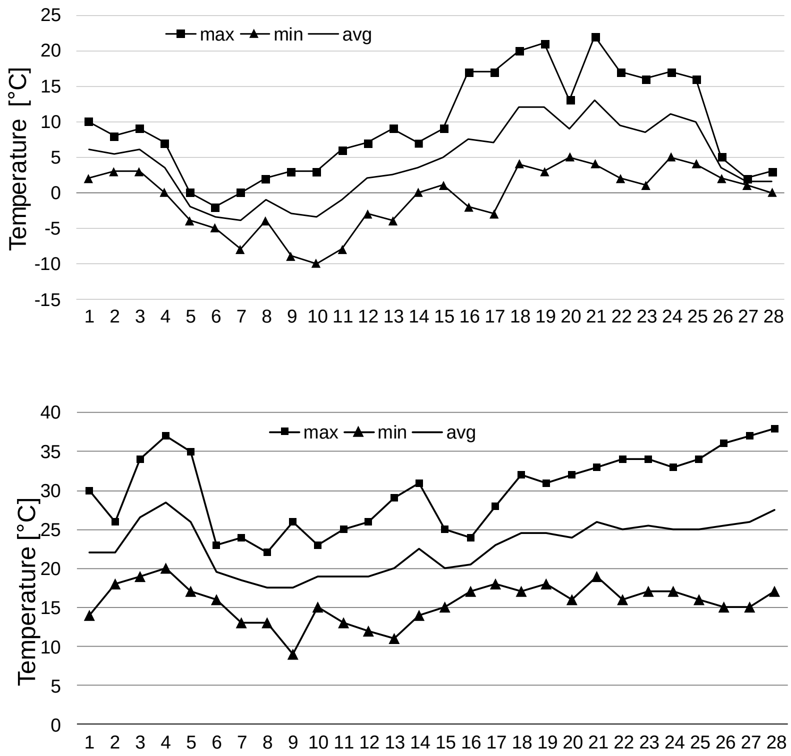


Fig. 2. Outside temperature in: (a) February 2023 and (b) August 2023.

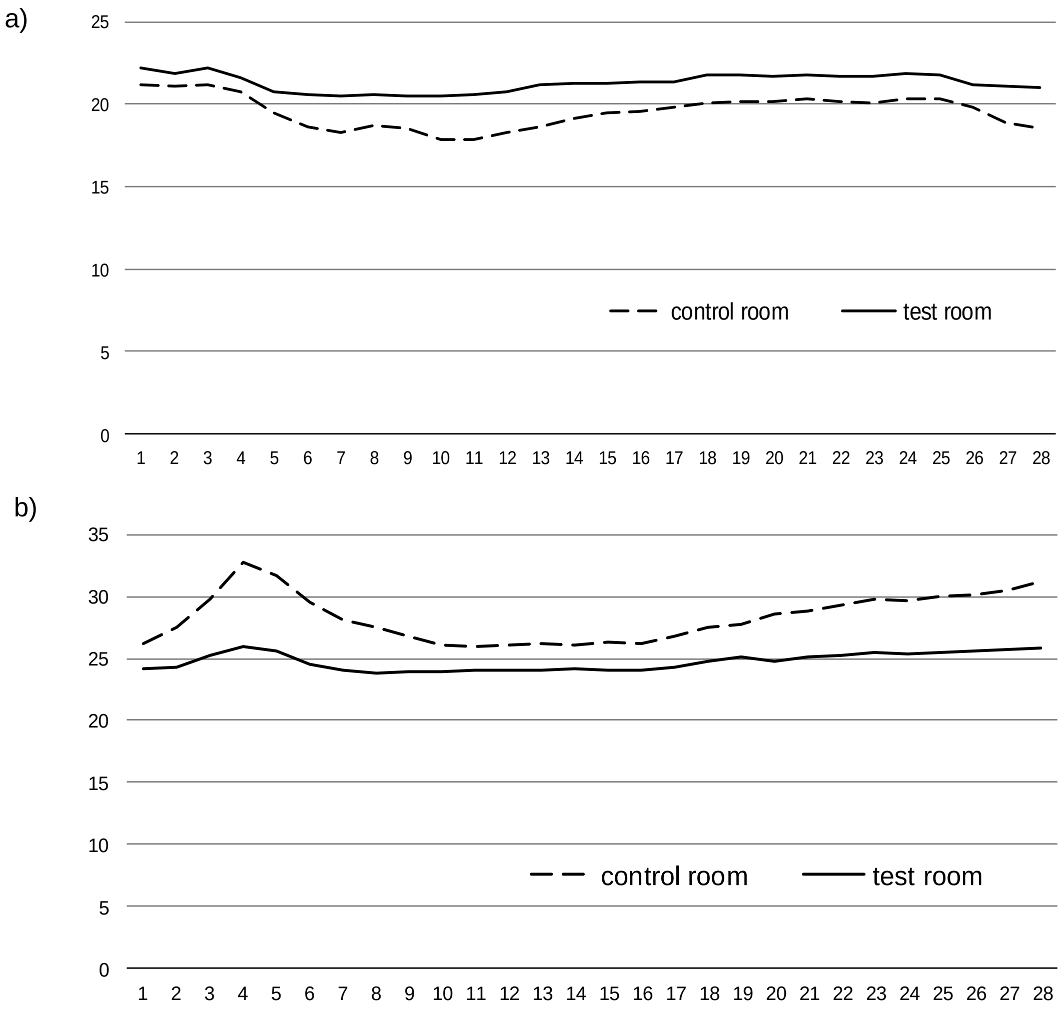
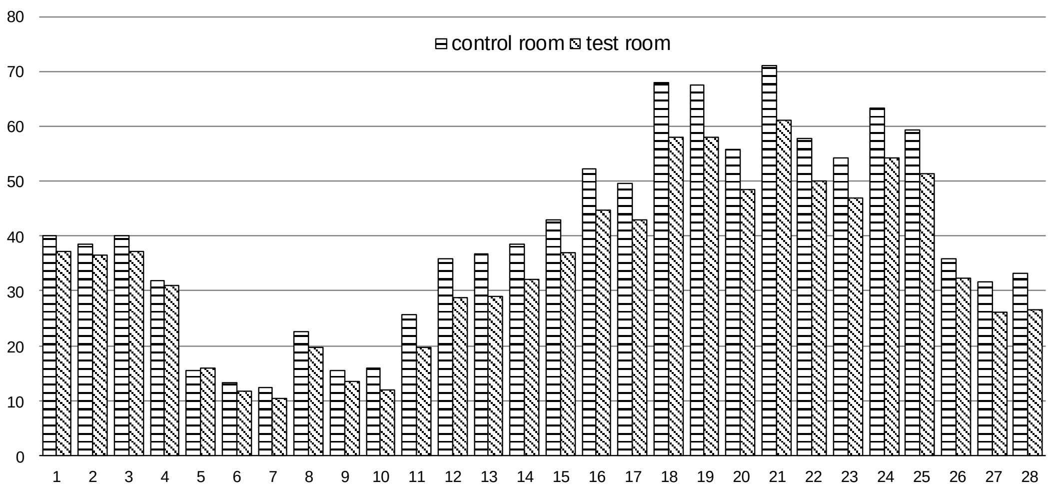


Fig. 3. Average temperature in the control and test room for: a) February 2023 and b) August 2023.

From Figure 3, it can be seen that in the winter the blinds raise the temperature in the room by an average of 1.76°C, while in the summer they lower the temperature by an average of 3.57°C.

Figure 4 shows the heat load of the room in kWh for February and August 2023.



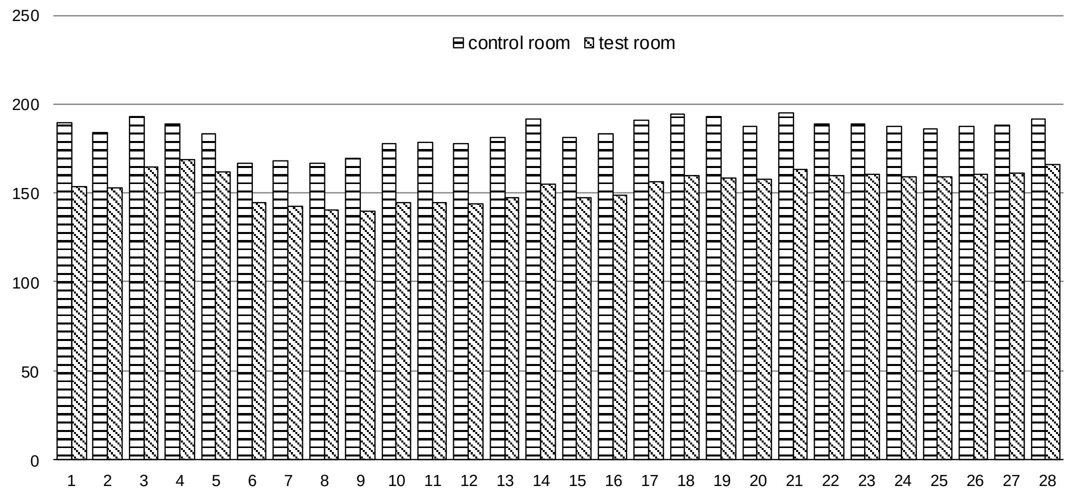


Fig. 4. The heat load in kWh for: February 2023 (top) and August 2023 (bottom).

Based on the diagrams shown in Figure 4, it can be seen that the presence of blinds on the windows contributes to reducing the heat load in winter by 15.75% and in summer by 19.45%. This means that it is necessary to use 15% less energy for heating in winter and 20% less energy for cooling in summer.

4. CONCLUSIONS

Window blinds are one of the elements that affect the energy performance of buildings. The effectiveness of simple, external blinds for windows was analyzed in this paper. They are cheap, easy to mount on existing windows and the most often used on windows in buildings in the Republic of Serbia. The characteristics of blinds in terms of energy efficiency were evaluated based on the value of the heat load through the window with and without the blinds, for the coldest and warmest months of the year. The presented results show that the blinds reduce the temperature in the room by 3.57 ºC in the summer and increased it by 1.76 ºC in the winter. The cooling load was reduced by about 19.45%, and the heat load by about 15.75%, and so was the energy consumption for cooling and heating of the tested room.

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