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THE PROFITABILITY ANALYSIS OF ENHANCEMENT OF PARAMETERS OF THE THERMAL INSULATION OF BUILDING PARTITIONS

A. ŻYCZYŃSKA[1], T. CHOLEWA[2]

The energy saving tendencies, in reference to residential buildings, can be recently seen in Europe and in the world. Therefore, there are a lot of studies being conducted aiming to find technical solutions in order to improve the energy efficiency of existing, modernized, and also new buildings. However, there are obligatory solutions and requirements, which must be implemented during designing stage of the building envelope and its heating/cooling system. They are gathered in the national regulations.

The paper describes the process of raising the energy standard of buildings between 1974–2021 in Poland. Therefore, the objective of this study is to show energy savings, which can be generated by modernization of thermal insulation of partitions of existing buildings and by the use of different ways of heat supply. The calculations are made on the selected multi-family buildings located in Poland, with the assumption of a 15 years payback time.

It is shown that it is not possible to cover the costs of the modernization works by the projected savings with the compliance to the assumption of 15 years payback time.

Keywords: energy efficiency, final energy, heat transfer coefficient, useful energy, heating costs

1. Introduction

Energy consumption in residential buildings comprises about 63% of the energy consumption in the European building sector [1]. Therefore, it is very important to decrease the energy consumption in existing and future buildings, which may be performed with the use of different energy efficiency solutions described by Balta et al. [2], Bojić [3], Ciampi et al. [4] and Schuler et al. [5].

During the design of a new building, or modernization of an existing one, it is necessary to take the building energy standard requirements into account, since they are frequently defined as requirements for a building in terms of its energy consumption.

[1] Department of Historic Building Preservation, Faculty of Civil Engineering and Architecture, Lublin University of Technology, Nadbystrzycka 40, 20-618 Lublin, Poland, e-mail: a.zyczynska@pollub.pl

[2] Faculty of Environmental Engineering, Lublin University of Technology, Nadbystrzycka 40B, 20-618 Lublin, Poland

Thus, the implementation of energy savings polices, which are obligatory, contribute to energy savings at the beginning of a building process and also by the exploitation of the building, which was mentioned by Yuan et al. [6], Życzyńska [7], Życzyńska [8], Zhang [9] and Zhao et al. [10].

Since January 1st, 2014, for the post-2021 scenario, according to the Polish national regulations, the new requirements for thermal insulation for building partitions and the indicator of demand for non-renewable primary energy for different types of buildings have come into force. A clear tightening of these requirements would result in the need for thicker layers of thermal insulation of building partition, or the use of materials with better thermal parameters, as well as equipment of buildings with heating, ventilating, cooling, or with installations for efficient hot water supply. Thus, raising the energy standard of building would reduce its demand for energy, bring energy savings, and thus, will generate financial savings.

The financial effects depend mainly on the charges for heat networks and the price of fuel used in the heat source. However, obtaining energy and financial effects involves greater expenditure on investment, what is shown in this paper.

2. Materials and Methods

2.1. Description of the building

The analysis was–made for the residential building consisting of 35 flats used by 80 inhabitants. The characteristics parameters of the building were: the usable area equal to 2016 m^2, and the height of the storey equal to 2.70 m; which gave the heated volume equal to 5443.2 m^3. The building was located in the open space, in the third climatic zone (there are five climatic zones in Poland) with computational external air temperature equal to -20°C. The indoor air temperature was assumed for the building on the level of 20°C. The calculated number of heating degree-days were equal to 3825. The building was equipped with gravitational ventilations; therefore, the minimum required air exchange in rooms was assumed as 0.5 h^{-1}, which gave the total air stream of ventilating 2721.6 m^3h^{-1}.

Moreover, the building had a basement, which was not heated. Thus, the indoor air temperature was defined on the basis of the heat balance for that space. The heat gains from the insolation were assumed for vertical surfaces and the double window pane with the coefficient of the radiation transmittance equal to 0.75. However, the internal heat gains were assumed as an average of 4.6Wm^{-2}; from the range for the residential building from 3.5 to 6.0Wm^{-2}.

The calculations were made for eight variants (from W1 to W8 – see Table 2), which were meant to show changes introduced to standards or technical requirements in the scope of the heat transfer coefficient of building partitions.

In order to define the final energy for heating, the different heat sources (from A to E- see Table 1) were assumed. Additionally, the heating installation was equipped with full automatic exchangers and local regulation, as well as with well insulated pipes. Furthermore, it was working without the storage tank. Partial efficiencies were assumed in accordance with the Decree of the Minister of Infrastructure [11], and the total efficiency was calculated as the ratio of partial efficiencies (Table 1). In order to estimate the financial savings, taking into consideration the heat tariff and the calorific value of fuel, the following parameters were assumed: the constant charge O_{mA} = 2857€ per MW, and variable charge O_{zA} = 9.52€ per GJ for district heating, the charge for natural gas O_{zB} = 13.81€ per GJ, the charge for the liquid petroleum gas (LPG) O_{zC} = 27.38€ per GJ, for the light fuel oil O_{zD} = 23.81€ per GJ, and the charge for coal O_{zE} = 7.14€ per GJ.

Table 1

Efficiencies of heat sources A, B, C, D and E

Description	Fuel	Efficiency				
		Partial				Total
		Generation η_{Hg}	Accumulation η_{Hs}	Distribution η_{Hd}	Regulation η_{He}	$\eta_{H\,tot}$
A	district heating	0.98	1	0.95	0.93	0.866
B	natural gas	0.97	1	0.95	0.93	0.857
C	LPG	0.97	1	0.95	0.93	0.857
D	light fuel oil	0.97	1	0.95	0.93	0.857
E	coal	0.89	1	0.95	0.93	0.786

2.2. Heat transfer coefficients of building partitions

Values of heat transfer coefficients of building partitions for each variant were assumed for the calculation as the limiting values, which were in force in the given period of time. The results are presented in Table 2. Variants from W6 to W8 refer to changes in the perspective of defined time frames, which exceed the year 2021 and were introduced in the Decree of the Minister of Infrastructure, Construction and Maritime Economy [12].

Table 2

Heat transfer coefficients of the building partitions for each variant

Variant	The year of being in force	Heat transfer coefficients of the building partitions U [W m^{-2}K^{-1}]					
		External wall	Roofs	Ceilings above unheated rooms	Walls of unheated cellar	Windows	Doors
W 1	1974	1.16	0.70	1.16	1.06	3.0	3.5
W 2	1982	0.75	0.45	1.0	1.06	2.6	3.5
W 3	1991	0.55	0.30	0.60	1.06	2.6	3.0
W 4	2002	0.30	0.30	0.60	0.74	2.6	2.6
W 5	2008	0.30	0.25	0.45	0.66	1.8	2.6
W 6	2014	0.25	0.20	0.25	0.66	1.3	1.7
W 7	2017	0.23	0.18	0.25	0.66	1.1	1.5
W 8	2021	0.20	0.15	0.25	0.66	0.9	1.3

3. Results and Discussion

3.1. The requirement for thermal power and useful heat for heating

For each variant, the calculations of thermal power (Φ) for heating, according to the standard EN 12831:2003 [13], and the calculations of demand on useful heat for heating ($Q_{H,nd}$) according to the standard EN ISO 13790:2008 [14], were made. Also the indicator of the power referred to 1m^3 of the heated cubage (EV_H) and the indicator of useful heat in reference to 1m^2 of the useful heated surface (EA_H) were calculated. The results are presented in Table 3. However, Figure 1 and Figure 2 depict the drop in the value of $Q_{H,nd}$ and EA_H by successively changing requirements, within the range of heat transfer coefficient for building partitions.

In Table 4 the decrease of the useful heat expressed in percentages among following variant is given. The decline of the thermal power among actual requirements (W5) and the requirements of access (W8) amount to 22.5 %. When it comes to the useful heat, it equals to 34.2%, which may have a significant influence on the limitation of operating costs of heating.

Table 3

Thermal power and heat demand for analysed variants

Variant	Φ	Φ_T	$Q_{H,nd}$	Q_D	EA_H	EV_H
	W	W	GJ year^{-1}	GJ year^{-1}	kWh m^{-2}year^{-1}	Wm^{-3}
W 1	184169	147155	1160.1	1280.1	159.9	33.8
W 2	144962	107948	875.6	932.4	120.6	26.6
W 3	127066	90052	723.8	782.9	99.7	23.3
W 4	107999	70985	567.7	613.0	78.2	19.8
W 5	96168	59153	469.4	511.7	64.7	17.7
W 6	84301	47287	383.2	412.5	52.8	15.5
W 7	79871	42857	349.0	372.8	48.1	14.7
W 8	74598	37585	309.0	325.6	42.6	13.7
Φ_V = 37014 W Q_V = 332.6 GJ year^{-1}						

where:
Φ – thermal power
Φ_T – heat loss by heat transmission
Φ_V – ventilation heat loss
$Q_{H,nd}$ – demand on useful heat for heating
Q_D – demand on heat for heat transmission
Q_V – demand on heat for ventilation
EA_H – indicator of the useful heat in reference to 1 m^2
EV_H – indicator of the power referred to 1 m^3 of the heated cubage

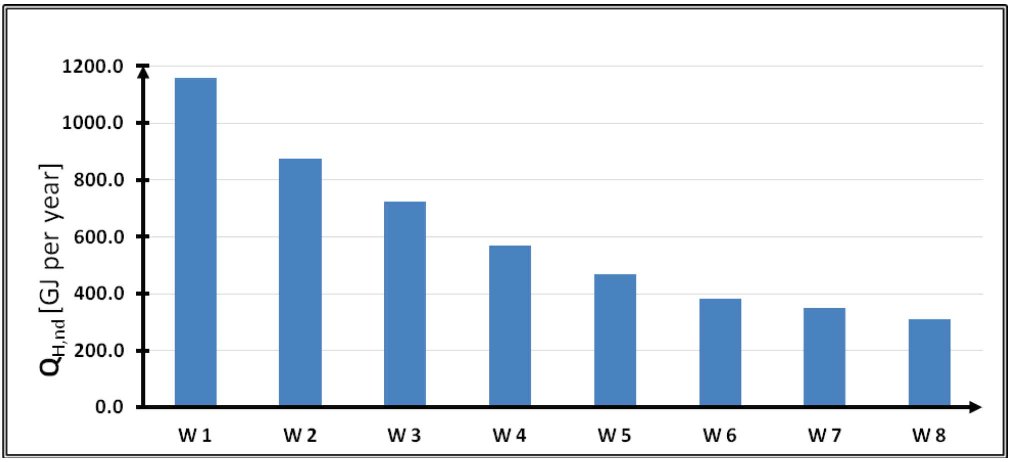

Fig. 1. Decrease in the value of useful heat for heating the buildings for analysed variants.

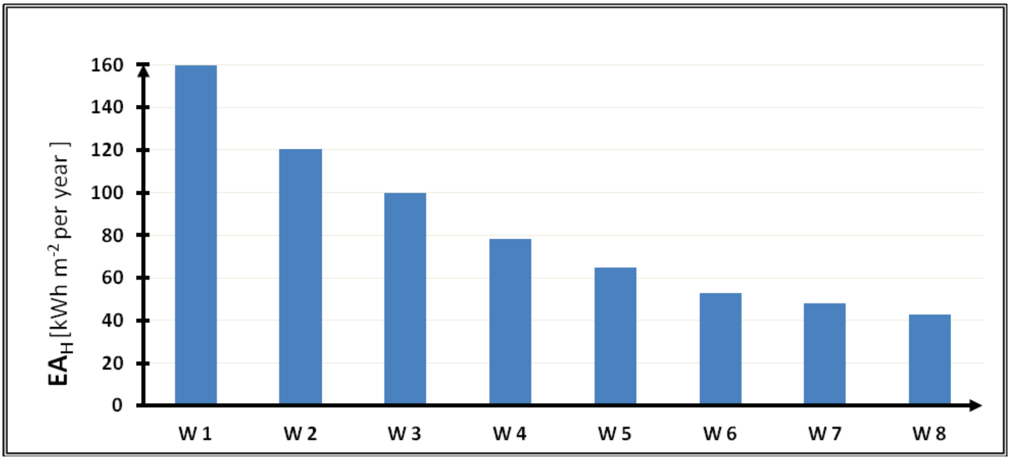

Fig. 2. Decrease in value of indicator of useful heat in a reference to $1 m^2$ for analysed variants.

Table 4

The decrease of thermal power and useful heat between analysed variants

Variant	Thermal power			Useful heat		
	Φ	ΔΦ		$Q_{H,nd}$	$\Delta Q_{H,nd}$	
	kW	kW	%	GJ $year^{-1}$	GJ $year^{-1}$	%
W 1	184.2			1160.1		
		39.2	21.3		284.5	24.5
W 2	145.0			875.6		
		17.9	12.3		151.8	17.3
W 3	127.1			723.8		
		19.1	15.0		156.1	21.6
W 4	108.0			567.7		
		11.8	10.9		98.3	17.3
W 5	96.2			469.4		
		11.9	12.4		86.2	18.4
W 6	84.3			383.2		
		4.4	5.2		34.2	8.9
W 7	79.9			349.0		
		5.3	6.6		40.0	11.5
W 8	74.6			309.0		
Comparison between variant W5 and W8						
W 5	96.2			469.4		
		21.6	22.5		160.4	34.2
W 8	74.6			309.0		

3.2. Final energy consumption for heating

The demand of analyzed residential building for final energy for each variant was calculated according to the Decree of the Minister of Infrastructure [11], with the use of the equation 3.1 and 3.2, and results of those calculations are presented in Figure 3.

$$Q_{K,H\,(A,B,C,D,E)} = Q_{H.nd} / \eta_{H,tot\,(A,B,\,C,\,D,\,E)} \tag{3.1}$$

$$\eta_{H,tot\,(A,B,\,C,\,D,\,E)} = \eta_{H,g\,(A,B,\,C,\,D,\,E)} \cdot \eta_{Hs(A,B,\,C,\,D,\,E)} \cdot \eta_{H,d\,(A,B,\,C,\,D,\,E)} \cdot \eta_{H,e\,(A,B,\,C,\,D,\,E)} \tag{3.2}$$

where:

$Q_{K,H\,(A,B,C,D,E)}$ – final energy demand for heating [GJ year^{-1}]

$Q_{H.nd}$ – demand for useful heat for heating [GJ year^{-1}]

$\eta_{H,tot\,(A,B,\,C,\,D,E)}$ – total efficiency of heating system [-]

$\eta_{H,g\,(A,B,\,C,\,D,\,E)}$ – efficiency of heat generation [-]

$\eta_{Hs\,(A,B,\,C,\,D,\,E)}$ – efficiency of heat accumulation [-]

$\eta_{H,d\,(A,B,\,C,\,D,\,E)}$ – efficiency of heat distribution [-]

$\eta_{H,e\,(A,B,\,C,\,D,\,E)}$ – efficiency of heat regulation [-]

Figure 4 presents the calculations of energy savings of final energy consumption and of thermal power for variants from W6 to W8 in reference to the obligatory requirements (variant W5).

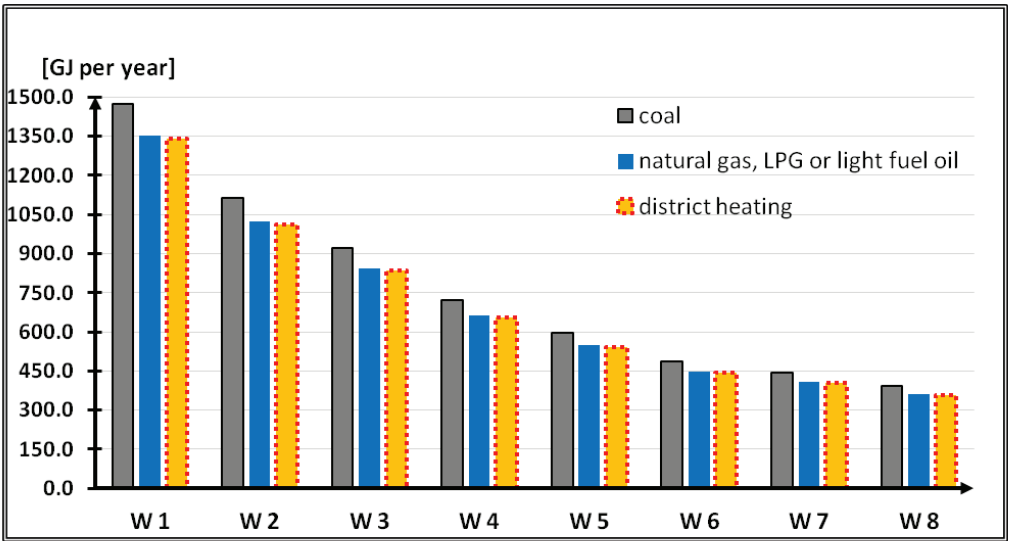

Fig. 3. Final energy demand for heating.

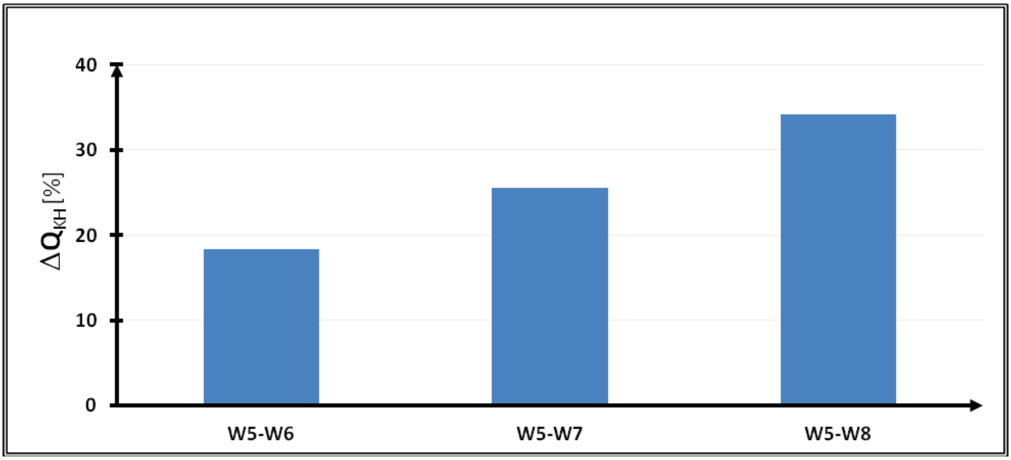

Fig. 4. Savings of final energy demand for heating in comparison to variant W5.

3.3. Savings in heating costs

Savings in heating costs (Table 5) result from the limitations of thermal power and the final energy demand. These savings were estimated with the use of the definition of floating charges for 1GJ of heat accepting the heat value of the given fuel and current average prices of these fuels in the market. In order to include the estimated price changes of fuels in the analysis, the increase (3%) of the prices was assumed in the scale of the year with the use of the corrective coefficient k. When it comes to the case A, the calculations were carried out in compliance with the equation 3.3, and the remaining cases B, C, D, E were performed in accordance with the equation 3.4. For each case, financial savings related to $1m^2$ of the useful heated surface were calculated with the use of the equation 3.5, and are presented in Figure 5.

$$\Delta O_{rA} = k \cdot (12 \cdot \Delta \Phi_A \cdot 10^{-3} \cdot O_{m,A} + \Delta Q_{KH,A} \cdot O_{z,A}) \tag{3.3}$$

$$\Delta O_{r,(B,C,D,E)} = k \cdot \Delta Q_{KH,(B,C,D,E)} \cdot O_{z,(B,C,D,E)} \tag{3.4}$$

$$\Delta O_{j\ r,(A,B,C,D,E)} = \Delta O_{r,(A,B,C,D,E)} / A_f \tag{3.5}$$

where:

$\Delta O_{rA};\ \Delta O_{r,(B,C,D,E)}$ – financial savings for analyzed heat sources [€ per year]

$\Delta O_{j\ r,(A,B,C,D,E)}$ – individual financial savings [€ per m^2 and year]

k – the corrective coefficient of the rise in prices of fuels [-]

$\Delta \Phi_A$ – the decrease of the ordered power for heat source A [W per month]

$\Delta Q_{KH,A}$; $\Delta Q_{KH,(B,C,D,E)}$ – the decrease of heat demand for analyzed heat sources (from A to E) [GJ per year]

$O_{m,A}$ – the constant charge for ordered power [€ per MW and month]

$O_{z,A}$; $O_{z,(B,C,D,E)}$ – the variable charge proper for analyzed heat sources (from A to E) [€ per GJ]

A_f –heated usable area of the building [m^2]

Table 5

Financial savings

Variant	Corrective coefficient of the rise in prices of fuels (k)	Financial savings [€ per year]				
		district heating	natural gas	LPG	light fuel oil	coal
		A	B	C	D	E
W5-W6	1.0300	1395	1474	2837	2467	807
W5-W7	1.1255	2119	2184	4330	3765	1231
W5-W8	1.2668	3171	3274	6492	5645	1846

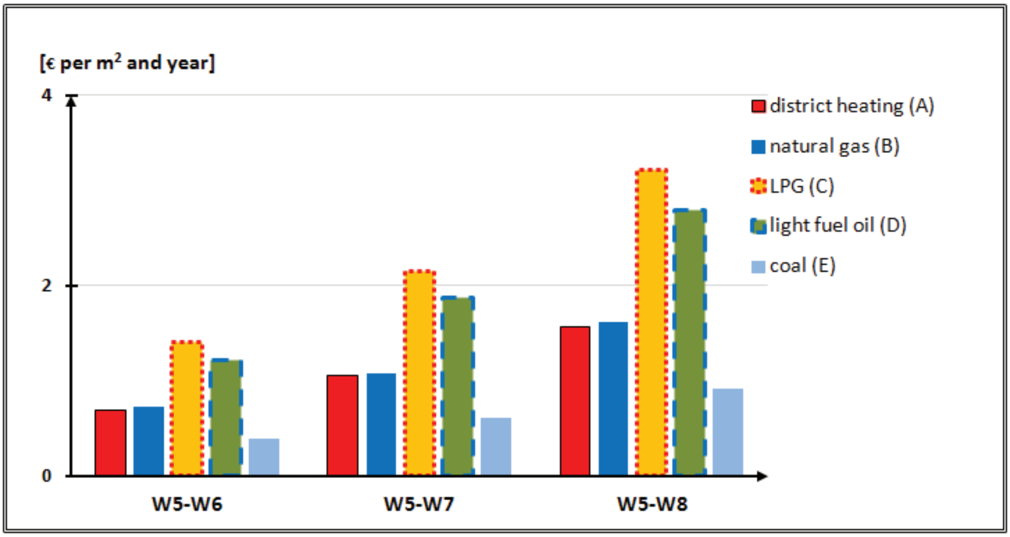

Fig. 5. Financial savings related to 1m^2 of heated usable area of the building.

On the basis of the calculated annual financial savings a supplementary cost of modernization work were defined, which might be done in the analyzed building by assumption of a 15 years payback time (Table 6).

Also (using the equation 3.6 and equation 3.7) the maximum cost of the modernization work related to 1m^2 of heated usable area of the building was defined, which might be devoted to the constructive works and the investment would be profitable (Figure 6).

$$N_{(A,B,C,D,E)} = t \cdot \Delta O_{r,(A,B,C,D,E)} \qquad (3.6)$$

$$nj_{(A,B,C,D,E)} = N_{(A,B,C,D,E)} / A_f \qquad (3.7)$$

where:

$N_{(A,B,C,D,E)}$ – supplementary financial savings for the analyzed heat sources obtained by the increase of thermal insulation in comparison to W5 [€]

t – 15 years payback time

$\Delta O_{r,(A,B,C,D,E)}$ – annual financial savings for analyzed variants of heat sources [€ per year]

$n_{j(A,B,C,D,E)}$ – individual supplementary financial savings for analyzed heat sources obtained by the increase of the thermal insulation in comparison with W5 [€ m^{-2}].

Additional modernization work of building envelope should consist in the improvement of the heat transfer coefficient for building partition by the increase of the thickness of insulating materials of the walls, the roof, and the ceiling over the basement, and also mounting of windows and doors, which was characterized by improved thermal parameters. The results shown in Table 7 refer to the currently requirements in force. Therefore, the additional thicknesses of insulating materials were also calculated, taking into consideration the assumed heat conduction coefficients (λ) to fulfill requirements, which will be obligatory in the future (the Decree of the Minister of Infrastructure, Construction and Maritime Economy [12]).

Table 6

Financial savings which may be spend on modernization work

Variant	**Financial savings [€]**				
	district heating	**natural gas**	**LPG**	**light fuel oil**	**coal**
	A	**B**	**C**	**D**	**E**
W5-W6	20932	22104	42550	37000	12103
W5-W7	31787	32754	64943	56472	18472
W5-W8	47571	49112	97377	84676	27697

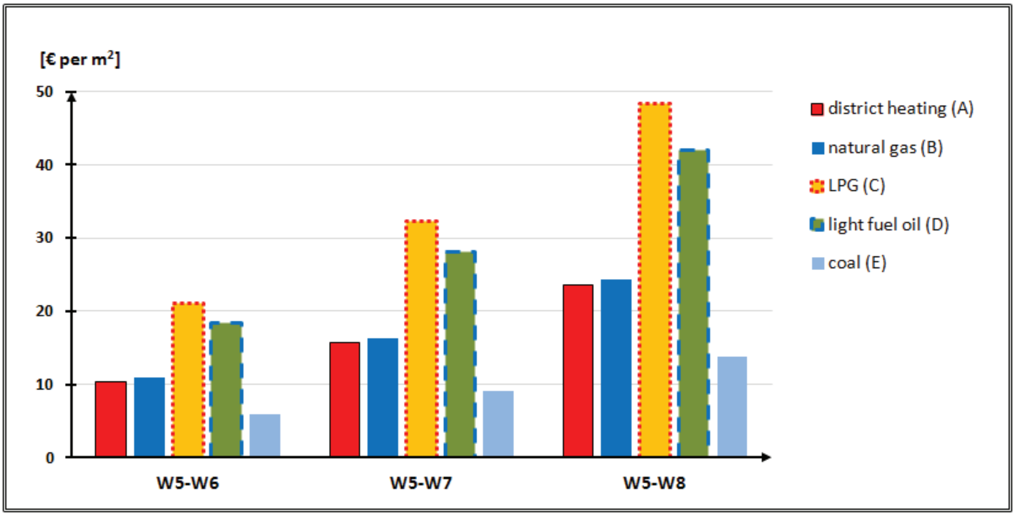

Fig. 6. Financial savings which may be spend on modernization work related to 1 m^2 of heated usable area of the building.

Table 7

Heat transfer coefficients of building partitions and additional thicknesses of insulating materials

Building partition	Assumed value of λ [W m^{-1}K^{-1}]	Heat transfer coefficient U [W m^{-2}K^{-1}] and additional thicknesses of insulating materials d [cm]						
		W5	W6		W7		W8	
		U	U	d	U	d	U	d
External wall	0.038	0.30	0.25	2.6	0.23	3.9	0.20	6.4
Roofs	0.042	0.25	0.20	4.2	0.18	6.6	0.15	11.2
Ceilings above unheated rooms	0.038	0.45	0.25	6.8	0.25	6.8	0.25	6.8
Windows	-	1.8	1.3	-	1.1	-	0.9	-
External doors	-	2.6	1.7	-	1.5	-	1.3	-

The decline in heat demand reduces the need for the final energy, which should generate the cost savings regardless of the method of heating the building. However, the reduction in operating costs for heating involves the growth of the costs of the construction works. With a simple 15 years payback time for those works and at the low values of the variable fee (O_z), it is unlikely to be covered by the projected savings. At the current price relations between different fuels, the most beneficial is the case of liquid petroleum gas and light fuel oil.

4. Conclusions

The introduction of the new regulations on thermal insulation of building envelopes leads to the need of increasing, the thickness of insulation for walls and another building partition in relation to the currently abiding requirements within the adopted periods of time.

Significant restrictions of heat transfer coefficient for windows and external doors lead to the use of modern technology in the production of these items.

These actions contribute to the decrease of energy consumption in residential buildings, which constitutes a main goal of energy policy of many counties in Europe and in the world.

It was shown, on the example of Poland, that the tightening of building regulations (W8) in relation to the current requirements (W5) should ultimately reduce the building energy demand by about 30%. The decline in heat demand reduces the need for the final energy, which should generate the cost savings regardless of the method of heating the building. However, the reduction in operating costs for heating involves the increase of the costs of the construction. With a simple 15 year payback time for the works, and at the low values of the variable fee for fuels, it is unlikely to be covered by the projected savings. But the requirements included in the new regulations on the thermal insulation of building envelopes must be taken into account in design of new or modernized building, even if they are not attractive from the economical point of view and lead to decrease the energy consumption in the residential buildings.

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