CONFERENCE PROCEEDINGS

5th INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

EDITORS
ALEKSANDRA KRSTIĆ-FURUNDŽIĆ
MILENA VUKMIROVIĆ
EVA VANIŠTA LAZAREVIĆ
AND ALEKSANDRA ĐUKIĆ

PLACES AND TECHNOLOGIES 2018

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EDITORS:
Aleksandra Krstić-Furundžić, Milena Vukmirović, Eva Vaništa Lazarević, Aleksandra Đukić
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THE IMPACT OF USERS' BEHAVIOUR ON SOLAR GAINS IN RESIDENTIAL BUILDINGS

Rajčić Aleksandar
Faculty of Architecture, University of Belgrade, Bulevar Kralja Aleksandra 73/II, Belgrade, Serbia, rajcic@arh.bg.ac.rs
Radivojević Ana[1]
Faculty of Architecture, University of Belgrade, Bulevar Kralja Aleksandra 73/II, Belgrade, Serbia, ana@arh.bg.ac.rs
Đukanović Ljiljana
Faculty of Architecture, University of Belgrade, Bulevar Kralja Aleksandra 73/II, Belgrade, Serbia, djuli@arh.bg.ac.rs

ABSTRACT

Regulations governing the relevant procedures for the energy certification of buildings in Serbia do not consider the impact of users' behaviour on the level of heat loss or gain. In the case of solar heat gains, the gains are calculated both through transparent, as well as through non-transparent thermal envelope positions. Solar gains through transparent parts - windows and balcony doors are dominant, and depend on thermal properties of windows, orientation, shadings. In this regard, the regulation stipulates that all transparent (and semi-transparent) surfaces in the residential areas, other than those oriented to the north, northeast and northwest, must have non-transparent protection from direct solar radiation in the summer period. Shading elements can be permanent and movable, and their shading effect is defined by the standard EN 13790.

Users express different attitude towards the possibilities of solar gains provided through the glazed parts. This is mainly determined by the dynamics of moving (lifting) the shadings, which depends on their presence and, to a large extent, on the heating system (with the assumption that in buildings connected to the district heating system and the lump sum of heat consumption per m^2, users are not motivated to contribute actively to the heat gains).

The paper analyses the ratio of lifted / lowered (outer) shadings at different times of the day in the winter period on several examples of collective housing in Belgrade, with the aim of establishing the effective calculated area of the window for solar gains. The comparison of the obtained results with the parameters of the reduction due to sun protection equipment defined by the standard EN 13790, aims to establish and promote the design values that are realistic for use in the energy certification procedure of residential buildings.

Keywords: Residential buildings, Solar gains, Windows, Shadings, Users' behaviour

Introduction

Estimations and calculations of energy performance of buildings consider definition of certain scenarios regarding building characteristics, climatic conditions and the use of a building. Such presumptions also predefine a typical model of users' behaviour, which is usually understood as inalterable. However, in practice, the way some space is used is a subject of a change that happens either due to the change in time (diurnal or seasonal changes), or as a result of a change of behaviour of the occupants,which might have an impact on the amount of energy that the building consumes. This situation is confirmed by several recent researches that study

1 Corresponding author

the relationship between the users' behaviour and energy efficiency of buildings (Ben and Steemers, 2014; Guerra-Santin et al., 2018; Guerra-Santin and Itard, 2010).Regarding the correlation between the users' behaviour and energy consumption, windows, i.e. transparent parts of façade tend to be especially sensitive and conditioned by the applied operation mode and consequent potential for solar gains.

According to the regulations in Serbia that govern the relevant procedures for the energy certification of buildings (Rulebook on energy efficiency of buildings, 2011),the solar heat gains are calculated both through transparent and non-transparent parts of thermal envelope. Solar gains through transparent parts, which represent dominant heat gains in general,depend on thermal properties of windows, their orientation andthe existence of shadings. With respect to the significant impact that solar heat gains through windows might have in the summer period, the need for non-transparent protection from direct solar radiation for all the windows except those oriented to the north, northeast and northwesthas been declared by the regulations. The presence and type of shadings is especially in conjunction with the way users use them, influencing the energy performance of the building, but the calculation procedure does not consider the influence of occupants' behaviour. It has been shown that, in research, there is always a dilemma when defining the model and method of calculating the energy performance of buildings in terms of elements of thebuilding whose application is susceptible to user influence, such as are the shading devices (*Đukanović, 2015)*. The unpredictability of the way of using external shading devices may be best seen by observing large multi-storey residential buildings,in which there is a repetition of identical rooms, both in width and in height of the building (Figure 1).

Erection of the multifamily housing was typical for the post WWII period. The mass construction in this building sector was especially present in the period from 1970 till 1990.Hence, according to the research of the building typology of housing stock in Serbia (Jovanović Popović et al., 2013), buildings dating from this period today represent about 22% of the total housing stock. In 1973, the requirements and technical norms for the design of residential buildings and apartments were introduced, which imposed the obligation to install effective external protection in the form of blinds made of wood, metal or plastic, with the exception of openings in the loggias that could remain unprotected. Consequently blinds are normally present on the buildings from the mentioned period. It is noteworthy that on buildings, regardless of the time of day or weather (sunny or cloudy) or orientation, the outer blinds are in the most cases slightly lowered and the impression is that in average, they cover about 50% of the window surface. There are few rooms where the blinds descend all the way to the end. In the case of Belgrade, the most of such buildings are connected to the district heating system that is dominantly charged per square meter.This system of charging does not stimulate users to behave rationally, i.e. to regulate the temperature in the rooms using thermostatic valves, to raise the outside blinds during the day due to solar operation, and to lower them at night due to the reduction of thermal losses. Therefore, even opening of windows in the winter periodfor the purpose of thermoregulation in the room is not uncommon.

Figure 1: View of typical multi-storey residential buildings in Belgrade showing different ways of using external blinders along the façade

Since the method of the use of elements of external window protection together withusers' habits in their exploitation, reflect on the energy balance of the rooms, i.e.on the need for thermal energy for heating in the winter,this complex problem is the particular subject of this paper.

Definition of model and research methodology

In order to examine and quantify the particular impact of user's behaviour on energy consumption, a theoretical model-building has been created followed by different scenarios of the use of shading devices.

Volumetric and material properties of the analysedmodel-building

Having in mind basic characteristics, volumetric and structural, of the multifamily housing from the period of the mass construction, theoretical model has been created (Figure 2).

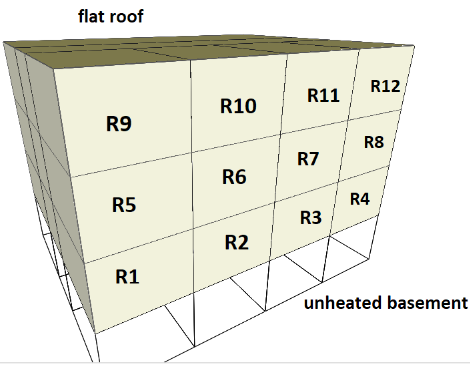

Figure 2: Theoretical model - building

The model has the following volumetric characteristics:

- Three above ground levels with heated rooms,
- One underground level with unheated rooms,

- Floor height H = 2.8m,
- Width of the room (R1-R12) b = 4m,
- Depth of the room (R1-R12) d = 5m.

In the continuation of the previous research on influence of disposition and orientationon energy performance, selection of typical rooms has been made and investigated (Rajčić et al., 2016). Hence, the rooms R1, R2, R5, R6, R9 and R10 were analysed, while the others were considered symmetrical. The analysed rooms have different sizes of the thermal envelope and, accordingly, different energy demand for heating.

Taking into account different structures and materials that were in use during the reference period of construction (1970-1990), typical structures of the time were assumed as elements of the thermal envelope of the model-building and presented in the Table 1.

Table 1: Relevant elements of model-building thermal elements

Element of building thermal envelope	U value [W/m²K]	description
Main façade wall	0.816	concrete wall+thermal insulation+concrete cladding
Lateral façade wall	0.816	concrete wall+thermal insulation+concrete cladding
Floor above unheated basement	0.948	wooden flooring+cement screed+thermal insulation+concrete slab
Flat roof	0.655	concrete slab+thermal insulation+hydro insulation+cement screed

Since the buildings were built decades ago, their window characteristics were presumed in three typical variations that might beactually present in reality (Table 2):

- Present, i.e. original state,
- Improvement 1 (windows were replaced before the adoption of the Rulebook on energy efficiency in buildings in 2012, usually with 3 chamberPVC windows), and
- Improvement 2 (windows were replaced after 2012 with high performance windows in accordance with the Rulebook).

Table 2: Thermal properties of different types of windows regarding the assumed state of improvement

label	State of the window	U [W/m²K]	Glazing factor g [-]	Framing factor F_F	Air tightness class	Number of air exchanges per hour
PS	Presentstate	3.3	0.8	0.25	medium	0.7
I1	Improvement 1	2.5	0.6	0.25	medium	0.7
I2	Improvement 2	1.3	0.35	0.25	good	0.5

Apart from the window type, paper analyses another variable related to the window characteristics, in particular the size of a window, i.e. the share of openings in the façade wall, which is analysed as 60%, 50% and 40%.

Assumed climatic conditions

Calculations of solar heat gains were conducted considering Belgrade as a geographical location of the analysed buildings. Relevant data regarding the mean sum of the solar radiation has been adopted from the *Rulebook* (Figure 3).

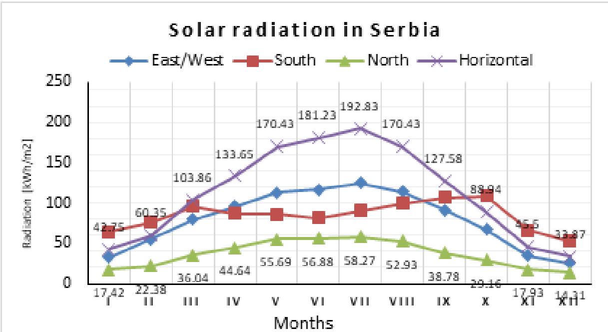

Figure 3: The mean sum of the solar radiation for Belgrade by months

Constant location parameters that were applied in this research are:

- HDD(Heating Day Degrees)=2520,
- Building is exposed to wind, with more than one façade,
- Fs=0.9 (position shading factor - unshaded position),
- Fw=0.9 (reduction factor for non-perpendicular position).

Unlike the constant parameters, Fc - reduction factor due to sun protection equipment (type of curtains) was assumed as variable,in accordance with standard EN 13790:

- Fc=0.9 (internal curtains, white),
- Fc=0.6 (the assumed medium condition that is not stated in the standard),
- Fc=0.3 (external blinds).

Results

Calculations of energy demands for heating were conducted for number of scenarios obtained by a combination of different variables, which reflect the effects of different ways of using window blinds by users (Table 3).

Table 3: Review of different types of variables used for various scenarios

Type of variables	VARIATIONS		
Vertical room position	ABOVE UNHEATED SPACE	MIDDLE FLOOR	BELLOW THE ROOF
Horizontal room position	MIDDLE	CORNER	
Room orientation	north	east/ west	south
Window condition	original state (PS)	improvement 1 (I1)	improvement 2 (I2)
Window/wall ratio	60%	50%	40%
Fc (reduction factor)	0.9	0.6	0.3

All calculations were conducted using non-commercial software KnaufTERM 2 Pro as the calculation tool. Two of the analysed scenarios are presented.

Scenario 1

The first scenario refers to the combination of the following variables:

- Different window condition (PS/ I1/ I2),
- Different position of a room in the building (R1/ R2/ R5/ R6/ R9/ R10),
- Different share of the windows in the main façade wall (60% / 50% / 40%),
- Different values of reduction factor Fc (0.9/ 0.6/ 0.3).

The focus of the scenario is on the window characteristics, i.e. its condition, as well as the combined impact of the window/wall ratio and different level of protection against solar radiation on the energy demand for heating of a room.

This scenario was performed on different cases of orientation of the rooms: north, east/west and south, andresults that refer to the north and the south orientation are presented (Figures 4 and 5). For each of the analysed rooms, horizontal bars in a diagram present window/wall ration (40-60%), with variations in values of specific annual energy for heating as a result of different values of reduction factor (0,9-0,3). Colours of the bars match the colours of the appropriate energy class.

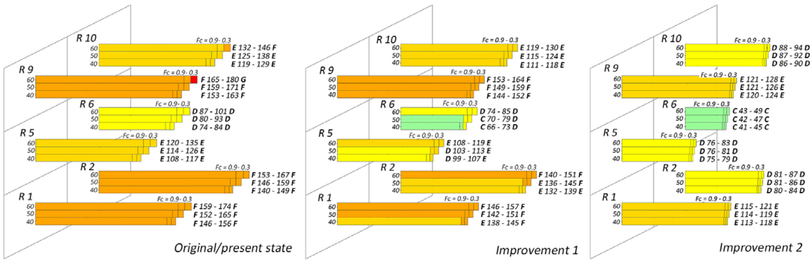

Figure 4: Specific annual energy for heating $Q_{h.an}$ ***[kWh/m²]*** and energy class of rooms for north orientation of themain facade

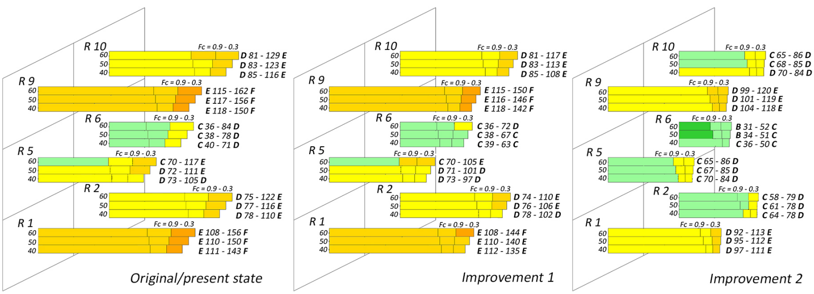

Figure 5: Specific annual energy for heating $Q_{h.an}$ ***[kWh/m²]*** and energy class of rooms for south orientation of themain facade

In the case of the north oriented main façade, the results indicate that more exposed rooms, need more energy for heating - Room 9 is the most exposed, while Room 6 is the least exposed (Figure 4). Regarding the specific annual energy for heating and energy class of analysed room, rooms express different energy classes. Depending on the combination of the size of the window and the type of window protection, the differences in the energy classes are within 4 classes for original windows (D-G), as well as for the improvement 1 (C-F), while for the improvement 2, the energy classes vary in the range of 3 classes (C-E).In the same room, the energy class does not generally vary due to the size of the window.

A similar trend is evident in the case of the south-oriented main façade (Figure 5).Energy requirements vary among the four energy classes regardless of the condition in which they are, but less heating energy is needed compared to the north orientation.In the same room, the energy class varies in the range of two classes, depending on the window size (larger windows - the lower class).

Scenario 2

The second scenario refers to the combination of the following variables, with a constant average window size adopted (50% of the share in the main façade):

1. Different window condition (Present/ Intervention 1/ Intervention 2),
2. Different correction factor Fc (0.9/ 0.6/ 0.3),
3. Different rooms (R1/ R2/ R5/ R6/ R9/ R10),
4. Different orientation (north/ east/west/ south).

The focus of this scenario is on the influence of orientation. Hence it was performed on different cases of orientation (north, east/west, south), with reference to the influence of the state of the window (Figure 6).For each of the analysed rooms, horizontal bars in a diagram present window condition, with variations in values of specific annual energy for heating as a result of different values of reduction factor (0,9-0,3). Colours of the bars match the colours of the appropriate energy class.

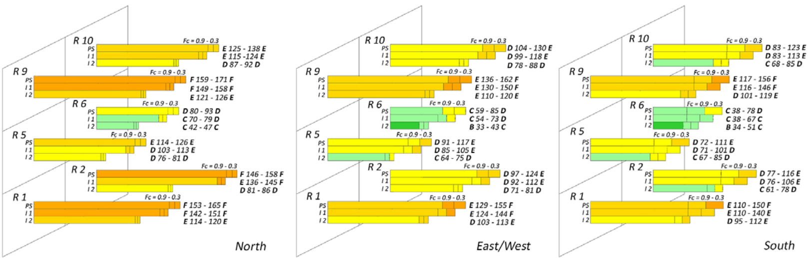

Figure 6: Specific annual energy for heating $\boldsymbol{Q_{h.an}}$ ***[kWh/m²]*** and energy class of rooms regarding the orientation of themain facade

The results indicate that the most exposed roomneed more energy for heating - Room 9 is the most exposed, while Room 6 is the least exposed. Energy class of a room vary in the range of four classes in the north orientation (C-F), i.e., five in the east/west orientation (B-F) and in the south orientation (B-F).

In the same room, the energy class varies within 2-3 classes depending on the condition of the window (original/present state - poorer class, intervention 1 - better class, intervention 2 - the best grade).

Conclusions

The complex scenarios of the conducted research have enabled the following conclusion to be drawn:

1. Energy required for heating is directly proportional to the size of the window openings, and inversely proportional to the factor Fc.
2. With the increase of the quality of the window (intervention 1 and 2), decreases the energy needed for heating, although g factor also decreases.
3. The required energy for heating is inversely proportional to the factor Fc.
4. The most energy is needed for north-oriented rooms, less for east/west oriented, and least for south-oriented rooms.

Finally, all of the conclusions undoubtedly confirm the importance and the impact that the user's behaviour might have on the energy performance of a building.

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