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FEASIBILITY ANALYSIS OF UPRGADING AN OLD BUILDING TO THE STANDARD REQUIREMENT OF A LOW ENERGY REQUIREMENT BUILDING

ANALIZA MOŻLIWOŚCI PRZYSTOSOWANIA BUDYNKU W STARYM BUDOWNICTWIE DO STANDARDÓW BUDYNKU NISKOENERGETYCZNEGO

Abstract

The paper presents a case study analysis of the energy demand for an old building located in Cracow. Some improvements in construction of the building envelope, especially in thermal insulation and in the heating system, have been analyzed. Reduction of the energy demand index has been shown in the three variants that were considered. The goal of this study was to assess the possibility of obtaining low energy demand in a typical old poorly insulated building.

Keywords: *energy demand*, *modernization*, *low energy requirements building*

Streszczenie

Artykuł stanowi analizę przypadku zapotrzebowania na energię dla budynku w starym budownictwie. Wprowadzono ulepszenia w konstrukcji budynku, głównie poprawiając izolację, a także w instalacji ogrzewania. Wykazano redukcję wskaźnika zapotrzebowania na energię dla trzech rozważanych wariantów. Celem analizy było sprawdzenie możliwości przystosowania budynku w starym budownictwie do standardów budynku o niskim zapotrzebowaniu na energię.

Słowa kluczowe: *zapotrzebowanie na energię, modernizacja, budynki o niskim zapotrzebowaniu na energię*

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1. Introduction

In recent times, energy saving has become an important topic of discussion at the scientific fields of energetic and environmental engineering. The global economy is mostly based on fossil fuels such as gas, petroleum and coal. The main issues are the limited amounts of conventional fuels and the pollution caused by using them in every area of human life. In Poland, more than 90% of energy comes from fossil fuels [1] and the structure of energy consumption is equal to that of other Western European countries [2].

Table 1

The structure of the energy demand in Poland [3]

Direct Consumption	Total energy [TJ]	Percentage [%]
Mining and quarrying	56129	1.8
Manufacturing	905346	28.7
Electricity supply	110976	3.5
Water supply; waste management	23276	0.7
Construction	67552	2.1
Transport	704082	22.3
Household	821257	26
Agriculture	153895	4.9
Other	315288	10

Table 1 shows that in Poland, 26% of final energy consumption is derived from households. The EC Directive 2002/91/EC on the energy performance of buildings [4] also presents that in the European Union, more than 40% of energy consumption comes from the residential and tertiary sector. Therefore, the residential buildings are the target area to reduce energy consumption and related greenhouse emissions through improvements to the energy efficiency of these buildings [4]. Literature points out that coupling energy efficiency measures with increased renewable energy production techniques enables the generation of some or all of a building's energy consumption, thus reducing dependence on fossil fuels [5, 6]. The undertaken action should focus both on the demand and supply side of energy as is indicated in, for example, Demand – Side Management.

2. Purpose and scope

The paper presents a case study of energy performance enhancement methods in a residential building constructed in the 1980's. The subject of the study was built in the north part of Cracow. The main goal of the analysis was to check the feasibility of transforming a typical old, residential, multi-family building into a low energy requirement building by upgrading heating and ventilation installations. The National Fund for Environmental

Protection (Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej NFOŚiGW) defined that 40 kWh/m^2,year is the usable energy demand index in single and multi-family building with low energy requirement standard [7].

The presented assessment includes the calculation of energy demand for the purposes of heating and ventilation in existing state (variant 0) and also after two modifications (variant 1 and variant 2). Variant 1 is based on the improved thermal insulation of the building envelope to achieve significant reduction of heat losses. Variant 2 includes all solutions from variant 1 and also few more improvements, for example, a thicker insulation layer, a reduction of thermal brides and the appliance of an energy efficient heat distribution system with high heat recovery.

3. Methodology

All calculations presented in this paper were done with the Audytor OZC 6.1 Pro computer program. The calculations are based on:
– A Standard PN-EN ISO 13790 [8],
– The ordinance from the Polish Ministry of Infrastructure from 6 November 2008 on the methodology of calculating the energy performance of buildings [9].

The assessment of the energy standard of a building requires the calculation of usable energy demands based on standard PN-EN ISO 13790 [8]. In order to make the analysis more accurate, the subroutine 'Energy performance of the building' was used. The second method enables the estimation of the energy demand for domestic hot water (DHW) and operation of auxiliary devices (pumps or fans). Moreover, with the option 'Energy performance of the building' it is possible to evaluate the amount of non-renewable primary energy consumption. Calculations done with both methods enable the examination of whether or not it is possible to reach the standard of a low energy requirement building.

3.1. Description of building

The examined building consists of a cellar, 50 dwellings and 4 shop premises, which are located in one underground and four above-ground floors having a total surface area of 3527 m^2. The estimated number of users is about 150 (3 people per dwelling). The main construction elements are made from reinforced concrete and the rest are constructed from prefabricated components. The external walls are not thermally insulated (Table 2). Ceilings are also made from prefabricated components and insulated with 2 cm of foamed polystyrene. The roof is ventilated and insulated with 12 cm of mineral wool. In wooden windows and doors, leakages occur causing heat loss and drafts.

3.2. Variant 0 – building in existing state

The building is equipped with heating installation supplied from the district heating network (MPEC Cracow), which does not have thermostatic valves or any devices for temperature regulation. Domestic hot water is prepared individually with gas boilers. The airflow in the building is calculated according to PN-EN ISO 12831-2009 [8] and is provided by natural ventilation.

Table 2

Building envelope heat transfer coefficients – Variant 0

Name	Insulation	U [W/m²K]
Cellar external wall	Foamed polystyrene 5 cm, λ = 0.045 W/mK	0.486
External wall	–	0.479
Ceiling	Foamed polystyrene 2 cm, λ = 0.045 W/mK	1.145
Ceiling over cellar	Foamed polystyrene 4 cm, λ = 0.045 W/mK	0.686
Ventilated roof	Mineral wool 12 cm, λ = 0.050 W/mK	0.322
External window	–	2.60
External door	–	3.50

3.3. Variant 1 – first modification

The first modification in the building serves to reduce the energy consumption for the purposes of heating and ventilation and is based on improvements only in the building envelope thermal insulation. The building heating and ventilation systems are not changed in this variant.

In this variant, the insulated building envelope meets the regulations of Ordinance of Ministry of Transport, Building and Maritime Economy from 5 July 2013 [10]. Table 3 includes the modification with inserted layers of foamed polystyrene (λ = 0.040 W/mK) and mineral wool (λ = 0.050 W/mK) as well as the replacement of windows and doors.

Table 3

Building envelope heat transfer coefficients – Variant 1

Name	Insulation	U [W/m²K]	U_{max} [W/m²K] [7]
Cellar external wall	Foamed polystyrene 5 cm	0.486	0.650
External wall	Foamed polystyrene 12 cm	0.247	0.250
Ceiling	Foamed polystyrene 7 cm	0.497	1.000
Ceiling over cellar	Foamed polystyrene 10 cm	0.358	1.000
Ventilated roof	Mineral wool 22 cm	0.196	0.200
External window	–	1.300	1.300
External door	–	1.700	1.700

3.4. Variant 2 – second modification

The second modification in the building for further reduction of the energy demand for the purposes of heating and ventilation is based on further improvements in the building envelope insulation (Table 4) in order to meet guidelines for low energy requirement buildings [7]. Natural ventilation is replaced with mechanical ventilation with heat recovery. An air handling unit equipped with a highly efficient counter-current heat exchanger with 78%

efficiency is planned to be installed on the roof. The fresh air is transported to the bedrooms and living rooms of the apartments and is exhausted by ducts in the kitchens and bathrooms.

In order to achieve optimization of energy demand, the heating installation will be modernized (hydraulic regulation, pipelines insulation). Mechanical ventilation does not allow for the installation of open furnace gas hot water boilers, so it was assumed that DHW would be heated by the standard local heating system.

Table 4

Building envelope heat transfer coefficients – Variant 2

Name	Insulation	U [W/m^{2}K]	U_{max} [W/m^{2}K] [7]
Cellar external wall	Foamed polystyrene 20 cm	0.185	0.200
External wall	Foamed polystyrene 20 cm	0.156	0.200
Ceiling	Foamed polystyrene 7 cm	0.465	1.000 [10]
Ceiling over cellar	Foamed polystyrene 10 cm	0.358	1.000 [10]
Ventilated roof	Mineral wool 30 cm	0.146	0.150
External window	–	0.800	1.300
External door	–	0.800	1.500

4. Results of calculations

Table 5 and Table 6 present results of the calculations of the seasonal usable energy demand for heating and ventilation. The building in its existing state (variant 0) has very high energy consumption, which reaches a level of 190–200 kWh/(m2,year) depending on the calculation method.

In the variant 1, the undertaken modifications enable a significant reduction in energy demand. The usable energy index (yearly seasonal unit usable energy demand for heating and ventilation [11]) decreased from 191 to 93 kWh/(m^2,year) in the method based on PN-EN ISO 13790:2009[8] (Table 5) and decreased from 202 to 99 kWh/(m^2,year) in the method based on ‘Energy performance of the building’[9] (Table 6). The building in variant 1 approaches the standard required of an energy efficient building [12].

Due to further improvements in the building envelope and the installation of mechanical ventilation with heat recovery as described in variant 2, the reduction of the usable energy demand index reaches a satisfactory level of 33 kWh/(m^2,year). As a result, the examined building achieved the standards of a low energy requirement building (below 40 kWh/(m^2,year)) [7].

The results of the energy demand calculations for heating, ventilation, domestic hot water and supply to auxiliary devices are included in table 7. The lower value of the primary energy index (EP) relative to the final energy index (EK) results from the choice of heat source. Energy from cogeneration has a low effort indicator (w_i) at the level of 0,8. Relatively small electric energy demands do not have such an influence on the final result of primary energy at the variant 0 and 1. The situation changes in the variant 2 because of mechanical

Table 5

Calculation of seasonal usable energy demand for heating and ventilation in accordance with PN-EN ISO 13790:2009 [8]

Variants	$L_{H,m}$	Q_D	Q_{iw}	Q_{ve}	$\eta_{H,gn}$	Q_{sol}	Q_{int}	$Q_{H,nd}$	$Q_{H,nd}$	EU
	[h]	[GJ/ year]	[GJ/ year]	[GJ/ year]	[–]	[GJ/ year]	[GJ/ year]	[GJ/ year]	[kWh/ year]	[kWh/m² year]
0	6102	1529	265	901	0.19	838	511	2431	675191	**191**
1	5307	628	265	901	0.45	857	511	1177	326808	**93**
2	4304	442	156	413	0.44	861	511	414	114973	**33**

Table 6

Calculation of seasonal usable energy demand for heating and ventilation in accordance with 'Energy performance of the building'[9]

Variants	$L_{H,m}$	Q_D	Q_{iw}	Q_{ve}	$\eta_{H,gn}$	Q_{sol}	Q_{int}	$Q_{H,nd}$	$Q_{H,nd}$	EU
	[h]	[GJ/ year]	[GJ/ year]	[GJ/ year]	[–]	[GJ/ year]	[GJ/ year]	[GJ/ year]	[kWh/ year]	[kWh/m² year]
0	6399	1455	249	1029	0.19	529	383	**2564**	712068	**202**
1	5963	597	249	947	0.59	529	383	**1259**	349753	**99**
2	4596	421	147	412	0.61	529	383	**425**	118123	**33**

Abbreviation: $L_{H,m}$ – heating season length [h], Q_D – loss of heat by building envelope [GJ/year], Q_{iw} – loss of heat by internal walls and ceilings [GJ/year], $Q_{V,e}$ – loss of heat by ventilation, $\eta_{H,gn}$ – heat gain efficiency ratio [–], Q_{sol} – solar energy gain [GJ/year], Q_{int} – domestic (internal) heat gain [GJ/year], $Q_{H,nd}$ – total usable energy demand for heating and ventilation with heat gains taken into account [GJ/year], EU – usable energy demand index without auxiliary devices [kWh/m²rok]

Table 7

Calculation of seasonal usable energy demand for heating and ventilation in accordance with 'Energy performance of the building' [9]

Variants	$Q_H + Q_{V,nd}$	$Q_{K,nd} + Q_{K,V}$	$Q_{W,nd}$	$Q_{K,W}$	$E_{el,pom}$	EU	EK	EP
	[kWh/ year]	[kWh/ year]	[kWh/ year]	[kWh/ year]	[kWh/ year]	[kWh/m² year]	[kWh/m² year]	[kWh/m² year]
0	712068 + 0	996735 + 0	98069	106597	11201	**233**	**316**	**269**
1	349750 + 0	489571 + 0	98069	106597	10312	**130**	**172**	**153**
2	80431 + +37692	88164 + +41316	98069	185170	31707	**70**	**98**	**98**

Abbreviation: $Q_{H,nd}$, $Q_{K,nd}$ – respectively, usable and final energy demand for heating and natural ventilation [kWh/year], $Q_{V,nd}$, $Q_{K,V}$ – respectively, usable and final energy demand for mechanical ventilation [kWh/year], $Q_{W,nd}$, $Q_{K,W}$ – respectively, usable and final energy demand for DHW, $E_{el,pom}$ – final energy demand for auxiliary devices.

Energy demand index: EU – usable energy, EK – final energy, EP – primary energy.

ventilation, which consumes more electrical energy. In variant 2, the central preparation of domestic hot water also has a negative influence due to heat losses in the pipelines. According to current regulations, the maximum value of the primary energy index for multi--family buildings is 105 kWh/(m^2year) [10], which means that only the building in variant 2 meets the requirements from 'Energy performance of the building'.

5. Analysis of heat losses

Figs. 1, 2, 3 compare differences in heat losses between the three analysed variants. There are significant changes in the heat demands for ventilation, from 35.7% (Fig. 1) in variant 0 through to 50.2% (Fig. 2) in variant 1 and to 40.5% (Fig. 3) in variant 2. This inequality is caused by differences in the insulation of the building. In variant 0, where the building envelope does not consist of any foamed polystyrene layer, the percentage of heat losses for ventilation is the lowest. Due to the modernization of the thermal insulation in variant 1 and no changes in ventilation, the percentage of heat losses for ventilation is higher by about 15%. In the last case (variant 3), further improvements were taken (a thicker insulation layer and mechanical ventilation with heat recovery), which generates a decrease in heat losses for ventilation.

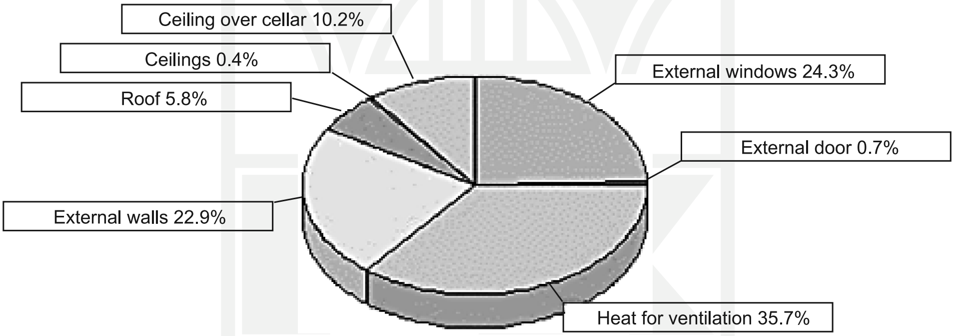

Fig. 1. Heat losses – Variant 0

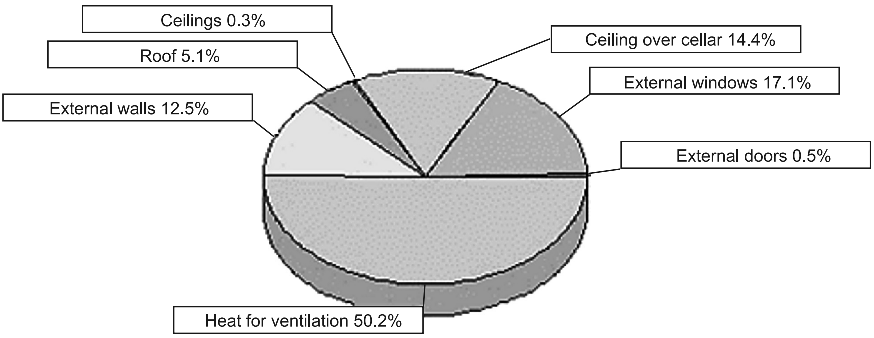

Fig. 2. Heat losses – Variant 1

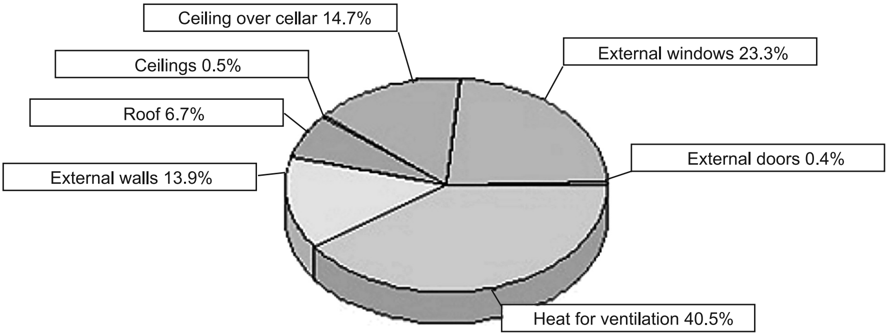

Fig. 3. Heat losses – Variant 2

6. Conclusions

Due to increasing energy consumption, comprehensive action connected with energy saving should be undertaken. The case study of building in Cracow confirms that achieving a standard of low energy requirement building is possible. The decrease in the overall energy demand is significant when reduction reaches a level of 16% of the initial value (EU = 202 kWh/m^2/year). The main differences between variant 1 and variant 2 are the thickness of the insulation layer and the installation of mechanical ventilation. Achieving the standard of low energy requirement building is possible only with a mechanical ventilation system with heat recovery. As a result, final costs in variant 2 will be far greater than in variant 1. What is more, the realization of mechanical ventilation in an already inhabited building might be almost impossible. In conclusion, variant 2 is much more energy saving, but unfortunately also unprofitable. In existing buildings, variant 1 seems to be more beneficial, while the reduction of energy demand is significant, the expenditures should not be burdensome.

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