Alina Wróbel*, Andrzej Wróbel*

Determinants of Thermal Insulating Properties of Walls Using Thermographic Method**

1. Introduction

Modern building industry is becoming increasingly oriented at saving energy while simultaneously providing users with appropriate indoor thermal comfort in all weather conditions. Energy-efficient buildings[1] are gaining popularity, passive buildings[2] are appearing (also in Poland). Building technologies are becoming more and more complex, now and again walls of different construction and thermal parameters are used in the same building. Such buildings need to be scrupulously designed and their execution must be equally precise.

The monitoring of building projects [4] conducted in recent years revealed that more than half of the projects did not meet the requirements of thermal protection contained in existing legislation. The projects often lack in solution details regarding thermal insulation. Building acceptance procedures for the quality of thermal insulation are not carried out as well; there are no accepted procedures for *in situ* examining of thermal insulating properties of buildings. The problems of thermal insulation defects in buildings (commonly occurring in new buildings), residents have to face on their own.

"Thermograms may be used as an argument in discussions between the investor, designer and contractor, however, other evidence will be additionally needed (open pits, calculations) to any potential court action" [5]. For this reason there is a demand for thermographic examination of buildings. The more that this

* Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow

** The study was conducted under the research project no. NN526119133 financed by the Ministry of Science and Higher Education.

1 In the absence of a generally adopted classification, an energy-efficient building is considered to be such a building whose energy demand for heating is 30% lower than approved by current regulations.

2 A passive building has a very low energy demand for heating – less than 15 kWh / ($m^2 \cdot$ year).

is a remote, non-destructive method, which does not require making pits. Thermographic inspections of new buildings during the first winter of their exploitation are not widely carried out, though.

2. Termographic Building Inspection

Thermographic examinations of buildings may be carried out both from their external and the internal sides. Their objective may be:

- detection of installations carrying hot or cold media in the walls and ceilings,
- location of the sites of water installation failures,
- non-destructive examination of the wall structure of historic buildings,
- detection of defects in thermal insulation of walls,
- estimating heat losses through the walls.

Most of the thermographic measurements requires a diversity of temperatures on both sides of the test wall, and some of them require the maintenance of a stable state of heat exchange.

Although numerous thermographic imaging procedures are performed, in few cases their elaboration goes beyond simple calculation of the temperature and thermal image printing. Most attention is paid to the nonhomogeneity of temperature distribution on the imaged surface, being evidence of the occurrence of thermal bridges (Fig. 1). Uniform temperature and no thermal bridges does not mean good wall insulation properties (Fig 2).

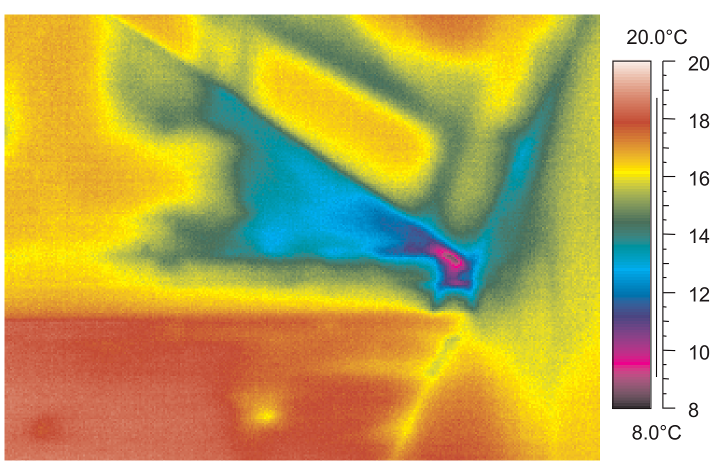


Fig. 1. Thermogram of the inner surface of the building outer walls conducted on 8.02.2008 at approximately 23:00, with the outdoor air temperature of 0°C

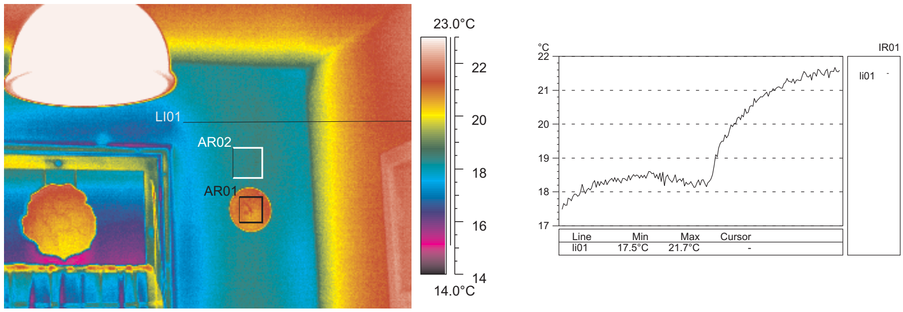


Fig. 2. Thermogram of the inner surface of the outer wall conducted on 3.01.2010 at approximately 20:00, with the outdoor air temperature of –8.0°C

Some measure of insulation properties is the temperature difference between the air inside the apartment and the surface of the wall, however, its value also depends upon the air temperature difference inside and outside the building.

3. Possibility of Estimating the Value of the Heat Transmission Coefficient Based on Thermographic Measurements

Heat transmission coefficient U [W/(m^2·K)] is the ratio of the heat flow density transmitting through the wall to the difference in air temperature on both of its sides. This is one of the most important parameters describing walls, specifying thermal transmission through them, taking into account heat conduction properties of materials and heat exchange conditions on both sides of the wall. The smaller the value of the coefficient, the better insulating properties of the wall. The heat transmission coefficient is determined for the conditions of stable heat exchange from the following equation:

$$U = \frac{q}{T_i - T_e} = \frac{1}{R_T} \tag{1}$$

where:

- q – heat flux density,
- T_i – air temperature on the warm side of the wall,
- T_e – air temperature on the cold side of the wall,
- R_T – total thermal resistance of the wall.

The heat transmission coefficient is defined for heat exchange in a steady state, and thermographic measurement lasts too short to conclude on its basis that the state was really steady. Determination of heat exchange through the external walls of the building depends on the atmospheric conditions which we have no influence upon, as well as the manner of heating, which must be examined and possibly modified for the period required for the proper thermographic imaging.

How then to plan thermographic observations so that the exchange of heat does not differ significantly from the steady state? An inspection of the object and obtaining information on the types of walls for their insulation properties and thermal inertia might prove helpful. These parameters determine the response time to temperature changes and the time needed to reach a steady heat exchange.

Fluctuations of the outside air temperature may be traced using for example information from the Institute of Meteorology and Water Management or road weather stations, posted on the "TRAX elektronik" websites. In order to clarify whether information about the outside air temperature obtained from road weather stations adequately reflect the variability of temperature at the surveyed buildings, which are a bit distant from the surveying stations, experimental measurements were carried out. The air temperature outside the building was measured (thermocouple with automatic recording of data, sheltered from direct sunlight) and then it was compared with the values obtained from a road weather station located at a distance of approximately 1 km from the building [7]. The values of air temperature in the period 14.11.2009–21.12.2009 have been presented in figure 3. The number of conducted measurements was 973. Maximum differences were: –3.4 and +4.2°C during a large decrease in temperature (weather changes). The standard deviation of the temperature differences between measurements was 0.87ºC.

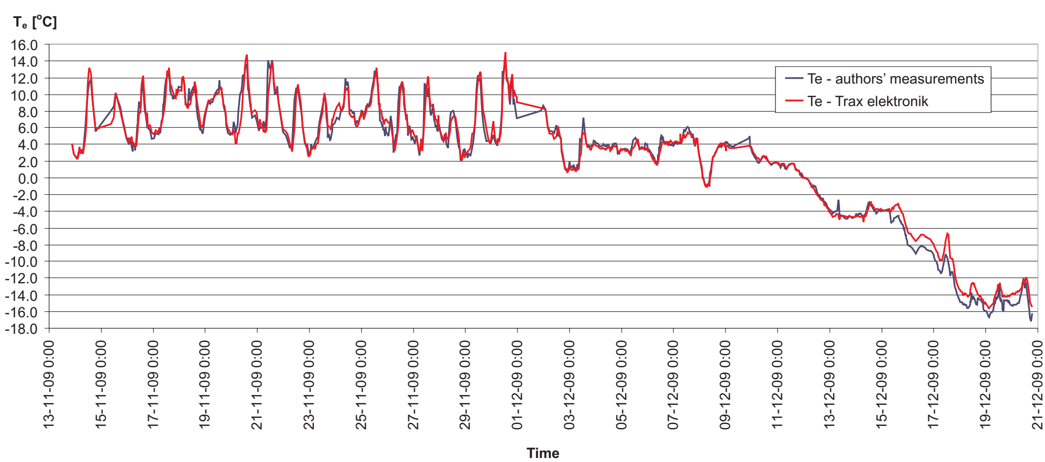


Fig. 3. Outside air temperature measured at the examined building and at a road weather station located at a distance of 1 km from the building

Perfect external conditions (for the period presented in Fig. 3) remained in the period between 4 or 5 December (depending on the type of the wall – the light one stabilizes faster) to 8 December. After 8 December the external conditions were extremely unfavourable for the quantitative thermographic examinations of the buildings, and in the second half of November the conditions were similar to the “cyclically changing”.

On the basis of knowledge of the wall type, its “response” to temperature changes, the knowledge of heating and weather forecast, it is possible to plan a day or two in advance termographic observations “in the steady-state heat flow”.

A condition of a steady heat flow through a wall with fixed atmospheric conditions is a constant and steady flow of heat to the inside of the building. It is therefore important for the indoor heating to work continuously and evenly. Proposed by [1] statement of the inhabitants that the temperature was not adjusted by them for several hours is not equivalent to its steady value.

The heating which is operating intermittently causes large changes of heat flux transmitting through the wall despite the apparent impression of invariability of the indoor environment. The dependence of heat flux density from the method of heating have been presented in figure 4 and figure 5. Both measurements were conducted in the same room (at a different time), with the daily fluctuations in the air outside not exceeding 4°C, for a cellular concrete wall in a single family dwelling house. During the first measurement central heating system with automatic control maintaining a pre-set temperature was operating. As it is shown in Figure 4 the maintenance of the desired temperature was carried out with considerable variations thereof, which resulted in large changes of heat flux density. After changing to a constant electric heating power, fluctuations in air temperature inside the room and the heat flux density were significantly decreased (Fig. 5). In both cases, the heat flux density changes kept pace with fluctuations in temperature (shape of the waveform was very similar in time). Fluctuations of a few degrees in air temperature outside the building did not affect the value of the heat flux density, as they were in fact suppressed in the wall.

During the examination of multi-family buildings it was found that the central heating system maintains the temperature of indoor air in different ways. Figure 6 refers to a building from the fifties of the last century with a central heating system with high inertia and stability. By contrast, figure 7 illustrates a high variability of temperature inside a room of a new multifamily building with automatic controls.

The measurements were conducted, which intended to determine a coefficient U in a residential building. The examined wall of the east exposure was built of cellular concrete, and in some parts (1.5 m × 1.5 m) as a frame structure. The values of heat transmission coefficient U were calculated for both walls, based on the measurement with heat flow meters and the thermographic technique. The difference between air temperature and the temperature of the wall surface was determined from a single thermogram, as shown in figure 8. This temperature difference multiplied by the heat transfer coefficient adopted by the standard [2] gives a value of heat flux density. The values of heat transmission coefficient U obtained from both of these methods have been presented in figure 9.

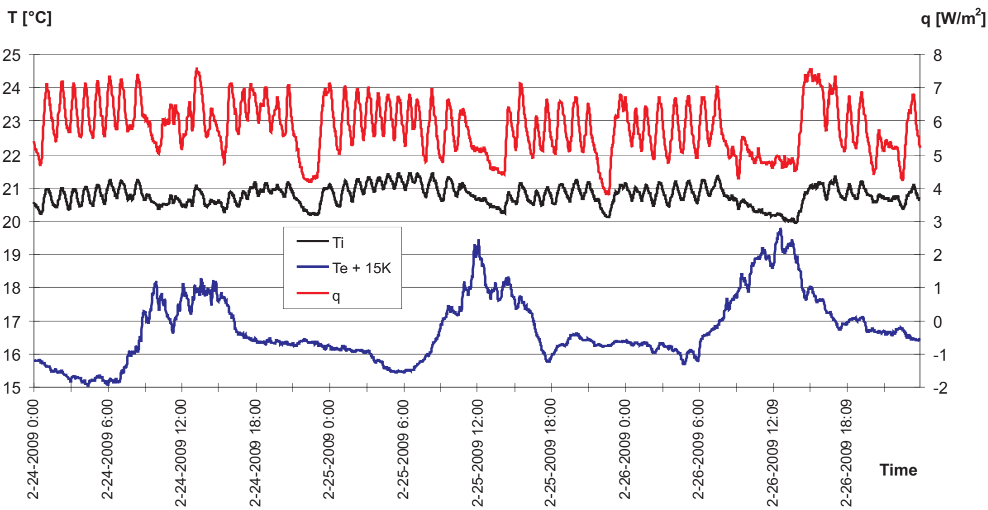


Fig. 4. The air temperature inside and outside of a single-family building and the heat flux density with central heating with automatic control

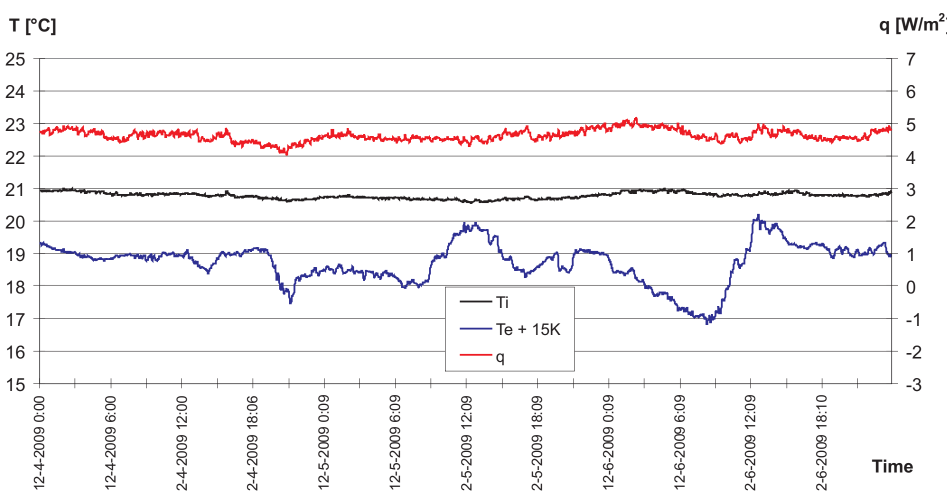


Fig. 5. The air temperature inside and outside of a single-family building and the heat flux density with a steady electrical heating

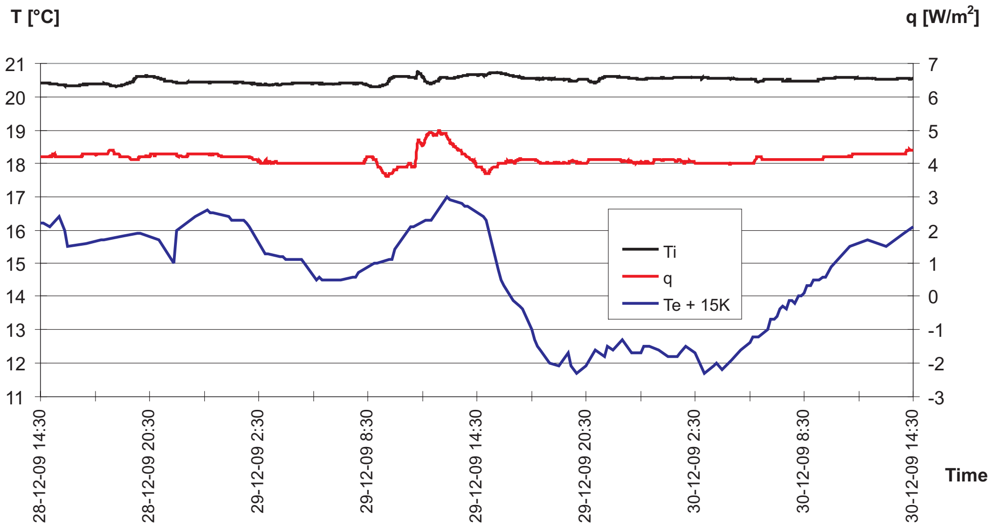


Fig. 6. The air temperature inside and outside of a multifamily building and the heat flux density with a stable central heating

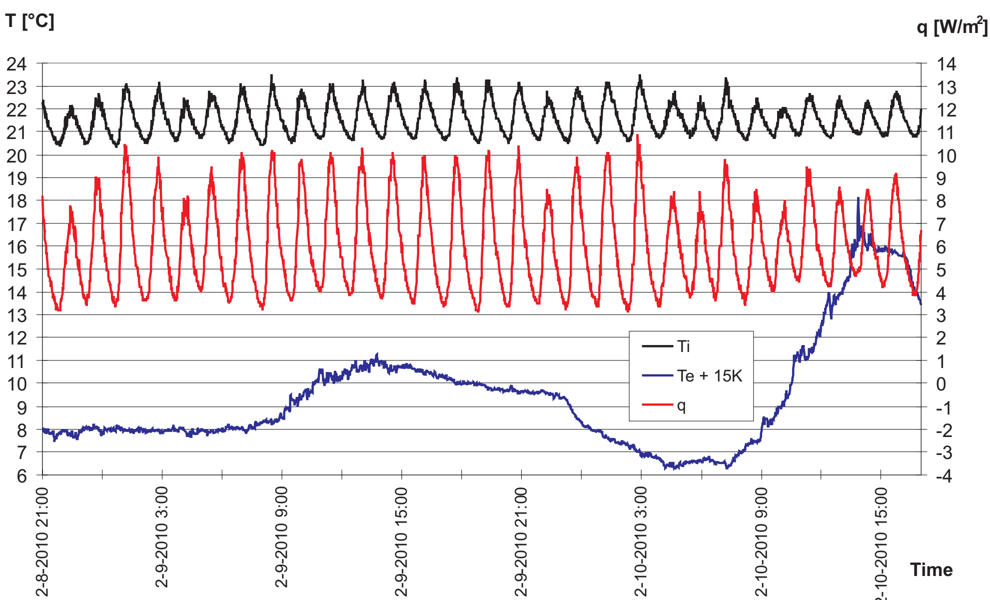
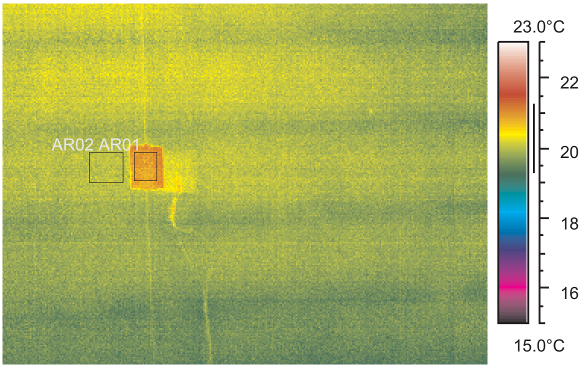


Fig. 7. The air temperature inside and outside of a multifamily building and the heat flux density with automatic regulation of central heating



Object parameter Value:
Emissivity 0.95
Object distance 3.0 m
Ambient temperature 20.0°C
Atmospheric temperature 20.0°C
Label Value
IR : max 21.4°C
IR : min 19.2°C
AR01 : avg 21.0°C
AR02 : avg 20.1°C

Fig. 8. Method of measuring air temperature and wall surface with thermographic method

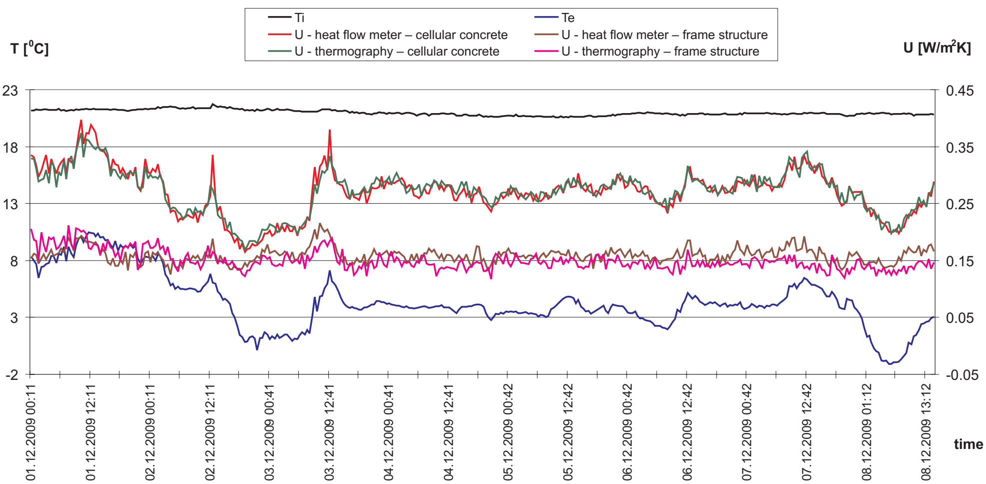


Fig. 9. The course of wall examination of an actual building

Heat transmission coefficient values calculated on the basis of declared effective insulating properties of materials and actual wall thickness are: 0.280 W/(m^2·K) and 0.167 W/(m^2·K) for the masonry wall and frame wall, respectively. The values obtained from *in situ* measurements in the steady state are similar.

A high compliance rate of the coefficient U values obtained with two surveying methods is also visible. The measure of this compliance is a standard deviation of differences in the coefficient U, calculated for the period from 3.12.2009 at 18:11 to 7.12.2009 at 6:12 (169 measurements were conducted every half an hour): it is 0.0094 W/(m^2·K) and 0.0171 W/(m^2·K) for brick walls and frame walls, respectively.

Light walls reach the steady state of heat exchange much faster than the solid walls, which has been presented in figure 9.

4. Summary

Proper thermographic study of a building is not an easy matter. It is necessary to establish the objective of the study with the client. Contrary to appearances, this is not always easy and it requires considerable expertise, both in the scope of thermography as well as construction. Having identified the issue it is essential to carry out a thorough analysis of the building thermal properties, depending on all of the factors which may have any impact upon it. This will allow to plan the time and conditions for implementation of thermographic observations, together with other complementary measurements.

An inconvenience associated with a quantitative evaluation of construction defects using thermographic method (with a single measurement performed) is a necessity of a careful selection of the observation time, which makes it difficult (even impossible at times) to plan long-term works. The need for additional measurements to be carried out (of temperature outside the building in the longer term) increases labour consumption of thermographic measurements.

It poses numerous problems to determine the heat transmission coefficient needed to determine the value of heat flux density on the basis of thermograms. For rooms where there is no forced air flow, the heat transmission coefficient does not differ substantially from the standard values [2].

An undeniable advantage of thermography is obtaining information regarding a large surface of the examined wall. The overall non-invasiveness of the method is of a great significance as well (it does not interfere with the examined temperature field and does not affect the object in a destructive manner), which is important in the case of examining historical buildings, or those where access to the surface is restricted.

A practical solution for determining the parameters of thermal insulation of walls may be a single-point heat flux density measurement with a heat flow meter, simultaneous with the thermographic imaging. Unfortunately, this greatly increases the observation time, as the heat flow meter heats up at the time of fixing it to the wall, and the correct reading is obtained only after the stabilizing of a heat flow.

The project of the standard [6] indicates heat flow meter as a tool for in situ measurements of thermal resistance. During the measurements with the use of a heat meter, the measured area (an active area of the meter) should be representative for the examined element. For modular elements, the meter should cover the total number of modules, which means a selection of a meter so as to match the nature of a wall and the use of a thermographic camera at its location.

The studies of a building carried out in actual conditions demonstrate a compliance of the results obtained from both of the tested methods. So perhaps it is time to develop a standard related to the quantitative thermographic research in construction, as it is allowed by the quality of the currently offered equipment, and it is not covered by standard PN-EN 13187 of June 2001 [3].

References

[1] Grudzińska M., Ostańska A.: *Rewitalizacja osiedli z budynkami wielkoblokowymi w aspekcie analizy energetycznej*. Przegląd Budowlany, 6, 2009.

[2] PN-EN ISO 6946: *Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła – Metoda obliczania*.

[3] PN-EN 13187: *Właściwości cieplne budynków – Jakościowa detekcja wad cieplnych w obudowie budynku – Metoda podczerwieni*.

[4] Pogorzelski A.: *Powszechne braki i wady projektów i możliwość ich usunięcia*. Konferencja Naukowo-Techniczna "Energooszczędne budownictwo mieszkaniowe", Mrągowo 2001.

[5] Pogorzelski J., Sarosiek W.: *Najczęstsze błędy projektowe w zakresie ochrony cieplnej budynków mieszkalnych*. Konferencja Naukowo-Techniczna "Systemowe podejście do izolacji cieplnej budynków", ITB, Mrągowo 1998.

[6] prEN 12494: *Building components and elements – In-situ measurement of the surface-to-surface thermal resistance*.

[7] TRAX elektronik: http://www.traxelektronik.pl, 2009.