

Energy monitoring of low-energy houses in northern Poland

Part two: *Verification of the thermal quality of cooling baffles*

R Stachniewicz¹, A Święcicki¹, B Sadowska¹ and W Sarosiek¹

¹ Faculty of Civil and Environmental Engineering, Białystok University of Technology, 45E Wiejska Street, 15-351 Białystok, Poland
e-mail: r.stachniewicz@pb.edu.pl

Abstract. This article is the second of a two-part cycle describing the assessment of some characteristics of selected buildings with a reduced energy demand that were built in north-eastern and central Poland. Two low-energy buildings (built in 1999-2001) and several buildings of NF15 and NF40 class were analyzed. Projected demand indicators for useful energy of these buildings range from 10.4 and 14.6 kWh/(m²·yr) for NF40 to 30,2 kWh/(m²·yr) for NF15. One the most important factors affecting the efficiency of low-energy buildings are: thermal quality of the housing and its tightness. This paper presents the results of the tests carried out to verify design assumptions, in particular thermal insulation of partitions, weight of thermal bridges and air tightness and its impact on the energy demand for heating and ventilation.

1. Introduction

In the first part of the case study on several low-energy buildings in north-eastern and central Poland, the continuation of which is this paper, the analyzes made to verify the planned energy performance of some of the buildings under consideration are described. On the example of the low energy building (LE1) the assessment of the effect of using a ground heat exchanger and a recuperator in the mechanical ventilation system for the energy consumption for ventilation was also presented. The important role of these elements in reducing the thermal energy consumption necessary to heating the ventilation air in winter and the positive effect of the ground heat exchanger on the thermal comfort of occupants in the summer period has been demonstrated.

The assessment of the actual energy performance of the considered buildings [1] showed the achievement of the projected indicators required by the adopted target energy standard. This would not be possible without providing adequate thermal quality of the partitions and good air tightness of the building's envelope. These are factors that must not be underestimated at the design stage. The practice that the authors met with shows, however, that the implementation stage is equally important, because even the best theoretical assumptions can be squandered by their improper implementation.

2. Description of the tests carried out and their results

In this publication, the assessment of thermal characteristics of the elements of building envelope was taken. The thermal quality of external partitions of selected buildings was verified by infrared thermography and analysis of recorded thermograms. The assessment of the actual values of thermal transmittance coefficients U of the external walls was made on the basis of measurements of heat flux as well as internal and external temperature. The values of exemplary, linear thermal bridges and their compliance with the requirements of building standards have also been analyzed [2].

For the purpose of verification of the "thermal quality" of the envelopes of analyzed buildings, elevation thermograms were made in the winter period (figures 1, 2, 3 and 4). The evaluations were



carried out with the cloudy sky and at external air temperatures close to 0 °C. The measurement time was chosen so that the conditions specified in the standard [4] were described in [5][6][7][8].

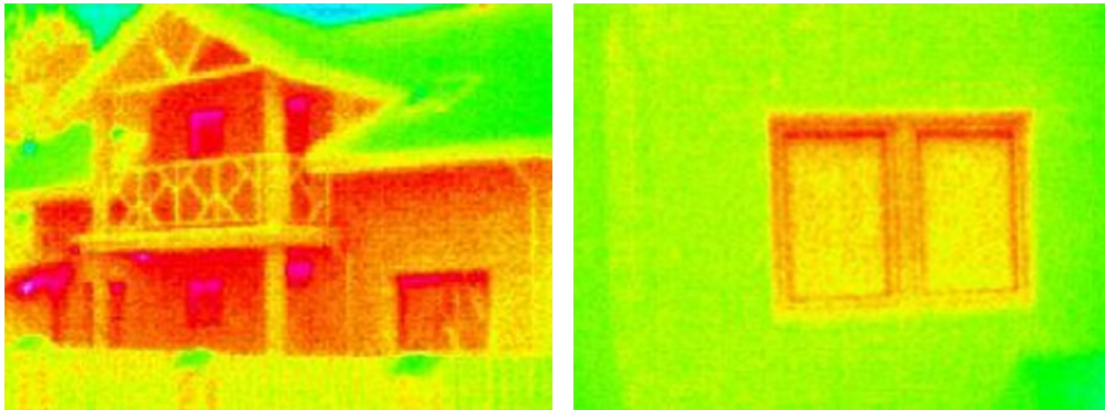


Figure 1. Thermogram of entrance elevation (N) and the detail of the ground floor window (elevation N); low-energy building LE1.

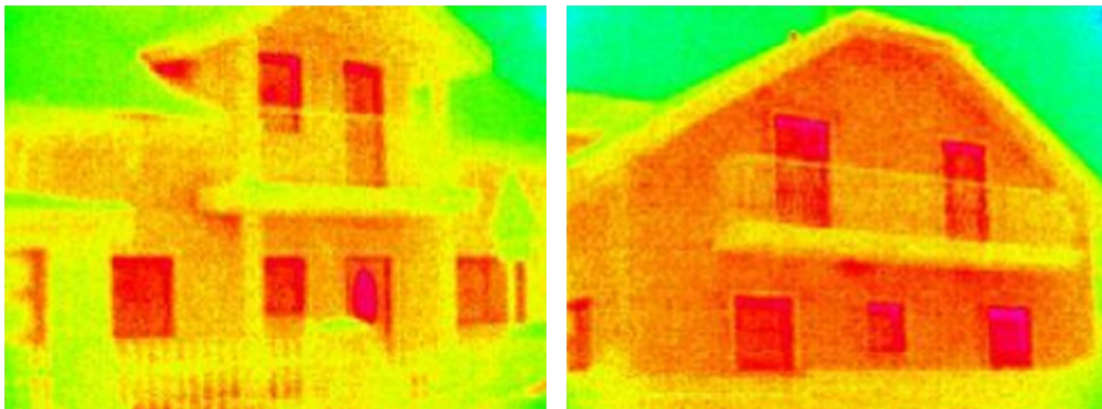


Figure 2. Thermogram of entrance (NE) and side elevation (NW) of the low-energy building LE2.



Figure 3. Thermogram and photo of the building in the NF40 standard - front elevation (S).

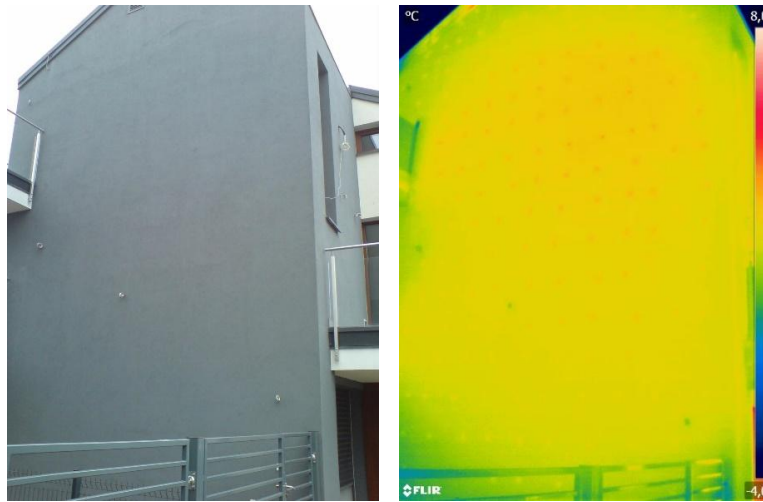


Figure 4. Thermogram and photo of the building in the NF40 standard - side elevation (W).

In buildings NF40 (1), in addition to the registration of gas consumption and the performed thermographic assessment, control measurements were made to determine the actual values of thermal transmittance coefficient of the external partitions. They were determined based on the obtained values of thermal flux and temperatures of internal and external air. N and W orientation barriers were selected for the tests to compensate for the effect of insolation. During the measurements, heat meters, thermocouples and Ahlborn recorder were used. The measurements were carried out in accordance with the recommendations given in the ISO 9869 [3].

The heat setting points were selected using a thermal imaging camera, which allowed to eliminate the influence of thermal bridges, gaps and wiring of the electrical system that could affect the correctness of the heat transfer coefficient U (figures 5 and 7) [9]. The registration was carried out for a period of 13 days at five-minute intervals. A total of 3,744 readings were obtained. On this basis, the thermal transmittance coefficient was determined using the mean rise (Figure 6 and 8) method. Thanks to this, the influence of momentary fluctuations of thermal flux and temperature difference was reduced [8].



Figure 5. The location of the heat meter on the tested western wall of the NF40 building (1) - a thermogram and photo.

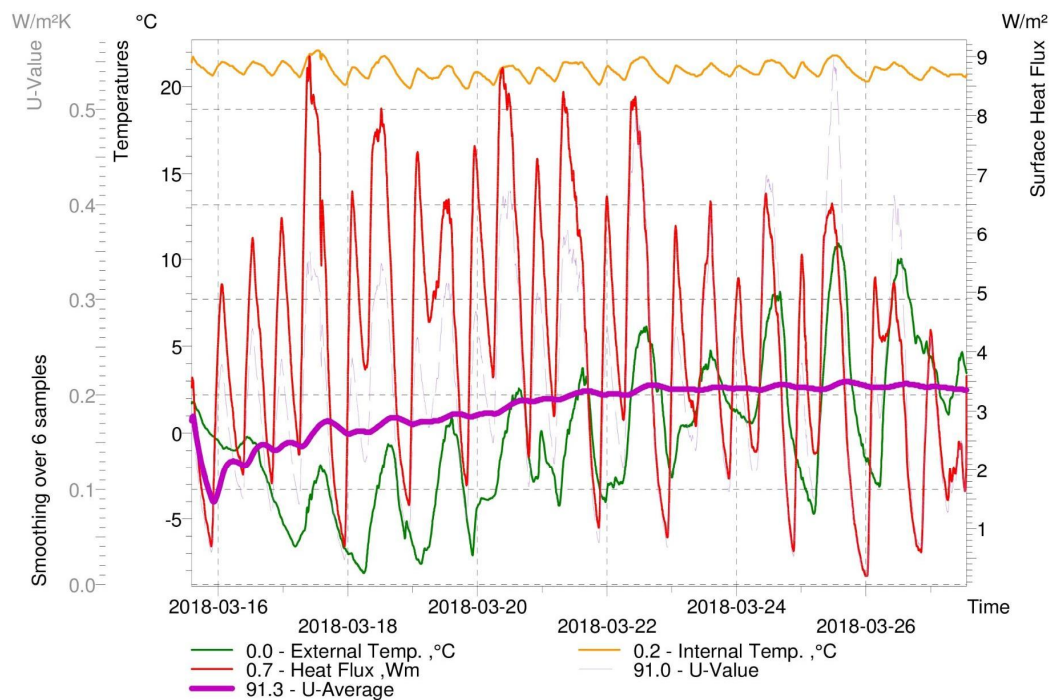


Figure 6. Graph of the thermal transmittance coefficient for the western wall in the NF40 (1) building.

Thermal transmittance coefficients U determined by the HFM method in a building erected in the NF40 standard amounted to $0.20 \text{ W}/(\text{m}^2 \cdot \text{K})$ and $0.42 \text{ W}/(\text{m}^2 \cdot \text{K})$. Values obtained from measurements of heat fluxes and temperature of baffles differ from the designed values of $0.14 \text{ W}/(\text{m}^2 \cdot \text{K})$. The value of thermal transmittance coefficient U for the first measuring point is worse than assumed but still consistent with the maximum value for the NF40 standard. In the case of the second measuring point assessed (pier between window openings), it was found to be less than allowed by the above-mentioned standard. It is the effect of such and not the other position of the measuring point. Above 100% increase in the thermal transmittance coefficient U is related to the overlap in the tested cross-section of the influence of thermal bridges from both windows - the lower thickness of the door frame insulation [1].



Figure 7. Heat meter on the tested northern wall of the LE (1) building (pier between window openings) - thermogram and photo.

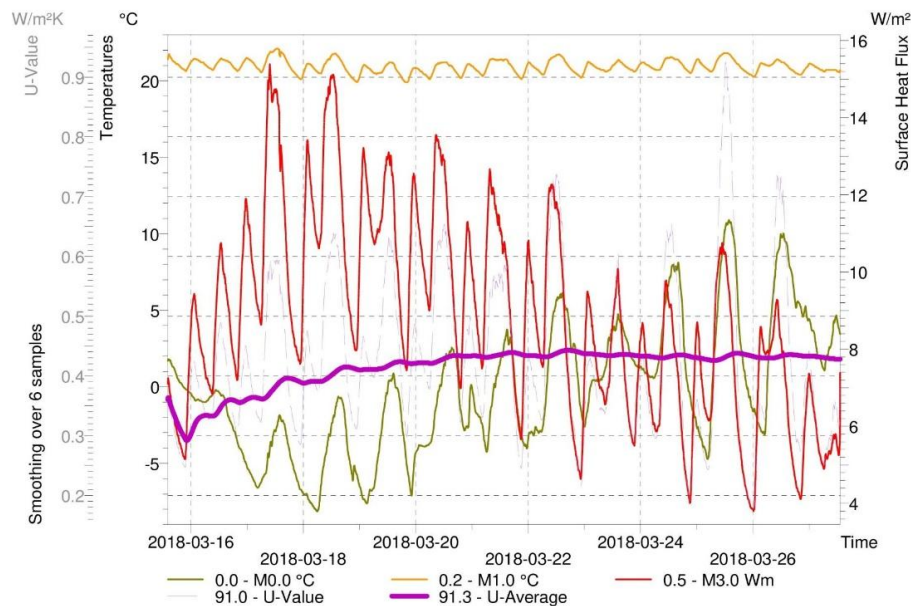


Figure 8. Determination of the thermal transmittance coefficient for a wall with a pier between window openings in building NF40 (1).

Thermal imaging of the internal temperature distribution in the vertical profile of the north and west wall corner was also carried out. The recording of thermograms was carried out with a thermography camera for a period of 13 days. From the whole registration period, 5 days were selected with the most stable outside temperature - day / night differences around $\pm 5^{\circ}\text{C}$, overcast throughout the registration period [3]. Thermograms were analyzed taking into account internal conditions such as: air temperature, reflected temperature, relative air humidity, emissivity of the tested surfaces. The results of the distribution of temperatures recorded for five days are shown below (figure 9 - right).

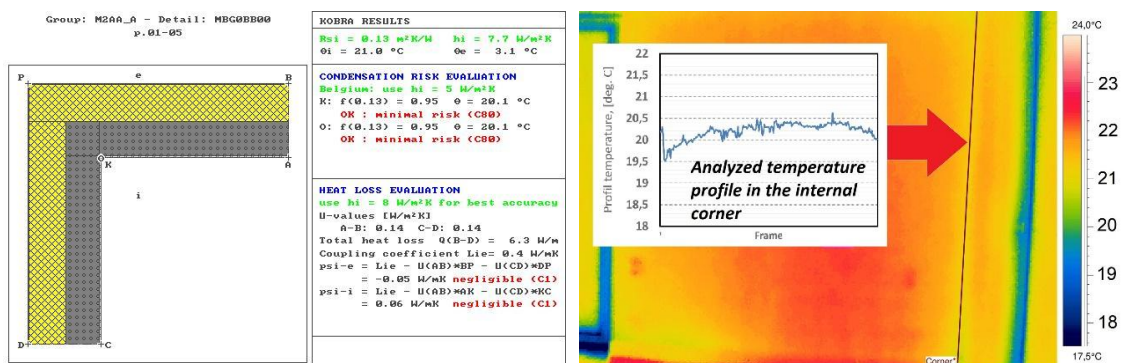


Figure 9. Calculation of thermal bridge in the corner of the tested room in the NF40 building (1) and the average temperature value from the vertical profile in the examined corner (period of 5 days - 1440 thermograms).

On the example of external corner of the NF40 (1) building, the calculated theoretical values of heat transfer coefficients in the places of occurrence of the linear bridge were verified. This was done by comparing the internal temperature of the bridge surface determined by the KOBRA program with the value obtained from thermography measurements.

The analysis took into account the average internal temperature of 5 days of 20.95°C and external 3.1°C , i.e. conditions during the thermography tests. The temperature value on the inner surface of the external corner calculated with the Cobra program is 20.1°C (figure 9 - left), while the average value

obtained from thermographic measurements 20.2 °C. This suggests the convergence of computational values of the thermal transmittance coefficients of linear thermal bridges with real values.

In the case of the buildings in the NF40 (1) and NF15 (1) standards, the calculated values of linear thermal transmittance coefficients of analyzed thermal bridges (table 1) do not exceed the recommendations of the NF standard [2]. For comparison, there are given the values of linear heat transfer coefficients of the thermal bridges considered in the thermal insulation variant U, baffles in which they occur, at the level of current thermal protection requirements (TR) [10]. According to the minimum obligatory technical requirements for a single-family building in NF40 standard, the limit value of linear thermal transmittance coefficients is 0.10 W/(m·K) (0.30 W/(m·K) for balcony slabs), and in the NF15 standard 0.05 W/(m·K) for all cases of linear thermal bridges [2]. With regard to buildings in the standard of thermal protection requirements, there are no such recommendations.

Table 1. Calculated values of linear thermal transmittance coefficients of exemplary thermal bridges for selected buildings.

standard of the building	external corner of the wall connection		window jamb					
	the assumed energy standard		in the thermal protection standard (TR) ¹⁾		the assumed energy standard		in the thermal protection standard (TR) ¹⁾	
	Ψ_i	Ψ_e	Ψ_i	Ψ_e	Ψ_i	Ψ_e	Ψ_i	Ψ_e
LE (1)	0.08	-0.11	0.11	-0.14	0.01	0.05	0.01	0.05
NF40 (1)	0.06	-0.05	0.09	-0.06	0.05	0.10	0.04	0.08
NF15 (1)	0.04	-0.05	0.06	-0.10	0.02	0.05	0.02	0.04

¹⁾ Current technical requirements for buildings [10].

According to the analysis plan, the influence of the level of airtightness of monitored buildings on the amount of usable energy demand for heating and ventilation was examined. The air leakage tests show that the building in the LE1 standard is characterized by the indicator $n_{50} = 1.20 \text{ h}^{-1}$, in the NF40 (1) standard $n_{50} = 1.00 \text{ h}^{-1}$, and NF15 (1) $n_{50} = 0.44 \text{ h}^{-1}$ [2]. In both NF buildings, therefore, the formal criterion defined by the guidelines was met, which is $n_{50\text{max}} = 1.00 \text{ h}^{-1}$ for NF40 and $n_{50\text{max}} = 0.60 \text{ h}^{-1}$ for NF15. In the case of the LE1 building, reference can only be made to the recommendations in the applicable technical conditions and $n_{50} \leq 1.50 \text{ h}^{-1}$ for mechanical ventilation. As you can see, the LE1 building meets these recommendations. Assuming the results of the leak tests carried out in the above-mentioned buildings, computational indices of demand for usable energy were obtained:

- LE1: 40.2 kWh/(m²·yr),
- NF40 (1): 30.2 kWh/(m²·yr),
- NF40 (3): 14.6 kWh/(m²·yr).

Airtightness is an important factor in shaping the energy balance of a building [11]. The graph (figure 10) shows the impact of the airtightness level on the usable energy demand of the buildings LE1, NF40 (1) and NF15 (1). The change in the level of the n_{50} parameter from 0.6 h⁻¹ to 1.0 h⁻¹ and 1.5 h⁻¹ corresponds to the increase in the calculation of the usable energy demand by 3.7 and 8.2% respectively.

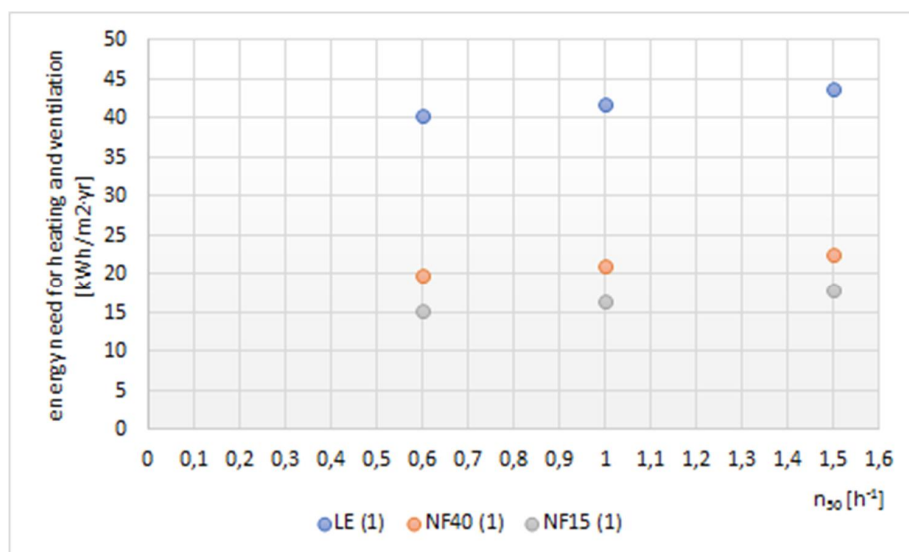


Figure 10. Energy demand for heating and ventilation at various levels of air tightness of buildings.

3. Summary

The measurements and the calculations made on their basis indicate generally good thermal performance of the analyzed buildings allowing for obtaining detailed parameters assumed at the design stage, i.e. thermal transmittance coefficients U and low values of linear thermal bridges Ψ , air tightness and thermal homogeneity of external baffles.

The energy indicators determined on the basis of multi-seasonal energy measurements were within the limits of the values forecasted for different standards of low-energy buildings. Undoubtedly, this is to ensure high airtightness of the assessed buildings at a much lower level than the recommendations of technical conditions ($n_{50} \leq 1.5 \text{ h}^{-1}$) and meet the requirement of minimizing the effect of linear thermal bridges. The refinement of sensitive details of construction nodes and joinery fixation means that the values of linear heat transfer coefficients do not exceed the required $0.05 \text{ W}/(\text{m} \cdot \text{K})$ for buildings NF15 and $0.10 \text{ W}/(\text{m} \cdot \text{K})$ for the NF40 standard. In view of the standard of thermal protection requirements, this criterion is currently not specified. The correctness of the detail solution for linear thermal nodes is confirmed by the performed thermography inspection.

The research was carried out as part of the work no. S/WBiIŚ/3/2016 and financed from funds for the education of the Ministry of Science and Higher Education.

References:

- [1] Technical documentations, including energy performance certificates for the analyzed buildings
- [2] Guidelines for the priority program "Efficient use of energy. Subsidies for loans for the construction of energy-efficient houses " 2015 The National Fund for Environmental Protection and Water Management
- [3] International Organization for Standardization (ISO). Thermal Insulation—Building Elements—In-situ Measurement of Thermal Resistance and Thermal Transmittance; ISO 9869-1 2014, ISO: Geneva, Switzerland
- [4] PN-EN 13187 2001 Właściwości cieplne budynków -- Jakościowa detekcja wad cieplnych w obudowie budynku -- Metoda podczerwieni, PKN
- [5] Wróbel A 2010 Termografia w pomiarach inwentaryzacyjnych obiektów budowlanych, *Rozprawy i monografie AGH*, **no. 209**, Kraków
- [6] H. Nowak 2012 Zastosowanie badań termowizyjnych w budownictwie, Oficyna Wydawnicza Politechniki Wrocławskiej
- [7] Walker N Nowicki A N 2012 Infrared Thermography Handbook, *The British Institute of Non-Destructive Testing*, **vol. 1&2**
- [8] Kisilewicz T, Wróbel A 2009 Diagnostyka termowizyjna przegród w zmiennych warunkach brzegowych *Fizyka budowli w teorii i praktyce t. IV*, 75-78

- [9] Evangelisti L, Guattari C, Gori P and De Lieto Vollaro R 2015 In Situ Thermal Transmittance Measurements for Investigating Differences between Wall Models and Actual Building Performance, *Sustainability*, **no. 7**, 10388-10398
- [10] Regulation on technical specifications of buildings and their locations, Regulation of the Minister of Transport, Construction and Maritime Economy of 5 July 2013, Journal of Laws item 926 of 2013 as amended.
- [11] Domy energooszczędne. Podręcznik dobrych praktyk 2012 *Krajowa Agencja Poszanowania Energii S.A.*