Measurement Automation Monitoring, Mar. 2017, no. 03, vol. 63, ISSN 2450-2855

Tadeusz KRUCZEK, Ireneusz SZCZYGIEŁ, Grzegorz KRUCZEK, Piotr KOWALCZYK
INSTITUTE OF THERMAL TECHNOLOGY, SILESIAN UNIVERSITY OF TECHNOLOGY
22 Konarskiego St., 44-100 Gliwice, Poland

Comparative assessment of heat insulation properties of thermal resistant paints with use of infrared camera

Abstract

To reduce heat losses from buildings various methods are used. One of them is applying so called "thermal resistant paints". These paints can be put in principle on the inner but also on outer surfaces of building external walls. The aforementioned paints are put on a surface in the similar way as other paints in building construction technology and form a thin insulation layer. The acting of this paints consists in causing a noticeable temperature drop within this layer and simultaneously on the wall surface. This work presents the experimental rig, measurement procedures and selected measurement results.

Keywords: thermovision infrared measurements, thermal resistant paint.

1. Introduction and aim of the work

For the diminution of heat losses through external walls of buildings and other objects many various techniques, methods and materials can be applied [1, 2, 3]. One of them is the coating of wall surface with a thin layer of special paints containing unique ingredients. These paints can be used for covering the outer walls surface inside or outside buildings.

The aim of this work was the recognition of insulation properties of such paint layers and evaluation of potential expected effects.

For testing these paints it was necessary to prepare special samples. Typical gypsum plates manufactured according to standard PN-EN-ISO 6946, which are very often used in building construction technology, were applied to prepare these samples. The thickness of this plate amounted to 12.5 mm. The plate was cut to obtain the samples of size 200 × 200 mm. Afterwards, the pieces of the plate were covered with the tested paints. Several different samples are shown in Fig. 1. On the painted surfaces the special areas were formed which were useful for observation of considered thermal effects as well as for checking the thickness of the paint layer. Additionally, reference rectangles with the use of black paint of emissivity of 0.95 for checking emissivity of the tested paints were painted on the tested layers (see Fig. 1, black rectangles).

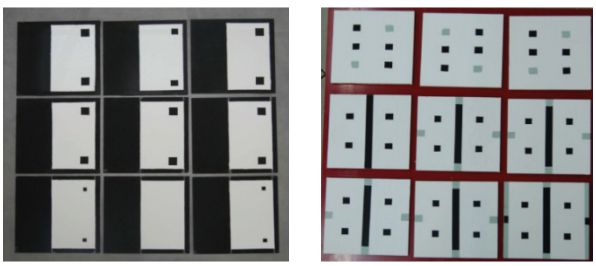

Fig. 1. The gypsum samples covered with the considered materials used in the experimental testing

2. General description of experimental rig and measurements

The main element of the experimental unit was a measurement board 1 with the exact flat front surface, Fig. 2. To ensure a uniform temperature field on the measurement surface the board was made of copper. The board was heated or cooled by a work agent flowing inside the copper tubes 2 welded to rear side of the mentioned board, Fig. 2. The work agent at required temperature was prepared in a cryostat. Four pieces of such boards were put into measurement chamber of the laboratory unit, Fig. 3. During the experiments the tested samples 5 were fixed to measurement board, Fig. 3. For the measurement of temperature on the front side of the tested samples the infrared camera (IR camera) 8 was used, Fig. 3. In Fig. 4 there is presented a general scheme of the experimental rig. It is known that infrared measurement results are sensitive to the thermal radiation of surrounding elements, therefore it is necessary to determine this effect [4, 5]. For that reason the temperature values of inner surfaces of the measurement chamber walls were measured by means of about 20 glued thermocouples 6 (Fig. 4) and recorded periodically by the computerized data acquisition system [4, 5]. To avoid an uncontrolled flow of air through the measurement chamber, the chamber had a relatively good level of air tightness. The air temperature inside the chamber was formed by additional independent cryostat 9 which supplied the work agent 11 to a heat exchangers 3 located inside the work chamber, Fig. 4.

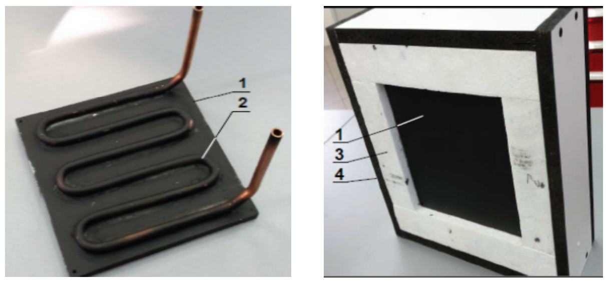

Fig. 2. Construction of main heating/cooling board; 1-copper board, 2-tortuous tube for cooling/heating agent, 3-thermal insulation, 4-external casing

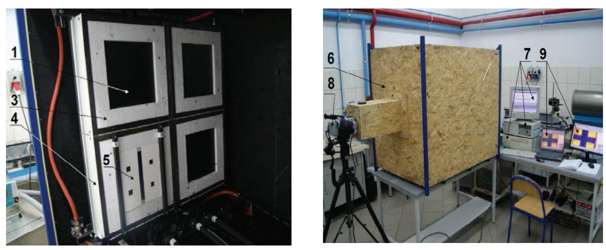

Fig. 3. Laboratory unit inside (on the left) and seen from outside (on the right), 1-copper board, 3-thermal insulation, 4-external casing, 5-tested sample, 6-measurement chamber, 7-computer data acquisition system, 8-infrared camera, 9-computer control system of infrared camera

During experiments the temperature distributions on the front side of the tested samples were measured and recorded by means of infrared camera. The final results of such measurements are very sensitive to measurement errors [6, 7, 8]. The main task of the walls chamber was to create unambiguously defined surroundings of the tested surface [5]. The temperature of the air inside the measurement chamber was kept at the required level. This air temperature and the temperature of inner surfaces of the chamber walls were continuously measured and recorded [7], (see thermocouples 5, 6, Fig. 4).

Generally, the measurement results were recorded by means of IR camera after reaching the conditions of steady state in heat transfer by the measurement system. In these conditions all temperature values were stable over time. During experiments the following quantities were measured and recorded: IR camera thermograms, temperature in several points on inner surfaces of measurement chamber walls, the temperature of copper boards, general air temperature inside the abovementioned chamber and the temperature of air in the immediate vicinity of the examined surfaces of tested samples. Usually the thermograms were recorded ten times for each measurement. Next, the measurement results recorded by IR camera were exported by the camera software and read with three significant decimal digits. The arithmetic mean calculated on the basis of the aforementioned ten recorded thermograms was used for further analysis. The arithmetic mean of temperature was rounded to two significant decimal places. The measurements were performed with the use of IR cameras FLIR SC2000 and FLIR SC620.

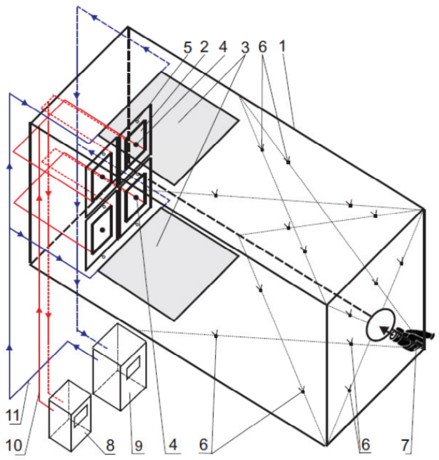

Fig. 4. Scheme of the laboratory unit, 1-work chamber, 2-copper board, 3-bottom and top air cooler/heater, 4-thermocouples for measurement of the copper board temperature. 5-thermocouples for measurement of air temperature in the immediate vicinity of the tested samples, 6-thermocouples for temperature measurement of work chamber walls, 7-infrared camera, 8-cryostat for heating/cooling the copper boards and simultaneously tested samples, 9-cryostat for cooling/heating air inside the work chamber, 10-circulating agent in the heating/cooling system of copper boards, 11-circulating agent in system of keeping air temperature at a required level

Fig. 5. `Measuring equipment for measurement of the thickness of paint layers, dial thickness gauge (on the left) and 3D scanner (on the right)

3. Analysis of selected measurement results

There are presented the measurement results of the examined samples denoted by X15, X16, X17 and X18. Figure 6 shows the thermogram, which was made for a temperature of copper boards amounting to 55°C. The measurement results were recorded after the stabilization of temperature distribution i.e. for the conditions of steady state in heat transfer.

In Fig. 6 eight rectangles with names: X15, X16, X17, X18, P01, P02, P03 and P04 were located on the thermogram. These surfaces show average temperature values of areas covered with “thermal resistant paints” (X15, X16, X17, X18) and the temperature of reference surfaces with measurement areas denoted as P01, P02, P03 and P04. The areas X15, X16 have size of 86 × 93 pixels and the areas P01, P02 of 38 × 93 pixels and they are located on samples X15 (lower left side) and X16 (lower right side). However, the areas X17, X18 have dimensions of 86 × 100 pixels and the fields P03, P04 are of 38 × 100 pixels. They are located on samples X17 (top, on the left) and X18 (top, on the right). The areas X15, X16, X17 and X18 were used to measure the temperature of paint and the areas named as P01, P02, P03, P04 were used for measuring the temperature of reference surfaces. The size of areas from X15 to X18 have been designated for the determined surfaces of plates, for which previously was measured the thickness of tested paint. The areas with size of 86 × 93 pixels cover field samples with size of 7.2 × 7.8 cm, however, dimensions of 86 × 100 pixels corresponds to the area size of 7.2 × 8.3 cm on the tested sample. The size of other rectangles (denoted by P01÷P04) was determined randomly, because they were only the reference surfaces.

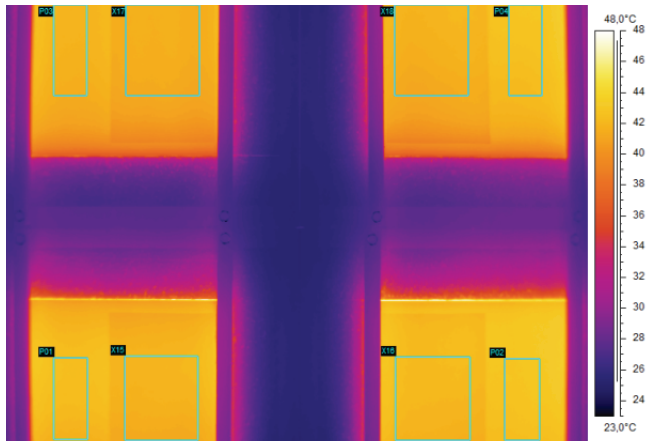

Fig. 6. Thermogram of temperature distribution for the temperature of copper boards 55°C (the areas located horizontally from the left bottom corner: P01, X15, X16, P02; from the left top corner: P03, X17, X18, P04)

The aforementioned thermogram for sample X17 was examined and a temperature drop was very small on that, because the temperature difference between surfaces was equal to 0.28 K. A noticeable temperature drops occurred on plates X15, X16 and X18, where the differences between temperature of reference surfaces and temperature of painted surfaces amounted to 0.53 K (sample X15), 0.66 K (sample X16) and 0.87 K (sample X18), respectively. The temperature drop is closely connected with the paint thickness, which for the plate X15 amounted to 0.39 mm, for the sample X16 was equal to 0.40 mm and for plate X18 the thickness of paint amounted to 0.44 mm. However the plate X17 has the higher thickness of paint (0.46 mm), the temperature drop is the lowest. Figures 7, 8 show the approximate appearance of paint surface and changes of layer thickness according to the size of considered area (Fig. 7) and according to the measurement path length inside this area (Fig. 8).

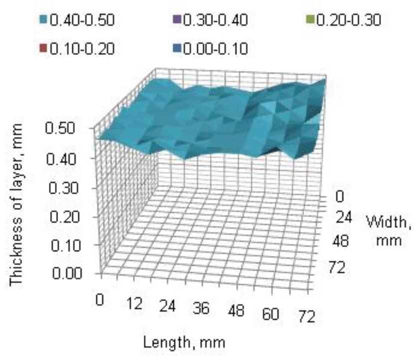

Fig. 7. Surface graph of the layer thickness for the sample X18

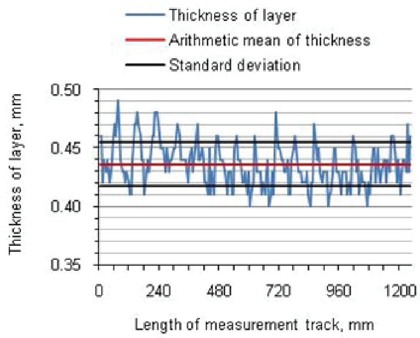

Fig. 8. Graph of the thickness distribution of paint layer along the measurement path length for the sample X18

Figure 9 shows the thermogram for different situation than the previous ones because it is made for a temperature of copper boards amounting to 10°C. So, in this case the samples were cooled and the direction of heat flow was opposite to the previous one. The temperature of air within measurement chamber was equal to 30.5°C. The photos were recorded during the steady state of thermal parameters within the measurement chamber. There are X15, X16, X17 and X18 samples in the same positions as previously. Eight rectangular measurement areas denoted by X15÷X18 and P01÷P04 have been created in the similar way as in the previous description. These areas had the same sizes and realized the same functions as previously.

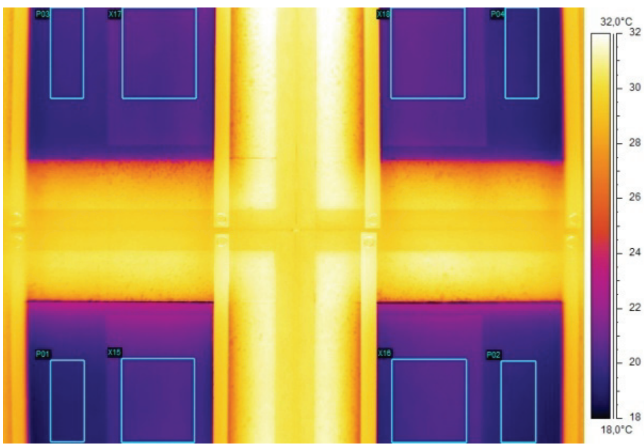

Fig. 9. Thermogram of the temperature distribution in the case of cooling the copper boards (the areas located horizontally from the left bottom corner: P01, X15, X16, P02; from the left top corner: P03, X17, X18, P04)

As it was explained, in this case the direction of the heat flux flow was changed because temperature of the copper boards was lower than air temperature. Heat flowed from surroundings through the examined samples to copper plates. In these conditions the rise of temperature of the examined surface was observed by comparison with the temperature of reference surface. The temperature difference between the examined surface of paint and reference surface for plate X15 amounted to 1.06 K. The similar difference for plate X18 was equal to 1.11 K, while the rise of temperature on plate X16 was equal to 0.98 K. The temperature difference for sample X17 was the lowest as in first example, because it was equal to 0.51 K. The thickness of layers was not changed. During the aforementioned experiments the temperature difference between copper boards and examined surfaces amounted to 10 K on average.

In the measurements of the thickness of paint coatings was used also a 3D scanner. In Fig. 10 there is presented an example of high resolution image of the tested coating surface obtained with the use of such scanner.

Fig. 10. Visual image example of the surface structure of the tested coating obtained by means of 3D scanner

In the Table 1 there are shown the results obtained for several tested samples. Generally it should be emphasized that the measurement results are very sensitive to measurement conditions and the thickness of paint layer. The thickness of paint layers, the temperature difference ΔT between the paint cover and reference surface (i.e. surface without painting) and term $\Delta T/\delta$ responsible for the heat conduction through the layers and uncertainties of these quantities are presented in this Table.

Tab. 1. Difference of temperature for selected samples for various temperature values of copper boards

Symbol of sample	Average thickness of paint layer within IR camera tested area		Temperature of copper boards					
			10.0 °C			55.0 °C		
	δ, mm	**u_δ**, mm	**ΔT**, K	**$u_{\Delta T}$**, K	$\frac{\Delta T}{\delta}, \frac{K}{mm}$	**ΔT**, K	**$u_{\Delta T}$**, K	$\frac{\Delta T}{\delta}, \frac{K}{mm}$
X15	0.39	0.035	1.06	0.24	2.72	0.53	0.40	1.35
X16	0.40	0.029	0.98	0.29	2.50	0.66	0.29	1.64
X17	0.46	0.027	0.51	0.29	1.12	0.28	0.25	0.61
X18	0.44	0.019	1.11	0.21	2.53	0.87	0.39	1.98

In case of layer thickness the uncertainties are presented as experimental standard deviation ($u_\sigma = s_\sigma$). However, for temperature difference these uncertainties are calculated as combined standard uncertainty consisted of uncertainty of temperature measurement of paint surface and uncertainty of temperature measurement for test area located on reference surface.

The final arithmetic mean of the temperature was calculated for N=10 thermograms where each of them had the same measurement area containing N_p pixels. Therefore the final average temperature $\bar{T}$ was calculated on the basis of $(N \cdot N_p)$ temperature values. It is easy to prove that this temperature can be calculated as follows:

$$\bar{T} = \frac{\sum_{j=1}^{N} \bar{T}_j}{N} \tag{1}$$

where: $\bar{T}_j$ – arithmetic mean of temperature for single measurement area located on ***j***-th thermogram, °C; N – number of thermograms (and simultaneously measurement areas).

Thus, the measurement consists of N sets and each of them has N_p measurement results, so the standard deviation (or experimental variance) can be calculated from the relationship:

$$s_T^2 = \frac{\sum_{j=1}^{N} (N_p - 1)\, s_{Tj}^2 + \sum_{j=1}^{N} N_p (\bar{T}_j - \bar{T})^2}{N N_p - 1} \tag{2}$$

where: N_p – number of points (pixels) inside the measurement area located on thermogram; s_{Tj}^2 - experimental variance of the temperature values inside j-th measurement area characterizing their dispersion about mean temperature $\bar{T}_j$.

Then, the standard deviation was calculated for all N sets:

$$s(T_Y) = s_T = \sqrt{s_T^2} \tag{3}$$

where $Y \equiv X$ or $Y \equiv P$ and the standard deviation was treated as standard uncertainty. Temperature difference between paint surface and reference surface is defined as:

$$\Delta T = |T_X - T_P| \tag{4}$$

Thus, the combined standard uncertainty for temperature difference ΔT between the examined area X15 and the reference area P01 takes the following form:

$$u_{\Delta T} = \sqrt{(s(T_{X15}))^2 + (s(T_{P01}))^2} \tag{5}$$

During the tests with lower temperature of copper boards (CBs) the temperature difference between painted and reference surfaces were obtained higher than in previous experiments when the temperature of CBs was higher than the temperature of air. It proves that these paints can efficiently function on inner side of external building walls as well. Summing up, if these paints are put on the inner surfaces of walls (when the environment temperature is lower than the temperature inside house) the amount of heat flowing through the building wall into surroundings will be diminished because the temperature of painted surfaces inside the building will be increased (see Fig. 9) and the intensity of heat exchanging between the air and wall inner surfaces will be reduced. Similarly, if these paints are put on the outer surfaces of the building walls the heat flux flowing through the building wall into surroundings will be also reduced because the temperature of painted surfaces will be decreased (see Fig. 6) and the intensity of heat exchanging between the air and wall outer surfaces will be reduced as well.

4. Final remarks

The measurement results allowed to compare the insulation efficiency of various kinds of the tested paints. It was also possible to estimate the scale of the temperature drop inside the protection layer of considered coatings in relation with the thickness of these layers as well as the content of applied special component.

The results of comparison of heat protection features of different thermal resistant paints used in building technology have been presented in this paper. There were examined various types of paints with different contents of the special components enhancing their insulation properties. Due to marketing reasons the names, symbols and compositions of the tested paints cannot be specified. Because of the same reasons the presented results are mainly of qualitative character. However, they express potential range of value of tested parameters. Calculated uncertainties (Tab. 1) indicate that obtained results are very sensitive to conditions of measurement.

The scientific work was supported by Faculty of Energy and Environmental Engineering of the Silesian University of Technology within the statutory research.

5. References

[1] Chwieduk D.: Sun energetics of the building (in Polish), Wyd. Arkady, Warszawa, 2011.

[2] Nemec P., Caja A., Lenhard R.: Analysis of heat transfer limitation of wick heat pipe. Proceedings of the International Conf. on Experimental Fluid Mechanics EFM2009, Liberec, 2009, pp.230-235.

[3] Kruczek T.: Determination of annual heat losses from heat and steam pipeline networks and economic analysis of their thermomodernisation. Energy, vol. 62, pp. 120-131, 2013.

[4] Rochatka T.: A method of determining the heat flux density based on a thermovision photo (in Polish), Measurement Automation Monitoring, vol. 57, No 10, pp. 1183-1186, 2011.

[5] Kruczek T.: Use of infrared camera in energy diagnostics of the objects placed in open air space in particular at non-isothermal sky. Energy, vol. 91, pp.35-47, 2015.

[6] Minkina W., Dudzik S.: Infrared Thermography - Errors and Uncertainties. Wiley & Sons, UK; 2009.

[7] Kruczek T., Szczygieł I., Kruczek G., Kowalczyk P.: Examination of heat insulation features of thermal resistant paints with use of IR camera. Proc. of Internat. Conf. QIRT2016, Book of Abstracts, pp. 111-112, http://qirt.gel.ulaval.ca/archives/qirt2016/papers/067.pdf, 2016, Gdańsk.

[8] Madura H. et al.: Thermovison measurements in practice (in Polish). Agenda Wyd. PAK, Warszawa, 2004.

Received: 22.11.2016 Paper reviewed Accepted: 02.02.2017

Tadeusz KRUCZEK, PhD

Study and doctor's thesis at Mechanical and Energy Faculty of Silesian University of Technology. Research activity in area of rational use of energy, techniques of thermal and infrared measurements, thermal diagnostics of objects. Author or co-author of more than 180 various scientific papers. Scientific visits in different foreign universities and research institutions. Member of Energy Comm. of Polish Acad. of Science, Katowice Dep., Head of Laboratory of Thermal Technology in ITT.

e-mail: tadeusz.kruczek@polsl.pl

Prof. Ireneusz SZCZYGIEŁ

Study, PhD and DSc at Mechanical and Energy Faculty of Silesian University of Technology. Research activity in area of heat and mass transfer, numerical heat and mass transfer, thermodynamics, thermal diagnostics of objects. Author or co-author of more than 140 various scientific papers. Scientific visits in foreign universities and research institutions. Member of Comm. of Thermodynamics of Polish Acad. of Sci., Head of Div. of Heat Transfer and Nuclear Power Engineering.

e-mail: ireneusz.szczygiel@polsl.pl

Grzegorz KRUCZEK, PhD Student

Study at Energy and Environmental Engineering Faculty of Silesian University of Technology and one year at Technical University of Stuttgart, Germany. Professional trainings in Istituto Motori, Neapol, Italy (3 months) and in General Electric Engineering Design Center, Warsaw (twice). He deals with numerical modelling of thermal processes, especially in internal-combustion engines. Co-author of 8 papers (2 in international journals).

e-mail: grzegorz.kruczek@polsl.pl

Piotr KOWALCZYK, BSc

He is a 5-th year student of Environmental Protection at the Silesian University of Technology at the Faculty of Energy and Environmental Engineering, co-author of 2 scientific papers. He is interested in special temperature measurements with use of thermocouples and infrared cameras.

e-mail: p.kowalczyk900@gmail.com