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The choice of the optimal level of the primary energy index for the collective residential buildings

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Abstract. This paper presents an optimal method of choosing a primary energy ratio, depending on the solutions regarding the building's technical equipment. A global cost method was used in the analysis, as that method allows for determining the requirements in relation to the type of the building and the way of energy supply. Analysis regards five -storey building, where 4 floors were repetitive. The building represents a standard of the collective residential buildings. 4 chosen scenarios were analysed: basic one (thermal protection requirements following the requirement valid in Poland in 2008 - SEB), presently valid (including a modernisation helping to fulfil the actual building rules) – SEB^* , low energy building – LEBand passive building standard - VLEB.

1. Introduction

In accordance with Article 5 of valid Polish Building Law [1] the parties of the building process are required to undertake the activities necessary to minimize a building's negative impact on the environment. The mentioned above activities shall include designing process, building process and exploitation of the buildings. It refers to such stages as: building material production, structure erection, building's exploitation, it's demolition and utilisation or after-demolition material recovery.

In order to evaluate the efficiency of the applied in the building solutions one can use an analysis of building's life cycle costs related to the calculation of the future cash flows. Recently, the most popular method of evaluation of energy performance of the building is LCC - global cost method $-C_{G}$. "Optimum level in relation to the costs" means such an energy performance efficiency level, which provides the lowest costs during the estimated life cycle. The lowest costs are established, taking under consideration the investment costs related to the energy, maintenance and exploitation costs including the energy and savings costs. This is why an analysis optimal in terms of the costs is a powerful tool promoting the energy related modernisation of the buildings [2-8]. It provides a possibility of choosing the optimal solution for a low value of the global cost. Kurnitski and others have prepared a number of the papers regarding the mentioned above subject, presenting the analyses of residential and office buildings [9-11]. The analyses of the residential buildings are focused mainly on establishing the optimum value of primary energy ratio during a typical way of usage (one-family or multi-family buildings). The collective residential buildings are the special cases of the residential buildings. A share of energy necessary for DHW preparation increases significantly in such type of objects. It results mainly from smaller surface of the apartments and lower surface ratio per one inhabitant. In this paper the optimal value of primary energy ratio was established for a collective

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residential building based on the global cost method, depends on the applied solutions for the technical equipment. An influence of the primary assumptions on the gained value of primary energy ratio was also analysed.

2. Description of method

In the analyses conducted for the collective residential building and its technical equipment an algorithm of global costs calculation was used, according to the standard regarding the economic evaluation of the building's energy systems [12]. The method was used to establish an optimal level of primary energy and the analysis of primary parameters impact on the searched optimum.

2.1. Establishing usable, final and primary energy

An usable energy was established by means of the Polish requirements resulting from building's energy performance certificate law [13]. The monthly balance sheet method is taking into account the heat losses resulting from transfer or ventilation as well as the solar and indoor heat gains.

2.2. Establishing global cost

The global costs of the building and its elements are calculated as a sum of initial investment costs and discounted annual exploitation costs in the calculation period [12]. The analysis of global costs was conducted using the below presented formula:

$$C_{G}(\tau) = C_{in,inv} + \sum_{j=1}^{j_{x}} \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \cdot R_{d}(i) \right) - V_{f,\tau}(j) \right]$$
(1)

where: $C_G(\tau)$, global cost in relations to initial year, PLN; $C_{in, inv}$, investment costs, PLN; τ , calculation period, a; $C_{a,i}(j)$, component's annual costs in i-year, PLN; $R_d(i)$, discount rate (for i-year), -; $V_{f,\tau}(j)$, residual value, PLN.

3. Sensitivity analysis

This paper presents a sensitivity analysis for establishing the energy optimum by means of global cost method, including the changeability of the initial parameters:

- installation solutions 4 heat sources were analysed: gas central boiler (GCB), district heating (DH), ground heat pump (GHP), pellet boiler (PB),
- money value annual inflation rate, WIBOR (VM),
- increase of investment costs (IC),
- electricity price development (EPD).

3.1. Description of the analysed variants – building's technical equipment

3.1.1. *Quality of building's envelope*. Table 1 presents the analysed variants of changeability of heat transfer coefficients for building's envelope, participation of thermal bridges and air tightness of the building responding with the process of achieving the requirements regarding the low energy building. SEB* variant is approximately 15% better than SEB variant.

Table 1. Heat transfer coefficient of the external partitions U (W·m⁻²·K⁻¹), thermal bridges (%) and building's tightness depending on energy standard (h⁻¹).

Variant	Wall	Ground floor	Flat roof	Door	Window	Thermal bridges	Air tightness
SEB	0.30	0.45	0.25	2.60	1.80	15	3.0
SEB*	0.25	0.35	0.20	1.80	1.30	15	3.0
LEB	0.22	0.30	0.16	1.80	1.30	10	3.0
VLEB	0.15	0.20	0.12	1.30	0.90	5	1.0

3.1.2. Quality of ventilation system. As a part of the conducted analyses the following variants of ventilation systems were foreseen [14]:

- V1 natural, the designed ventilation air stream was established at the level of 5050 $\text{m}^3 \cdot \text{h}^{-1}$
- V2 hybrid, for the calculations of hybrid ventilation it was assumed to decrease the air stream by 59% in relations to the required heat stream, appointed due to the hygiene reasons
- V3 mechanical, exhaust, air flow control was installed according to a load resulting from usage profile, decrease of air stream to 50% was assumed in relations to the required heat stream (following the hygiene reasons)
- V4 mechanical, supply and exhaust in relations to the load, heat recovery 50%,
- V5 mechanical, supply and exhaust in relations to the load, heat recovery 70%,
- V6 mechanical, supply and exhaust in relations to the load, heat recovery 80%.

3.1.3. Quality of heat source. for all analysed variants it was assumed to use 4 systems of energy supply to the building based on:

- boiler room with gas condensing boiler (GCB variant),
- district heating supply system (DH variant),
- boiler room with a ground source heat pump (GHP variant),
- boiler room with pellet boiler (PB variant).

3.1.4. Analysed variants. Table 2 presents the analysed variants depending on the quality of the building's envelope and ventilation system.

Table 2. Summary of analysed technical variants.

TV_1	TV_2	TV_3	TV_4	TV_5	TV_6	TV_7
SEB	SEB*	LEB	LEB	VLEB	VLEB	VLEB
V1	V2	V3	V4	V4	V5	V6

3.2. Description of analysed economic variants

3.2.1. Value of money – (VM). The changeability of discount rate and annual inflation rate according to table 3 were assumed in the analyses. A reference point in the analysis is the values described as ,,*base". The value of money for base parameters was assumed according to the economic data valid on December 2015 – from 3 months period.

	VM_1	VM_1,5	VM_base	VM_2	VM_2,5	VM_3
annual inflation rate -R _i	1.0	1.5	-0,7	1.8	2.5	2.6
WIBOR	4.0	4.3	1.75	4.1	4.6	4.4
discount rate -R _R	3.0	2.75	2.47	2.25	2.00	1.75
VAT	23	23	23	23	23	23

Table 3. Variants of the interest rates (inflation or WIBOR), (%).

In the analyses of the impact of a changeability of interest rates level on the value of global cost the coefficient of exploitation prices increase and change of energy prices was assumed to be 0%.

3.2.2. Increase of investment costs (IC) in time. In the conducted analysis the initial costs of the investment (year zero) were defined according to the status for I quarter of 2012 as the average costs incurred for building's erection and handing over for use, according to the material outlays catalogue SekoCenbud. The individual unit investment costs were grouped into following categories:

- IC_1 –construction elements influencing the energy consumption sun blinds,
- IC_2 –investment costs of the installed devices related to energy consumption chimney, heat source, central heating system, DHW preparation or ventilation,
- IC_3 -investment building costs having an impact on the energy consumption windows, thermal insulation,

• IC_4 –investment building costs – body of the building, water and sewage systems, gas system and electricity.

Depending on the technical variant the investment costs related to the building and heat system are the subjects of modification.

		TV_1	TV_2	TV_3	TV_4	TV_5	TV_6	TV_7
Total investment costs divided into parts regarding building, systems and energy source								
GCB	BUILDING	1884	1894	1909	1875	1901	1901	1901
	SYSTEMS	239	255	225	561	561	559	558
DH	BUILDING	1883	1893	1907	1873	1899	1899	1899
	SYSTEMS	239	257	227	566	565	564	562
CHD	BUILDING	1883	1893	1907	1873	1899	1899	1899
GHP	SYSTEMS	272	287	251	587	588	587	585
DD	BUILDING	1884	1894	1909	1875	1901	1901	1901
PB	SYSTEMS	224	243	214	554	556	554	549

Table 4. Unit building costs for base variant in base, r Livin	$LN \cdot m^{-2}$	base, Pl	IC	variant	base	costs for	building	Unit	Table 4.
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The sensibility analysis includes the coefficients of investment costs increase in time according to table 5, considering in that way the behaviour of trading parties.

Table 5. Variants of growth rates of investment costs over time.

IC_1	IC_base	IC_2	IC_3
90% base	100%	110% base	120% base

The analyses of impact of investment costs changeability on the value of global cost do assume the basic financial parameters but do not assume the electricity price development.

3.2.3. Energy price development (EPD). In Polish market economy it is difficult to estimate the average annual rates of energy and it's carriers prices increase, so some scenario of the changes was assumed, according to table 6.

	EPD_base	EPD_1	EPD_2	EPD_3
gas	0.0~%	0.5 %	1.8%	3.3%
electricity	0.0~%	0.5 %	1.2%	2.5%
district heating	0.0~%	0.5 %	0.8%	1.3%
pellets	0.0~%	0.5 %	1.1%	2.4%

 Table 6. Variants of rising energy costs over time.

In the analyses of the impact of energy costs changeability on the value of global costs the coefficient of exploitation costs increase at level 0% was assumed.

3.3. Multi-variants analysis

Considering the changeability of financial end economic coefficients according to tables (tab. 3, tab. 5, tab. 6) the analysis was taking into account the relations between the investment costs (IC) and electricity price development (EPD) for two money values in time:

- base parameters (VM_base),
- variant with the highest inflation value (VM_3) suits the lowest discount rate.

4. Description of analysed building

4.1. Building and architectural characteristics

The analysis was conducted for a five-storey building with 4 repetitive floors, representing the class of the collective residential buildings. The building is rectangular with the dimensions: 53.9 m and 11.9 m, the height of one level is 2.5 m and the building shape coefficient $\text{A/V}_{e}=0.33 \text{ m}^{-1}$. In the

heated part of building $A_f = 2483 \text{ m}^2$ with the regulated temperature there is 77 double rooms including toilets. The surface of a typical room (with toilet) - 17.9 m². The assumed load of the building is at level of 80%, the unit consumption of hot water is 25 dm³ per person and per day.

4.2. Energy characteristics

4.2.1. Usable energy. Usable energy for heating and ventilation $Q_{H,nd}$ was determined assuming the following:

- the internal exploitation temperature $+20^{\circ}$ C,
- unit heat capacity at level of $370000 \text{ J} \cdot \text{K}^{-1} \cdot \text{m}^{-2}$
- indoor heat gains based on the building's usage profile at the level of $3.5 \text{ W} \cdot \text{m}^{-2}$,
- localisation in Poznan,
- sun heat gains not including shading of the building.

Table 7 presents the change of coefficient of usable energy depends on the given variant. Following the improvement of building characteristics a share of usable energy for DHW increases in the balance.

Table 7. The value of coefficient of heat losses, transfer and ventilation related heat losses as well as usable energy for a purpose of heating, ventilation and DHW preparation depending on given variant.

	H _{tr} /A _f	H _{ve} /A _f	$Q_{H,nd}/A_f$	Q _{W,nd} /A _f	t _{sg}
	$W \cdot m^{-2} \cdot K^{-1}$	$W \cdot m^{-2} \cdot K^{-1}$	kWh·m ⁻² ·a ⁻¹	kWh·m ⁻² ·a ⁻¹	h
TV_1	0.59	0.79	91	24	5875
TV_2	0.46	0.44	50	24	5196
TV_3	0.40	0.42	42	24	4992
TV_4	0.40	0.19	23	24	4318
TV_5	0.26	0.19	13	24	3898
TV_6	0.26	0.13	9	24	3602
TV_7	0.26	0.10	7	24	3367

4.2.2. *Final energy*. The coefficient of final energy was determined assuming the changeability of efficiency coefficients. Determining the final energy for the purpose of auxiliary energy, the time of auxiliary devices work was taken into consideration and, based on the catalogue data, the unit powers of technical devices were defined.

4.2.3. Primary energy. The primary energy was defined depending on the technical variant and the type of applied heat source. At the figures 1a to 1d the proportions between the particular elements of primary energy were presented – for the analysed building, the changing variants of energy performance characteristics and used heat sources. An improvement of building's envelope and supplied air flow control result in decrease of primary energy ration by 61% in case of gas boiler: from 151.6 to 59.2 kWh·m²·a⁻¹, in case of district heating system by 58%: from 115.5 to 48.7 kWh·m²·a⁻¹, in case of ground heat pump by 56% from 120.4 to 53.3 kWh·m²·a⁻¹. In case of pellet boiler the balance sheet includes the share of electricity with an input coefficient equal, in Polish conditions, w_{el}=3 at level of 66.5% of total primary energy for variant TV_7. The improvement of energy characteristics up to variant TV_7 means simply a decrease of the primary energy from PE = 37.3 to 28.1 kWh·m²·a⁻¹, which means a change at the level of 24.6% in relation to PE for TV_1 variant.



Figure 1. Changeability of primary energy in relations to the technical equipment of the building, dividing into the separate elements a) GCB – gas condensing boiler, b) DH – district heating, c) GHP – ground heat pump, d) PB – pellet boiler

5. Choice of EP_{opt} for basic economy coefficients

 PE_{opt} (fig. 2), was defined, using the basic macro-economy parameters, applying the global costs method, based on 7 items of changeability of primary energy ration for the collective residential building and the analysed heat source referring the designated values to the changeability of global cost appointed for gas condensing boiler.

b)

Investment costs / Global costs, PLN·m⁻²

3800

3600

3400

3200 3000

2800 2600

2400

2200

2000 L

GCB_Cg

20

40

-

GCB_IC

60

80

100

120

140

PE, kWh·m⁻²·a⁻¹

160





Point PE_{opt} , optimal in terms of global costs, changes depending on the heat source used in the building. The lowest value it achieves in case of pellet boiler, the highest - for the gas boiler, the solution mostly used in Polish new boiler rooms. In case of district heating system, in comparison to the gas boiler, PE_{opt} shifts by 21 kWh·m⁻²·a⁻¹, while the global cost for the optimum values decreases up to 115 PLN·m⁻².

For the ground heat pump in relation to the gas boiler PE_{opt} changes by 16 kWh·m⁻²·a⁻¹, when the global cost decreases by 50 PLN·m⁻². For the pellet boiler PE_{opt} point is strongly indicated and equals 65.5 kWh·m⁻²·a⁻¹, when the global cost increases by 120 PLN·m⁻².

A difference of the global costs, in case of a different heat sources in the building, results, among the other, from the costs of heat source and costs of energy – their variability for the analysed variants were presented by means of a line with the tags. In the same time for each of the heat sources the value of global cost changes.

6. Sensitivity analysis

6.1. Sensitivity analysis of global costs results in relation to value of money (VM) in time

The detailed analysis of relationship between the global costs and character of financial parameters changes in reference to variant TV_1 and VM – base was presented on the below figures, respectively to the analysed heat sources. The analysis indicates an insignificant sensitivity to the change of financial coefficients.



Figure 3. Absolute change of global costs in relations to the basic parameters (VM_base) and building's technical variant TV_1 a) GCB - gas condensing boiler, b) DH- district heating, c) GHP – ground heat pump d) PB – pellet boiler

Analysing the variability of global costs increase including the improvement of energy characteristics of the building up to a base variant the primary cost for the collective residential building decreases to variant 3, and then it rises. An application of better air handling unit causes the

increase of the global costs. The improvement of technical equipment of the building impairs the impact of value of money in time.

6.2. Sensitivity analysis of global cost results in relation to the change of the initial investment costs *(IC)* in time

The variability of value of money in time translates into foreseen increase or decrease of the goods and services prices. The increase of the investment costs (IC) up to 120% of the initial value results in the increase of the global costs by 18% for each analysed variant.

The difference of the global costs increases when the insulation of the building is improved. Below the detailed analysis of the relationship between the global costs and price increase character is presented (fig. 4)



Figure 4. Absolute change of the global costs in relations to the basic parameters (IC_base) and building's technical variant TV_1 , a) GCB – gas condensing boiler, b) DH – district heating, c) GHP – ground heat pump, d) PB – pellet boiler

6.3. Sensitivity analysis of the global cost results in relation to electricity performance development *(EPD)* in time

When the energy prices rise the variable increase of global cost is noticeable, along with the improvement of the building's technical equipment in relation to the analysed heat source.

Moving from EPD_base to EPD_3 variant for each of analysed source shows the movement into lower value of primary energy with the simultaneous increase of the global costs.

The highest increase of the global costs can be recognised for a gas condensing boiler, while the lowest for the building with pellet boiler.

The detailed analysis of the relationship between the global costs and the character of prices increase is presented in the below figures (5a to 5d).

The decrease of relative global costs change results from the improvement of the building technical equipment and the decrease of final energy supplied to the building. A consideration of an increase of the energy costs (from variant EPD_base to EPD_3 variant) in the change of the global costs depends on the building's energy performance characteristics and for a gas condensing boiler it is 14% (TV_1 variant) and 5% for TV_7 variant.



Figure 5. Absolute change of the global costs in relations to the basic parameters (EDP_base) and building's technical variant TV_1 , a) GCB – gas condensing boiler, b) DH – district heating, c) GHP – ground heat pump, d) PB – pellet boiler

7. Summary

Appointing the optimal value of PE_{opt} , in terms of the global costs, the initial assumption shall be analysed. A change of macro-economic parameters (discount rate, WIBOR) from the low inflation (VM_base) to so called high (VM_3) results in a shifting into lower value of primary energy with simultaneous increase of the global costs. More important is an increase or decrease of goods and services prices and energy costs. The general regularities are similar to these observed in the analyses for the residential buildings. However the detailed values, zero places or slope of the curves of variability of the costs are different. The differences result, in the particular way, from the different initial assumptions regarding the value of the money and costs of energy.

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