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Energy monitoring of low-energy houses in northern Poland Part one: *Characteristics of buildings and their energy demand*

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Energy monitoring of low-energy houses in northern Poland

Part one: *Characteristics of buildings and their energy demand*

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Abstract. Slowing development of low energy buildings in Poland and other EU is the lack of recommendations, compliance with which would guarantee the achievement of specified energy level. An attempt of a comprehensive approach to such a standard was made in 2013 by a program and the subsidy system for passive residential buildings. Two energy requirements were defined (NF15 and NF40) with appropriate specifications for building assemblies and installations. The maximum of the energy consumed during the heating season was specified as well as limits for other energy use. This publication is the first of two articles on the assessment of selected characteristics of several buildings with a reduced energy demand, which were built in north-eastern and central Poland. It is an introduction in which the assessed buildings were characterized both in terms of their designed technical and functional parameters as well as real energy supplies related to their heating and ventilation.

1. Introduction

The development of construction with low energy demand is a fact in Poland and other EU countries. The observed increase in interest in energy-efficient buildings results in a regular increase in the number of buildings with good energy performance [1, 2, 3]. However, because the share of building maintenance needs in global energy consumption is estimated at approx. 40%, the dynamics of launching buildings with reduced energy demand in the market should still be considered too slow.

A difficulty in popularizing low energy buildings in Poland was the lack of recommendations, compliance with which would guarantee the achievement of specified energy level. The first attempt of a comprehensive approach to such a standard was made in 2013 by a program to improve the energy efficiency of new residential buildings - priority program of the NFEPWM [4, 5].

The subsidy system was intended for in this program. Practically it was an award for achieving a certain level of energy quality. Two energy requirements were defined (NF15 and NF40) with appropriate specifications for building assemblies and installations. The numbers in energy requirements (15 and 40) specify the maximum value of usable energy demand for heating during the heating season divided by the heated area of the building [kWh/m²·yr]. There are two groups of detailed requirements:

- regarding the building envelope - affecting the index of seasonal energy demand for heating EU,
- regarding the efficiency of central heating, mechanical ventilation and hot water installations - affecting the final energy index EK.

Several low-energy buildings in Poland, are described in this article. Among them were both buildings meeting the standards NF15 and NF40 as well as energy-efficient buildings (hereinafter referred to as LE) built in 1999-2001, more than a decade before the creation of these standards. As part



of environmental observations conducted in these buildings, the actual values of selected parameters shaping the energy performance were measured or determined based on measurements. From the point of view of the energy quality of buildings, only the energy used for heating is relevant. The energy used to heat domestic hot water may cause a blurring of the result of the energy quality assessment of the building. Therefore, this article does not deal with the energy used hot water preparation.

2. Characteristics of the analyzed buildings

Low-energy buildings (LE) located in Białystok are identical in terms of their construction [6]. Both are two-story, without a basement and with an unheated garage thermally insulated. They only have a different heating system. The first of LE buildings (figure 1) has a traditional heating system with panel radiators supplied from a gas boiler, while the second one uses accumulation electric heaters with dynamic discharge.

Parameters of LE houses:

- usable heated area - 177 m²,
- garage area - 21 m² (unheated),
- building volume - 732 m³.

Solutions and materials used in external partitions in low-energy buildings are:

- three-layer walls of 47 cm thickness (made of 18 cm calcium-silicate brick, 18 cm mineral wool and 11 cm calcium-silicate brick),
- floor on the ground (concrete floor slab 10 cm + polystyrene 10 cm + concrete floor 6 cm + parquet / terracotta),
- roof in a wooden structure (with a layer of 2 cm polystyrene + glass wool 18 cm),
- double glazed, tight windows with gas inside the space between the panes,
- tight entrance door, insulated.



Figure 1. View of the front façade (NW direction) of the low-energy building LE1 (the LE2 building in addition to the color details is identical) - and the air intake to the ground heat exchanger

LE houses are equipped with mechanical ventilation system with heat recovery. The external air is supplied to the recuperator via a ground heat exchanger in which the ventilation air entering the interior of heated zone is preheated. In the summer season, after exchanging the contribution in the recuperator to the "summer" ground heat exchanger is used to cool the air blown into the building. The effect is obviously far from the standard air conditioning, but it allows to obtain a reduced internal temperature during the 24 hours during the highest outdoor temperatures.

The building of NF40 class - NF40 (1) (figure 2) located in Warsaw is a semi-detached building, without a basement, three-story, with an area of 269,4 m² (with a garage in the block of the building) and a volume of 759.8 m³. A foundation slab was made in this building with polystyrene of 20 cm thickness. The walls were made of 18 cm calcium-silicate blocks and polystyrene 20 cm (15 cm in the garage). The building has a gable roof, wooden with a layer of thermal insulation in the form of mineral wool 30-40 cm thick. The windows are three glazed, tight, with a noble gas. Doors are insulated. The source of heat in the building is a dual-purpose, condensing gas boiler. In most heated rooms, a floor system was used, and only in bathrooms on the second floor, wall heating.



Figure 2. View of the front façade (S direction) of the building - NF40 (1)

Buildings NF40 (2), NF40 (3) and NF40 (4) located in Bialystok and around are two-story, without basements. Their usable areas are: 177 m², 238,7 m² and 180,4 m². These buildings have wooden roofs insulated with mineral wool 30-40 cm thick.

Building NF40 (2) has an unheated garage with an area of 32,4 m². The walls are made of hollow bricks (thickness 30 cm) and 20 cm of mineral wool. Under the foundation slab 25 cm thick polystyrene was used. The walls of the NF40 (3) building were made of hollow bricks (25 cm thick) and polystyrene (20 cm thick). In the floor on the ground polystyrene 10 cm was used. Building NF40 (3) has a garage with an area 35 m². In the NF40 building (4), the walls were made of an aerated concrete (40 cm thick) and polystyrene (22 cm thick) as well as 15 cm of polystyrene is used in the floor on the ground.

In the building of NF15 class (with the areas of 215 m² and 140,5 m²), thicker thermal insulation layer was used, which resulted in lower heat transfer coefficients (table 1). In the NF15 (1) building (figure 3), the walls are made of cellular concrete (24 cm thick) and polystyrene (32 cm thick). In the double-pitched roof with a wooden structure used 50 cm mineral wool. Floor on the ground is insulated by polystyrene of 40 cm thick. In the NF15 (2) building, the walls were made of hollow bricks (25 cm thick) and polystyrene (40 cm thick). Flat roof was insulated with mineral wool (50 cm thick), and the floor on the ground with thermal insulation layer of 40 cm.



Figure 3. View of the building (S and E direction) of NF15 class - NF15 (1)

The basic thermal characteristics of the baffles of the analyzed buildings are shown in Table 1.

Table 1. Thermal characteristics of selected partitions baffles of the analyzed low-energy buildings [1]

level of thermal protection requirements	thermal transmittance coefficient U (W/m ² ·K)				
	wall	roof, sloping roof	floor on the ground	window	door
technical requirements WT1997	≤ 0,30	≤ 0.30	≥ 1.50¹⁾	≤ 2.00	≤ 2.60
low-energy (LE1)	0.195	0.176	0.184	1.90	2.00
low-energy (LE2)	0.195	0.176	0.184	1.90	2.00
requirements of the NF40 standard	≤ 0.20	≤ 0.15	≤ 0.25	≤ 1.10	≤ 1.30
NF40 (1)	0.14	0.11	0.10	1.00	1.30
NF40 (2)	0.103	0.110/0.140	0.092	0.73 – 0.81 basement: 0.84 / 0.91	0.87
NF40 (3)	0.10	0.138/ 0.118	0.151/0.145	0.74 – 0.90	1.20/ 1.30
NF40 (4)	0.118	0.109/0.11	0.124/0.125	0.75/0.80	0.97/1.1
requirements of the NF 15 standard	≤ 0.20	≤ 0.15	≤ 0.25	≤ 1.10	≤ 1.30
NF15 (1)	0.081/0.082 /0.089	0.089/ 0.086	0.090	0.63 – 0.70	0.65
NF15 (2)	0.072	0.071	0.071	0.55 – 0.65	0.57

¹⁾ Required resistance of floor and ground layers.

Estimates of investment costs of buildings built in various energy standards are discussed in articles [7, 8, 9]. The cost of a low-energy house (LE1) was about 5% higher than the cost of an object designed in accordance with the requirements of Polish technical conditions. In the case of a building in the NF40 standard, this difference can be about 13%, and in the case of the NF15 building even 30%.

3. Description of the measurements and results

In the context of the thematic scope of this publication, the research carried out is aimed at determining the demand indicators for final energy as well as determining the effectiveness of using a ground heat exchanger and recuperator in mechanical ventilation system. In some of the buildings referred to at the beginning of paper, a constant registration of consumption of energy carriers was carried out. It allowed to determine the real energy consumption. The effectiveness of a mechanical ventilation system with a ground heat exchanger and a recuperator was assessed by analyzing the results of measurement of air temperature of external environment, behind the ground heat exchanger, behind the recuperator and the supply air temperature to the heated zone of building LE1.

month \ day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
September	1	2	2	2	1	2	1	2	1	1	2	2	1	2	2	2	2	2	2	2	3	1	2	2	2	2	2	3	1	2	
October	2	2	2	3	2	2	2	2	2	2	2	3	2	2	2	2	2	3	2	3	2	2	2	2	3	2	2	2	3	2	2
November	3	3	2	2	2	2	3	2	2	2	2	2	4	11	10	10	9	7	7	12	4	1	4	2	6	9	3	7	4	6	
December	9	5	9	8	6	9	9	6	7	7	9	10	6	7	7	9	7	9	7	9	8	3	8	8	11	10	10	8	6	7	9
January	8	9	10	12	12	11	13	12	13	13	10	10	9	10	9	8	9	8	10	9	11	11	13	10	12	14	11	11	12	12	10
February	9	10	8	8	8	6	7	7	9	10	9	10	13	11	9	10	9	8	8	11	10	11	8	9	9	8	8	10	10		
March	9	8	10	9	9	9	9	8	8	8	6	7	8	8	8	6	6	5	5	5	5	4	5	3	4	6	7	6	6	7	6
April	6	6	6	5	7	5	5	4	6	5	5	5	4	6	3	4	4	5	3	2	3	3	3	3	3	3	2	4	2	3	
May	3	4	3	2	3	2	3	3	3	3	3	2	3	2	2	2	1	2	1	2	2	2	1	2	1	2	2	1	1	2	1

Figure 4. Diagram of gas consumption in the LE1 building in one of the heating seasons

In one of the low-energy buildings (LE1) described in this article, long-term measurements of gas consumption were carried out, as well as measurements allowing to evaluate the effectiveness of the ground exchanger used for preheating the ventilation air. The measured gas consumption in this building in 2015-2017 amounted to 2,855 m³, or 29,341 kWh. In individual years it was as follows: in 2015: 808,3 m³ (8,308 kWh), in 2016: 1028.3 m³ (10,657 kWh), and in 2017: 1,018.1 m³ (10,463 kWh). Table 2 shows the daily gas consumption in LE1 building in an exemplary heating season. On the basis of the measurement of instantaneous gas consumption for heating and hot water, it was possible to determine the actual length of the heating season and it was possible to divide energy for heating the building and for preparing hot usable water. The analysis of the results recorded by the gas consumption recorder clearly shows the shortening of the heating season in relation to the standard season. The yellow field in the diagram (figure 4) indicates the actual heating season, while the extension of the yellow area by blue fields is the standard heating season in the IV climate zone, appropriate for the location of the LE1 building. White fields show gas consumption from May to September, except for the standard heating season.

In the building of the NF40 class (NF 40 (1)) average annual gas consumption for heating and ventilation amounted to 937.3 m³, which gives 10 003 kWh. The measured gas consumption in the heating season for heating and ventilation in the NF15 building (1) amounted to 314.4 m³, which gives 3,187.5 kWh. The results of these measurements allowed to estimate the actual demand for usable energy for heating and ventilation, as shown in Table 2.

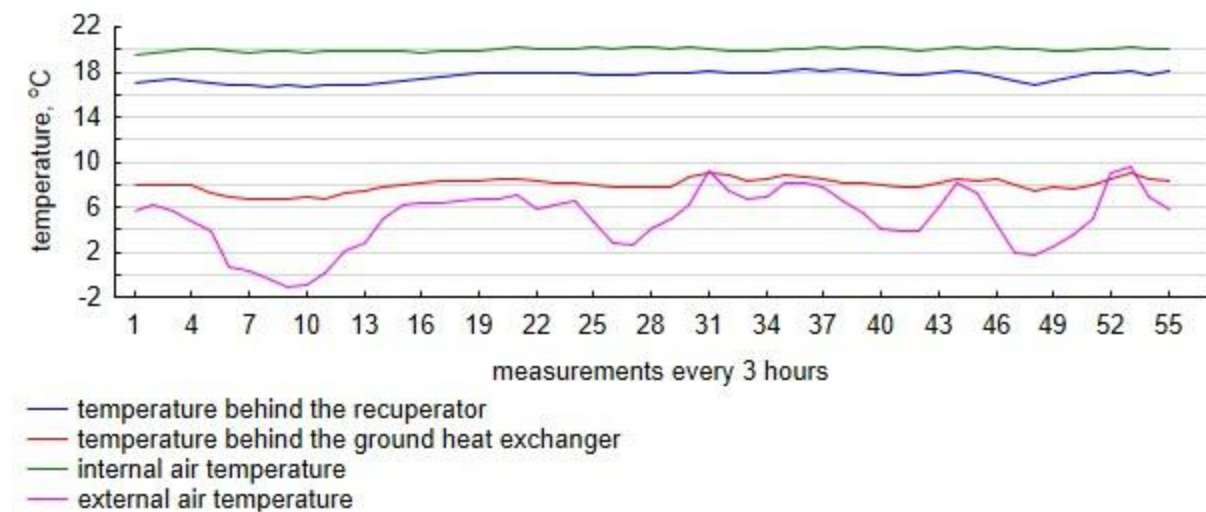
The usable energy for heating and ventilation of other buildings described in Table 1, determined on the basis of calculations, is [1]:

- LE1: 36.7 kWh/(m²·yr),
- NF40 (2): 29.2 kWh/(m²·yr),
- NF40 (3): 17.6 kWh/(m²·yr),
- NF40 (4): 18.9 kWh/(m²·yr),
- NF14 (2): 10.4 kWh/(m²·yr).

Table 2. Index of seasonal energy demand for heating of monitored low-energy buildings

standard of building	EU _H (kWh/(m ² ·yr))		
	calculated value	based on measurements	requirements
low-energy (LE1)	39,8	41,7	-
NF 40	19,9	37,13	40
NF 15	14,6	14,83	15

To be able to determine the efficiency of the ground heat exchanger in the LE building (1), the temperature of external air, behind the ground heat exchanger, behind the recuperator and the internal was measured (Figure 5 and Figure 6).

**Figure 5.** Temperature measurement results in the winter season - measurements every 3 hours.

There is a noticeable effect of the ground heat exchanger on the temperature of the air supplied to the recuperator, as well as on the "smoothing of the temperature line". In the winter season, there is also a significant, because by approx. 8°C, "boost" temperature line behind the recuperator. In total, both tested elements (ground heat exchanger and recuperator) cause (in the case of the winter period visible in Figure 5) supplying ventilation air to the flat with a temperature of approx. 15-18°C instead of the outside temperature, that is approx. -1 to +9°C.

The effect of using a ground heat exchanger and recuperator in the ventilation system is also observed in the summer period (Figure 6), however, the difference is that the work of the ground heat exchanger causes the inflow of air to the building at a temperature lower than the outside temperature (on average, considering the night and day). A significant decrease of the temperature of the ventilation air supplied to the building takes place during the day, while during the night the lower external temperature causes that the cooling effect may not occur (figure 5).

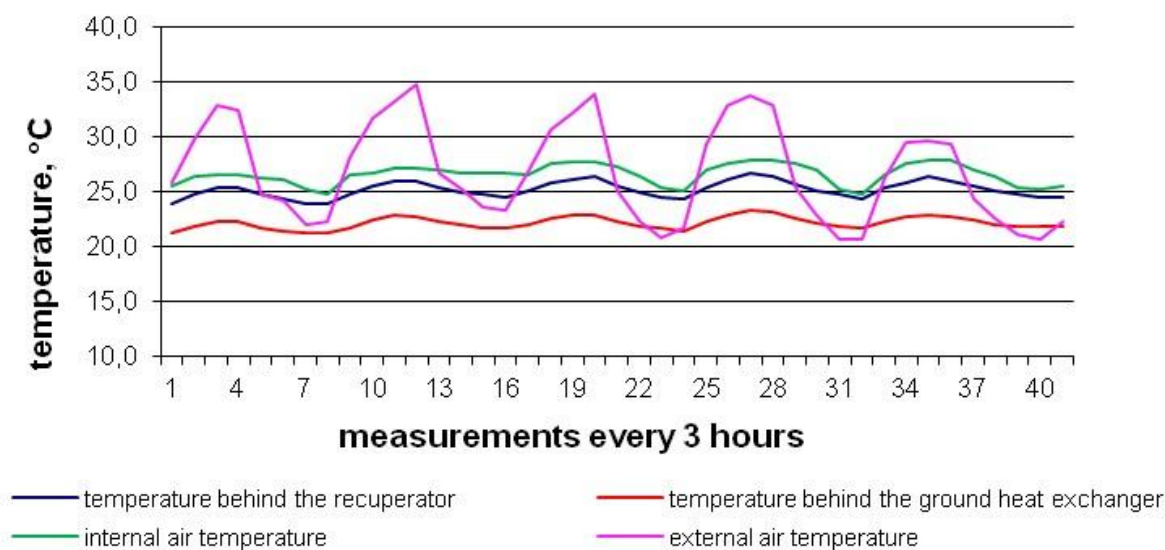


Figure 6. Temperature measurement results in the summer season - measurements every 3 hours

In summer, the temperature measured behind the recuperator with a summer insert is higher than just after the ground heat exchanger by only approx. 4°C, which is an unavoidable, unfavorable effect of the work of fans that force the air circulation. The same effect occurs in winter, resulting in increased efficiency of the recuperator. Generally, the described ventilation system results in a slight (0.2°C) in the assessed summer period (figure 5), a decrease in the average internal temperature of the air relative to the outside, but (which is definitely more important) its stabilization at $\pm 1.6^{\circ}\text{C}$ with respect to fluctuations in outdoor temperature $\pm 0.1^{\circ}\text{C}$.

4. Summary

The analysis of energy consumption monitoring carried out in low-energy buildings showed the possibility of obtaining energy indicators characterizing the assumed standard, previously calculated in advance (energy performance and energy performance certificate). It also turned out that the mechanical ventilation system with a ground heat exchanger and a recuperator is relevant in this respect. The effect of their use in the LE (1) building is not only to reduce energy consumption, but also to stabilize the internal temperature, which is important from the point of use and thermal comfort. In the summer period the ground heat exchanger also assumes the function of a quasi-air conditioner. In the period analyzed in this paper, its application in LE (1) used without significant increase in investment cost (no air conditioning system and related costs) decreased the internal temperature in relation to the external air temperature by 7.7°C. This was especially noticeable in periods of high outside temperatures and high insolation.

On the example of a low energy building LE (1) in which detailed monitoring was carried out and observation from almost twinning as to the construction and operating parameters of the low-energy building LE (2), it can be concluded that the conscious and rational use of a low energy building allows obtaining energy performance indicators at the standard level NF40, despite the fact that these buildings (erected in the years 2000-2002) do not meet the detailed requirements of this standard. This is important because the investment costs of the low-energy building were only slightly higher (by approx. 5%) than the cost of building erected in accordance with the requirements of TR [10].

The cost of constructing a building in the NF 40 or NF 15 standard is already much higher (by 13 and 30% respectively) and, in the absence of subsidies from the state, it is often the reason not to invest in improving the energy standard.

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