

ENERGY EFFICIENCY OF RESIDENTIAL BUILDINGS IN SERBIA

by

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Original scientific paper

UDC: 697.51.004

DOI: 10.2298/TSCI100430017S

In this paper, presented is the state-of-the-art of energy Efficiency of residential buildings in Serbia. Special attention is paid to energy efficiency in already existing buildings. The average energy consumption in residential buildings in Serbia is over 150 kWhm⁻² per year, while in developed European countries it is about 50 kWhm⁻² per year. In this paper examined is the contribution of ventilation losses, through the windows of low quality, regardless whether they are poorly made, or made from bad materials, or with no adequate glass. Besides ventilation losses, which are of major importance in our buildings, special attention is paid to transmission losses, which are consequence of the quality and energy efficiency of the facade. All of the above statements are proved by measurements obtained on a representative building of the Block 34 in New Belgrade, built in the eighties of the last century. In addition to measurements performed the calculation of energy consumption for heating during winter has been made. The results of two different methods of calculation of energy consumption for heating are compared with the values obtained by measuring.

Key words: energy efficiency, residential buildings, heat losses, measurements of heat losses, thermal imaging camera, calculation methods

Introduction

In developed countries, the global contribution to the energy consumption of buildings, both residential and commercial, is between 20% and 40%. During the last two decades primary energy input has grown by 49% and CO₂ emissions by 43%. Current predictions indicate that this growing trend will continue [1]. On the other hand it has been shown that conventional energy efficiency technologies, such as thermal insulation, low-emissivity windows, window overhangs, and day lighting controls can be used to decrease energy use in the new commercial buildings by 20–30% on average, and up to 40% for some

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building types and locations [2-4]. In this paper energy efficiency of residential buildings in Serbia will be presented. Previous results can be found in [5-9].

During the eighties of the last century whole quarts of cities, like New Belgrade, were built by the system of fast construction. Nobody paid any attention to energy efficiency of apartments. Facades were constructed without the application of knowledge about the building physics. The windows were also of poor quality. All of this contributed to the fact that the energy consumption in these apartments was above 150 kWh/m² per year. This paper represents a summary of the research that authors have made in the past five years. The measurements carried out on an apartment building in New Belgrade, in Block 34, are presented. Also, calculated values of energy consumption for heating are compared with measurements.

Measurements on the residential building

During winter of 2004/05, in the period from December 31st 2004 to January 11th 2005, several measurements were carried out on the residential building in Boulevard Zorana Djindjića 213, in Block 34 in New Belgrade. Measurements were made in three apartments belonging to the first, the second and the third floor, one above the other. Building envelope consisted of:

1. Floor towards unheated basement, total area of 258.85 m²,
2. Ceiling towards unheated attic, total area of 258.85 m², and
3. External wall, with a total area of 1387.90 m², consisted of three walls of different structures. The walls are designated as WALL 1, WALL 2 and WALL 3, and differences are taken in calculations. As the measurements were made on the WALL 1, wall elements and their characteristics are presented in Table 1.

Table 1. Total heat resistance of the WALL 1

No	Material	δ	ρ	c	\square	λ	δ/λ
		cm	kgm ⁻³	Jkg ⁻¹ K ⁻¹	–	W per mK	m ² per kW
1	Gypsum	1	1400	840	12.00	0.7	0.014
2	Vapor barrier	0.01	2700	940	600000.0	203	0.000
3	Polystyrene	2	30	1260	45.00	0.041	0.488
4	RC	8	2500	960	90.00	2.33	0.034
5	Polystyrene	6	25	1260	40.00	0.041	1.463
6	RC	6	2500	960	90.00	2.33	0.026

Total heat resistance of the WALL 1 is $R=2.02$ m²K/W, while the U value is $U=1/R_{tot}=0.46$ W per m²K, which is less than $U_{max}=0.90$ W per m²K (according to national standard SRPS U.J5.600).

Measurements

Measurements were made in three apartments on the first, the second and the third floor. Before measurements, the following changes were performed: In the apartment on the third floor windows were changed. The new plastic windows with low glass emission coefficient and overall thermal transmittance of $U = 1,1 \text{ W per m}^2\text{K}$ were embedded. In the apartment on the first floor the windows were sealed with tape to suppress ventilation losses. On the second floor no changes were made.

Measurements of temperature, relative humidity, heat flux and ventilation losses were made. From the outside, the facade was recorded using thermal imaging camera. The temperature was measured at five spots in each apartment: on the wall towards the street (northern side, S) from the outside (SS) and the inside (SU); on the wall towards the inner yard (southern side, J) from the outside (JS), and the inside (JU), and finally, in the middle of the apartment (S). Relative humidity was measured in the middle of each apartment. Also, relative humidity was measured on the second floor, in the northern side wall from the outside (SS), and on the southern wall from the outside (JS). Heat flux was measured at one spot in each apartment on the northern wall from the inside. Ventilation losses were measured on apartments on the first, the second and the third floor in the room with area 13.01 m^2 , and height 2.48 m . Recording with thermal imaging camera was done on the southern and the northern wall from the outside. In figure 1. scheme position of sensors is shown. The total number of measured parameters is 39.

Measurements equipment

For humidity and temperature measurements sensor with thermocouples Pt1000 were used. Data were transferred to industry computer (PLC), via AD^{-1} converter; collected data were transferred to the computer, using modem, in which the data were accumulated for each hour.

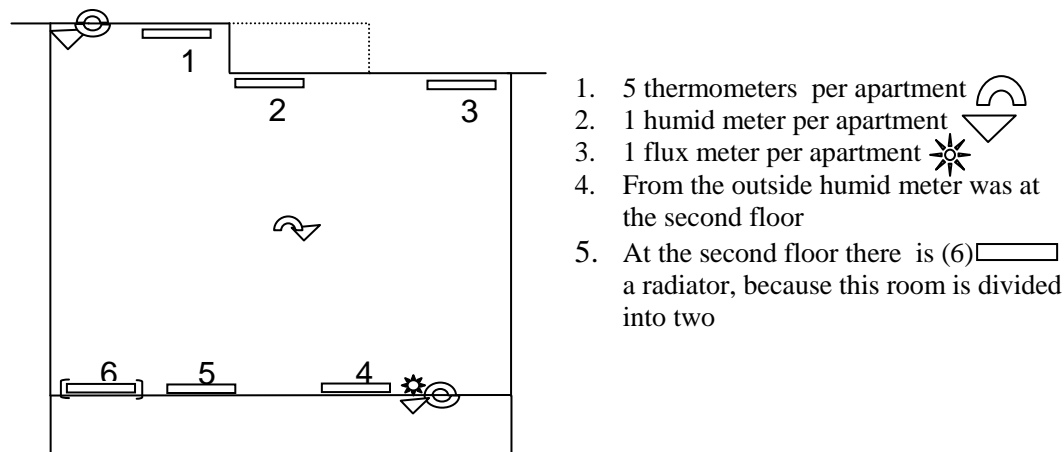


Figure 1. Scheme position of sensors

Heat fluxes were measured with flux meters at one spot in each apartment, and the measured heat fluxes were checked using temperature difference at each place and known heat resistance of the façade wall. Ventilation measurements were based on national standard SRPS U.J5.100 (1983) with correction for the influence of temperature according to LAB 08 – 2 – 08 – 055 I LZ 254 Recording was performed using thermal imaging camera.

Temperature measurements

In figures 2a, 2b and 2c temperature measurements in the apartments on the first, the second and the third floor are given. For the first floor, five temperatures were measured (two from the outside, JS and SS and three from the inside, JU, S and SU). It turned out that two thermocouples didn't function well, thus one temperature measurement on the second floor (SS) and one on the third (JS) were missing. In the above mentioned figures given are the temperature changes during the time, measured every hour during 12 days time period. Each curve is plotted using $24 \times 12 = 288$ points, showing the accuracy of measurements.

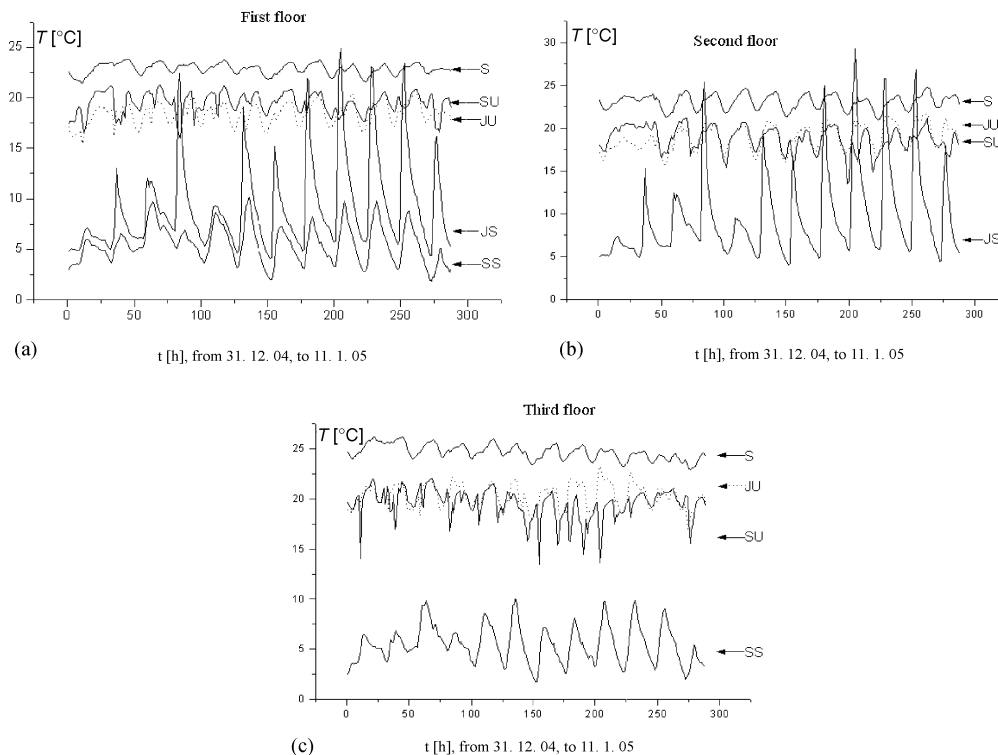


Figure 2. S – air temperature in the middle of the apartment, SU –the internal temperature of the northern wall, JU – the internal temperature of the southern wall, JS –the external temperature of the southern wall, SS – the external temperature of the northern wall

By analyzing figures 2a, 2b and 2c one can conclude: the number of peaks is 12, each peak belongs to a single day; external temperatures were below those measured inside the apartments; the variation of the external wall outside temperature during switch of day to night was less on the northern (SS) than on the southern (JS) side. Those variations are the consequence of the fact during measurements was twelve sunny days, when the outside temperature of the southern wall was nearly 30 °C. Air temperature measured at the wall inside the apartments was lower if compared to the temperature measured in the middle of apartment. The averaged temperature on the third floor was at least 2 degrees above the average temperature at the first and second floor, due to replacement of windows on the third floor, which resulted in smaller heat losses.

Relative humidity measurements

In figure 3 relative humidity ρ inside the apartments and on the outer area of the southern and the northern facade measured each hour during the same period of 12 days is presented. Variations of the relative humidity are greater at higher temperature changes as it is the case on the southern side of the building, where temperature changes are greater. Time variations of relative humidity in the apartment on the third floor is lower than variation in humidity in the apartments on the second and the first floor, which can be a consequence of the windows replacement, which caused less infiltration.

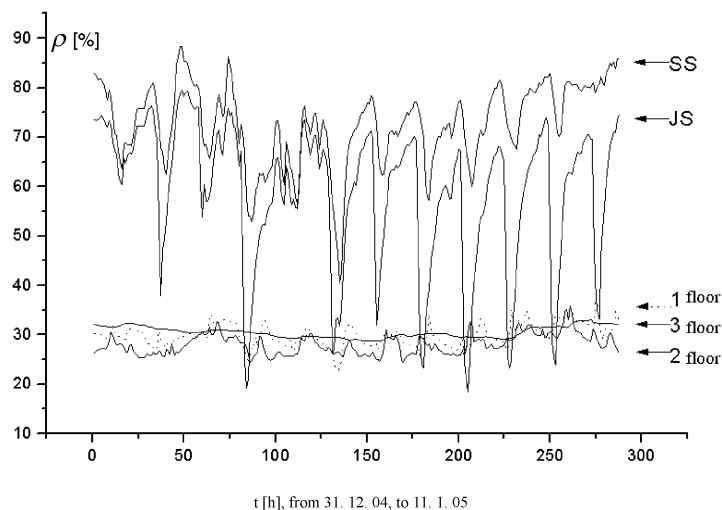


Figure 3. JS – the outside relative humidity of the southern wall, SS – the outside relative humidity of the northern wall

Measurements of the heat flux

In figure 4 given are the results of measurements of heat flux across the northern wall in all three apartments versus time, recorded every hour during measurement period of 12

days. In figure 5 presented are the measured and calculated values of heat flux. Heat fluxes were calculated using measured temperatures for the representative floors on the northern wall (the outside and the inside), and calculated heat resistance of the wall (Table 1). Measured and calculated values of heat flux are in very good agreement.

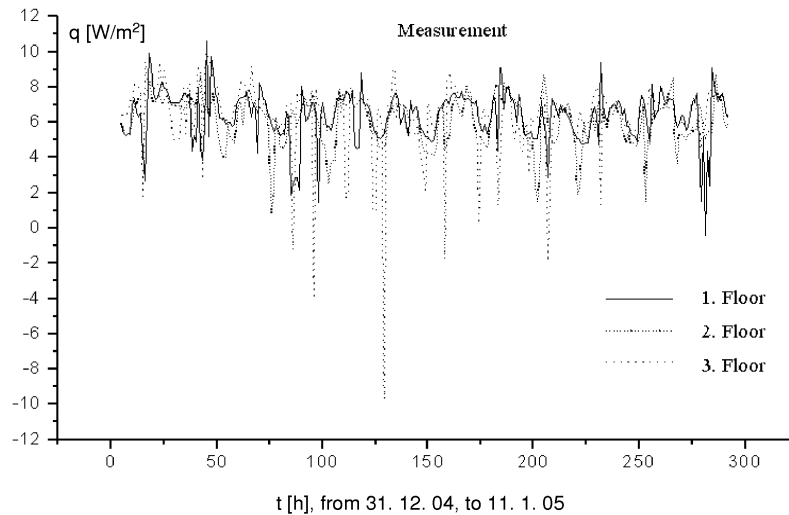


Figure 4. Heat flux density q through the northern wall in all three apartments

Agreement of calculated and measured values of heat flux is even better on the diagrams shown in figures 6a and 6b. Peaks, which are shown on some diagrams, are due to the noise in the measurement signal.

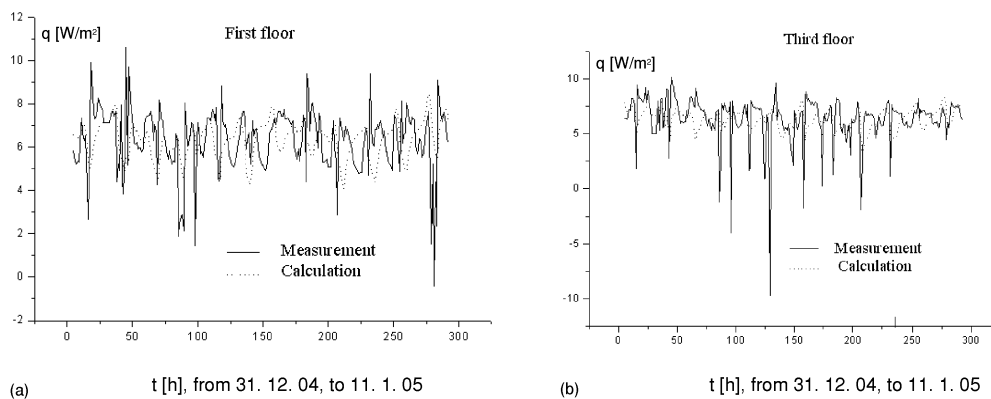


Figure 5. Comparison of measured and calculated heat flux density over time (a) for an apartment on the first floor and (b) an apartment on the third floor

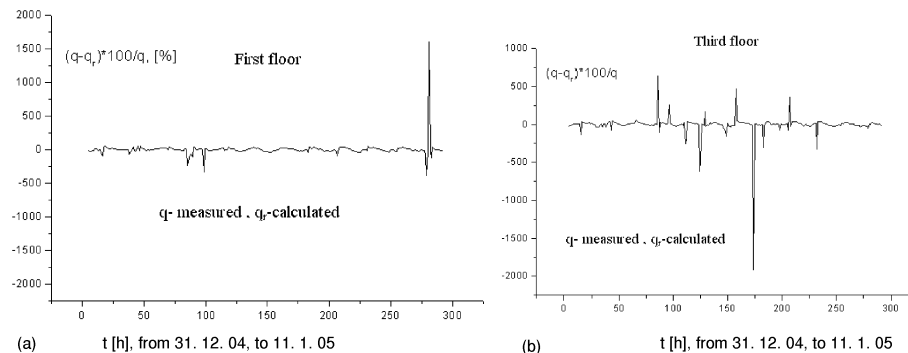


Figure 6. Relative difference of measured and calculated heat fluxes density over time (a) for the first and (b) for the third floor

Ventilation losses measurements

Ventilation losses are the result of poor quality of embedded windows, or thermal heat bridges at the connection of windows and structure of the object itself. In this paper measurements of ventilation losses of façade windows were thoroughly examined. Measurements were carried out in the same building, on the first and the third floor, in the bedroom with 13.01 m² floor area and height 2.48 m.

Examination was performed according to national standard SRPS.U.J5.100 (1983) – Heat techniques in buildings-ventilation losses in apartments. Equipment consisted of: the exhaust fan of the 1000 m³h⁻¹ capacity, equipped with calibrated measuring pipe for measuring the blown-out air, electronic micro nanometer, and prefabricated panel assembled at the entrance door, and a digital thermometer. Some of these elements are shown in figure 7.

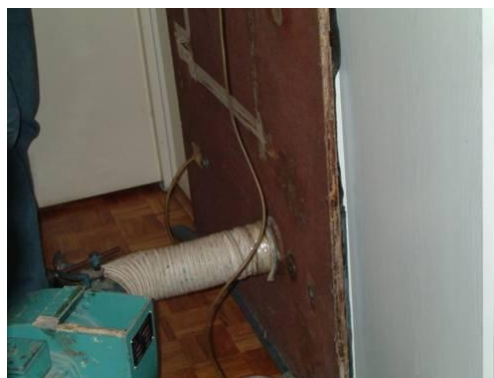


Figure 7. Outside of prefabricated door connecting measured pipe and fan

In each apartment three measurements were made and they are shown in Tables 2 and 3. The volume of air taken from the room under sub pressure of 50 Pa during 5 minutes was measured. Pressure was controlled in the room and outside.

Table 2. Apartment on the first floor

Apartment No. 3 – first floor	Measurement No.1	Measurement No.2	Measurement No.3
\dot{V} [m ³ h ⁻¹]	208	213	202
n [ach per h]	6.44	6.6	6.26
Number of changes	$n = 6.4$ ach per h		

Table 3. Apartment on the third floor

Apartment No. 13 – third floor	Measurement No.1	Measurement No.2	Measurement No.3
\dot{V} [m ³ h ⁻¹]	164	392	380
n [ach per h]	5.08	5.20	4.68
Number of changes	$n = 5.0$ ach per h		

Average temperature was controlled too. Number of air changes in the room on the first floor was 6.4 ach per h while in the governing room on the third floor was 5 ach/h. Allowable number of air changes is $n = 2$ ach per h. It is obvious that the value of n is smaller in the room with new windows. New windows were of good quality, however, sealing between new windows and construction was not done properly. It can also be seen from thermal imaging camera measurements. Connection of new windows and construction was warmer.

Ventilation losses effect

The amount of heat to be added Q [Jh⁻¹] due to air mass flow \dot{m} [kg h⁻¹] during the unit time, can be expressed by the following form:

$$Q = \dot{m}c_p\Delta T = nVc_p\Delta T \quad (1)$$

From expression (1) specific heat losses can be calculated:

$$q = \frac{Q}{S} = nhc_p\Delta T \quad (2)$$

In the above expression h is the height of the room. If room is heated s [hd⁻¹] hours per day and d [da⁻¹] days per year, and when change of J to kWh is taken, it is obtained

$$q = 3,33 \cdot 10^{-4} nhsd\Delta T \quad (3)$$

In Belgrade, according to the district heating company "Beogradske elektrane" $s = 16$ h/d, the number of days in the year when heat is delivered is $d = 160$ d/a and $\Delta T = 5$ K. Thus, from expression (3) it is obtained:

$$q = \begin{cases} 25.6 \text{ kWhm}^{-2}\text{a}, & n=2 \text{ [achh}^{-1}\text{]} \\ 64.0 \text{ kWhm}^{-2}\text{a}, & n=5 \text{ [achh}^{-1}\text{]} \\ 81.9 \text{ kWhm}^{-2}\text{a}, & n=6.4 \text{ [achh}^{-1}\text{]} \end{cases} \quad (4)$$

From expression (4) it is obvious that ventilation heat losses due to air exchange are more than just important, when compared with 110 kWhm^{-2} , which is a characteristic value of total energy consumption. Reducing the number of air changes of 5 or 6 ach/h to 2 ach per h according to the standard, considerable energy savings could be achieved.

Thermal imaging camera measurements

Using thermal imaging camera the heat losses due to thermal bridges in the facade and windows sealing was recorded, on the front and the rear facade of the building in Boulevard Zorana Djindjica 213, in the area of the first to the third floor, figure 8.



Figure 8. Analyzed floors on the front (north) and the rear (south) facade

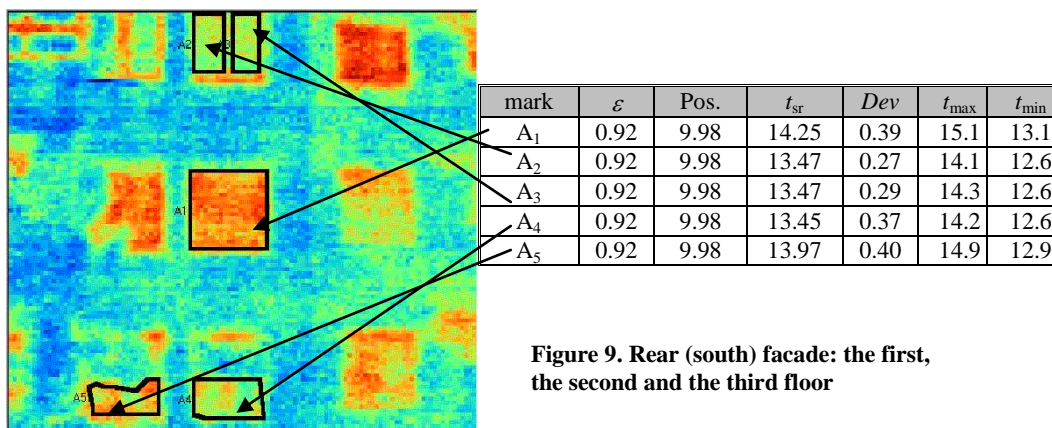


Figure 9. Rear (south) facade: the first, the second and the third floor

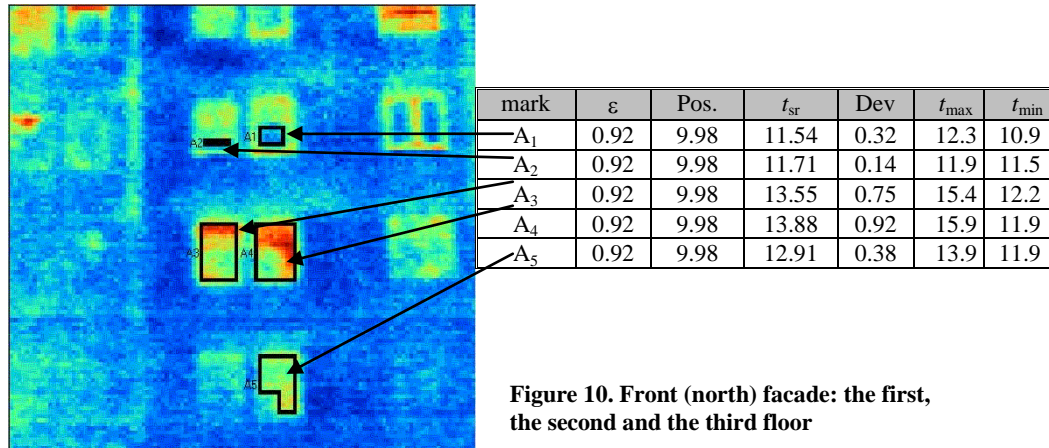


Figure 10. Front (north) facade: the first, the second and the third floor

Recording conditions were ideal. It was cloudy day, so that no facade was under sunlight. Outdoor air temperature was 8 °C. From figures 9 and 10 it can be seen that the temperature at the windows ranged from 10.9 °C to 16.3 °C, which is in agreement with the fact that facade must be warmer than the outdoor air. From the figures it can be concluded:

- windows on the second floor are warmer than the windows on the third floor for 2 °C, due to the newly embedded windows, and
- on the first floor, the bottom third of the windows is warmer than the rest of windows area, due to the fact that the blinds were covering the top portion of the windows (windows covered with blinds were better insulated).

Heat consumption – measurements and calculation

Measurements of energy consumption for heating in the building in Boulevard Zorana Djindjića started in the heating season 2002/03. In 2002 reconstructed was the substation by replacing circulation pumps, enabling heating system operation with variable mass flow. Pumps with variable speed can save up to 60% of power consumption on annual basis [10, 11]. Heat meter implemented in the substation enabled measurement of heat consumption. All radiators belonging to home installation are equipped with thermostatic radiator valves, which enable users to carry out local control of the heating effect. Each heating body is equipped with allocator, so the heat consumption can be monitored for each apartment.

Calculation of the energy required for heating is based on heat balance equations for each building construction element. The energy (heat) balance at the building zone level includes the following terms (only sensible heat is considered): transmission heat transfer between the conditioned space and the external environment; ventilation heat transfer (by natural ventilation or by a mechanical ventilation system), transmission and ventilation heat transfer between adjacent zones; internal heat gains (including persons, appliances, lighting and heat dissipated in, or absorbed by, heating, cooling, hot water or ventilation systems); solar heat gains (direct, through windows, or indirect, via absorption in opaque building

elements); storage of heat in, or release of the stored heat from, the mass of the building; energy needs for heating.

There are two basic types of calculation method: (a) quasi-steady-state methods, calculating the heat balance over a sufficiently long time (typically one month or a whole season), which enables one to take dynamic effects into account by an empirically determined gain and/or loss utilization factor, and (b) dynamic methods, calculating the heat balance in short time steps (typically one hour) taking into account the heat stored in, and released from, the mass of the building.

The International Standard EN ISO 13790:2008 covers three different types of method: a fully prescribed monthly quasi-steady-state calculation method (plus, as a special option, a seasonal method); a fully prescribed simple hourly dynamic calculation method; and calculation procedures for detailed dynamic simulation methods.

The monthly calculation gives correct results on an annual basis, but the results for individual months close to the beginning and to the end of the heating and cooling season can have relative errors. The alternative simple method for hourly calculations has been added to facilitate the calculation using hourly user schedules (such as temperature set-points, ventilation modes, operation schedule of movable solar shading and/or hourly control options based on outdoor or indoor climatic conditions). This method produces hourly results, but the results for individual hours are not validated, and individual hourly values can have relative errors.

In figure 11a are shown the measured heat consumption for four heating seasons, compared to the calculated values for each month during the heating season. The applied method for calculation of the required heat is a fully prescribed monthly method in accordance with EN ISO 13790, using weather data for the typical meteorological year (TMY) in Belgrade [12]. For each building zone and each calculation step (one month), the building energy needs for space heating, $Q_{H,nd}$, for the conditions of continuous heating, are calculated as given by equation:

$$Q_{H,nd} = Q_{H,ht} \cdot \eta_{H,gn} \cdot Q_{H,gn} \quad (5)$$

Differences which appear in the monthly consumption during the various heating seasons are a consequence of different weather conditions – particularly the outdoor air temperature and wind speed, which mostly affects the transmission and ventilation losses, the number of sunshine hours, which affect the heat load, *etc.* The average monthly outdoor air temperatures are shown in figure 11b along with the values obtained from TMY. It is clear that TMY is a good representation of weather conditions that occur during the winter in Belgrade. The largest deviations were reported during February, which are also reflected in the calculated value of the heat consumption.

The whole building is a block type building and consists of five lamellas, starting from number 209 to 217. Lamella 1 and 5 are located at the ends of the building, while the lamellas 2, 3 and 4 are in the middle. Substation is located in the basement of lamella 3 (No. 213) and supplies the entire building. Flats in lamella 3 have less specific heat losses than the apartments in the lamellas 1 and 5, and thus lower power consumption for heating, as a result of smaller areas of facade elements in relation to the square meters of floor apartments. The annual consumption of heat in the lamella 3 is lower by 5 to 15% compared to the average of the entire building, depending on the heating season (figure 12a).

Especially monitored is the consumption of heat in lamella 3 apartments where, during the heating season 2004/2005, reconstructions were made. Reduce of heat consumption is most evident in the apartment on the third floor, where windows were replaced, resulting in the reduction of approximately 18%. The apartment on the first floor, where are the sealing of windows impact the reducing of ventilation losses, has savings of about 12% annually (figure 12b).

Further, a fully prescribed simple hourly dynamic calculation method was applied for the period when measurements took place. Calculation was performed for the apartment on the second floor, with net floor area of 69 m². Figure 13 shows the transmission losses Q_{tr} , ventilation losses due to natural ventilation Q_v and total losses $Q_{H,ht}$, as the sum of transmission and ventilation ones. On an annual basis the ratio between transmission and ventilation heat losses is about 60/40%. The ratio $Q_{tr} \times Q_v^{-1}$ changes over time. During the hours of no wind dominant is the transmission heat loss, while the hours with the increased wind speed result in Q_{tr} and Q_v equal values. During 12 days of monitoring heat losses, the average ratio $Q_{tr} \times Q_v^{-1}$ was 68/32%. It can also be seen that the overall heat losses, even at one point, did not reach the project value of 7.972 kW (obtained for the design outdoor temperature of -15 °C), which is the installed capacity of the radiators in the apartment. This is due to relatively high external air temperatures, which did not fall under -5 °C. The average wind speed was 3.2 ms⁻¹, not exceeding the value of 7.1 ms⁻¹ (figure 14). The maximum heat loss occurred on 6th of January at 4 AM, with the outdoor temperature of -2.6 °C and wind speed of 7 ms⁻¹, and it amounted to $\Phi_{H,ht} = 4.856$ kW.

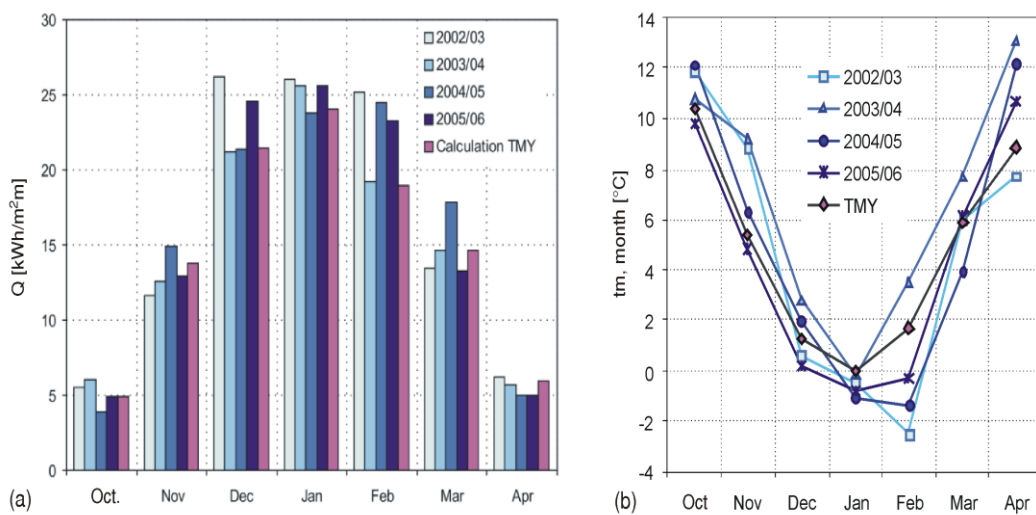


Figure 11. Measured heat consumption during the four heating seasons and calculated values using TMY (a); Average monthly temperatures of the outdoor air (b)

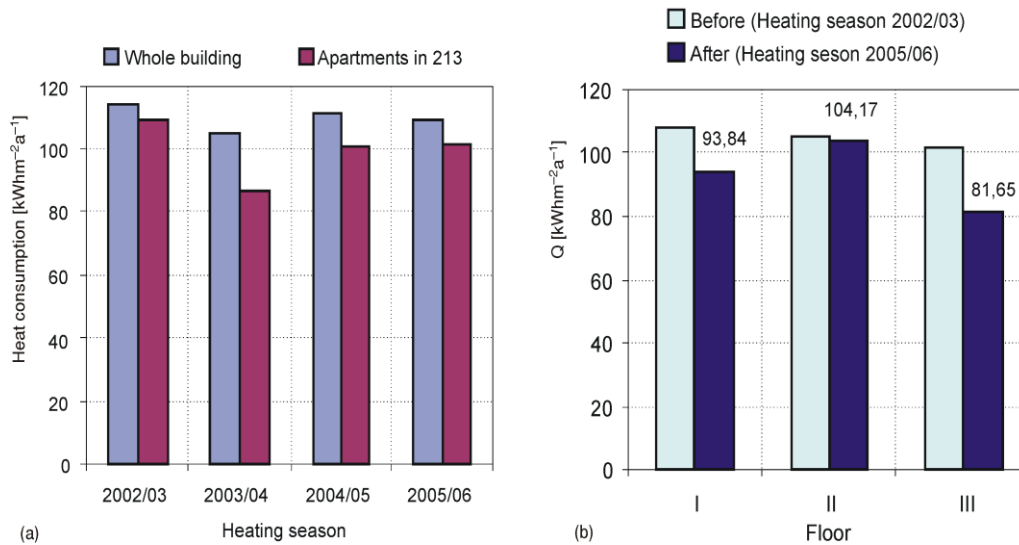


Figure 12. Measured heat consumption in the whole building (209 – 217) and heat consumption in lamella 213 (a); Seasonal heat consumption of three apartments in 213 (b)

The overall heat losses that should be compensated by the heating system are reduced by heat gains. Internal heat gains Q_{int} include heat gains from persons, appliances and lighting. By assuming the standard schedule of occupancy, and heat flow rate from appliances and lighting for residential buildings, the daily profile of Q_{int} is obtained. When calculating Q_{sol} , orientation of the windows was taken into account, as well as the coefficient that defines the thermal mass of the building – dynamic internal capacity C_m [JK⁻¹].

Figure 15 shows profiles of internal and solar heat gains during 12 days, as well as the total heat gain. The obtained hourly profiles of all components now enable calculation of the actual amount of heat to be supplied by the heating system, using equation (5).

The dimensionless gain utilization factor is calculated as:

$$\eta_{H,gn} = f(\gamma_H, a_H) \quad (6)$$

where γ_H is the dimensionless heat-balance ratio for the heating mode:

$$\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}} \quad \text{and} \quad (7)$$

- a_H is a dimensionless numerical parameter depending on the time constant,
- $Q_{H,ht}$ is the total heat transfer for the heating mode, and
- $Q_{H,gn}$ represents the total heat gains for the heating mode.

Finally, the heat flow to be compensated by the heating system $Q_{H,nd}$ is obtained, and compared with actual heat losses reduced by the heat load, which comes from the internal and solar heat gains (figure 16).

Figure 16 shows the impact of heat load that reduces heat loss. The greatest reduction of heat loss occurs during the afternoon hours, while at night there is no loss reduction.

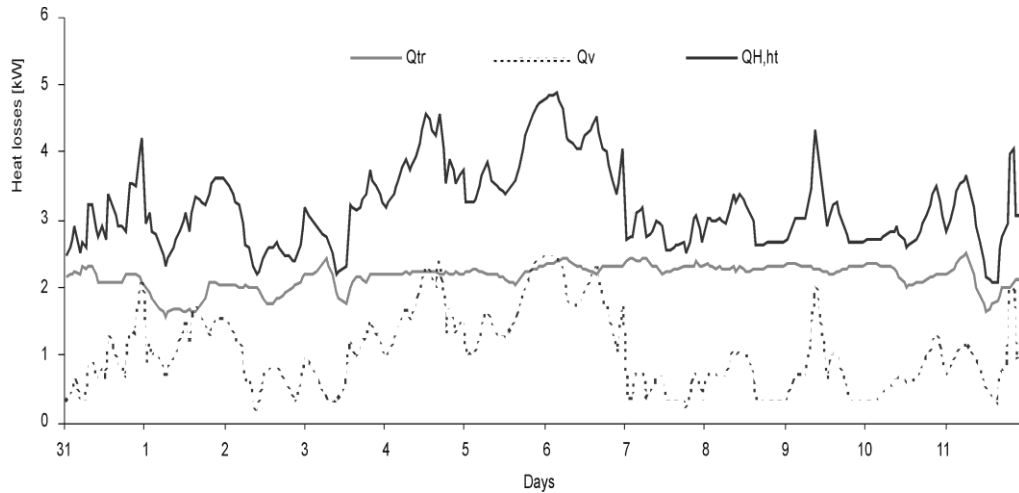


Figure 13. Calculated heat losses of the apartment on the second floor during 12 days (31.12. – 11.1.) using weather data of TMY in Belgrade

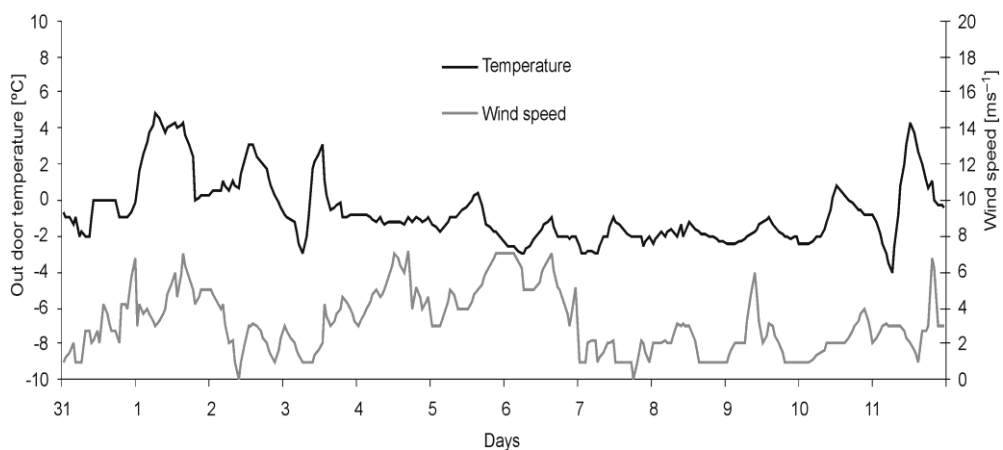


Figure 14. Weather data of TMY for Belgrade during 12 days (31.12. – 11.1.) – the outdoor temperature and wind speed

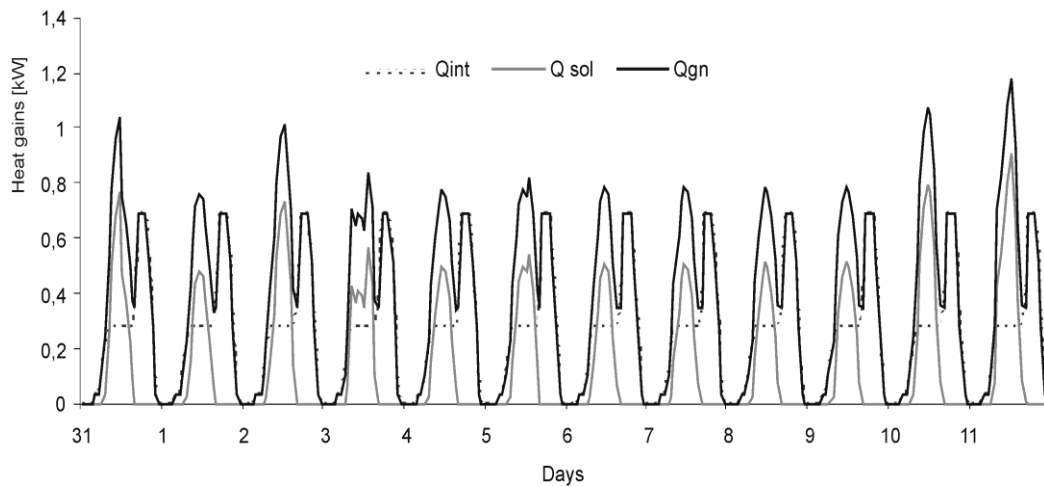


Figure 15. Calculated heat gains of the apartment on the second floor during 12 days (31.12. – 11.1.) using weather data of TMY for Belgrade

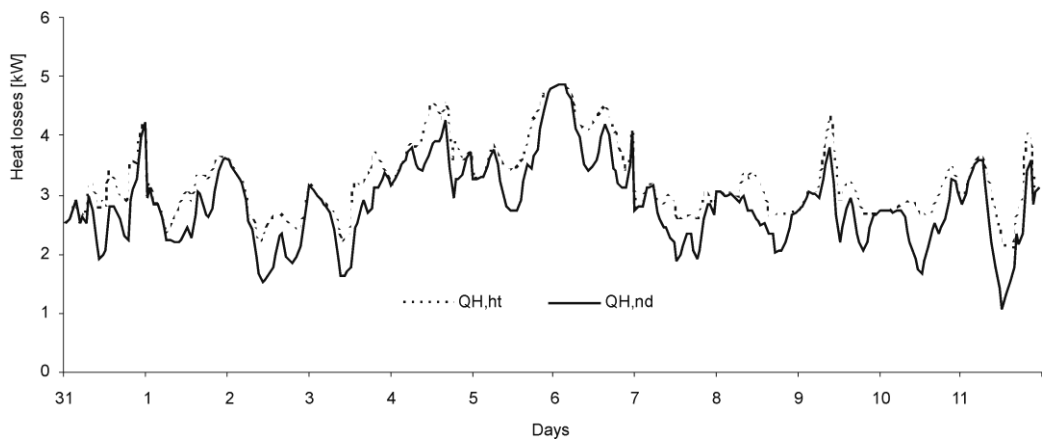


Figure 16. Calculated heat gains of the apartment on the second floor during 12 days (31.12. – 11.1.) taking into account internal and solar heat gains

In Table 4 given are the values of the average measured heat consumption and the calculated heat consumption per day in January, as well as the differences between calculation methods. The values obtained by calculation are slightly lower than the measured ones, which is due to the following effects: calculating values are obtained using TMY weather data; daily schedules of occupancy, and heat flow rate from appliances and lighting are taken for the typical residential buildings; calculation values are obtained for the set-up temperature of 20 °C, while the measured indoor air temperature was higher (around 22 °C – figure 2).

Table 4. Measured and calculated heat consumption

Average measured [kWhm ⁻² per day]	Monthly method [kWhm ⁻² per day]	Simple hourly method [kWhm ⁻² per day]
0.81	0.77	0.79
Relative difference of measured and calculated (%)	- 4.8	- 2.7

Conclusions

Based on the measurements made in Boulevard Zorana Djindjića 213 in New Belgrade, it can be concluded that:

- The increase in average temperature in the apartment on the third floor, where new windows of high quality were embedded, is about 2 °C. The new windows reduced ventilation losses, which can be seen from minor variations of relative humidity;
- Measurements have proved that thermal insulation of walls is constructed according to the designed projects, because the measured and calculated heat fluxes were the same. This is possible only if the heat conduction resistance of wall is the same as predicted by the design;
- Solar gain cannot be neglected, because southeastern side is exposed to sunlight and temperature rise to 30°C during the day. Comparing the variations of temperatures on the southern and the northern facade it can be concluded that the period was sunny. The difference was great when the day was sunny. Thus, we concluded that sunny were 9 out of 12 days during which measurements were recorded;
- Ventilation losses were high in the case of wooden windows;
- Reduced heat consumption is most evident in the apartment on the third floor, where windows were replaced, resulting in the reduction of approximately 18%;
- The apartment on the first floor, where the sealing of windows impact the reduction of ventilation losses, has savings of about 12% annually, and
- Finally, calculation methods and use of weather data for TMY provide results that are well consistent with the measurements on an annual basis.

Acknowledgements

The authors are indebted for financial support of Ministry of Science of the Republic of Serbia through grants No. 18228 and No. 18032.

Nomenclature

A	- area [m ²]	n	- number of air changes per hour [achh ⁻¹]
a	- numerical parameter depending on the time constant [-]	Q	- quantity of heat per hour [Jh ⁻¹], [kW]
c	- specific heat capacity [kJkg ⁻¹ K ⁻¹]	q	- specific heat flux [Wm ⁻²]
d	- days per year coefficient [da ⁻¹]	R	- heat resistance [m ² KW ⁻¹]
h	- height [m]	S	- net floor area [m ²]
m	- mass flow rate [kgh ⁻¹]	s	- hours per day coefficient [hd ⁻¹]

T	– thermodynamic temperature [K]	ρ	– density [kgm^{-3}]
ΔT	– temperature difference [$^{\circ}\text{C}$]	Φ	– heat flow rate for the heating mode [kW]
t	– temperature [$^{\circ}\text{C}$]	φ	– relative humidity [%]
U	– thermal transmittance [$\text{Wm}^{-2}\text{K}^{-1}$]		
\dot{V}	– volumetric air flow rate [m^3h^{-1}]		
w	– wind speed [ms^{-1}]		

Greek letters

γ	– heat balance ratio for the heating mode [–]
δ	– layer thickness [cm]
η	– gain utilization factor [–]
λ	– thermal conductivity [$\text{Wm}^{-1}\text{K}^{-1}$]
μ	– water vapor diffusion resistance factor [–]

Subscripts

H	– heating
H,gn	– heat gains for the heating mode
H,ht	– heat transfer for the heating mode
H,nd	– heat needed for continuous heating
int	– internal heat gains
sol	– solar heat gains
tr	– transmission
v	– ventilation

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Paper submitted: April 30, 2010

Paper revised: July 3, 2010

Paper accepted: July 5, 2010

