

Determination of the equivalent thermal conductivity coefficient for paints and thermoreflective layers

In accordance with the technical conditions to be achieved in 2022, the Ministry of Transport, Construction and Maritime Economy has prepared a draft regulation that should be met by buildings and their location.

This project specifies, includes the requirements for the insulation of building partitions, which must be met by newly constructed and modernized buildings. One of the most important requirement is to decrease thermal permeability coefficient U . this is very important because it changes the thickness of the insulation that will have to be used.

Currently, the heat transfer coefficient for walls should be smaller than $0,2 \text{ W}/(\text{m}^2\text{K})$. In practice, this means that the wall must be covered with a conventional insulation material approximately 25 cm thick.

In case of last years: 2014 year – $U_{\text{maks}} = 0,25 \text{ W}/(\text{m}^2\text{K})$, 2017 year – $U_{\text{maks}} = 0,23 \text{ W}/(\text{m}^2\text{K})$, tendencies to lower the maximum U -value and hence increase the insulation thickness can be noticed. These changes significantly affect the increase in investment costs.

Investors' activities focus on increasing thermal insulation by using additional partitions on the walls of buildings made of materials with low heat conduction coefficients, for example: glass wool mats, polystyrene boards and thermoreflective materials.

The technology of thermoreflective protection consists in limiting the transport of heat between media of different temperatures by means of infrared radiation. In this field, one of the most modern solutions is the use of paints - thermoreflective coatings, which are characterized by a high reflectivity of infrared radiation, up to 98%. The reflection of this radiation towards a heat source with a higher temperature creates a so-called heat barrier on the reflecting surface, which is much more effective than conventional thermal insulation materials.

Thermoreflective coat produced on the Polish market is PScoat. It is used for interior and exterior painting as well as roofing. PScoat thermo-reflective masses are widely used in industry as insulation of pipelines, tanks, silos etc.

The transfer of heat between media of different temperatures taking place at the level of infrared radiation and heat conduction can be captured by the surrogate mechanism of heat conduction provided that the equivalent thermal conductivity coefficient is measured for the thermoreflective coverage.

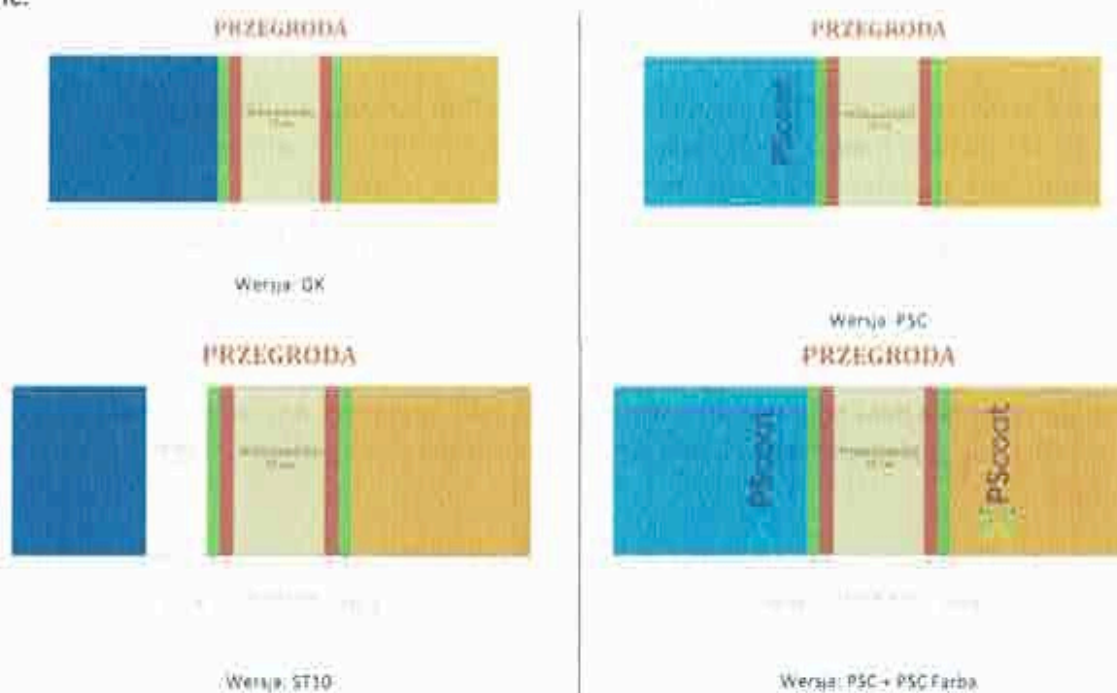
Describe of the research method

The test consists in creating the climatic conditions as close as possible to those prevailing in winter: the temperature outside -15°C and in the living room $+20^{\circ}\text{C}$. The aim of the test is to determine how the use of PSccoat thermal insulation coatings affects the heat transfer through the test partition.

Tests were carried out on the test partition in the following variants:

1. Double-sided plasterboards - without the use of the PSC system
2. Double-sided plasterboards – covered by PSC system from the cool side
3. Double-sided plasterboards + from the cool side: Styrofoam of 10 cm of thickness without PSC system
4. Double-sided plasterboards – covered by PSC system from the cool side and also additional layer which is part of PSC system

Pic.



Test samples

PSC system:

- Basis
- Thermal layer
- Façade paint

All system components are water-based products. The total thickness of the system layer is 0.35 mm, and the thickness of the PSC paint layer is 0.1 mm.



Electricity consumption studies

Aim of research:

The aim of the study is to determine the impact of the use of PSC series products on the consumption of electricity necessary to maintain the temperature in the heated zone - simulation of savings resulting from the use of PSC series products.

Conditions and research description:

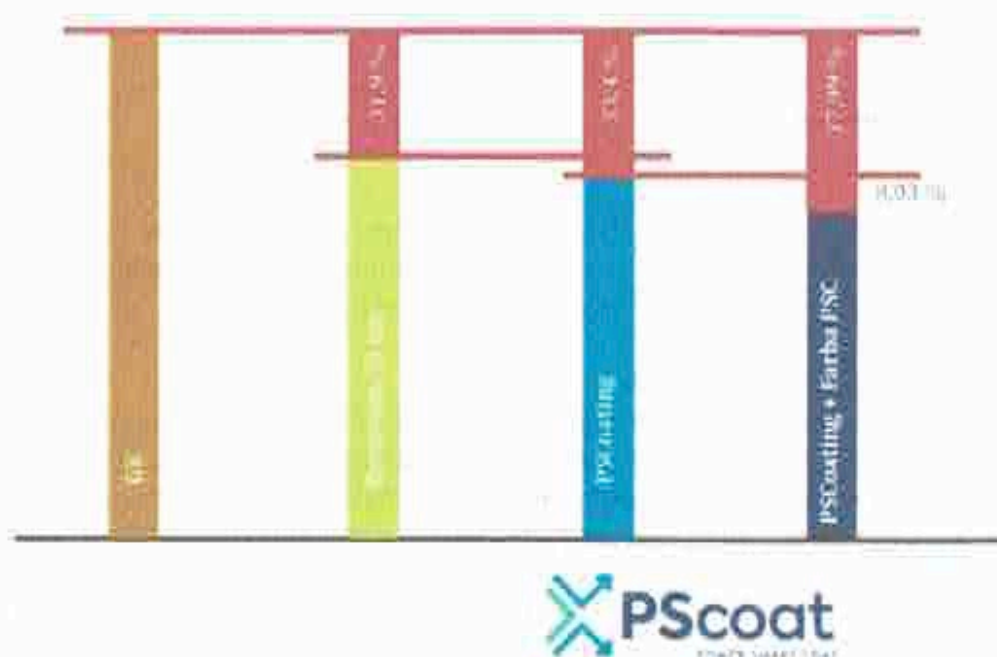
The test consisted in maintaining the average temperature in hot and cold zones for 24 hours. Stable thermal conditions were brought into both zones of the simulator and then maintained for a total period of 24 hours. The costs of maintaining the temperature in the cold zone were not measured - the stability of external conditions was assumed, while the consumption of electricity necessary to maintain the temperature in the hot zone was the subject of this study. Measurements of electricity consumption and temperature were made using the Optris PI 640 thermal imaging camera and Uniwnet RST4R3 controllers with connected thermocouples.

Results:

The results of the study are presented below in tabular and graphical form. Savings between particular versions of partitions were included in absolute terms - the value of savings was compared to the base partition.

wersja przegrody	zuzycie w ciągu 24h [kW]	Oszczędność
GK	6,58	-
PSC	4,38	33,43%
ST10	4,48	31,91%
PSC + Farba PSC	4,08	37,99%

Tabela 2 Wyniki badania poboru energii elektrycznej



Rys. 5 Wykres poboru energii elektrycznej – oszczędności w ujęciu bezwzględny

Determination of the thermal conductivity coefficient:

1. Assumptions:

- a. The dimensions of the partition: 2.19 m x 2.19 m,
- b. The research environment is constant throughout all research,
- c. The only variable between studies is the partition.
- d. Lambda of mineral wool: 0.044 [W / m² * K]; thickness: 10cm
- e. Lambda of drywall: 0.23 [W / m² * K]; thickness: 12mm
- f. Lambda of OSB boards: 0.16 [W / m² * K]; thickness 12mm
- g. Heater efficiency: 1



2. Known data:

- a. Thermal resistance of control partition:
 $R_0 = 2,826 \text{ [m}^2 \cdot \text{K/W]}$
- b. Thermal resistance with styrofoam,
 $R_1 = 5,098 \text{ [m}^2 \cdot \text{K/W]}$
- c. Temperature difference between the media:
 $\Delta T = 35^\circ \text{K}$
- d. The amount of electricity supplied to the research environments,
 - $Q_0 = 6580 \text{ Wh}$
 - $Q_1 = 4480 \text{ Wh}$
 - $Q_{PSC,1} = 4380 \text{ Wh}$
 - $Q_{PSC,2} = 4080 \text{ Wh}$
- e. Powierzchnia badanej przegrody,
 $P = 4,796 \text{ m}^2$
- f. Grubość warstw izolacji termicznej PScocat,
 $d = 0,00035 \text{ m}$

3. Description of research method

Knowing the above values, we determine the value of the heat flux that passed through the control partition [Q_0 ']. Assuming that the difference in electricity consumption results only from the change introduced in the obstacle, we determine the value [Q_0 '] based on the proportion of thermal resistance of the control partition and the partition with polystyrene insulation.

Knowing the value of the heat flux for the control partition and the difference in electricity consumption, on this basis, we can determine the resistance of the partitions insulated with the PScocat system. In order to verify the correctness of calculations, use this method to determine the resistance for a partition insulated with polystyrene.

4. Calculations

Determining the efficiency of the heating system:

$$\zeta = \frac{\Delta Q'}{\Delta Q}$$

where:

ζ - efficiency of the heating system [%]

$\Delta Q_0'$ - The difference of the calculated heat fluxes between the control partition and the partition insulated with 10 cm styrofoam.

ΔQ - The difference in electricity consumption in the tests of the control partition and the partition insulated with 10 cm of polystyrene.

$$\Delta Q = Q_0 - Q_1 = 2100 \text{ Wh}$$



$$\Delta Q' = Q'_0 - Q'_1 = \left(\frac{1}{R_0} - \frac{1}{R_1}\right)24h + 4,796m^2 * 35^\circ K$$
$$\Delta Q' = 635,617 Wh$$

$$\zeta = \frac{635,617 Wh}{2100 Wh} = 0,303$$

Determination of energy losses of the control partition in the total energy consumption of the environment.

$$\frac{1}{R_0} = Q'_i$$
$$\frac{1}{R_1} = Q'_i - \Delta Q$$

$$0,354 = Q'_i$$
$$0,196 = Q'_i - 2100Wh$$

$$Q'_i = 4704,43 Wh$$

Determination of the thermal energy of the control partition, taking into account the efficiency of the heating system.

$$Q_i = Q'_i * \zeta = 1 425,44 Wh$$

Determination of thermal resistance for partition with PScoat

$$Q'_1 = Q'_i - (Q_0 - Q_{PSC,1}) = 4704,43 Wh - 2200,00Wh = 2504,43 Wh$$

$$Q_1'' = Q'_1 * \zeta = 758,03 Wh$$

Total heat flux for the entire partition for 1h:

$$Q_1''^{1h} = \frac{Q_1''}{24h} = 31,584W$$

Total heat flux for 1 m³ of a partition insulated with polystyrene:

$$Q_{S,0,1} = \frac{Q_1''^{1h}}{P} = \frac{31,584W}{4,796 m^2} = 6,585 W/m^2$$



Determination of the thermal transmittance of a partition insulated with the PScoat system:

$$U_{PSC,1} = \frac{Q_{S,0,1}}{\Delta T} = \frac{6,585 \frac{W}{m^2}}{35^\circ K} = 0,188 \frac{W}{m^2 * K}$$

where:

$U_{PSC,1}$ – thermal transmittance of PScoat layer

ΔT – temperature difference

Determination of the thermal resistance of a partition insulated with the PScoat system:

$$R_{PSC,1} = \frac{1}{U_{PSC,1}} = 5,319 \frac{m^2 * K}{W}$$

Determination of the equivalent thermal resistance for the PScoat partition itself:

$$R_{PSC} = R_{PSC,1} - R_0$$

$$R_{PSC} = 5,319 \frac{m^2 * K}{W} - 2,826 \frac{m^2 * K}{W} = 2,493 \frac{m^2 * K}{W}$$

Determination of a replacement lambda for the PScoat insulation system:

$$\lambda_{PSC}^* = \frac{d}{R_{PSC}}$$

where:

d – insulation thickness of PScoat = 0,00035 m

$$\lambda_{PSC}^* = \frac{0,00035m}{2,493 \frac{m^2 * K}{W}} = 0,00014 \frac{W}{m^2 * K}$$

Determination of the thermal resistance for an insulated PScoat + PScoat interior partition:

$$Q_2' = Q_1' - (Q_0 - Q_{PSC,2}) = 4704,43 Wh - 2500,00Wh = 2204,43 Wh$$

$$Q_2'' = Q_2' * \zeta = 667,23 Wh$$

Total heat flux for the entire partition for 1h:

$$Q_2''^{1h} = \frac{Q_2''}{24h} = 27,81W$$



Total heat flux for 1 m² of a partition insulated with polystyrene:

$$Q_{s,0,2} = \frac{Q_1^{1h}}{p} = \frac{27,81W}{4,796 m^2} = 5,797 W/m^2$$

Determination of the thermal transmittance of a partition insulated with the PScoat system:

$$U_{PSC,2} = \frac{Q_{s,0,1}}{\Delta T} = \frac{5,797 W/m^2}{35^{\circ}K} = 0,166 \frac{W}{m^2 * K}$$

Determination of the thermal resistance of a partition insulated with the PScoat system:

$$R_{PSC,2} = \frac{1}{U_{PSC,2}} = 6,038 \frac{m^2 * K}{W}$$

Determination of the equivalent thermal resistance for the PScoat partition itself:

$$R_{PSC,2}^* = R_{PSC,2} - R_0$$
$$R_{PSC,2}^* = 6,038 \frac{m^2 * K}{W} - 2,826 \frac{m^2 * K}{W} = 3,215 \frac{m^2 * K}{W}$$

Conclusions:

According to the above calculations, the equivalent resistances for the PScoat and PScoat + PScoat interior insulation system exceed the resistance of polystyrene with a thickness of 10cm and $\lambda = 0,044 \frac{W}{m * K}$.

The results are as follows:

Resistance of PScoat:

$$R_{PSC}^* = 2,493 \frac{m^2 * K}{W}$$

Resistance of PScoat+PScoat interior:

$$R_{PSC,2}^* = 3,215 \frac{m^2 * K}{W}$$



PScoat heat transfer coefficient λ_{PSC} :

$$\lambda_{PSC} = 0,00012 \frac{W}{m \cdot K}$$

PScoat interior heat transfer coefficient $\lambda_{PSC,i}$:

$$\lambda_{PSC,i} = 0,000416 \frac{W}{m \cdot K}$$

Remarks:

For the PScoat insulation system, the equivalent thermal resistance of the partition should be used to calculate the thermal transmittance [U] due to the fact that increasing the thickness of the PSC system coating does not guarantee a linear improvement of the thermal parameters of the partition.

The favorable values of the thermal resistance result from the fact that the heat exchange in ordinary thermal insulation materials takes place by changing the vibration frequency of the material particles, while for thermo-reflective coatings the main mechanism is thermal radiation.

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Attachment number 1 : Research report

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