ENERGY PERFORMANCE OF SINGLE FAMILY HOUSES IN SERBIA
Analzsis of Calculation Procedures

by

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Energy certification of buildings in Serbia was introduced in 2011 and energy label depends on energy need for heating per unit floor area of heated space, calculated by the fully prescribed monthly quasi-steady-state method defined by ISO 13790. In the Republic of Serbia, most of families live in single-family houses built before the energy certification of buildings was introduced. Therefore, the estimation of energy performance of the existing buildings is important for labeling, and evaluation of energy saving measures and energy strategies to be implemented. This paper examines the applicability of monthly method defined by National legislation on the existing buildings stock in Serbia, by comparing it to the more accurate dynamic simulation method. Typical single-family houses are taken as a test case, since they are responsible for about 76% of energy consumption for heating. The results show that the dynamic simulation method estimates 21% to 54% higher energy need for heating, compared to the monthly method. Also, the monthly method estimates up to 13% higher savings by typical building envelope energy saving measures, compared to the dynamic simulation. This paper recommends improvement in procedures for calculation of building energy performance index to better assess energy consumption, effects of energy saving measures, and create solid background for developing and implementing of energy saving strategies.

Key words: *energy certification, single-family houses, quasi-steady-state method, dynamic simulation method*

Introduction

The building sector is responsible for about 40% of total final energy use and 36% of total CO_2 emissions in EU [1] . Increasing energy efficiency and use of RES in the building sector are fundamentally important for decrease of EU dependency on energy imports, fossil fuels consumption and GHG emissions. Consequently, European legislation has set out a cross-sectional framework of targets for achieving high energy performances in buildings. Key parts of this European regulatory framework are the Energy Performance of Buildings Directive 2002/91/EC (EPBD) [1], and its recast [2]. Among other objectives directive contains the requirement for a building energy performance certificate as *a certificate recognized by the Member State which includes the energy performance of a building calculated according to a methodology*. The transposition of these Directives into national legislation, influences the achievement of energy saving targets.

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Based on the EPBD [1, 2], the Republic of Serbia, as a member of the Energy Community, introduced building energy regulations and certification in 2011. The Rulebook on Energy Efficiency of Buildings [3] and the Rulebook on Conditions, Content and Manner of Issuance of Certificates of Energy Performance of Buildings [4] established annual energy need for heating per unit floor area of heated space $q_{\mathrm{H,nd}}$ as the key energy performance indicator (EPI), used for building energy labeling. The Rulebook [3] also defines the fully prescribed monthly quasi-steady-state method based on EN ISO 13790 [5] as calculation methodology for $q_{\mathrm{H,nd}}$.

To achieve a suitable grading of buildings and relevant label based A-G bands, it is crucial to consider creating building energy performance database and benchmarking in the conception, development and implementation of energy efficiency policies. Gathering energy information to populate a database with a representative sample of the building stock is not only expensive but also technically complex. It is not surprising that only a few nations have undertaken this task to date [6]. A more cost-effective approach to database generation is the application of building energy simulation to a variety of building types. Careful selection of building types and calculation methods is critical to the validity of the database [7]. Wang *et al.* [8] provided the review on quantitative energy performance assessment methods for existing buildings. Authors gave short description of dynamic simulation and steady state methods and their applications.

Various efforts have already been made to estimate energy performance of the existing buildings in Serbia. Jovanović and Kavran [9] have analyzed, from architectural perspective, some key features of Serbian buildings stock and their energy performance and discussed buildings renewal strategies and their impact on energy savings. Vučićević *et al.* [10] used more analytical approach. They used dynamic simulation method based on TRNSYS 16 software to assess thermal performance of residential buildings in Belgrade and different energy saving strategies. They have shown that dynamic simulation results agree with measurements on existing buildings.

Regarding the single-family houses in Serbia, Turanjanin *et al.* [11] have used calibrated dynamic simulation in TRNSYS 17 as an assessment method of energy and economic performance of different heating systems.

The aim of this paper is to properly assess current certification procedures on the existing buildings stock and suggest improvements, by testing the calculation procedure of buildings EPI defined in [3], against the existing buildings stock in Serbia. The focus is on the most common types of single-family houses denoted as type A, type B, and type C. The results obtained by the fully prescribed monthly quasi-steady-state method are compared against the results obtained by more detailed and accurate calculation procedure based on the dynamic simulation in TRNSYS 17.

Existing buildings stock

For the Republic of Serbia, energy balances show that the building sector is responsible for 40% to 50% of total primary energy consumption. According to the National buildings typology, based on the Tabula project methodology [12], residential building stock in Serbia needs annually, only for heating, about 65 million MWh. About 76% of this consumption pertains to single-family houses and 24% to multi-family houses. The focus of this paper is on the existing single-family houses, since according to [12] 90% of families live in a single-family houses.

Usually, single-family houses are one-story or two-story free-standing houses. The construction system is with small spans, and as the rule construction material used is brick or brick block with slabs also with clay blocks. The use of thermal insulation in building envelope started approximately twenty years ago, its thickness does not exceed 5cm [9].

Building types examined in this paper are free-standing, single-family houses, built between 1946 and 1990. They comprise for about 70% of all family houses in Serbia. This paper analyses single family houses which are, according to [12], grouped in one of three types, regarding their period of construction, morphological, and thermo-physical characteristics of the envelope. Those are type A (built between 1946 and 1970), type B (1971-1980), and type C (1981-1990). A typical geometry for specific types, described in [12] was used for creating 3-D models of buildings.

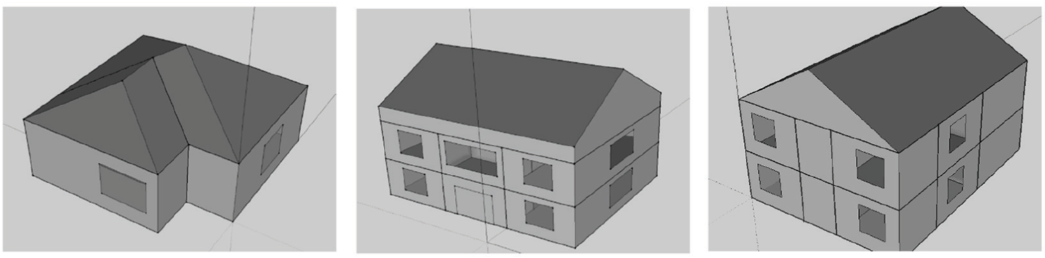

Figure 1. Examined typical geometry for building type A, type B and type

Type A is a free-standing single-family ground floor house, built between 1946 and 1970. This type was built in a massive construction system. The façade walls are of 38 cm solid brick, plastered on both sides. The foundation floor construction is a concrete slab on the filling, with no thermal insulation. The floor to the loft is wooden of the Karatavan type with the ceiling in the rendered reed. The windows are wooden two single pane sashes in wide casements, additionally equipped with external blinds.

Type B is a free standing single-family house with two floors, built between 1971 and 1980. The construction system is massive, with 38 cm brick façade walls similar to type A and concrete floors. The windows are wooden double sashed with single panes and wooden roller blinds. The gabled roof is a traditional wooden construction.

Type C is a free standing single-family house with two floors, built between 1981 and 1990. The façade walls are of 38 cm solid brick, plastered on both sides. There is minimal thermal insulation installed in the key elements of the thermal envelope, including 5 cm insulation in the external walls and 10 cm thermal insulation in the floor construction to the unheated attic. The roof is gabled, with short eaves and thermal insulation.

Calculation procedures

The fully prescribed monthly quasi-steady-state method and the dynamic simulation method are used to calculate annual energy need for heating and results are compared. Same values of input parameters and coefficients are used for both calculation methods. This refers to weather data for the Belgrade region (−12.1°C outdoor air design heating dry bulb temperature) for heating, building geometry, thermophysical properties of the building envelope including overall ventilation heat loss coefficient, H_V, and operating schedule of the heating system. However, there is a difference in using weather data. For the monthly method, the number of heating degree days (HDD) and average values for monthly solar irradiation are used, while for dynamic simulation, the hourly values for outside air temperatures and solar irradiation are used (TMY weather file). For both methods, space temperature of the heated space was 20 °C.

The monthly method calculates separately the transmission heat losses, infiltration heat losses, and solar heat gains and then sums them up to determine energy need for heating. This approach does not consider interactions between different heat transfer mechanisms, radiative heat losses to the surroundings, and the influence of building thermal mass. Geometric information needed for the monthly method are the thickness, and surfaces orientations and areas of the envelope elements. On the other hand, the dynamic simulation method requires 3-D model of the building thermal envelope surfaces.

Several dynamic methods are available in literature, such as the transfer function method (TFM) proposed by AHSRAE and, recently, the Heat Balance method or the simplified radiative time series (RTS) method [13]. The TFM method has found commercial application in calculation programs, such as TRNSYS [14] or Energy Plus [15]. In this paper TRNSYS 17 software is used.

Both methods, the monthly method and the dynamic simulation, are used to calculate annual energy need for heating per unit floor area of heated space $q_{H,nd}$, excluding internal gains from electrical appliances and people, for each building type and for different orientations: 0°, 90°, 180°, and 270°.

Since [3] prescribes maximum allowable U-values for different parts of the building envelope (external walls, windows, *etc*.), building types A, B, and C were analyzed for two scenarios: the original envelope construction, tab. 1 and construction after energy retrofit, tab. 2. In practice, energy retrofit usually means adding 8 cm thick insulation layer and changing existing windows with energy-efficient ones to achieve U-values within allowable limits defined by [3].

Table 1. U-values for building original thermal envelope elements [Wm^{-2}K^{-1}] [12]

	External walls	Windows	Ground floor	Ceiling towards unheated attic	Roof
Type A	0.97	3.50	1.70	0.93	2.65
Type B	0.97	2.80	1.48	2.30	2.65
Type C	0.50	2.80	1.48	0.30	0.32

Table 2. U-values for building thermal envelope elements after energy retrofit [Wm^{-2}K^{-1}]

	External walls	Windows	Ground floor	Ceiling towards unheated attic	Roof
Type A	0.34	1.30	0.39	0.33	0.35
Type B	0.34	1.30	0.39	0.35	0.35
Type C	0.34	1.30	0.39	0.30	0.32

Glass transmissivity, g_{gl},values are adopted according to [3-14]. Value for the existing windows is 0.755, while for energy-efficient windows used for the retrofit scenario, assumed value is 0.591. After energy retrofit, the airtightness of the building envelope is also improved. Therefore, values of H_V = 0.8 W/K for average sealing of the existing houses and H_V = 0.5 for good sealing after retrofit are adopted [3].

Fully prescribed monthly quasi-steady-state method

The fully prescribed quasi-steady-state method defined by [3] is robust and simple. For each building zone and each calculation step (month), the building energy need for space heating

for conditions of continuous heating is calculated. The main presumptions and simplifications of the monthly quasi steady-state method are:
- Calculation of infiltration and ventilation losses is based on the number of HDD for building location (Belgrade).
- Calculation of temperature of adjacent unheated spaces is based on the correction factor F_{xi}, which has a fixed value defined according to unheated space type (corridor, attic, *etc*.).
- Calculation of solar gains is based on average monthly values of solar irradiation for building location.
- The effects of building thermal mass are taken into consideration only through the gains utilization factor, $\eta_{H,gn}$, (for family houses in Serbia its value is 0.98 according to [3]).

The calculation procedure is explained with eq. (1)-(10):

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gh}\,Q_{H,gn} \tag{1}$$

where $Q_{H,nd}$ is the annual energy need for heating, $Q_{H,ht}$ – the total heat transfer for the heating mode, determined in accordance to eqs. (3) and (4), and $Q_{H,gn}$ – the annual heat gains.

The annual energy needs for heating, per unit floor area of heated space:

$$q_{H,nd} = \frac{Q_{H,nd}}{A_f} \tag{2}$$

The total heat transfer for the heating mode includes heat transfer by transmission, Q_T, and heat transfer by ventilation, Q_V:

$$Q_{H,ht} = Q_T + Q_V \tag{3}$$

$$Q_{H,ht} = (H_T + H_V)\,24\,HDD \cdot 10^{-3} \tag{4}$$

where H_T is the overall heat transfer coefficient by transmission, adjusted for the indoor-outdoor temperature difference (if applicable) and H_V is the overall ventilation heat loss coefficient, adjusted for the indoor-outdoor temperature difference (if applicable).

$$H_T = \sum_i (F_{xi}\,U_i\,A_i) + H_{TB}, \quad H_{TB} = 0.1\,A \tag{5}$$

$$H_V = 0.33 \sum_i V_i\,n_i \tag{6}$$

where H_{TB} are building transmission losses due to cold bridge effects.

$$Q_{H,gn} = Q_{int} + Q_{sol} \tag{7}$$

Annual heat gains $Q_{H,gn}$ include internal heat gains and solar heat gains:

$$Q_{sol} = F_{sh}\,A_{sol}\,I_{sol}\,\tau_{sol} \tag{8}$$

where $I_{sol}\tau_{sol}$ is the average monthly solar irradiation.

Equation (9) shows the effective solar collecting area of a glazed envelope element (*e.g.* a window):

$$A_{sol.gl} = g_{gl}\,(1 - F_F)\,A_W \tag{9}$$

Furthermore, eq. (7) indicates the effective solar collecting area of an opaque part of the building envelope

$$A_{sol,c} = \alpha_{s,c}\,R_{s,c}\,U_c\,A_c \tag{10}$$

Important presumption of the quasi-steady-state method is that all solar energy transmitted through windows is considered as useful heat gain as shown in eqs. (4), (8), and (9). In practice, this is not the case. Namely, not all solar energy transmitted through windows is kept inside thermal zone, but the portion is radiated back to the surroundings. Furthermore, not all solar energy kept within the thermal zone is used effectively to reduce energy need for heating. The reason for this is that the highest solar irradiation over the course of the day or heating season coincides with the highest outside air temperatures, resulting in space overheating by solar irradiation. Therefore, during the heating season, October 15 to April 15, solar irradiation will often lead to creating the cooling demand, instead of only covering for the heating demand. This is not considered by the monthly calculation method [3].

The interactions between different heat transfers mechanisms, effects of solar irradiation distribution over time, temperature distribution inside thermal envelope, temperature diffusivity and energy stored inside thermal envelope elements on energy consumption for heating, cannot be quantified with eqs. (1)-(10), but they are accounted for in the dynamic simulation.

Dynamic simulation method - TRNSYS 17

Compared to the monthly method, the dynamic simulation method increases accuracy, since it uses hourly values for temperatures and solar irradiation. Also, it considers interactions between different heat transfer mechanisms, radiative heat losses and the effects of the thermal mass of the building. The dynamic simulation uses weather and building data to solve set of energy balance equations for every hour during the simulation period.

In TRNSYS dynamic simulation, the elements of the thermal envelope such as walls are modeled according to the transfer function relationships of Mitalas and Arseneault [14] defined from surface to surface, fig. 2. For solar radiation so called Detailed Model - Gebhart Method is used.

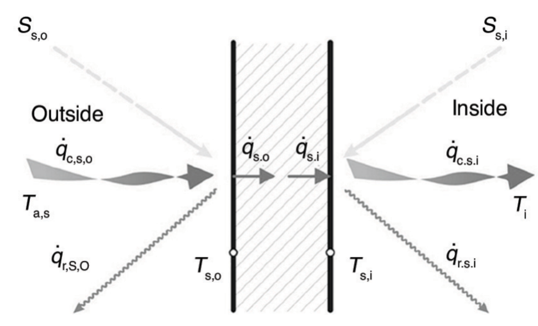

Figure 2. Surface heat fluxes and temperatures [14]

Energy balance equations include net radiative heat transfer $\dot{q}_{r,s,o}$ and $\dot{q}_{r,s,i}$ absorbed radiation heat fluxes $S_{s,o}$, $S_{s,i}$ condition heat fluxes $\dot{q}_{s,o}$ and $\dot{q}_{s,i}$, and convection heat fluxes $\dot{q}_{s,o}$ and $\dot{q}_{s,i}$. The detailed description of the TRNSYS mathematical model is avialable at [14].

Results and analysis

Results for both calculation procedures for building types A, B, and C and for different orientations and thermal envelope constructions are presented in tabs. 3-5. Energy need for heating, $q_{H,nd}$, solar energy transmitted through windows, q_{solt}, and infiltration losses, q_{inf}, all expressed per unit floor area of the heated space are calculated by the monthly method RBK and the dynamic simulation TRN, and compared. The difference in results obtained by the dynamic simulation is expressed in percentages relative to the monthly method.

In tabs. 3-5 higher values of overall heat transfer coefficient by transmission, H_T, correspond to the original construction of the building thermal envelope, while lower values correspond to the retrofit scenario. The shape factor, f_o, [3] is the ratio of building thermal envelope area and volume of heated space.

Table 3. Results for building type A (f_o = 1.26)

		$q_{H,nd}$			q_{solt}			q_{inf}		
	Rotation	RBK	TRN	diff.	RBK	TRN	diff.	RBK	TRN	diff.
Thermal envelope for original construction										
H_T = 1.079	0°	243	361	49%	125	105	– 16%	42	45	8%
	90°	236	363	54%	168	94	– 44%	42	45	8%
	180°	236	354	50%	168	150	– 11%	42	45	8%
	270°	243	356	47%	125	137	– 9%	42	45	8%
Thermal envelope for retrofit scenario										
H_T = 0.422	0°	92	103	11%	110	71	– 35%	26	28	8%
	90°	92	105	13%	111	64	– 43%	26	28	8%
	180°	86	96	11%	149	102	– 31%	26	28	8%
	270°	92	98	6%	111	93	– 16%	26	28	8%

Table 4. Results for building type B (f_o = 0.67)

		$q_{H,nd}$			q_{solt}			q_{inf}		
	Rotation	RBK	TRN	diff.	RBK	TRN	diff.	RBK	TRN	diff.
Thermal envelope for original construction										
H_T = 1.311	0°	172	209	22%	175	171	– 2%	43	46	8%
	90°	175	213	22%	151	133	– 12%	43	46	8%
	180°	178	216	21%	126	114	– 9%	43	46	8%
	270°	175	214	22%	151	133	– 12%	43	46	8%
Thermal envelope for retrofit scenario										
H_T = 0.450	0°	60	64	7%	128	103	– 19%	27	29	8%
	90°	62	68	9%	110	80	– 27%	27	29	8%
	180°	64	69	8%	92	70	– 24%	27	29	8%
	270°	62	67	9%	110	80	– 27%	27	29	8%

Table 5. Results for building type C (f_o = 0.76)

		$q_{H,nd}$ [kWhm^{-2}]			q_{solt} [kWhm^{-2}]			q_{inf} [kWhm^{-2}]		
	Rotation	RBK	TRN	diff.	RBK	TRN	diff.	RBK	TRN	diff.
Thermal envelope for original construction										
H_T = 0.730	0°	125	182	45%	128	122	– 5%	43	46	8%
	90°	125	182	46%	128	114	– 11%	43	46	8%
	180°	125	182	45%	128	122	– 5%	43	46	8%
	270°	125	182	46%	128	114	– 11%	43	46	8%
Thermal envelope for retrofit scenario										
H_T = 0.425	0°	68	67	– 1%	99	83	– 16%	27	29	8%
	90°	68	68	0%	99	78	– 22%	27	29	8%
	180°	68	67	– 1%	99	83	– 16%	27	29	8%
	270°	68	68	0%	99	78	– 22%	27	29	8%

For of building types A, B, and C original envelope constructions, characterized with poor thermal insulation *i.e.* higher values of overall heat transfer coefficient H_T (1.07, 1.311, and 0.73, respectively), dynamic simulation gives significantly higher values for $q_{H,nd}$ compared to the monthly method. Depending on the geometry, f_o, and thermal envelope characteristics, the relative difference is from 21% for type B to 54% for type C. Results show that for examined building types orientation does not have significant influence on $q_{H,nd}$ values. The reason is small share of windows are in external envelope (10% to 15% of the vertical envelope area) and relatively symmetric geometry of buildings – almost square base, with a similar share of windowed area for each orientation. Results for infiltration losses obtained by the dynamic simulation are 8% higher for all analyzed setups.

To analyze how different values of input variables and EPI, such as H_T, H_V, f_o and relative size of widowed area, influence comparability of results obtained by the monthly method and the dynamic simulation, the special theoretical cases are investigated. Namely, single-floor and two-floor, free-standing, single-family houses, with a rectangular base and no thermal insulation (similar to type A and type B) are used. Houses with these features comprise for more than 60% of single-family houses in Serbia [12]. Energy retrofit scenario, which includes two typical energy saving measures - adding thermal insulation on external walls and ceiling to unheated attic, and replacing existing windows with energy efficient ones – is also analyzed.

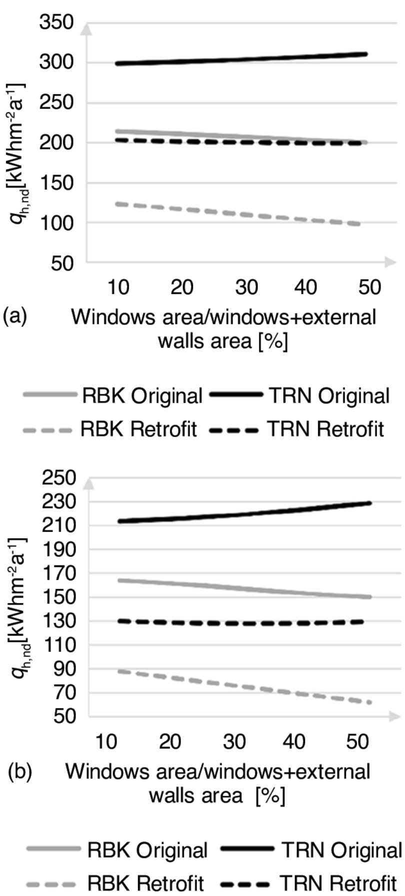

Figure 3. Heating energy needed for theoretical; (a) single-story house with square base and (b) two-story house with square base

Results are illustrated at fig. 3 and they show that the difference between dynamic simulation and the monthly method results increases as the shape factor f_o decreases (*i.e.* number of floors decreases) and windowed area increases.

Same as for the building types A, B, and C, analysis shows that the monthly method underestimates transmission and radiation losses through the envelope and overestimates the effect of solar heat gains on the reduction of heating energy need. The overestimation of solar gains and their effect on heating energy need is evident since per the monthly method an increase of widowed area, leads to a linear decrease of energy need for heating, fig. 3. Dynamic simulation, which incorporates hourly irradiation values and detailed radiation model, including radiative losses through the envelope, does not confirm this dependency.

Overestimation of solar gains and underestimation of transmission losses by monthly method compared to more accurate dynamic simulation affectc the estimation of energy savings by energy efficiency measures. Estimated savings for adding 8 cm insulation to external walls and ceiling to unheated attic, and windows replacement are shown on fig. 3.

Estimation of savings from individual measures, including external walls insulation, windows replacement and roof insulation, calculated by the monthly method and dynamic simulation, are further explained and presented on fig. 4. Savings are calculated for single-story and two-story house where windowed area is 10% of the external vertical envelope (external walls including windows and doors).

The estimated savings achieved by only adding 8 cm of thermal insulation to external walls and ceiling to unheated attic are 33% for single-story, and 34% for two-story house by the monthly method compared to 23% for single-story, and 26% for two-story house according to the dynamic simulation. Estimations of the energy savings from the windows replacement by the monthly method and dynamic simulation are in good accordance and they show 15% and 14% savings, respectively, for two-story, and 9% savings for the single-story house by both methods.

Savings from insulating the roof above the unheated attic are not accounted for by the monthly method, since unheated attic temperature is expressed through prescribed temperature adjustment factor, which has constant value of $F_x = 0.8$, regardless of the U-value of the roof construction.

On the other hand, the dynamic simulation, which uses energy balance to calculate unheated attic hourly temperature, shows that by insulating roof, 8% or 10% savings can be achieved for the single-story and the two-story houses respectively. The issue of temperature adjustment factor was also addressed by Rajčić *et al.* [16].

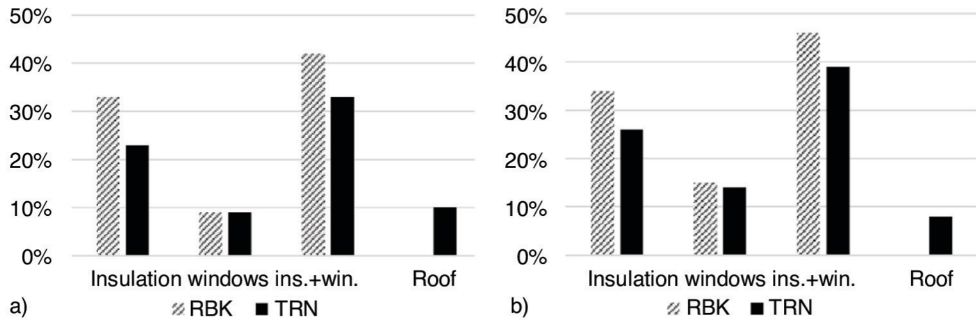

Figure 4. Estimated savings from energy efficiency measures for theoretical; (a) single-story house and (b) two-story house

Concusions

The fully prescribed monthly quasi-steady-state method defined by [3], was tested against the existing Serbian buildings stock, Belgrade climate conditions, and compared to more detailed and accurate calculation by the dynamic simulation in TRNSYS 17. Results and analysis show that for the existing buildings stock the monthly method can be used adequately only to qualitatively rate building envelope thermal performance. Compared to more detailed calculation procedure, it underestimates energy need for heating of the existing buildings by 21% to 54%, depending on geometry and thermal properties of the envelope. Also, solar heat gains and their effects on energy need for heating are overestimated by the monthly method, which is particularly problematic for building constructions with higher percentage of windowed area.

This paper suggests that the dynamic simulation should be used over the monthly calculation method to gain relevant information on energy performance of existing single-family houses in Serbia and create a national database, necessary for the benchmarking. The use of the dynamic simulation as a calculation method would increase the validity of the results, provide more detailed information and a wider variety of outputs, while the only additional input required for the dynamic simulation, compared to the monthly method, is 3-D model of the building envelope surfaces.

The use of the dynamic simulation is also recommended for evaluation of different energy saving strategies and measures, since the monthly method tends to overestimate the effect of typical building envelope energy saving measures like insulating the external walls, while completely failing to recognize measures like roof insulation improvement.

Future research efforts should focus on further development of the building energy certification scheme in the Republic of Serbia. The key issues include the update of EPI definition, development of the national buildings energy performance database and the update of A-G bands reference scale.

Nomenclature

A_c – projected area of the opaque part, [m^2]
A_{sol} – effective solar collecting area of the building envelope, [m^2]
A_f – floor area of the heated space, [m^2]
A_w – overall projected are of the glazed element (*e.g.* window area), [m^2]
F_F – frame area fraction in accordance with, [3]
F_{sh} – shading reduction factor in accordance with, [3]
F_{xi} – temperature adjustment factor
f_o – shape factor in accordance with, [3]
g_{gl} – total solar energy transmittance of the transparent part of the element
H_T – overall heat transfer coefficient by transmission, [WK^{-1}]
H_{TB} – building transmission losses due to cold bridge effects, [WK^{-1}]
H_V – overall ventilation heat loss coefficient, [WK^{-1}]
HDD – number of heating degree days
I_{sol} – annual solar irradiance, per unit area of collecting area of surface, [Wm^{-2}]
n – number of air changes per hour
$T_{s,i}$ – inside surface temperature
$T_{s,o}$ – outside surface temperature
$T_{a,s}$ – ambient temperature
T_i – inside temperature
$Q_{H,ht}$ – total annual heat transfer for the heating mode, [kWh]
$Q_{H,gn}$ – annual heat gains, [kWh]
$Q_{H,nd}$ – annual energy need for heating, [kWh]
$\dot{q}_{H,nd}$ – annual energy need for heating per unit floor area of heated space, [kWhm^{-2}]
$\dot{q}_{c,s,i}$ – convection heat flux from the inside surface to the air
$\dot{q}_{c,s,o}$ – convection heat flux to the outside surface from the boundary/ambient
$\dot{q}_{r,s,i}$ – net radiative heat transfer with all other surfaces within the zone
$\dot{q}_{r,s,o}$ – net radiative heat transfer with all surfaces in view of the outside surface
$\dot{q}_{s,i}$ – conduction heat flux from the wall at the inside surface
$\dot{q}_{s,o}$ – into the wall at the outside surface
$\dot{q}_{solt}$ – annual solar energy transmitted through windows, [kWhm^{-2}]
$\dot{q}_{inf}$ – annual infiltration losses, per unit area of heated space, [kWhm^{-2}]
$R_{s,c}$ – external surface heat resistance of the opaque part, expressed in square metre·kelvin per wat, [m^{2}KW^{-1}]
$S_{s,i}$ – radiation heat flux absorbed at the inside surface (solar gains and radiative gains)
$S_{s,o}$ – radiation heat flux absorbed at the outside surface (solar gains),
U_c – thermal transmittance of the opaque part, [Wm^{-2}K^{-1}]

Greek symbols

$\alpha_{s,c}$ – absorption coefficient for solar radiation of the opaque part, in accordance with, [3]
$\eta_{H,gn}$ – gains utilization factor, in accordance with, [3]
τ_{sol} – length of the considered month or season, in accordance with, [3]

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