Natália JASMINSKÁ, Katarína AZÁRIOVÁ, Tomáš BRESTOVIČ
Technical University in Kosice, Slovakia

SYSTEM FOR CALCULATING AND MODELING THE OPTIONS TO IMPROVE THE ENERGY EFFICIENCY OF THE BUILDING

The greatest potential for energy savings can be achieved in the residential sector, where nearly 40% of final energy consumption is spent in all the types of buildings. That's why the energy saving is the key goal of this age, because big part of the produced energy is spent just in dwellings, in which we live and work. Main part of spent energy in dwellings represents the space heating. So it is important to know how much energy is needed for the dwelling operation and what the opportunities to decrease the total energy are.

Keywords: building, energy efficiency, calculating, modeling

INTRODUCTION

Main focus to save the energy in dwellings has to be on already existing family houses, where the option of restoration and reconstruction is faster and less restricted compared to apartments, offices and other buildings, mainly because of faster financial realization and more options for altering the improvements. Also calculation of the heat loss of the object is less complicated for family houses than for other buildings. Saving shouldn't be reached only when it comes by implementing new technologies, building new almost zero energy houses, but it can be reached by renovating old buildings that are not energy efficient enough.

Figure 1 shows that the trend of energy consumption in the buildings in European diameter is growing. The trend in energy consumption for the residential sector in Slovakia after the fall recorded in 2007 is again increased and returns to the status recorded in 2006 [1, 2].

In order to reduce energy dependence on monopoly suppliers, are the common residents of family houses just through installing devices that use renewable energy sources (RES), or by the thermal insulation done by themselves many times. This reduces the portion of energy supplied.

Tool for identifying the energy loan of the building is the certification process of evaluation of the building. This is the main indicator for further improvements in this area.

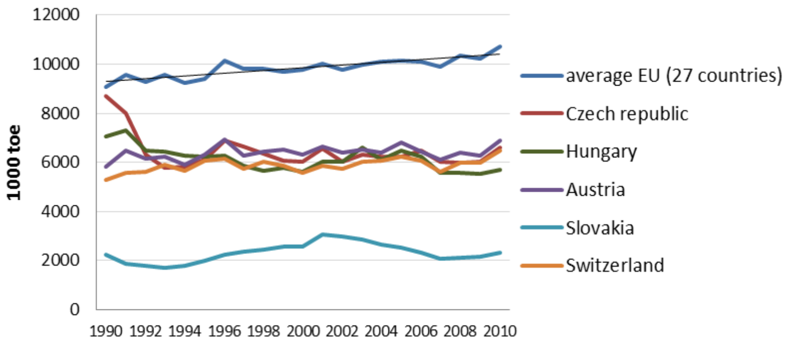

Fig. 1. Trend of spent energy in building sector for chosen countries
(1000 tones of oil equivalent)
Source: EUROSTAT

For existing buildings energy certification process is voluntary, so the owner does not have the basic information about how the house "managed" the energy.

1. STRATEGY

Energy performance of buildings (EPB) is determined on the basis of the calculated or actual annual energy consumption to meet the different needs associated with its typical use. It reflects the energy needs for heating, hot domestic water (HDW) preparation, cooling and lighting designed to maintain the set temperature conditions for buildings.

The energy performance of a building shall be expressed in a transparent manner and shall include energy efficiency and numeric indicators of primary energy consumption based on the primary energy factors for each energy carrier. Those carriers should be based on national or regional weighted averages or specific value for on-site production. The methodology for calculating the energy performance of buildings should take into account European standards and the methodology should be in accordance with relevant Union legislation [3, 4].

Since the energy certification for the buildings is required by 2006, only when sold or rented and by the completion of a new building or after major renovation for existing buildings, for other cases it is voluntary, there is not enough interest in these cases to establish the energy efficiency of buildings [5, 6].

On the other hand, mandatory certificated buildings have to have listed into certificate proposals of actions to improve the EPB, especially by the improving the thermal insulation properties of the building envelope and by incensement of technological efficiency and energy equipment of the building. In terms of increased construction costs these recommendations, however, are only slightly realized.

In a review of the certification process in Slovak Republic (SR) there is not available information about the projects and the realized thermal insulation of residential houses from owner's resources. There is also missing an overview of the operating evaluation, which would provide a realistic view of the achievable energy savings of buildings after reconstruction. These facts affect the assessment of the share of residential sector in total final energy consumption of SR.

One of the reasons that forced the homeowners to determine its energy needs are the costs associated with its use and efforts to implement actions to reduce it.

2. SCOPE OF CALCULATING MODEL

There are several calculating tools accessible via websites, which are managed by project-consulting companies. These companies offer on their sites simplified calculating tools, which have mostly predefined generalized computing values for the reference building and its total loss of energy and needs may vary significantly from reality. Implementation of the calculations for a particular object is available only after order of consulting service. In the final calculation there is often commercial reference to suitability of implement the corrective actions only through specific manufacturer, then the owner has no choice.

2.1. Implementation of the proposed actions to improve the EPB

Owners of existing buildings in order to reduce the costs for heating and HDW preparation as well as in order to avoid an increase of investment by contractors, have tried to implement EPB improving actions themselves and it is not just through thermal isolation of circuit walls, but also by the installation of new technologies based on renewable energy sources (RES), of course with the minimum interference in current technology.

To ensure that the implementation of these innovative actions is the most effective and it is helpful for homeowners to determine the approximate cost and returns of investment, it is necessary to have calculation for the energy loan of the building.

3. PROPOSAL FOR CALCULATING MODEL

There is proposed model of software support for already existing technical equipment whose purpose is to evaluate the current status, where the owner of the building can calculate the energy needs. Model works with the different combinations and choosing criteria where user can easily, through input of entry data in the simple application, model the solutions to improve the EPB. In this program you can easily realize energy saving by the proposed new construction types. This model works for family houses.

There is taking into consideration only one temperature zone as a simple calculation. This tool is used to be for quick reference on the EPB issue and for proposal of reducing the energy loan of the building.

3.1. Calculation tool for determining the energy needs for heating

Software tool includes the calculation of the total annual energy needs for heating of the observed object. Methodology of calculations is as follows:

1. Determine the climate zone where the building is located, database choosing. When the building is not ranked in the database, the user must choose the nearest location of database selection.
2. Enter the basic dimensions of the building, total floor area, the volume of heated space V_i, the real number of heating days and the basic conversion factors to determine the efficiency and performance of the heating system.
3. User through the simple selection criteria defines the characteristic of the building, which is given by external cooling surfaces. Computational assessment is made on the basis of the simplified method in accordance with *STN EN 12831: Heating systems in buildings. The method of calculation of the design heat input.* The values of heat transfer coefficients of all the constructions are calculated according to the standards of thermal technical properties of building structures and buildings.
4. Based on the dimensional characteristics and of a defined input parameters there is performed automatic calculation of the total specific and of the total heat loss from heat transfer and ventilation.
5. Annual energy demand for heating is calculated with respect to all the heat losses, the efficiency of the heating system, the real duration of the heating season and of flat rate solar heat gains.

In the spreadsheet there is able to return by clicking on the appropriate cell to the initial input sheet, it is also possible to see the notes for the correction factor f_k, which takes into account the level of insulation of thermal bridges.

The other lines in total calculation displayed the total calculated heat loss of the building in kW and annual energy demand in GJ·year^{-1} or in kWh·year^{-1}, which was calculated by the approximate equation (1).

Approximate equation for annual energy demand for heating

Total specific heat loss by heat transfer:

$$H_{T,i} = \sum_k f_k \cdot A_k \cdot U_k \quad [\mathrm{W \cdot K^{-1}}] \tag{1}$$

Total heat loss by heat transfer:

$$\Phi_{T,i} = H_{T,i} \cdot \left(\theta_{int,i} - \theta_e\right) \quad [\mathrm{W}] \tag{2}$$

Total specific heat loss of ventilation:

$$H_{V,i} = 0.34 \cdot V_i \cdot n_{min} \quad [\mathrm{W \cdot K^{-1}}] \tag{3}$$

Total heat loss of ventilation:

$$\Phi_{V,i} = H_{V,i} \cdot \left(\theta_{int,i} - \theta_e\right) \quad [\mathrm{W}] \tag{4}$$

Total heat loss of the building:

$$\Phi_i = \Phi_{T,i} \cdot \Phi_{V,i} \cdot f_{\Delta\theta,i} \cdot 10^{-3} \quad [\mathrm{kW}] \tag{5}$$

Total heat loss of the building:

$$Q_{heat} = \frac{\varepsilon}{\eta_o \cdot \eta_r} \cdot \frac{24 \cdot \theta_i \cdot D}{\left(\theta_{int,i} - \theta_e\right)} \cdot 3.6 \cdot 10^{-3} \quad [\mathrm{GJ} \cdot \mathrm{year}^{-1}] \tag{6}$$

when:
f_k - thermal corrective factor (–), A_k - total floor area (m^2), U_k - heat transfer coefficient (W·m^{-2}·K^{-1}), $\theta_{int,i}$ - internal calculating temperature (°C), θ_e - external calculating temperature (°C), V_i - volume of the heated space (m^3), n_{min} - minimum intensity of outdoor air exchange per hour (1·h^{-1}), $f_{\Delta\theta,i}$ - temperature correction factor, which takes into account the additional heat loss of rooms heated to a higher temperature than the adjacent heated room (–), ε - coefficient relating to the type of family house control heating (–), η_o - operating efficiency or ability to regulate the system (–), η_r - efficiency of the heating distribution (–), Φ_i - total thermal loss of the object (kW), D - heating degree days calculated based on the actual length of the heating season (K·day^{-1}).

4. EVALUATION OF THE SYSTEM

After entering all the actual parameters the homeowner has an overview what is the approximate annual energy demand for heating.

In the modeling section of the building characteristics, which is determined by the total heat loss, the homeowner can model how the benefit is after the implementation of corrective actions when selecting another type of construction. Whether the thermal insulation of exterior walls, floor, ceiling or windows and doors replacement for the higher quality.

After selection of the changes for new construction types, it is possible the immediate comparison of reduction of heat loss through the indicator of the total annual energy demand for heating.

Evaluation through an example

Location: Banská Bystrica, Slovakia
No. of heating days: 201 days
Building: one floor older, without basement
Total floor area: 150 m^2
Volume of the building: 500 m^3
Heating: standard natural gas boiler, older distribution

Construction type:

- ✓ Circuit walls without insulation: cross perforated standard bricks (th. 375 mm)
- ✓ Floor: plain concrete with the older insulation (th. 150 mm)
- ✓ Windows: older type double glazing, diameter 1.5×1.5 m (7 pc) + 0.5×0.5 m (2 pc)
- ✓ Doors: wooden with the glazing part, diameter 0.9×2 m and standard older fully wooden, diameter 0.8×2 m
- ✓ Ceiling: with the non-heated unoccupied attic, material HURDIS type

After input of all the building characteristics the model is calculating the total heat losses (see Fig. 2).

Back

Notes to fk	Description of item	Construction (selection)	Widt (m)	Lenght (m)	Ak (w·l) (m^2)	material thick./ thick. of insulation	fk-acc. to the insulation of thermal	Uk ($W{\cdot}m^{-2}{\cdot}K^{-1}$)	Ak.Uk.fk ($W{\cdot}K^{-1}$)
	Total floor area	floor	10,00	15,00	150,00	on land-Plain concrete (150 mm, old insulation)	1,26	0,60	113,40
	circuit construction	outer walls	2,98	16,98	50,60	Brick cross perforated (375 mm, without insulation)	1,40	1,46	103,43
	circuit construction	outer walls	2,98	26,43	78,76	Brick cross perforated (375 mm, without insulation)	1,40	1,46	160,99
	ceiling	ceiling	10,00	15,00	150,00	wit the attic-HURDIS	1,26	1,40	264,60
	all windows 1,5 x 1,5m (7pc)	window	10,50	1,50	15,75	old - double glazing	1,00	2,70	42,53
	all windows 0,5 x 0,5m (2 pc)	window	1,00	0,50	0,50	old - double glazing	1,00	2,70	1,35
	outer door 0,9 x 2m	outer door	0,90	2,00	1,80	wooden with the glazing part	1,00	4,70	8,46
	outer door 0,8 x 2m	outer door	0,80	2,00	1,60	the standard older	1,00	3,50	5,60

Fig. 2. Input of building construction characteristics

THE APROXIMATE CALCULATION OF THE HEAT LOSS OF THE BUILDING (STN EN 12831)

Area	**Banská Bystrica**				
External calculating temperature (θe)	-15,0	°C	Number of heating days (d)	201	day
Avr.annual outdoor temperature (θm, e)	8,0	°C	Heating degree days (D)	2412	K·day
Internal calculating temperature (**$\theta_{int,i}$**)	20,0	°C	Volume of the heated space (**V_i**)	400	m^3
Volume of the building (**V_b**)	500	m^3			
Total floor area (**A_k**)	150	m^2			
Temperature correction factor (**$f_{\Delta\theta}$**)	1,00				
Minimum intensity of external air exchange (**n_{min}**)	0,50	$1.h^{-1}$			
Heating regulation (**ε**)	0,63				
Operating efficiency (**η_o**)	0,90				
Efficiency of heating distribution (**η_r**)	0,95				

The total specific heat loss by heat transfer	**700,35**	$H_{T,i} = \sum_k f_k \cdot A_k \cdot U_k \quad (W \cdot K^{-1})$
The total heat loss by heat transfer	**24512,25**	$\Phi_{T,i} = H_{T,i} \cdot (\theta_{int,i} - \theta_e) \quad (W)$
The total specific heat loss of ventilation	**68,00**	$H_{V,i} = 0{,}34 \cdot V_i \cdot n_{min} \quad (W \cdot K^{-1})$
The total heat loss of ventilation	**2380,00**	$\Phi_{V,i} = H_{V,i} \cdot (\theta_{int,i} - \theta_e) \quad (W)$
The total heat loss of the building	**26,89**	$\Phi_i = \Phi_{T,i} \cdot \Phi_{V,i} \cdot f_{\Delta\theta,i} \cdot 10^{-3} \quad (kW)$
ANNUAL ENERGY NEED FOR HEATING Q_{heat}	**106,48**	$Q_{heat} = \frac{\varepsilon}{\eta_o \cdot \eta_r} \cdot \frac{24 \cdot \theta_i \cdot D}{(\theta_{int,i} - \theta_e)} \cdot 3{,}6 \cdot 10^{-3} \quad (GJ \cdot year^{-1})$
	29,58	$MWh{\cdot}year^{-1}$ **Construciti** **Hot water**

Fig. 3. The calculating tool to perform the annual energy needs for heating (initial condition)

When all the entries are filled, model is calculating all the losses of the building and also total energy demand per year (see Fig. 3).

4.1. Proposal for the corrective actions

One and easiest type of the suggestions for improving the EPB is to improve the thermal insulation characteristics of the exterior facade and also replace the windows and doors with the newer types with better heat transfer coefficient.

Then the building characteristics will be as follows:

- ✓ Circuit walls with new insulation th. 50 mm;
- ✓ Floor: plain concrete with the new insulation th. 80 mm;
- ✓ Windows: newer type from the producer who guarantee heat transfer coefficient $U_k = 0.7\ \mathrm{W \cdot m^{-2} \cdot K^{-1}}$;
- ✓ Doors: newer type from the producer who guarantees $U_k = 1.2\ \mathrm{W \cdot m^{-2} \cdot K^{-1}}$.

After input of all these new conditions into building characteristics the spreadsheet is as follows (see Fig. 4).

Back / Notes to fk	Description of item	Construction (selection)	Widt (m)	Lenght (m)	Ak (w·l) (m^2)	material thick./ thick. of insulation	fk-acc. to the insulation of thermal bridges	Uk ($W.m^{-2}.K^{-1}$)	Ak.Uk.fk ($W.K^{-1}$)
	Total floor area	floor	10,00	15,00	150,00	on land-Plain concrete [150 mm, 80mm]	1,26	0,23	43,47
	circuit construction	outer walls	2,98	16,98	50,60	Brick cross perforated [375 mm, 50mm]	1,40	0,52	36,84
	circuit construction	outer walls	2,98	26,43	78,76	Brick cross perforated [375 mm, 50mm]	1,40	0,52	57,34
	ceiling	ceiling	10,00	15,00	150,00	wit the attic-HURDIS	1,26	1,40	264,60
	all windows 1,5x1,5m (7 pc)	window	10,50	1,50	15,75	new quality (producer A)	1,00	0,70	18,90
	all windows 0,5x0,5m (2 pc)	window	1,00	0,50	0,50	new quality (producer A)	1,00	0,70	0,60
	outer door 0,9x2m	outer door	0,90	2,00	1,80	new quality	1,00	1,20	2,16
	outer door 0,8x2m	outer door	0,80	2,00	1,60	new quality	1,00	1,20	1,92

Fig. 4. Building characteristics model with the application of new conditions (corrective actions)

After input of all the entries for new construction types as the result is the final sheet with the new calculations, where the total heat loss of the selected house is $426\ \mathrm{W \cdot K^{-1}}$, what is by $274\ \mathrm{W \cdot K^{-1}}$ less than in previous calculation for the initial conditions.

The improvement of the total energy demand for the heating can be proved by comparison of the outputs:

1. **Total annual energy demand for the heating - initial conditions:**

$$Q_{heat,1} = 108\ \mathrm{GJ \cdot year^{-1}}\ \text{or}\ 30\ \mathrm{MWh \cdot year^{-1}}$$

2. **Total annual energy demand for the heating - after corrective actions:**

$$Q_{heat,2} = 68.44\ \mathrm{GJ \cdot year^{-1}}\ \text{or}\ 19.01\ \mathrm{MWh \cdot year^{-1}}$$

Then total savings are:

$$Q_{heat,1} - Q_{heat,2} = 39.56\ \mathrm{GJ \cdot year^{-1}}\ \text{or}\ 10.99\ \mathrm{MWh \cdot year^{-1}}$$

THE APROXIMATE CALCULATION OF THE HEAT LOSS OF THE BUILDING (STN EN 12831)

Area	**Banská Bystrica**			
External calculating temperature (θe)	-15,0	°C	Number of heating days (d)	201 day
Avr.annual outdoor temperature (θm, e)	8,0	°C	Heating degree days (D)	2412 K·day
Internal calculating temperature (**$\theta_{int,i}$**)	20,0	°C	Volume of the heated space (**V_i**)	400 m^3
Volume of the building (**V_b**)	500	m^3		
Total floor area (**A_k**)	150	m^2		
Temperature correction factor (**$f_{\Delta\theta}$**)	1,00			
Minimum intensity of external air exchange (**n_{min}**)	0,50	$1.h^{-1}$		
Heating regulation (**ε**)	0,63			
Operating efficiency (**η_o**)	0,90			
Efficiency of heating distribution (**η_r**)	0,95			

The total specific heat loss by heat transfer	**425,83**	$H_{T,i} = \sum_k f_k \cdot A_k \cdot U_k \quad (W \cdot K^{-1})$
The total heat loss by heat transfer	**14903,89**	$\Phi_{T,i} = H_{T,i} \cdot (\theta_{int,i} - \theta_e) \quad (W)$
The total specific heat loss of ventilation	**68,00**	$H_{V,i} = 0{,}34 \cdot V_i \cdot n_{min} \quad (W \cdot K^{-1})$
The total heat loss of ventilation	**2380,00**	$\Phi_{V,i} = H_{V,i} \cdot (\theta_{int,i} - \theta_e) \quad (W)$
The total heat loss of the building	**17,28**	$\Phi_i = \Phi_{T,i} \cdot \Phi_{V,i} \cdot f_{\Delta\theta,i} \cdot 10^{-3} \quad (kW)$
ANNUAL ENERGY NEED FOR HEATING Q_{heat}	**68,44**	$Q_{heat} = \frac{\varepsilon}{\eta_o \cdot \eta_r} \cdot \frac{24 \cdot \theta_i \cdot D}{(\theta_{int,i} - \theta_e)} \cdot 3{,}6 \cdot 10^{-3} \quad (GJ \cdot year^{-1})$
	19,01	**MWh·year^{-1}** **Construciti** **Hot water**

Fig. 5. The calculating tool to perform the annual energy needs for heating (after corrective actions)

4.2. Economical evaluation of the proposed corrective actions

In the price appreciation for the total costs on new material there are not included the work service prices, what can vary from the type of contractor. In this case we can count with the self-realization of carried out works, where the price of service is excluding from the total price appreciation.

- ✓ Price for insulation material (mineral wool th. 50 mm, extruded polystyrene 30 mm, floor insulation th. 80 mm) 3000 Euro
- ✓ Price for other material (glue, fasteners, glass-fiber mesh, bonding primer, plaster, metal rails and bars) 2500 Euro
- ✓ Price for new windows and doors 2000 Euro

1. **Approximate total investment for the new material: 7500 Euro**

   When the upper calorific value of natural gas is $H_i = 9.5$ kWh·m^{-3}, then with the total decreased energy by 10.99 MWh·year^{-1}, the natural gas saving is expressed by total volume 1157 m^3. To evaluate the price expression with the unit price 0.0386 Euro for 1kWh of the natural gas energy then:
2. **Total annual return through natural gas saving: 424 Euro**
3. **Total return of the investment: 18 years**

CONCLUSION

The homeowner can easily with the using of proposed calculating model evaluate his current status of the energy demand for the house and how are the energy heat transfer losses. He can use the calculating tool to model different conditions of the corrective actions and by that to see how the total energy demand is affected. This may be weather thermal insulation or replacement of windows and doors or to improve the heating distribution in the house.

From the evaluation of the investment returns, we can see that 18 years is to long period for the homeowners to invest. This also shows the suitability of the calculating model by the pre-evaluation of the future energy demands. Than the investor can calculate what is beneficial for him. As well as it points to the necessity to use other sources to decrease the energy demand, e.g. the RES techniques.

Acknowledgements

This article originated thanks to support within the Research and Development Operational Programme for the project: Centre for efficient integration of the renewable energy sources with the code ITMS: 26220220064, co-financed by the resources of the European Regional Development Fund.

REFERENCES

[1] Vranayová Z., Vranay F., Očipová D., Renewable energy for smart buildings in conditions of the Slovak republic, Journal of International Scientific Publication 2009, 3, 1, 486-493.

[2] Vranay F., Vranayová Z., Heating for intelligent building - case study, Visnik Nacionaľnovo universiteta, Ľvivska politechnika 2008, 627, 226-231.

[3] Tkáč J., Hvizdoš M., Distributed generation and renewable energy sources for sustainable life, [In:] Distributed Power Generation Systems, Plzeň: ZČU, 2005, 47-52.

[4] Urban F., Kučák Ľ., Analýza cien tepla pre konečného spotrebiteľa, Acta Mechanica Slovaca 2004, 8, 3-A, 591-596.

[5] Lichner M., Nagy R., Renovation of apartment buildings with respect to energy savings and greater efficiency, [In:] Energodom 2008, Materiały konferencyjne, Asterias, Kraków 2008, 271-278.

[6] Rybár R., Tauš P., Végsoov E., Daňko J., Návrh reštrukturalizácie systému výroby a dodávky tepla pre Deliusov pavilón = Suggestion of the heating system restructuralization for Delius pavilion, Acta Metallurgica Slovaca 2005, 11, 2, 225-230.

SYSTEM WYZNACZANIA I MODELOWANIA WARIANTÓW POPRAWY EFEKTYWNOŚCI ENERGETYCZNEJ BUDYNKÓW

Największy potencjał oszczędności energii tkwi w sektorze mieszkaniowym, który pochłania prawie 40% całkowitego jej zużycia dla wszystkich rodzajów budynków.

Oszczędzanie energii jest obecnie kluczowym celem działań, ponieważ duża jej część jest zużywana w mieszkaniach, w których żyjemy i pracujemy. Pokaźna część energii w mieszkaniach jest zużywana na ich ogrzewanie. W związku z tym ważne jest, aby wiedzieć, ile energii potrzeba do prawidłowego funkcjonowania mieszkania i jakie są możliwości obniżenia jej zużycia.

Słowa kluczowe: budowa, efektywność energetyczna, obliczenia, modelowanie