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An addendum to experimental test report on designating actual heat conductivity coefficients for construction profiles (brackets) of the following dimensions: 170x70x50 mm, 170x130x50 mm and 210x70x50 mm, 210x130x50 mm made from GD 350 steel, 2.5 mm thick, with Magnelis ZM 430 zinc coating produced by AGS.

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Introduction

This addendum considers a test report drawn up in March 2019 which was a final result of a test work on determining the heat conductivity coefficient for 2.5 mm-thick brackets made of GD 350 steel with Magnelis ZM 430 zinc coating, intended to fix ventilated facades. In formal terms, the addendum refers to the report developed under the Agreement No. 1/2019 (KFU/24/03/19) made on 07.03.2019 in Płock between AGS Sp. z o.o. and the Warsaw University of Technology - the Institute of Mechanical Engineering. The Agreement covered elaboration of concepts and development of a test stand for measurement of actual heat conductivity coefficients in profiles for construction fittings (windows, doors), brackets for sandwich walls, brackets for ventilated facades, as well as determination of actual heat conductivity coefficients (equivalent for thermal conductivity for uniform materials) for profiles for construction fittings (windows, doors), construction fasteners (brackets) for sandwich walls, construction fasteners for ventilated facades manufactured by AGS.

It should be mentioned that the purpose was to determine the heat conductivity coefficient including the heat transfer carried out between two surfaces. When determining the coefficient, no consideration was given to the process of heat coming from the air and penetrating the profile and the other way around.

Dimensions of the tested construction profiles are presented in the further part of the addendum.

1. The heat conductivity coefficient determination method

The coefficient for heat conductivity from a construction profile is determined based on a heat balance of a test stand. Disregarding any small heat losses to the surroundings, the numerical value of heat delivered to the stand by electric current in the heater is equal to the numerical value of heat penetrating the profile walls. Applying a direct electric current to power the heater allows to determine the heat power level delivered by the heater in a simple and accurate manner. This power equal the power of electric current flowing in the heater, and it can be determined as a product of voltage and current intensity.

Following the above correlations, we can determine the heat conductivity coefficient λ :

$$\lambda = \frac{U \cdot I \cdot \delta}{A \cdot (t_g - t_s)} \quad (1)$$

where:

U - voltage powering the heater [V]

I - current strength powering the heater [A]

A - heat exchange surface (bracket surface in contact with a cooler) [m²]

δ - dimension of the fastener in the direction of heat flux [m]

t_g - mean temperature on the heater surface [°C]

t_s - mean temperature on the cooler surface [°C]

It should be mentioned that the smallest profile heat exchange surface - restricting the heat exchange process - was the heat exchange surface A. The impact of roundness at the bends of the bracket body was taken into account when determining the value for that surface.

2. Structure of a test stand

The conducted tests included measurements of the conductivity coefficient for the 2.5 mm-thick brackets made of GD 350 steel, with the Magnelis ZM 430 zinc coating, intended to fasten ventilated facades. The tests covered the brackets of the following dimensions:

170x50x70 mm

210x50x70 mm

170x50x130 mm

210x50x130 mm

A figure of profiles with dimensions is presented below.

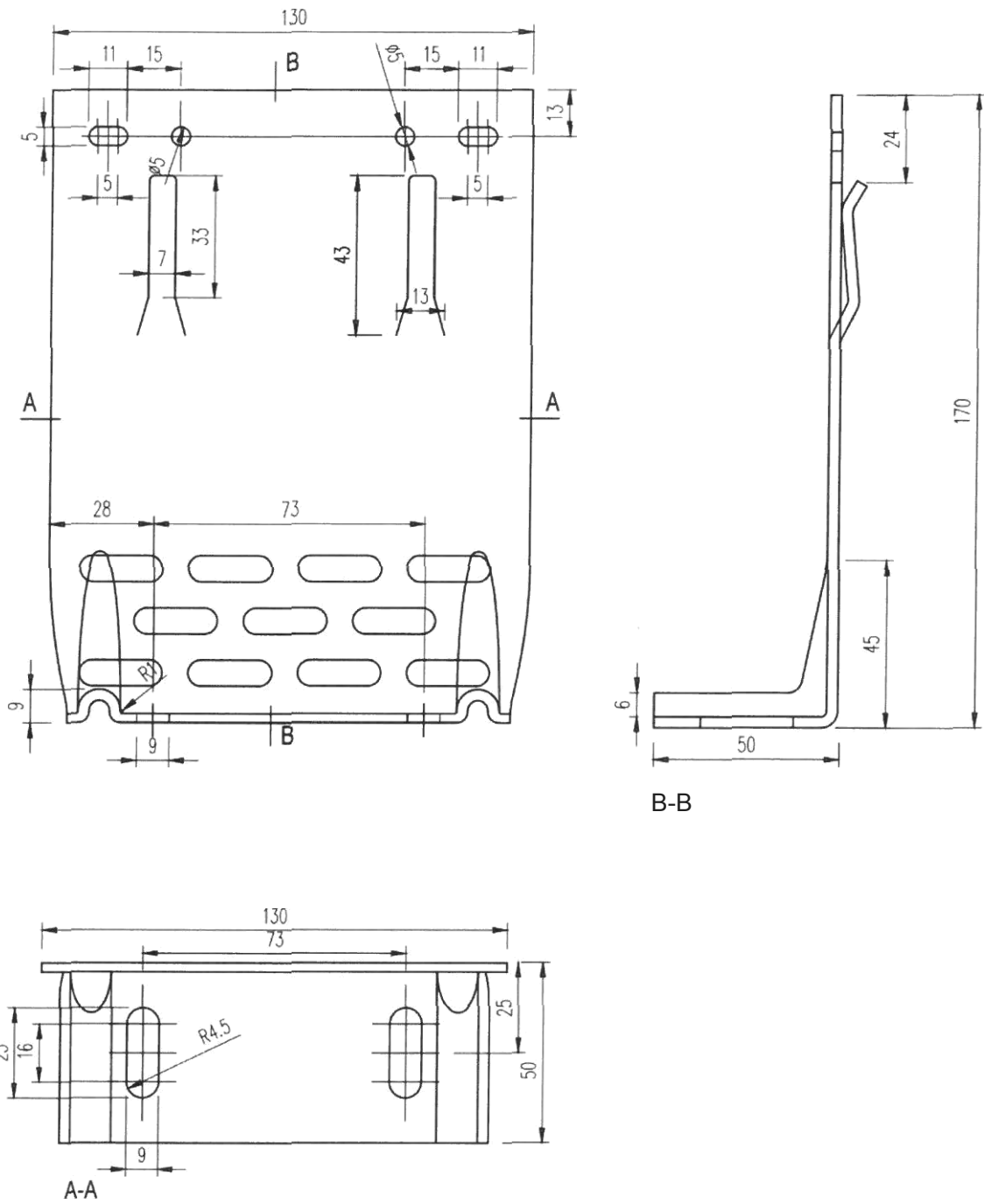


Figure 1. Dimensions of the tested 2.5 mm-thick brackets made of GD 350 steel, with the Magnelis ZM 430 zinc coating, intended to fasten ventilated facades.

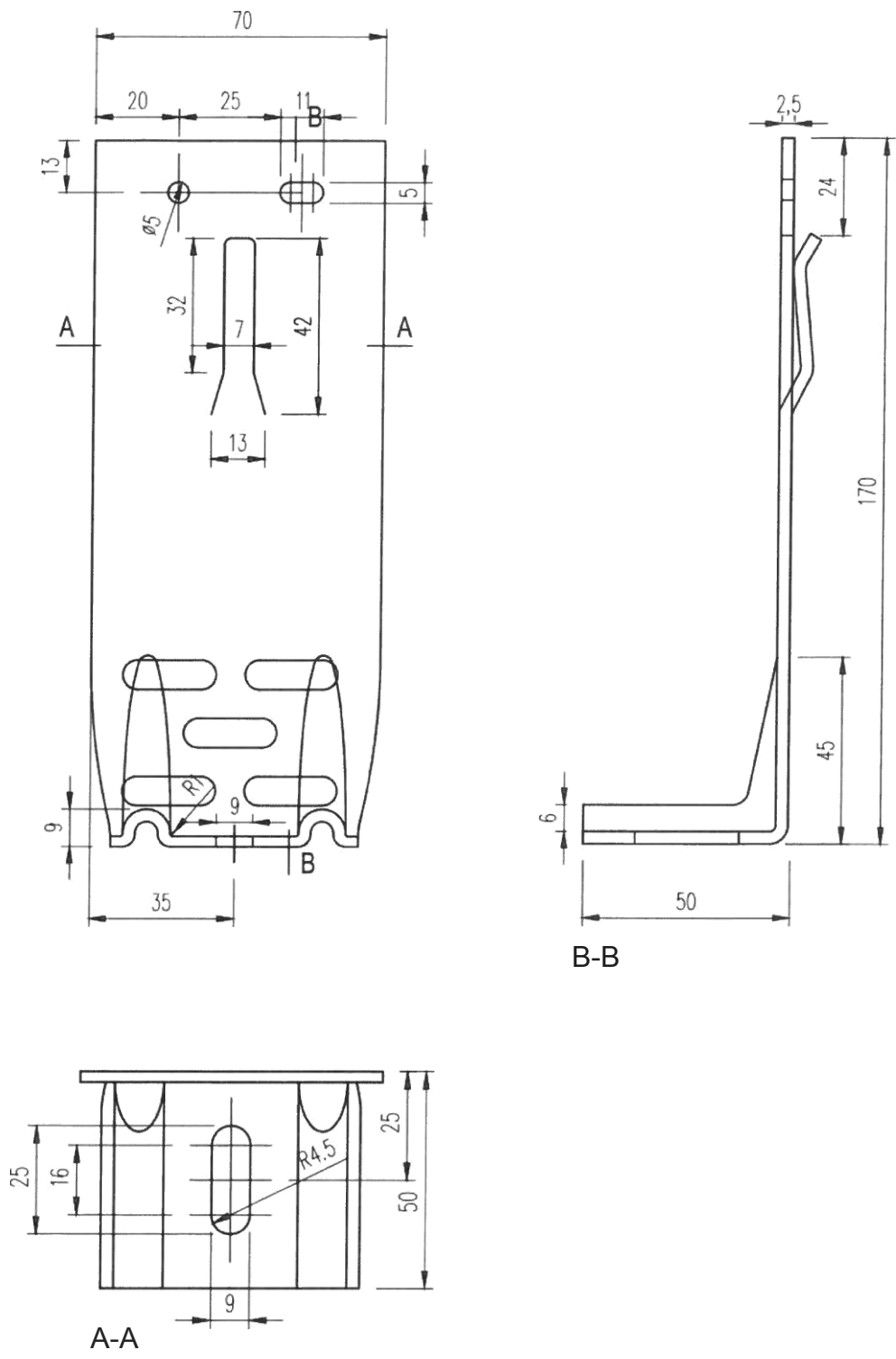


Figure 2. Dimensions of the tested 2.5 mm-thick brackets made of GD 350 steel, with the Magnelis ZM 430 zinc coating, intended to fasten ventilated facades.

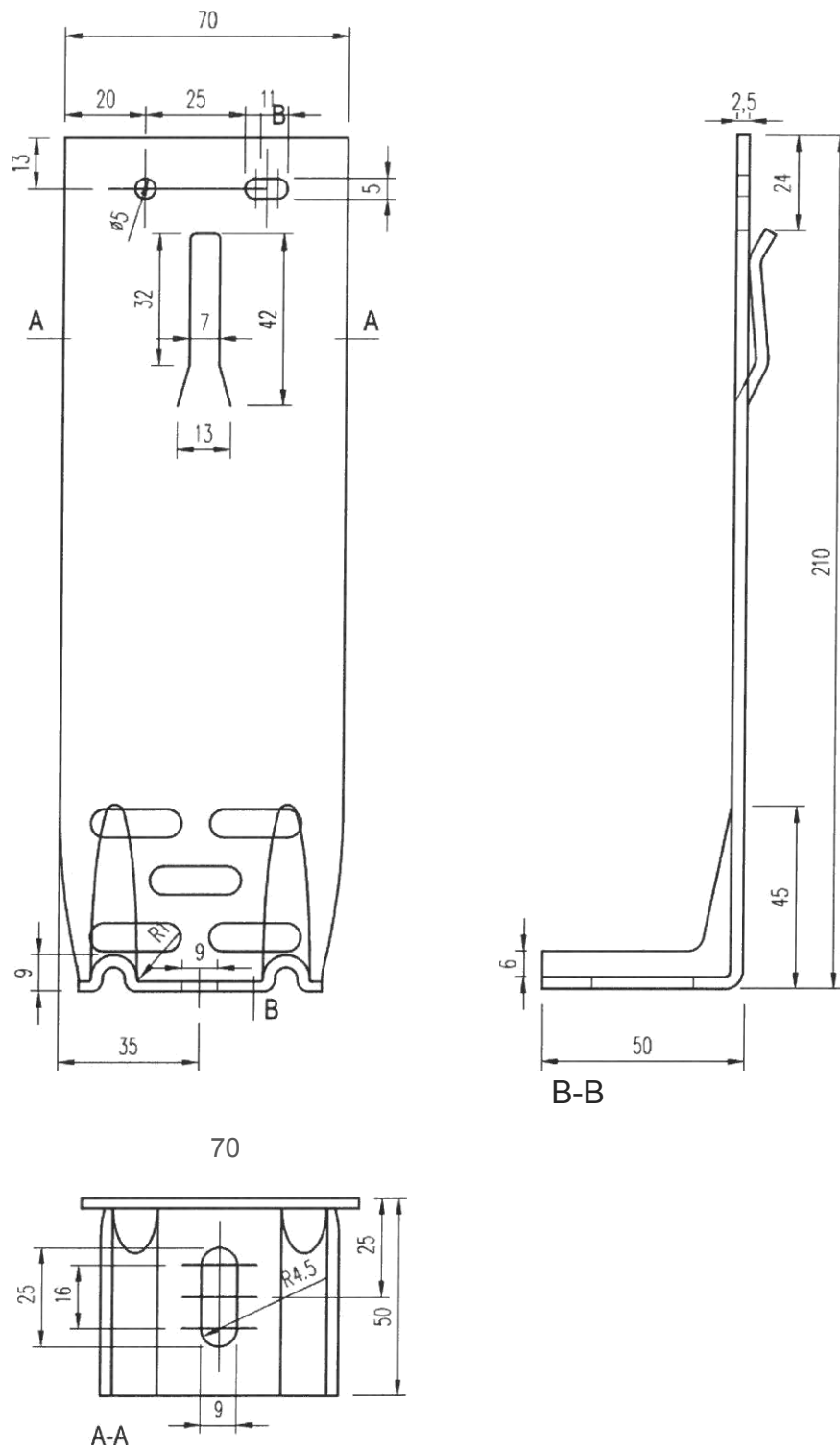


Figure 4. Dimensions of the tested 2.5 mm-thick brackets made of GD 350 steel, with the Magnelis ZM 430 zinc coating, intended to fasten ventilated facades.

The test stand was constructed based on the measurement concept presented in Chapter 1. A conceptual scheme is presented in Figure 5.

The main part of the stand is a unit - a tested profile connected to a heater and a cooler. There are two miniature thermocouples between the profile wall and the heater. There is a cooler fastened to the other end of the profile, and also in this case there are two miniature thermocouples between the profile wall and the heater. The surfaces of the heater, profile, thermocouples and cooler are covered with silicone paste that is a good heat conductor. The paste reduces the thermal contact resistance present at the connection of two heat conducting surfaces.

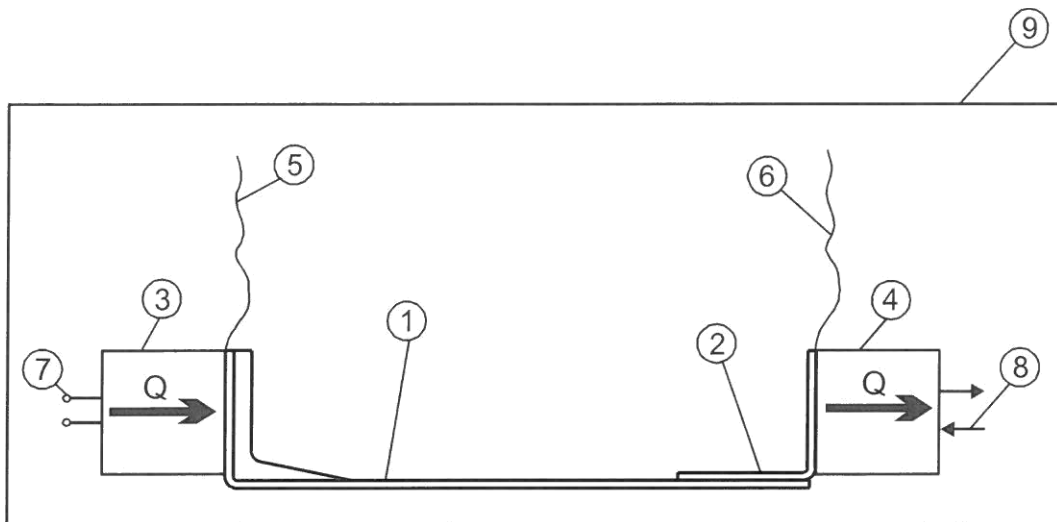


Figure 5. Conceptual scheme of a test stand Markings: 1 - tested bracket, 2 - angle plate, 3 - heater, 4 - cooler, 5, 6 - K thermocouples, 0.5 mm dia., 7 - electric power for the heater, 8 - water cooling, 9 - casing of the test stand made of polyurethane foam filled with thermal insulation (Styrofoam blocks + small Armaflex chips).



Figure 6. A view on the tested console with fastened heater and cooler.

The heater-profile-cooler unit is encapsulated in thermal insulation layers in a form of polyurethane foam panels ($\lambda=0.032 \text{ W}/(\text{m}^*\text{K})$), Styrofoam blocks ($\lambda=0.031 \text{ W}/\text{m}^*\text{K}$) and small Armaflex chips ($\lambda=0.036 \text{ W}/(\text{m}^*\text{K})$). The body of the stand is also made of the polyurethane foam insulation. The top part of the stand has a form of an open box. Such a structure is necessary due to the need to apply electrical connection to the heater, grounding and temperature sensors. The empty upper part of the stand is filled with Styrofoam blocks and small Armaflex chips before the final assembly and sealed with a panel made of polyurethane foam.

Figure 6 presents an assembled heater-profile-cooler unit. An insulation layer more than 80 mm thick and additional top and side insulation for the part of the stand body with Styrofoam blocks and Armaflex chips created exquisite insulation of the heater-profile-cooler unit. Virtually the whole surface of the stand had a stable surrounding temperature, and this was confirmed through a measurement with FLIR SC7600 thermal camera.

The heater was composed of a heating resistor and a thermal buffer in a form of a 50x50x70-mm block made from aluminum alloy. The heater was powered with direct current from a computer-operated TDK Lambda feeder. The feeder allowed for precise delivery of

current with proper voltage and strength parameters, as well as a read-out of actual voltage and strength values for the current flowing through the heater.

The cooler was an aluminum alloy block with dimensions of 50x50x90 mm, with a milled labyrinth channel directing the coolant from the ultra-thermostat Lauda (temperature maintenance accuracy ± 0.5 K).



Figure 7. A heater-bracket-cooler unit in a Dewar flask and a thermally insulating body.

170x50x70 mm and 210x50x70 mm brackets were located in the Dewar flask during the test with an intention to further reduce the thermal losses into the surroundings.

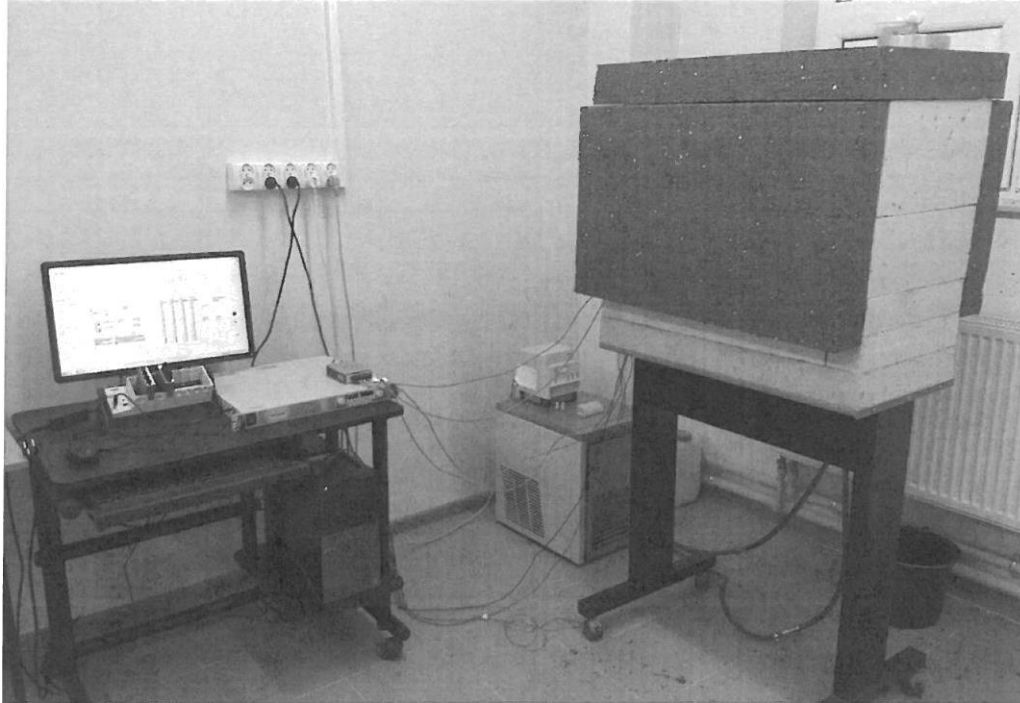


Figure 8. A complete test stand connected to the computer measurement system.

Another important component of a test stand was a computer system for temperature read-out and recording, not considered in the conceptual scheme. The system was composed of a computer, test cards - NI cDAQ-9172 and NI 9211 by National Instruments. Four thermocouples TP 201 by Czaki cooperated with the system. The system was intended to read and record the temperature during a test session.

Distribution of measuring sensors - thermocouples is presented in Figure 2. Two temperature sensors are located on the heat transmitting and receiving surfaces each. The parameters measured by the system were recorded through an installed software intended for readout, visualization and archiving of the test data. The heater installed on the stand was powered through a precise high-current feeder by TDK Lambda. After the first trial tests, it was configured so the output voltage was about 3.8 V for the 170x50x70 mm and 210x50x70 mm brackets, which corresponded to about 0.5 A of the current flowing through the heater. The presented current parameters are reflected in the power transmitted by the heater, about 1.9 W. The voltage transmitted from the feeder was about 4.9 V for the 170x50x130 mm and 210x50x130 brackets, which corresponded to about 0.7 A of the current flowing through the heater. The presented current parameters correspond to about 3.4 W of power transmitted by the heater. Approximately, the presented parameters were stable for the whole period of testing. The parameters of the current changed slightly during subsequent test sessions.

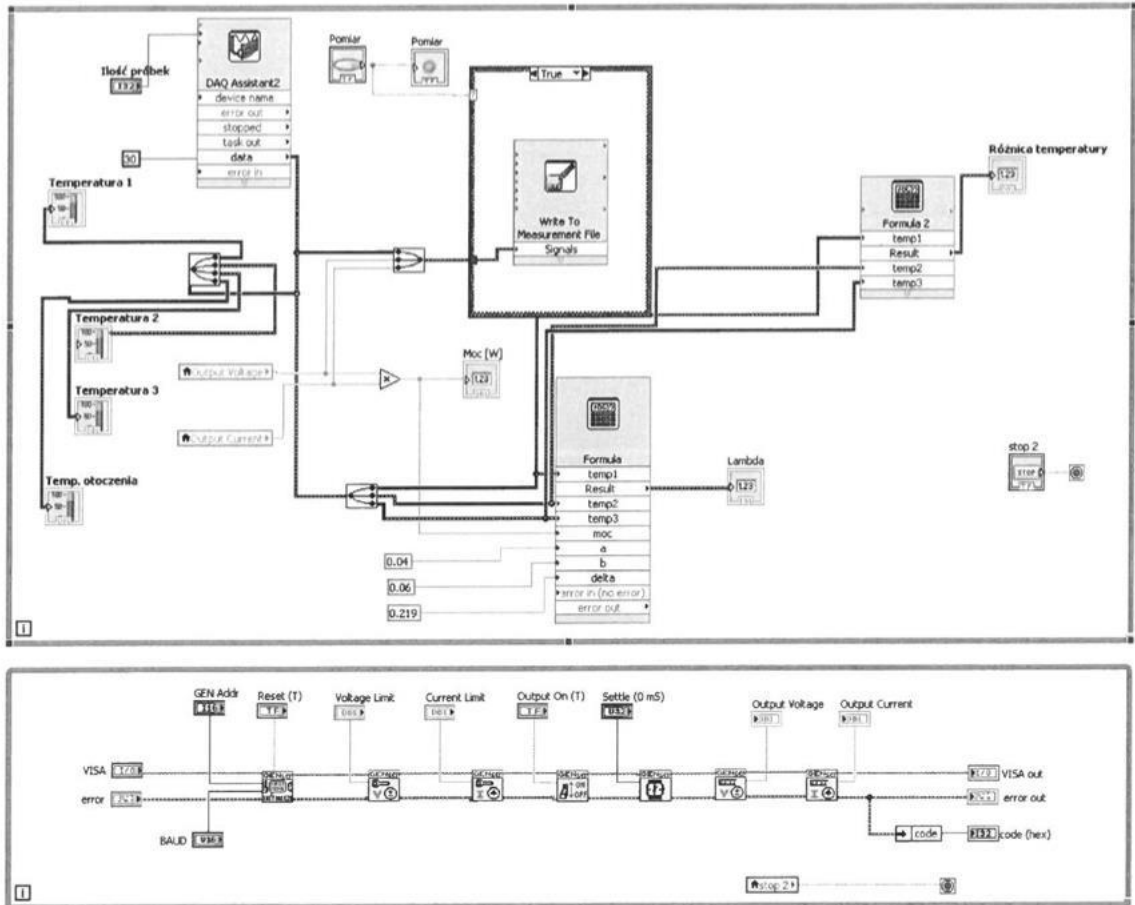


Figure 9. A. conceptual scheme of data flow in the measurement system created in the LabView environment.

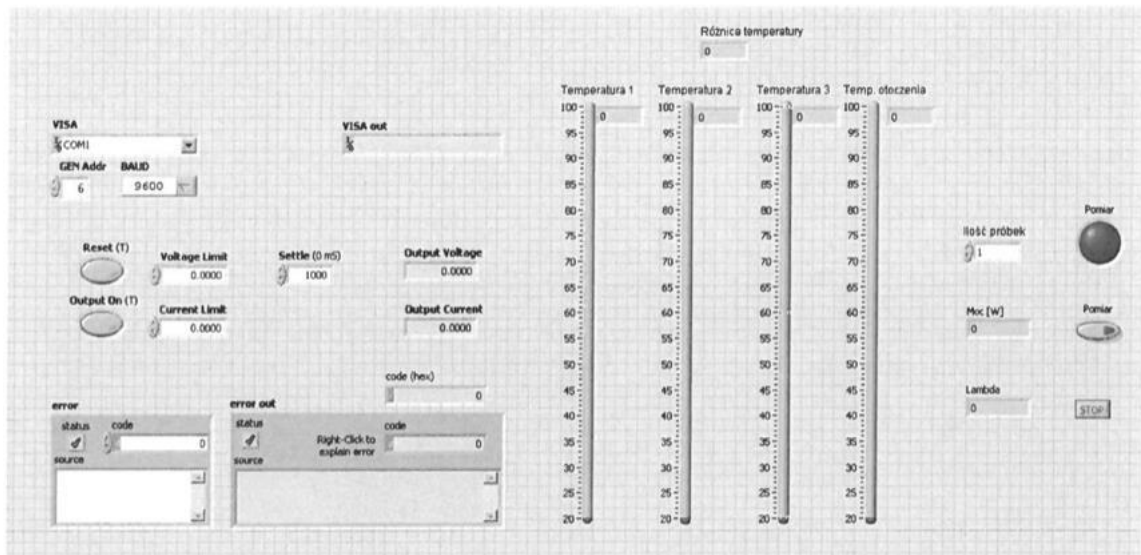


Figure 10. User interface for communication with a data flow control application.

3. Course of measurements and description of recorded data

The measurements were always carried out according to a fixed scheme. Based on the trial measurement carried out after the test stand was installed for the first time, it was found out that the actual test should be preceded by an hour-long heating of the stand at an amplified power level. This heating is intended to stabilize the thermal conditions of the test stand. Therefore, each hour-long actual test was preceded with an hour-long heating of the stand. The parameters recorded during each test session were averaged and used to determine the heat conductivity coefficient. The eventual value of the coefficient is the arithmetic mean of all designated partial values.

During the test the system recorded voltage and strength of the current powering the heater as well as the temperatures from all four temperature sensors - thermocouples. The measured values were recorded by the measurement system and saved in a text file format, and afterwards there were further processed. Also a thermal camera was used to determine the stand surface temperature.

Temperatures on the heating and cooling surfaces were recorded during a measurement session. The values were recorded with two K-type thermocouples with measurement cards NI cDAQ-9172 and NI 9211. The thermocouples measured the temperature in two spots on the heater surface. It is evenly distributed on the heater surface, and this is proven by approximate values read from both thermocouples during test sessions. The temperature of the heating surface was an arithmetic mean of the values

received from the two above-mentioned thermocouples. The temperature read-out procedure from the cooled surface of heat exchange was similar in character, and it consisted in averaging the temperature read in two spots of the cooling surface.

4. Calculation of the heat conductivity coefficient λ

The calculations were based on using a converted formula (1). Its version used for calculations has a following form:

$$\lambda = \frac{U \cdot I \cdot \delta}{a \cdot b \cdot (t_g - t_s)} \quad (2)$$

where:

a - profile surface length [m],

b - profile surface width [m],

The input data for calculations were the data collected by the computer system during the measurement. The data underwent some initial processing: rejection of the recorded data from outside the test scope, and afterwards averaging the data on each measured value.

The heat conductivity coefficient of uniform material was measured for the aluminum alloy cuboid PA6/ENAW2017/2007 with dimensions of 50x50x150 mm before the actual series of experiments. In the case of uniform materials this coefficient is equal to the thermal conductivity coefficient of the uniform material. The obtained value: 143.5 W/(m*K) is approximate to the values given by the alloy manufacturers.

The actual calculations consisted in calculating the heat conductivity coefficient λ based on the formula (2). The calculations results are presented in Table 1 and diagrams in the Figures 11-14.

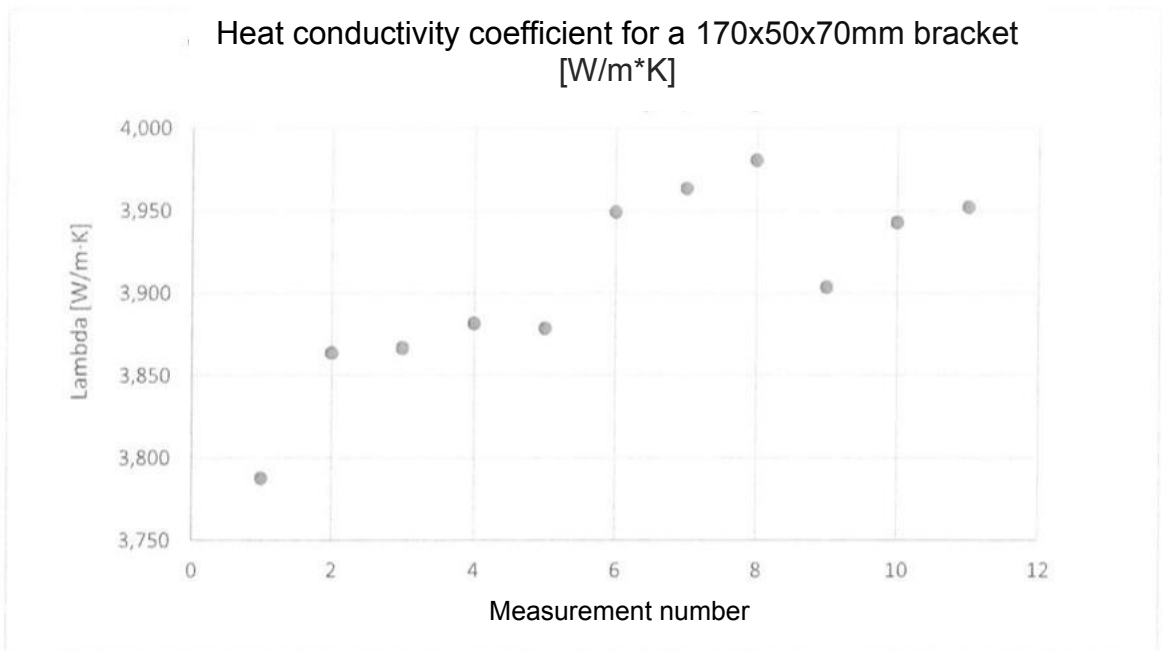


Figure 11. Results of the heat conductivity coefficient calculations for a 170x50x70mm bracket [W/m*K]

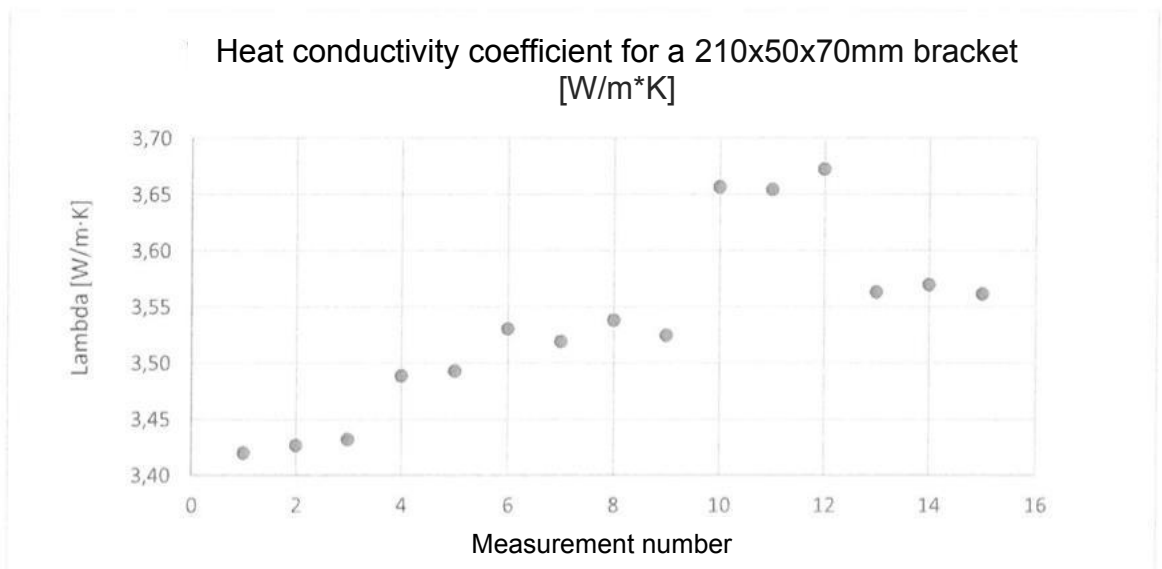


Figure 12. Results of the heat conductivity coefficient calculations for a 210x50x70mm bracket [W/m*K]

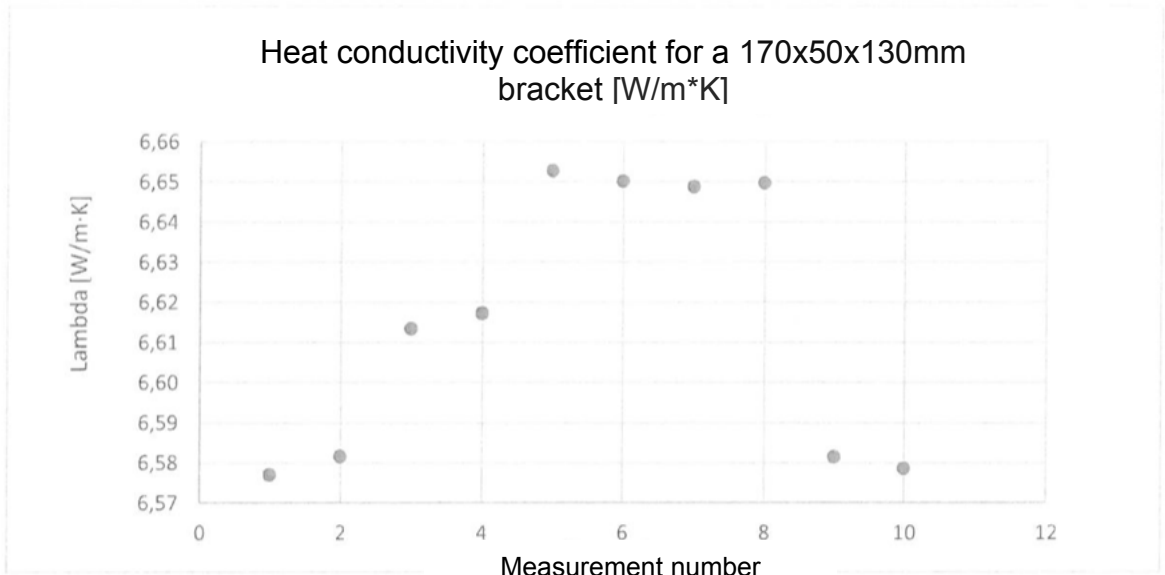


Figure 13. Results of the heat conductivity coefficient calculations for a 170x50x130mm bracket [W/m*K]

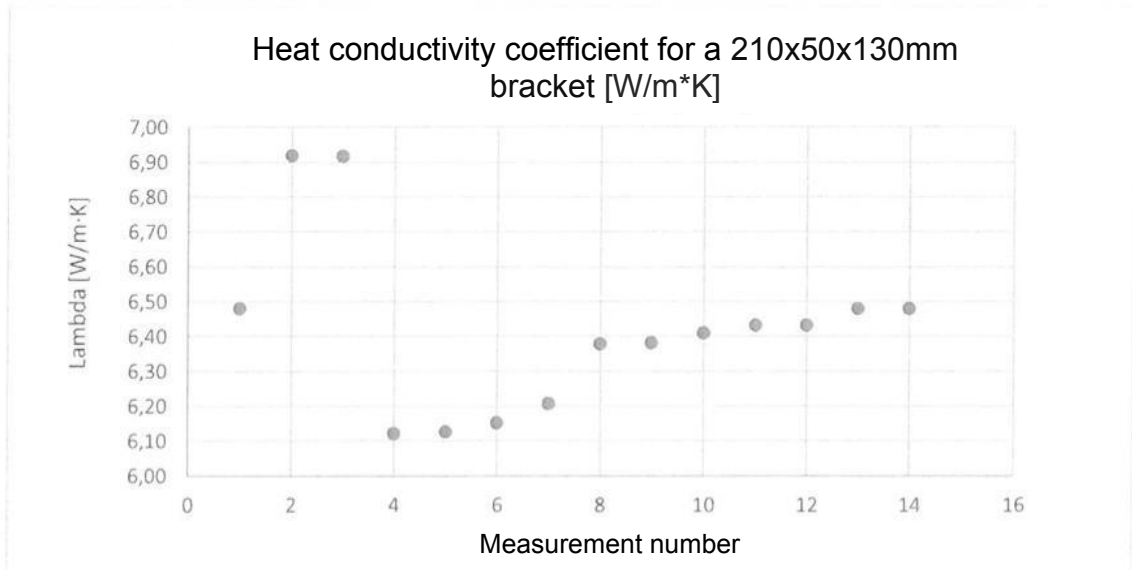


Figure 14. Results of the heat conductivity coefficient calculations for a 210x50x130mm bracket [W/m*K]

No.	2.5 mm thick brackets made of GD 350 steel, with Magnelis ZM 430 zinc coating	λ mean value from test series [W/m*K]
1	170x50x70 bracket	3.906
2	210x50x70 bracket	3.537
3	170x50x130 bracket	6.615
4	210x50x130 bracket	6.422

Table 1. Summary of calculation results for average conductivity coefficient for a 2.5 mm thick bracket made of GD 350 steel, with Magnelis ZM 430 zinc coating.

5. Estimating a calculation error for thermal transmittance rate λ

The measurement error consists of regular and random errors. A systematic error is a stable and unknown value alternating the measurement results and resulting from a disregarded significant factors that impacts the measured value. In the present case, accepting that the thermal transmittance rate is determined with formula (2), it can be assumed that there are no significant regular errors.

A random error, namely a deviation of the measurement result from the accurate value adopts various values while repeating the measurements in the same conditions. A random error cannot be completely eliminated, because it is caused by unavoidable inadequacies in measurement. Its value can be assessed by standard methods.

In order to obtain a small value of λ coefficient errors, the measurement system ensures high accuracy of measurement sensors combined with the computer system for data reading and recording. The use of measurement cards manufactured by National Instruments and thermocouples by Czaki allows to obtain a permissible error for temperature measurement not greater than 0.5 K. This error is relatively low due to a restricted measurement scope. The measurement with a permissible error of 0.5 K is achievable between 20°C and 100°C. All measurements made during the test series were in this scope.

The current voltage and strength powering the heater was measured with an internal measurement system of the TDK Lambda feeder, for which the permissible reading error was 0.5% for the voltage and 0.3% for the current strength. The heat exchange surface was determined based on the measurements of linear dimensions of the profile. The measurements were taken with a slide caliper with a measurement error of 0.1 mm.

A method of exact differential was employed to estimate the resulting measurement error for λ . Value of the resulting error was calculated for the measurements and with consideration of the above-mentioned values of partial errors. The obtained results are presented in the table below.

Dimensions of the bracket mm	Absolute error	Relative error %
170x50x70	0.163	4.77
210x50x70	0.113	3.32
170x50x130	0.333	9.75
210x50x130	0.245	7.18

Table 2. Comparison of calculation results for the maximum error of determining the heat conductivity coefficient for a 2.5 mm thick bracket made of GD 350 steel with Magnelis ZM 430 zinc coating for partial results.

6. Summary

While interpreting the numerical results presented in Table 1, we can conclude that they are of low values, and this proves that the concept of structure and the materials used in the profile structure are correct. AGS- the manufacturer of the profile - assumed an openwork structure extending the heat path as a means to reduce the heat conductivity coefficient. It is recommended to carry out further investigations in order to determine the impact exerted by the Magnelis ZM 430 coating on the heat qualities of the brackets. It is for sure that this impact is minor, and it may be hard to record. Summing up, the actions undertaken by AGS when designing and manufacturing the brackets for ventilated facades, with Magnelis ZM 430 coating, allowed to obtain brackets of low heat conductivity coefficient.

Literature

1. Polish Committee for Standardization, October 1999, Polska Norma PN-EN ISO 6946 Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczania. (Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.)
2. Polish Committee for Standardization, 1998 Polska Norma PN-EN ISO 7345: Izolacja cieplna. Wielkości fizyczne i definicje. (Thermal insulation. Physical quantities and definitions.)
3. Polish Committee for Standardization, 2007, Polska Norma PN-EN 10088-1:2007 Stale odporne na korozję. Gatunki stali odpornych na korozję. (Corrosion-resistant steels. Grades of steels resistant to corrosion.)
4. Manual for thermal camera FLIR SC7600, materials delivered by the manufacturer.

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