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Assessment of thermo-modernization in a multi-family building

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Abstract. This paper presents an evaluation of thermo-modernisation improvements applied over the years in the multi-family residential building. Those improvements have included the civil and mechanical activities. The civil activities were as follows: the application of the thermal insulation on the external walls and replacement of the windows. The mechanical activities were mainly focused on an adjustment of the heating system to the new reduced heating demands of the building. The heating system in the building was modified – the radiators were replaced with the new ones, the heating central unit was modernised. Moreover the local gas water heaters were eliminated. Then the building's energy performance characteristics, prepared according to the valid Polish methodology, were compared with the real consumption. It was found that after the application of thermo-modifications the heating demand was reduced, twice. The economy efficiency of the thermo-modernisation was evaluated by means of a method of the annual costs. The annual costs include the heating system exploitation costs, DHW preparation system and the auxiliary devices electricity costs.

1 Introduction

Thermo-modernisations in Poland have been performed in the buildings for more than 20 years. Initially, the modernisations were mainly related to the elimination of the defects in the buildings, first of all made of precast concrete slabs called "big slabs" – constructed commonly in the period of time from 50s to 80s of XX century. A possibility of systemic modernisation had appeared at the time of introduction of Order regarding the support of thermo-modernisation activities [1]. The legal regulations were a basis for complex thermo-modernisation. The additional thermo-insulation is commonly applied to the external walls, and the building's energy systems are modernised. From the pool of the admitted solutions the optimal variants, in terms of the exploitation and investment costs, are chosen.

An additional positive aspect, having an influence on thermo-modernisation works, is the Act on/concerning Ownership/Proprietorship of Premises. This Act provides the possibility to establish the housing cooperatives by the inhabitants of the multi-family buildings. The owners of the premises also own the common parts of the whole building

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and they decide about the necessary renovations. The biggest number of renovations is noticed in the buildings administrated by the cooperatives and these renovation works refer to the up-lifting of the residential premises standards [2].

In order to evaluate the performed thermo-modernisations a number of methods can be applied. The following tools of evaluation can be applied:
• energy audit,
• energy efficiency audit,
• energy performance certificate,
• comparison of real energy consumption in the building.

1.1 Energy audit

Energy audit [3] allows the collection of the information regarding the profile of the energy consumption in the building or the group of the buildings. It defines and quantifies the possibility of execution of the investments driving to profitable, from the economics point of view, energy savings and it informs about the received results of the analyses carried out in this field.

1.2 Energy efficiency audit

Energy efficiency audit [4] includes the energy consumption analysis. It defines the technical status of the building itself as well as its equipment and systems. It includes the list of undertakings, which are necessary in order to improve the energy efficiency and economic profitability evaluation as well as the possible to gain energy savings.

1.3 Energy performance certificate

The building energy performance certificate [5, 6] defines the volume of the energy necessary to secure the needs connected to the building's occupancy. It takes under consideration the usable, final and primary energy needed for heating, ventilation, DHW, cooling and inside lighting. It also includes the list of the possible to carry out civil works, which can improve, in terms of profitability, the energy characteristics of the building.

2 Energy efficiency evaluation

The items listed below were used for carrying out the energy efficiency evaluation of the thermo-modernisation improvements introduced in the multi-family building:
• data coming from the inventory of the building, technical devices and systems,
• the information provided by the building's superintendent,
• energy consumption data divided into the separate tasks,
• data referring to the changeability of climate over the years.

The comparison analysis with the real measurements was conducted based on the algorithm of energy performance certificate methodology [6]. The annual costs method was conducted for the evaluation of thermo-modernisations economy effectiveness. The annual costs have included the exploitation costs of the following systems: heating, DHW and electricity for the auxiliary devices.

3 Description of the analysed building

A subject of the analysis is a multi-family building, located in Kórnik town. The building is managed by Śrem Housing Cooperative. The building consists of basement (under the whole building), 5 floors, and usable area of A_f= 1693 m^3. The structure of the building is made of the reinforced concrete slabs – WUF-T technology, in the segmental arrangement with 3 staircases. The building was built in 1973 [7].

3.1 Building's structure characteristics

The systemic monolithic external walls are 25cm thick and the gable walls, additionally insulated with 5 cm thick layer of Styrofoam in 1973, were insulated by means of 10 cm of NEOPOR Styrofoam (heat transfer coefficient λ=0.031 W·m^{-1}·K^{-1}) in 2011. The works were carried out from April to August. The timber windows were replaced with plastic ones – the heat transfer coefficient of the new windows is U=1.5 W·m^{-2}·K^{-1}. The windows in the common areas – i.e. the staircases – were equipped with the ventilators. Figure no. 1 presents the northern elevation of the building before and after thermo-modernisation.

a)  b) 

Fig. 1. Northern elevation of the building a) before thermo-modernisation b) after thermo-modernisation.

3.2 Characteristics of the mechanical systems

The heating system, before the modernisation, was supplied by the district heating network with the parameters: 100/70°C. Domestic hot water was prepared locally in the premises by means of the gas flow boilers. Since 2009 the combi heating unit was applied, supplied by network with the changeable parameters in the heating season 95/70°C and the steady parameters on summer time – 65/30°C.

3.3 Housing characteristics

The multi-family building was divided into three segments. Left segment, where the walls are directed into south, north and east consists of staircase and two apartments of M3 type and one apartment of M2 type. Middle segment – with walls directed to north and south consists of the staircase and two M4 apartments. The right segment is a mirror reflection of the left segment.

77 persons are living in the building (11 children, 40 women and 26 men). Almost half of inhabitants are in the retirement age (23 women and 11 men). The average age of inhabitants is 43.2. Following the information of the district superintendent the demographic situation has improved within the last few years. 10 years ago most of the inhabitants were in the post-production age. For the last few years the tendency is slightly changing and younger people are living in the building - young couples, the couples with children. Figure no. 2 presents the average age of the inhabitants in all 40 apartments.

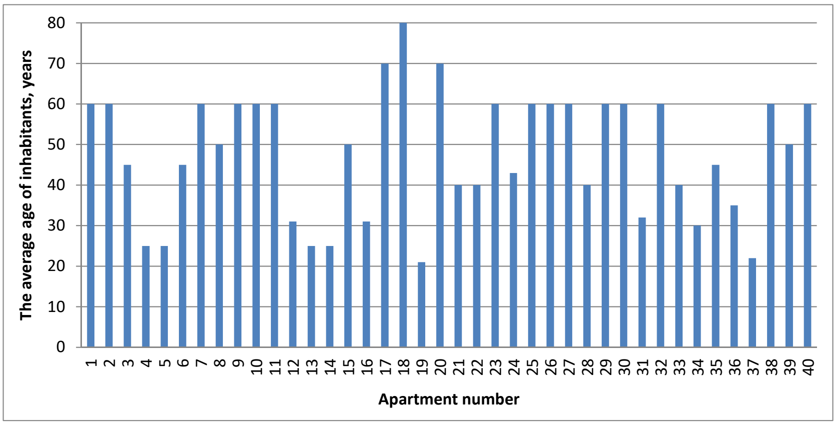

Fig. 2. Average age of inhabitants in the given apartment.

4 Analysed variants

4.1 Thermo-modernisation improvements

The analyses were conducted considering the thermo-modernisations carried out successively. Table 1 presents the sheet of the analysed variants.

Table 1. Analysed variants.

Source parameters	**Z1**	Heating unit before modernisation (before January 2009)
	Z2	Heating combo unit after modernisation (since January 2009)
Thermal parameters of the building	**T1**	Heating characteristics before thermo-modernisation (before September 2011, last heating season – 2010/2011)
	T2	Heating characteristics after thermo-modernisation (since September 2011, first heating season 2011/2012)

4.2 Climatic data

The analysis takes into consideration the real changeability of outdoor temperature in the analysed period of measurement, based on the temperature data collected by the weather station on Ławica airport in Poznań [8] (D2 variant) and the statistic climatic data (D1 variant) [9] (Table no. 2).

Table 2. Average monthly temperatures.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Statistic changeability of outdoor air temperature – **D1**												
	0.2	-1.8	2.7	8.3	13.0	16.8	18.3	18.4	13.5	7.0	2.2	-0.1
Real changeability of outdoor air temperature – **D2**												
to 31.12.08	-0.2	1.0	3.8	9.3	14.7	17.5	19.5	18.9	14.5	9.1	4.2	0.8
From 1.01.09 to 31.08.11	-2.8	-1.3	3.9	11.1	13.4	17.6	20.1	19.3	14.7	8.1	5.2	-0.7
from 1.09.11 to 31.12.14	-0.7	0.0	3.9	9.8	15.0	17.2	20.9	19.0	14.6	10.2	5.7	1.4

4.3 Variants in the measurement years

As the particular thermo-modernisation improvements were carried out successively, in table no. 3 the division into the variants considering the construction improvements and mechanical improvements introduced over the measurement years were presented, taking into account the accessible measurement data regarding the changeability of outdoor air temperature.

Table 3. Analysed variants over the measurement years.

Variant		Source parameters	Building's thermal parameters	Climatic data
to 01.01.2009	**A**	Z1	T1	D1
	B	Z1	T1	D2
from 1.01.2009 to 31.08. 2011	**C**	Z2	T1	D1
	D	Z2	T1	D2
after 1.09.2011	**E**	Z2	T2	D1
	F	Z2	T2	D2

5 Analysis of the measurements conducted in the building

5.1 Thermal energy for heating purpose

Based on the data regarding the heat consumption provided by Thermal Power Company in Śrem [10] it has been found that on the end of 2008 the heating unit has been changed into combi heating unit. On the fig. 3 the consumption of heating energy in the heating seasons of the measurement years has been presented. Additionally, on the time axis of the diagram it has been indicated the moment of execution of the given improvement, marked according to table no. 3.

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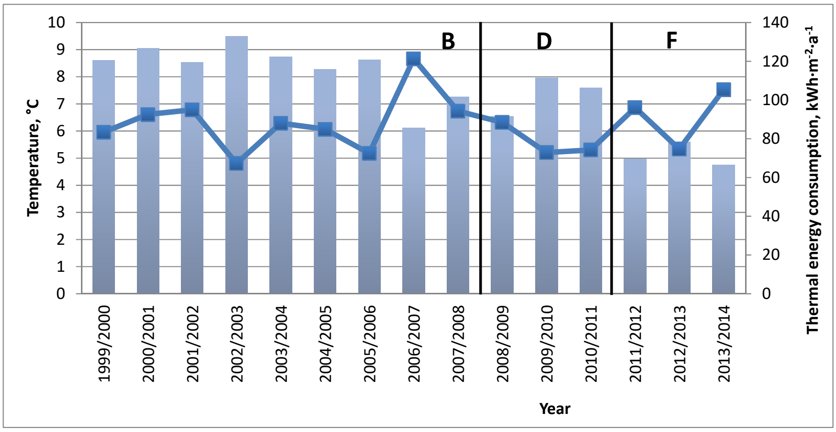

Fig. 3. Thermal energy consumption in the heating season for heating purpose, depending on the average temperature of outdoor air in heating season.

The consumption of thermal energy had decreased after thermo-modernisation in 2011.

5.2 Thermal energy for domestic hot water preparation

The data regarding consumption of thermal energy for DHW were archived as e-files only after changing the heating unit into combi one. The vertical line on fig. 4 indicates the time periods important for thermal analysis.

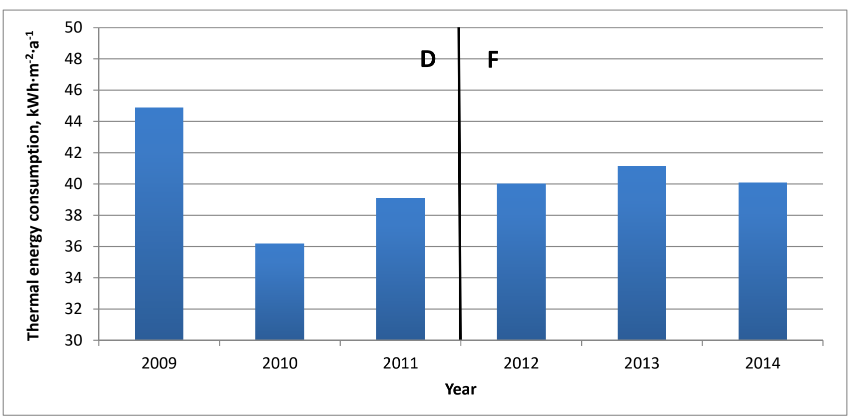

Fig. 4. Thermal energy consumption in heating season for DHW preparation.

The change of water settlement system from the individual gas boilers to the hot water meters, contributes to the water consumption decrease – 19% of consumption decrease in 2010 in comparison to the consumption in 2009. When inhabitants got used to the new system of domestic hot water supply they had come back to their old habits.

5.3 Water consumption

It results from the analysis of the consumption of hot and cold water as well as the water consumption for the utility and technical rooms that the consumption decreases over the measurement years. This is connected to the introduction of the individual hot water settlement in 2009.

Table 4. Water consumption in the building.

Year	**Annual consumption**		
	Hot water, m^3	Cold water, m^3	Total, m^3
2006	979.1	2054.6	3161.7
2007	974.1	2044.0	3146.0
2008	915.6	1921.4	2965.0
2009	704.9	1534.3	2482.0
2010	768.2	1450.5	2308.0
2011	762.7	1567.2	2593.0
2012	804.1	1576.5	2501.0
2013	895.6	1600.5	2471.0
2014	851.4	1564.5	2493.0

6 Theoretical energy characteristics of the building

The building's energy characteristics were conducted assuming the following:

- a division of the building into two zones, I – apartments with average temperature θ_{int}=21.4°C, II – staircases, θ_{int} =16°C,
- the heat gains depending on the number of inhabitants and apartment's equipment, including a coincidence factor,
- heat bridges following Wärmebrückenkatalog [11].

Table no. 5 presents the values of final energy ratio for heating purpose for the analysed variants, depending on the assumed data.

Table 5. Value of final energy ratio for the analysed variants.

	A	**B**	**C**	**D**	**E**	**F**
$Q_{K.H}$, $kWh{\cdot}m^{-2}{\cdot}a^{-1}$	210.5	194.3	210.4	203.9	107.1	96.8

The introduction of the construction and mechanical improvements (Variant F) allows to improve the final energy for heating and ventilation purposes - in relation to the variant B by 50%, and in relation to the variant D by 52.5%. The replacement of the heating unit from one function (variant B) to combi (variant D) had influenced the increase of final energy by 5%.

Figure no. 5 presents the coefficients of usable, final and primary energy for the analysed variants, including the division into the individual purposes. There are the division lines on the diagram for three time periods: before 2009 (variant B), between 2009–2012 (variant D) and from January 2012 (variant F). In the variants A, C, and E, which are the equivalents of variants B, D and F, the statistic changeability of outdoor temperature was assumed.

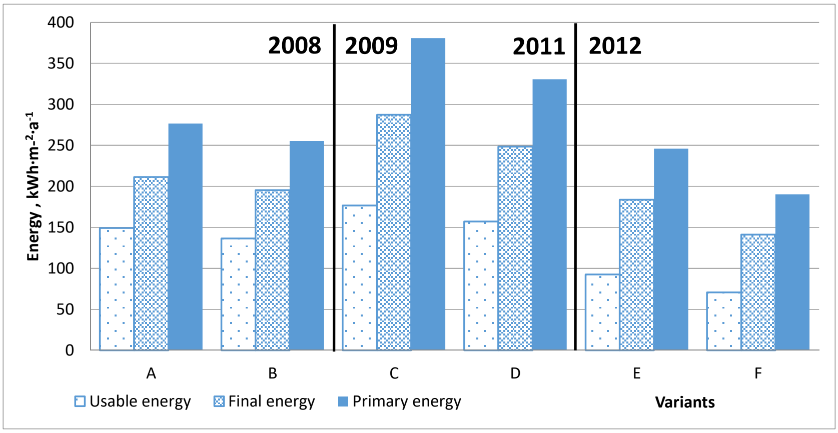

Fig. 5. Usable, final and primary energy coefficients divided into the particular goals.

The increase of thermal energy demand in variant D in comparison to variant B results from the change of function of the heating unit. Before December 2008 the unit was supplying only the heating demands, since 2009 it supplies both the heating system and DHW system. An application of the additional function: DHW preparation including the consumption measurement had had an impact on an increase of the system's energy demands. After 2012 - when the thermo-modernisation was introduced the heating & ventilation demands have dropped while DHW system demands were kept on the same level.

The diagram shows that assuming for the purpose of analysis statistic changeability of climatic data influences the decrease of usable, final and primary energy coefficients. It relates to the shorter and milder winters.

7 Comparison analysis

Figure 6 presents the comparison of the theoretical characteristics (EK_H) with the real measurements, considering in the same time, the data regarding the thermal energy consumption for heating and ventilation in the building during the analysed measurement years: 2000–2014.

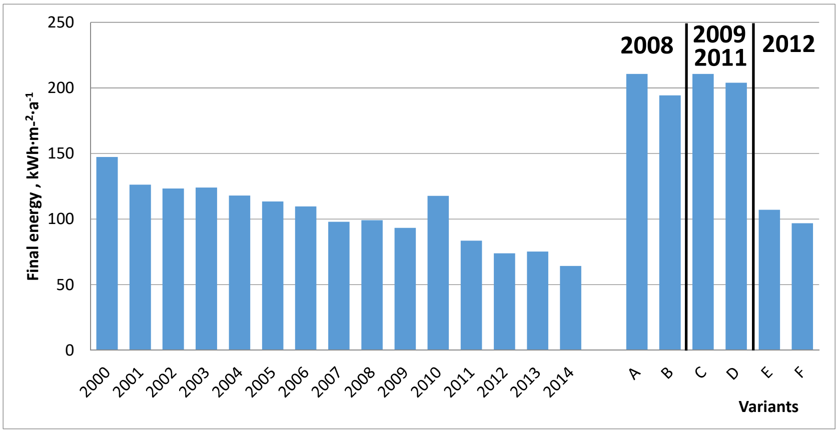

Fig. 6. Annual consumption of energy for heating and ventilation in the given year and the demand for final energy for heating in the analysed variants.

The results of the theoretical analysis for the data referring to year 2012 vary significantly from the values of actual consumption. In variant **F**, presenting the thermal status of the building after full thermo-modernisation, assuming the real changeability of outdoor air temperature, the theoretical coefficient is closed to the real consumption. In comparison to year 2012 it is bigger by 24%, in 2013 – by 22% and 2014 – 34%. The total costs of building's exploitation were appointed taking into account the energy costs following the tariffs valid for the inhabitants. The analyses are taking into account – for each source of energy – the tariffs valid in the individual years. Figure no. 7 presents the summary, annual energy costs for whole heating and DHW systems.

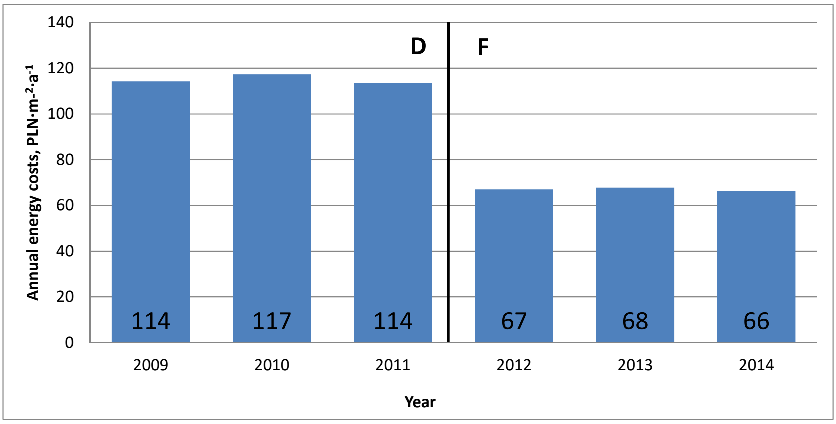

Fig. 7. Summary costs of thermal energy consumption for heating and ventilation, DHW and electricity for the auxiliary devices.

After conducting the full thermo-modernisation the energy costs in the period of time from 2012 to 2014 were kept on the comparable level and they have amounted, in average, to 67.10 PLN·m^{-2}. The conducted thermo-modernisation of the building had caused the decrease of the total costs of energy for the whole building in relation to 2009 and 2011 by 41%, and 43% in 2010. The monthly savings per person amount to 85 PLN. This amount, with a previous monthly fee equal to 254 PLN (example of the fee from the apartment where two persons are living) has allowed gaining almost 1000 PLN of savings.

8 Summary

The introduced thermo-modernisation had contributed in a decrease of the annual costs related to the exploitation of the building. The energy analysis and the number of profits coming from conducting the thermo-modernisation works in the building confirm the profitability of investments/ works related to reduction of the energy demands. The effects in terms of improvement of quality and comfort of life, safety, decrease of CO_2 emission to the environment and the financial savings shall be the arguments for conducting the thermo-modernisation improvements in the buildings. Only the investment costs become a problem. And due to above the works regarding the mechanical systems shall be conducted after the previous structural thermo-modernisation of the building. This attitude gives a possibility to select a source with lower power, corresponding with decreasing thermal demands of the building. The savings are higher in the building if the replacement of the one –function heating unit into the combi heating unit is preceded by the structural thermo-modernisation.

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