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THE HEAT CONSUMPTION AND HEATING COSTS AFTER THE INSULATION OF BUILDING PARTITIONS OF BUILDING COMPLEX SUPPLIED BY THE LOCAL OIL BOILER ROOM

ZUŻYCIE CIEPŁA I KOSZTY OGRZEWANIA PO DOCIEPLENIU PRZEGRÓD BUDOWLANYCH ZESPOŁU BUDYNKÓW ZASILANYCH Z LOKALNEJ KOTŁOWNI OLEJOWEJ*

The paper presents the indices of energy consumption obtained in operating conditions as well as the heating costs before and after the insulation of external partitions of eight multiple dwelling buildings supplied by the common heat source which is the local boiler room heated by light fuel oil. The heat distribution to the particular buildings is by the district heating network. In order to determine the average unitary indices of energy consumption aimed at heating of the whole building complex, the analysis of fuel consumption is carried out, with consideration of standard computational conditions. The analysis lasted for four years after the insulation of buildings, from 2008 to 2011; its results are compared to the ones obtained from the analysis conducted before the insulation, in 2006. The investment was realised in 2007. The obtained real energy consumption indices are compared to the current requirements of technical conditions. On the basis of the data referring to the operation of buildings, the decrease in the heat consumption due to the insulation of partitions, the variability of fuel price, and the costs of heat generation are estimated . Moreover, the decrease in the emission of pollutants into the atmosphere is defined, as well as the costs of heat generation, which would be incurred if there was no insulation of partitions, are estimated.

Keywords: *heat-transfer coefficient, the insulation of building partitions, heat energy consumption in a building, heating costs.*

W artykule przedstawiono wskaźniki zużycia energii uzyskane w warunkach eksploatacyjnych i koszty ogrzewania przed i po dociepleniu przegród zewnętrznych grupy ośmiu budynków mieszkalnych wielorodzinnych zasilanych ze wspólnego źródła ciepła. Źródłem ciepła jest kotłownia lokalna opalana olejem opałowym lekkim, dystrybucja ciepła do poszczególnych budynków następuje poprzez osiedlową sieć ciepłowniczą. W celu określenia średnich jednostkowych wskaźników zużycia energii na cele grzewcze dla całego zespołu budynków przeprowadzono analizę zużycia paliwa uwzględniając standardowe warunki obliczeniowe. Analizą objęto okres czterech lat po dociepleniu budynków od 2008–2011 r. i odniesiono do stanu przed dociepleniem z 2006 r., inwestycja była realizowana w 2007 r. Uzyskane rzeczywiste wskaźniki zużycia energii porównano do obecnie obowiązujących wymagań warunków technicznych. Na podstawie danych z eksploatacji budynków przeanalizowano spadek zużycia ciepła z tytułu docieplenia przegród, zmienność cen paliwa i kosztów eksploatacyjnych ogrzewania, określono spadek emisji zanieczyszczeń do atmosfery, oszacowano koszty eksploatacyjne ogrzewania jakie zostałyby poniesione w przypadku braku docieplenia przegród budowlanych.

Słowa kluczowe: *współczynnik przenikania ciepła, docieplenie przegród budowlanych, zużycie ciepła w budynku, koszty ogrzewania.*

1. Introduction

The sector of building industry is one of major consumers of heat energy in economy. For this reason, the energetic policy of particular countries aims at introducing the strategies which reduce the energy consumption in this sector. Energy that is essential to heat rooms has the biggest share in the structure of energy consumption in a building which is not equipped with air conditioning [2, 5, 13]. For various types of buildings, one analyses the possibility of saving the heat energy by enhancing the parameters of thermal insulation of a building structure, increasing the efficiency of heating systems, the appropriate choice of heat source as well as by energy management [1, 4], [6–8], [11–12]. The investments aimed at the decrease in the heat consumption in building engineering, have been realised for several years in Poland and many other countries. Such investments are financially supported by the European Union or national budget. The most significant outcomes of such ventures are heat savings which contribute to the decrease in fuel consumption, and consequently, results in the reduction of the emission of pollutants into the atmosphere, and the drop in the operating costs of heating. Financial support is conditioned upon the fulfilment of requirements referring to the heat insulation of building partitions. The heat energy savings calculated in various studies according to current algorithm based on the domestic regulations as well as European and Polish standards, are the approximate predictive quantities. It is possible to determine the true level of energy savings and its unitary indices of consumption which can be compared to the requirements, owing to the measurements of heat energy or fuel consumption, performed in the operating condition, for heating purposes in a building and subsequently, by the analysis of obtained results, simultaneously, allowing for the changes in outside

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** temperature and the length of the heating season. In the case of the high indices while managing the property, the steps should be taken to introduce conscious energy management in a building. The energetic savings and the average real indices of energy consumption for heating purposes, obtained in the operating conditions, are examined in the article.

2. The Description of object

Among the analysed group of eight buildings, two types can be distinguished: three one-storey, two-family houses made in the traditional way; and five three-storey, twelve-family buildings of one- or two-staircase made in the industrial technology, known as 'żerańska brick'. The district was built in the years 1968-1978, whereas the existing single-function oil boiler room as well as two-wire heating network were built in 2003. The location of buildings (third climate zone) and the route of network are displayed in fig.1.

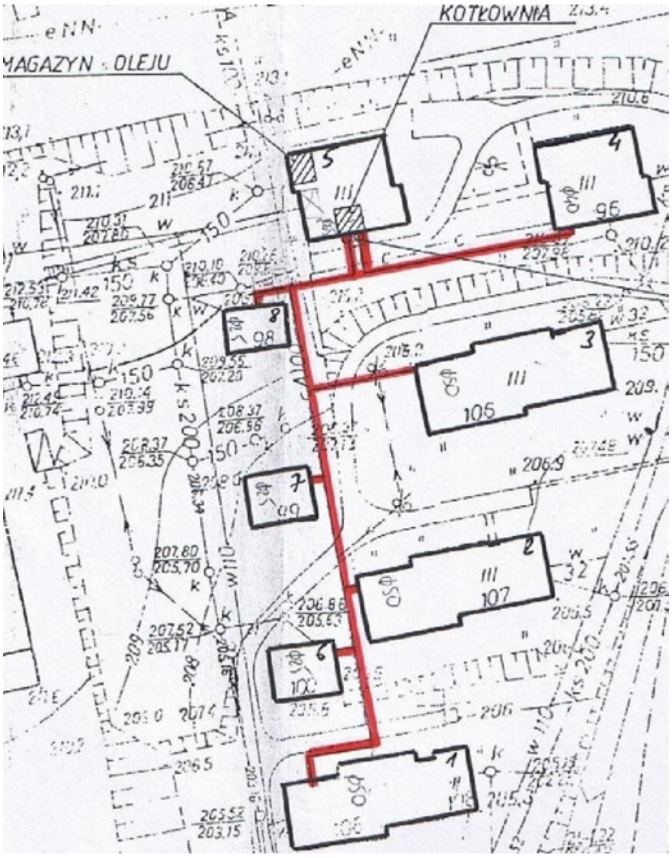

Fig. 1. The localization of dwelling-house complex together with the route of heating network

The total usable area which is heated amounts to 3745,5 m^2 where 66 apartments are located and is occupied by 246 people. The proprietor of the district is a homeowner association administered by a licensed property manager. The settlement of consumption costs is proportional to the heated usable area.

Before the insulation, building partitions in the objects were characterised by the following coefficients: heat transfer coefficients [15] expressed in [W/m^2K]: external walls – 1,15 or 1,12; ventilated slab roofs – 0,93 or 0,72; a roof – 1,43; the ceilings of cellars from 0,83; 1,00 to 1,01; floors on ground – 0,56 or 0,46; windows – 2,6 and 1,8 and the external doors – 2,5 or 1,8. The shape coefficient A/Ve (A – the sum total of the partitions area separating heated area from the external environment, not heated area and ground; Ve – cubic capacity of heating) of two-family buildings amounts to 1,01, whereas of the remaining ones to 0,53 or 0,54. The heating systems in buildings have not been modernised since their installation, at the end of 1970s'. The hydraulic regulation was realised by the orifices fixed at heaters and at the bottom of risers. However, the boiler room is equipped with the weather control panel which allows to regulate the system centrally. The generation of warm water takes place locally by electricity, in separate apartments. In 2007 the external walls, roofs and slab roofs in all buildings were insulated; the windows at staircases and external doors were replaced. The heating system stayed unchanged. The computational heat transfer coefficients of partitions after the insulation [15] expressed by [W/m^2K], amount to: external walls – 0,25; ventilated slab roofs – 0,22 or 0,21; a roof – 0,22; the ceilings of cellars - from 0,83 to 1,01; floors on ground - 0,56 or 0,46; staircase windows - 1,8 and external doors - 1,8. It should be stated that according to the administrator and users' information, before the insulation, the buildings were not sufficiently heated and the calculated temperatures of internal air were not achieved. Figure 2 shows the buildings before the commencement of investment; whereas figure 3 presents the already finished venture

3. The methodology of computations

The computations, conducted during the years 2008–2011, comprise the determination of the level of heat consumption for heating purposes; the emisson of pollutants; and the analysis of operating costs related to heating, and their comparison with the state from 2006. On the basis of the fuel supply documents, the consumption of light fuel oil for heating purposes could be analysed; and the unitary prices as well as the calorific value and density of light fuel oil could be assumed. The consumption of heat and the operating costs of heating were brought to the same level of reference. Thus, the values of corrective coefficient (φ), for the external computational conditions in a given year (assuming that internal temperature amounts to 20°C), were determined according to the dependence (1) and on the basis of the data concerning the length of the standard and real heating season; as well as the standard and measured average, monthly temperatures of outside air from the nearest weather station. The average index of the demand for the final energy and the non-renewable primary energy, was determined during the analysed period in every year. Owing to the fact that there is no individual measurement of heat consumption in buildings, the indices contain heat losses resulting from the generation and distribution of heat in the existing system. Subsequently, the obtained results are compared to the current requirements of technical conditions for dwelling buildings. The average, unitary prices of light fuel oil as well as the average unitary heating costs before and after the insulation are calculated in order to estimate the financial indices. The ecological effect is illustrated by the decrease in the emission of pollutants such as, carbon dioxide, carbon oxide, sulfur oxides, nitrogen oxides, dust and benzo-[a]-pyrene

The following dependencies are used in computations:

$$\phi = \frac{Sd_s}{Sd_r} \quad (1)$$

where:

- φ – the corrective coefficient for a given year
- Sd_r – the number of degree days for a given year
- Sd_s – the number of degree days for a meteorological station in a standard year (for the analysed case 3825,2 [day · K / year])

Fig.2 Buildings before the investment: two-family, one-staircase and two-staircase dwelling-house [15]

Fig.3 Buildings after the investment: two-family, one-staircase and two-staircase dwelling-houses [15]

$$Q_{co} = 0{,}001 \cdot \varphi \cdot V \cdot W_0 \cdot \rho \qquad (2)$$

where:

Q_{co} – the heat energy consumption for heating purposes [GJ/ year]
V – the volume of oil used for heating purposes [dm^3/year]
W_o – the calorific value of oil (42,6 MJ/dm^3 is assumed**)**
ρ – the density of oil (0,85 kg/dm^3 is assumed)

$$EK_H = 100 \cdot \frac{Q_{co}}{A_f \cdot 3{,}6} \qquad (3)$$

$$EK_H{}^* = EK_H \cdot \eta \qquad (4)$$

$$EP_H = w_i \cdot EK_H \qquad (5)$$

$$EP_H{}^* = w_i \cdot EK_H{}^* \qquad (6)$$

$$EP_{HWT} = 55 + 90 \cdot A/V_e \qquad (7)$$

$$EP_{HWT}{}' = 1{,}15 \cdot EP_{HWT} \qquad (8)$$

where:

EK_H – the average index of the demand for the final energy to heat the district, together with the losses on the grounds of the generation in the local source and transmission by the district heating network [kWh/m^2·year]

$EK_H{}^*$ – the average index of the demand for the final energy to heat the district buildings, reduced in the losses due to the generation and transmission [kWh/m^2·year]

EP_H – the average index of the demand for the non-renewable primary energy to heat the district, together with the losses due to the generation in the local source and transmission by the district heating network [kWh/m^2·year] acc[9]

$EP_H{}^*$ – the average index of the demand for the non-renewable primary energy to heat the district buildings, reduced in losses due to the generation and transmission [kWh/m^2·year]

EP_{HWT} – the average index of the demand for non-renewable primary energy to heat new buildings, determined according to the requirements of technical conditions [kWh/m^2·year] acc.[10]

$EP_{HWT}{}'$ – the average index of the demand for non-renewable primary energy to heat modernised buildings, determined according to the requirements of technical conditions [kWh/m^2·year] acc.[10]

A/V_e – the coefficient of building shape (0,57 1/m is assumed as the average value weighted for the whole group of buildings)

A_f – the usable area of rooms of regulated temperature (in total 3745,5 m^2 for all the buildings)

w_i – the expenditure coefficient of non-renewable primary energy (1,1 is assumed acc. [9])

η – the efficiency of energy generation in a boiler room and transmission of the district heating network (by the application of [9], 0,85 is assumed as the product of values 0,89 and 0,95)

$$K_r = V \cdot C_j \qquad (9)$$

$$K_r{}^* = \varphi \cdot V \cdot C_j \qquad (10)$$

$$k_j = \frac{K_r{}^*}{A_f \cdot 12} \qquad (11)$$

where:

K_r – the annual costs of the oil purchase [zl/year]
$K_r{}^*$ – the corrected annual costs of the oil purchase [zl/year]
k_j – the unitary cost of heating [zl/m^2·month]

C_j – the average gross price of fuel oil in a given year [zl/dm^3]

The ecological indices resulting from the fuel consumption are expressed by determining the emission of carbon dioxide (CO_2), carbon oxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), dust (TSP=PM10) and benzo-[a]-pyrene, employing the dependency (12) as well as the assumptions included in [14]:

$$E = B \cdot W \tag{12}$$

$$B = 0{,}001 \cdot \varphi \cdot V \tag{13}$$

where:
E – substance emission [kg]
B – fuel consumption [m^3]
W – the index of sling load [kg/m^3]

4. The analysis of results

The computational results are achieved on the basis of the above dependencies, the source data concerning operation, made accessible by the property administrator, and the information included in building documentation in tables 1, 2, 3, 4 as well as in the diagrams (figs. 4 and 5).

4.1. The heat savings concerning heating

The achieved real level of heat consumption on heating, obtained during the years 2008-2011 (2007 is assumed to be temporal due to the investment realisation) is referred to 2006 and extends from 16,3% to 21,5% for particular year

Table1. The demand for heat

Lp.	Year	φ	V	φ ·V	Q_{co}	q_j
-	-	-	dm^3/year	dm^3/year	GJ/year	GJ/m^2
1	2006	1,010	70713	71420	2586	0,690
2	2007	1,041	60779	63271	2291	0,612
3	2008	1,074	55151	59232	2145	0,573
4	2009	1,030	58025	59766	2164	0,578
5	2010	0,897	65164	58452	2117	0,565
6	2011	1,025	54684	56051	2030	0,542

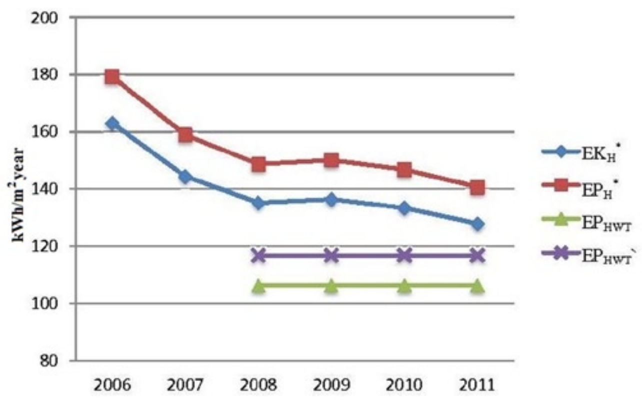

Fig. 4 The value of EK_H^* and EP_H^* in reference to EP_{HWT} and EP_{HWT}'

Nevertheless, the indices of the demand for energy which are displayed in fig.5 reach the following level:

– According to the requirements of technical conditions [10] for a 'new' building

EP_{HWT} = 106,3 kWh/m^{2}year

– According to the requirements of technical conditions [10] for a 'modernised' building

EP_{HWT}' = 116,9 kWh/m^{2}year

– The average index after thermomodernisation in the years 2008-2011, excluding 2007 of the realisation of investment, respectively

EK_H^* = 133,2 kWh/m^{2}year and **EP_H^* = 146,5 kWh/m^{2}year**

– The discrepancy between the real state and technical requirements:

Δ EP_H = 25,3 %

4.2. The operating costs

Table 2 contains the annual consumption costs incurred before and after the insulation of building partitions; the average unitary prices of fuel purchase; as well as the estimated unitary fees per month for 1m^2 of heated area. The annular costs of oil purchase (K_r^{**}) are shown in table 2, and the unitary heating costs (k_j^*) depicted in fig. 5, in the case of absence of insulation of external partitions (for each year, the level of heat energy consumption is assumed as in 2006; whereas the price of fuel purchase is assumed as the average value for a given year).).

Table 2. The operating costs

Lp.	Year	C_j	O_Z	K_r	K_r^*	K_r^{**}
-	-	zł/dm^3	zł/GJ	zł/year	zł/year	zł/year
1	2006	1,90	52,47	134188	135698	135698
2	2007	2,28	62,97	138648	144258	162838
3	2008	2,66	73,46	146933	157558	189977
4	2009	2,27	62,69	131640	135668	162123
5	2010	2,69	74,29	175032	157236	192120
6	2011	3,43	94,73	187557	192255	244971

Oz – the average cost of one GJ of heat energy for the group of buildings

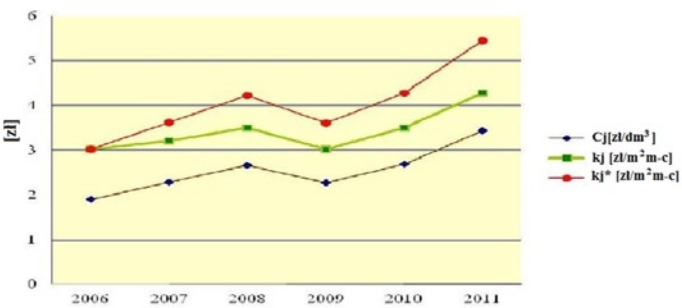

Fig. 5 The variability of unit costs of heating and prices of light fuel oil

4.3. The ecological effect

The emission of pollutants in the particular years of analysed period is shown in table 3, while its decrease with reference to 2006 is presented in table 4. The proportional drop in the emission of pollutants is designated as **ΔE**. The type of fuel has not been changed, hence the proportional decrease in the emission of every kind of pollutant is the same.

5. Summary

As a result of the insulation of external walls, roofs and slab roofs; as well as the replacement of external doors and windows at staircases, the real energy savings (achieved in the operating conditions) referred to the standard computational conditions of 2006 (before

Table 3. The emission of pollutants

Lp.	Year	B	SO_2	NOx	CO	CO_2	PM10	Benzo(a)piren
-	-	m^3/year	kg/year	kg/year	kg/year	kg/year	kg/year	kg/year
1	2006	71,42	364,2	142,8	40,7	192834	24,28	0,0186
2	2007	63,27	322,7	126,5	36,1	170832	21,51	0,0165
3	2008	59,23	302,1	118,5	33,8	159927	20,14	0,0154
4	2009	59,77	304,8	119,5	34,1	161368	20,32	0,0155
5	2010	58,45	298,1	116,9	33,3	157821	19,87	0,0152
6	2011	56,05	285,9	112,1	31,9	151335	19,06	0,0146

Table 4. The decrease in the emission of pollutants

Lp.	Rok	ΔE	ΔSO_2	ΔNOx	ΔCO	ΔCO_2	ΔPM10	ΔBenzo(a)piren
-	-	%	kg/year	kg/year	kg/year	kg/year	kg/year	kg/year
1	2007	11,4	41,5	16,3	4,6	22002	2,77	0,0021
2	2008	17,1	62,1	24,3	6,9	32907	4,14	0,0032
3	2009	16,3	59,4	23,3	6,6	31466	3,96	0,0031
4	2010	18,2	66,1	25,9	7,4	35013	4,41	0,0034
5	2011	21,5	78,3	30,7	8,8	41499	5,22	0,0040

the insulation) are within the range from 16,3 to 21,5% for particular years within the period of 2008 and 2011. The obtained decrease in the consumption of heat energy is lower than expected due to the lack of reliable hydraulic regulation of heating

The averaged for the whole group of buildings, the lowest value of final energy consumption index amounts to 127,9 kWh/m^{2}year in the operating conditions; whereas the value of non-renewable primary energy consumption index is 140,7 kWh/m^{2}year. In the case of averaged value, required for the buildings after the modernisation, amounting to 116,9 kWh/m^{2}year, the obtained value exceeds the required one of about 20,4%. Consequently, it is necessary to introduce subsequent activities so as to reduce the consumption of heat energy in the complex of buildings by raising the efficiency of use, consumption and transmission in the heating installation; as well as to provide the rational energy management by the users of buildings.

The decrease in the consumption of fuel takes place together with the decrease in the emission of pollutants which is characteristic of light fuel oil combustion, at the level equal to the level of energy saving

The energetic savings generate financial savings concerning the consumption costs of heating; nevertheless, the prices of fuel which rise constantly, reduce these effects substantially. In the discussed case, the unitary costs do not decrease despite the limitation on fuel consumption. Yet, from the analysis conducted before the insulation and after considering the rise in oil prices, the operating costs would be higher, for instance of about 27,3% in the last year. The increase in oil prices consumes the financial savings received from the reduction of heat consumption. The differences occurring between the obtained results for particular years show that the approach to the operation and usage of a building as well as its technical equipment exerts the impact on the real energetic and financial effects of thermomodernisation.

The improvement of heat insulation contributes to the freezing elimination in the fragments of buildings partitions and allows to achieve the inside temperature which provides comfort in heated rooms. The realised investment encompassing the whole complex of buildings simultaneously, increases substantially the aesthetic qualities and the market value of a property. These imponderable effects are also significant to the owners of properties.

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