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TRANSPARENT INSULATION EFFICIENCY DETERMINED BY DIFFERENT METHODS

OBLICZENIOWA EFEKTYWNOŚĆ IZOLACJI TRANSPARENTNYCH WYZNACZANA RÓŻNYMI METODAMI

Abstract

The paper summarizes the methods of calculating heat gain by transparent insulation using two national standards. The energy balance of the partition was evaluated taking its orientation into account. A comparison was conducted into the methods of assessing the effectiveness of transparent insulation.

Keywords: transparent insulation, heat gains, energy balance

Streszczenie

W artykule przedstawiono metody wyznaczania zysków ciepła uzyskiwanych poprzez zastosowanie izolacji transparentnej z wykorzystaniem dwóch norm. Wyznaczono bilans energetyczny przegrody uwzględniający warunki klimatyczne charakterystyczne dla danej orientacji. Przeprowadzono porównanie metod ze względu na efektywność izolacji transparentnej.

Słowa kluczowe: izolacja transparentna, zyski ciepła, bilans energetyczny

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1. Introduction

The concept of transparent insulation (TI) refers to a transparent material or a composition of several materials placed on the external layer of a building envelope. It is an effective technology that aims to reduce the heating demand by enhancing solar energy conversion and the capability of thermal energy storage [3]. Therefore, transparent insulation not only reduces heat loss by conduction but, unlike the traditional thermal insulation, also provides additional solar heat gains [4].

The heat gains are achieved through an appropriate transparent insulation construction and its utilization varies depending on the system [16]. The typical arrangement of components comprises the outer glass (or a layer of glass plaster), a transparent insulation material which allows solar radiation to be transmitted to the absorber, and transfers heat directly to the storage layer (massive wall). Effective transparent insulation materials used in such an application are made of plastics, such as polycarbonate with a structure of honeycomb or acrylic foam, or inorganic materials, which include fiber glass and aerogel. The diversified structure of transparent insulation allows for the design of an aesthetic façade components which easily combine with traditional insulation systems.

Transparent insulation enables heat to accumulate on the surface of the absorber and, by warming the accumulation layer, to transfer heat to the building [6]. Nevertheless, on cloudy days or during the night the insulation should have appropriate thermal insulation properties to minimize heat loss. Therefore, the TI is usually characterized by a low thermal transmittance U , a high solar energy transmittance g and low emissivity ϵ [2].

Many studies have examined the overall performance and heat transfer through TI [7, 13]. Furthermore, different numerical models to evaluate the thermal behaviour of these kinds of insulation materials can be found in this literature [17, 18]. These models differ in terms of their complexity and also take into account specific variables, in accordance with the model's application. Moreover, the effectiveness of the application of TI in external walls can be evaluated more precisely by a dynamic simulation using ESP-r [11], TRNSYS [10], tsbi3 software [15] or experimentally [12, 14].

In the latter paper, the efficiency of transparent insulation was calculated using two methods described in the Polish (ISO) and German (DIN) national standards. Both methods are based on the monthly, steady-state energy balance but also take into account different weather and material parameters. The study was designed to investigate the impact of the model's complexity on the accuracy of the results.

2. Calculation methods

2.1. The Polish Standard calculation method

An energy efficiency evaluation can be formulated using different calculation methods characterized by different levels of accuracy and complexity. In order to determine the overall energy performance of the building, and of its components, the monthly balance method can be applied. The effect of the transparent insulation application can be estimated according to the difference in heat fluxes (between gains and losses). Heat loss by the external envelope utilising TI can be calculated likewise as for usual elements. It can be stated that,

for the purpose of TI performance evaluation, transmission of the heat transfer coefficient can be limited to the direct heat transfer coefficient by the transmission to the external environment. Flux caused by neglect of linear and point thermal bridges heat loss can be expressed as:

$$Q_{tr} = A \cdot U_T \cdot \Delta\theta \cdot 24 \cdot n_i \quad (1)$$

where:

- A – total area of partition,
- U_T – total thermal transmittance,
- $\Delta\theta$ – average difference between indoor and outdoor air temperature,
- n_i – number of days in a month.

Despite the specific structure and optical characteristics, heat loss through a TI wall can be calculated in the same way as for a typically insulated wall. Nevertheless, heat gains are quite difficult to estimate and different approaches need to be applied.

The Polish national and European Standard [8] provides the basic guide for an assessment of the overall energy performance of a building. It applies to whole zone energy balance calculations but can be also be used to evaluate the performance of a specific part of a building's construction. The energy performance of transparent insulation can be estimated by reference to the difference between heat gain and heat loss, and calculations can be extrapolated for subsequent months.

Taking into account the effective collecting area and solar irradiance for a specific orientation and month, the calculation method detailed in the Annex to the National Standard allows the effect of additional solar heat gains during the whole year to be quantified. For non-heating zones, solar heat gain can be calculated as:

$$Q_s = I_{si} \cdot A_s \cdot 24 \cdot n_i \quad (2)$$

where:

- A_s – effective collecting area,
- I_{si} – solar irradiance on vertical surface at the given orientation.

Solar heat gains calculated by ISO depend on the orientation of the surface and shading by other external structures. The method takes account of climate, time and also location-dependent factors such as the Sun's position, and the ratio between direct and diffuse solar radiation. The solar energy-effective collecting area is equal to the area of a black-clad body having the same solar heat gain as the surface in question:

$$A_s = A_{TI} \cdot F_s \cdot F_F \cdot \frac{U_T}{U_{te}} \cdot g_T \quad (3)$$

where:

- A_{TI} – total area of the transparent insulation,
- F_s – shading coefficient,
- F_F – frame area coefficient (ratio of transparent insulation area to total area),
- U_{te} – thermal transmittance from the surface facing the transparent insulation to the external environment,
- g_T – total solar energy transmittance of the transparent insulation:

$$g_T = \alpha(g_{h,T} - c_{j,m} \cdot g_{n,T}) \quad (4)$$

where:

- $g_{h,T}$ – total diffuse solar energy transmittance of transparent insulation,
- $c_{j,m}$ – coefficients for the calculation of total solar energy transmittance,
- $g_{n,T}$ – total direct solar energy transmittance of transparent insulation,
- α – solar radiation absorption coefficient of a surface.

2.2. The German Standard calculation method

The German Standard [1] assume the same heat loss calculation method as in the ISO, but the heat gains by TI are determined in a different way. DIN assumes there to be a distinction in calculation methods for opaque constructions and envelopes with transparent insulation.

The general equation for solar heat gain in the case of opaque partitions is in two parts. The first addresses the energy yield as a result of energy absorption of solar radiation on the exterior surface of an opaque element. The calculation depends on the absorption coefficient of a surface, for solar radiation α and also for solar irradiance I_s . The second part of the formula concerns the thermal radiation loss due to heat emission, which depends on the average surface temperature and the atmospheric temperature $\Delta\theta_{er}$.

The heat gain of the partition with the transparent insulation is determined in a similar way, but taking into account the transparent insulation efficiency coefficient α_e and the shading coefficient F_s :

$$Q_{S, TI} = \sum (U \cdot A_{TI} \cdot R_{se} \cdot (\alpha \cdot \alpha_e \cdot F_s \cdot I_{si} - F_l \cdot h_r \cdot \Delta\theta_{er}) \cdot t_M) \quad (5)$$

The transparent insulation efficiency coefficient is determined by:

$$\alpha_e = \frac{g_{TI} \cdot R_{TI} \cdot F_F}{R_{se}} \quad (6)$$

where:

- h_r – surface coefficient of the transfer of radiative heat of the exterior surface,
- F_l – slope coefficient of the element,
- T_{TI} – thermal resistance of transparent insulation,
- g_{TI} – total effective solar transmittance,
- $\Delta\theta_{er}$ – average surface temperature and atmospheric temperature.

The substitution of (6) into (5) gives the overall formula for the heat gain generated by transparent insulation:

$$Q_{S, TI} = \sum (U \cdot A_{TI} \cdot (\alpha \cdot g_{TI} \cdot R_{TI} \cdot F_F \cdot F_s \cdot I_{si} - R_{se} \cdot F_l \cdot h_r \cdot \Delta\theta) \cdot t_M) \quad (7)$$

In certain cases the share of absorption coefficient α and/or shading coefficient F_s can be omitted from the equation. This depends on the transparent insulation system in question. The type of transparent insulation also influences the means of determining the total effective solar energy transmittance g_{TI} . In this type of TI there is no air gap (thermal resistance of an air gap R_{sp} is omitted) – so it can be assumed:

$$g_{TI} = g_T \quad (8)$$

3. Case study

For the purpose of a comparative analysis of the methods described, the single partition was taken into account. The dimensions were assumed to be 5.0 m in length and 2.4 m in height, reaching a total area of 12 m². The geometry was defined in such a way that the modeled wall matched the dimensions of the transparent insulation panels (1.0 × 1.2 m). The external wall was constructed from cellular concrete with a thickness of 0.24 m and 0.125 m of transparent insulation. It was assumed that TI covered the whole area of the partition to determine its energy balance precisely. The physical properties of the transparent insulation (thermal conductivity, solar energy transmittances) were adopted in accordance with the technical specifications of the material.

To determine the heat transfer through the partition, the climatic data developed for the EBPD certificate system [9] was used in the calculations. The interior air temperature was set at 20°C and one calendar year was assumed to be the calculation period. The monthly

Table 1

Material and weather parameters used in calculations

Parameter					Method	
No.	Description	Symbol	Unit	Value	ISO	DIN
1	total area of the transparent insulation	A_{TI}	[m ²]	12.0	V	V
2	absorption coefficient	α	[-]	0.95	V	X
3	solar energy transmittance coefficient	$c_{j,m}$	[-]	[8]	V	X
4	thickness of the wall (excluding TI)	d	[m]	0.24	V	V
5	thickness of transparent insulation	d_{TI}	[m]	0.125	V	V
6	frame area coefficient	F_F	[-]	1.0	V	V
7	slope coefficient	F_I	[-]	0.5	X	V
8	shading coefficient	F_S	[-]	1.0	V	V
9	total solar energy transmittance	g_T	[-]	0.54	X	V
10	total direct solar energy transmittance	$g_{n,T}$	[-]	0.6	V	X
11	total diffuse solar energy transmittance	$g_{h,T}$	[-]	0.4	V	X
12	surface coefficient of radiated heat transfer of the outer surface	h_r	[W/m ² K]	4.0	X	V
13	solar irradiation on vertical surface	I_{si}	[W/m ²]	Fig. 1	V	V
14	thermal conductivity of the wall	λ	[W/mK]	0.29	V	V
15	equivalent thermal conductivity of the transparent insulation	λ_{TI}^{eq}	[W/mK]	0.09	V	V
16	calculation period	t_M	[h]	[9]	V	V
17	average surface and atmospheric temperature (DIN allowing the adoption of a constant value for a moderate climate zone)	$\Delta\theta_{er}$	[K]	10.0	X	V

average values of the solar irradiation (depending on orientation) and the average differences between the indoor and external air temperature are shown in Fig. 1. All the parameters used in the calculations are detailed in Table 1.

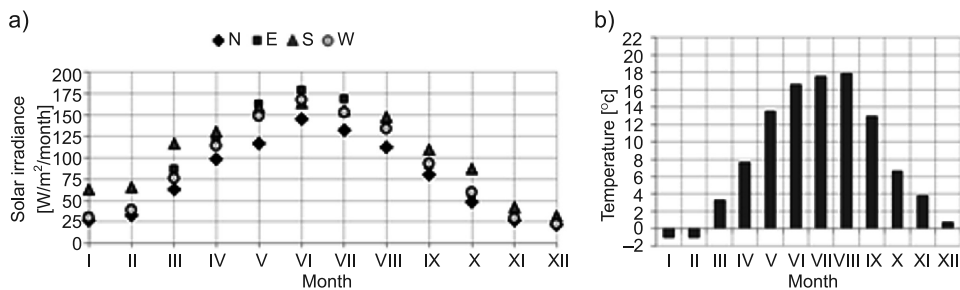


Fig. 1. Climatic data for Lodz: a) solar irradiance, b) outdoor air temperature

4. Results

Analysis showed that the energy balance obtained for a wall insulated with TI is positive for almost an entire year. Heat loss is almost equal to solar heat gain even during the coldest winter months, except for southwards facing orientations.

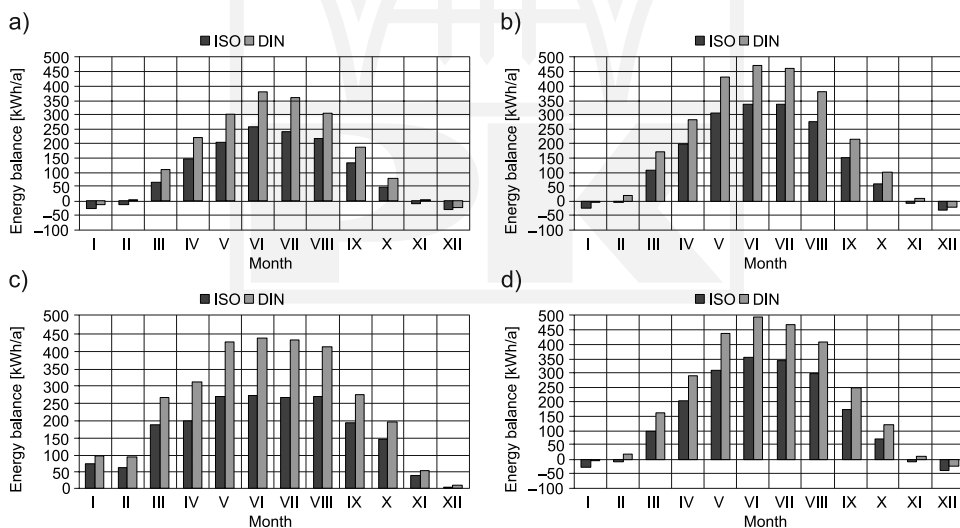


Fig. 2. Monthly energy balances for: a) north, b) east, c) south, d) west orientated insulated walls

Furthermore, it is noted that during these months, values obtained by both calculation methods are similar (Fig. 2). Nevertheless, calculations in accordance with DIN noticeably overestimate heat gain in comparison to values obtained by the ISO calculation method (Fig. 3).

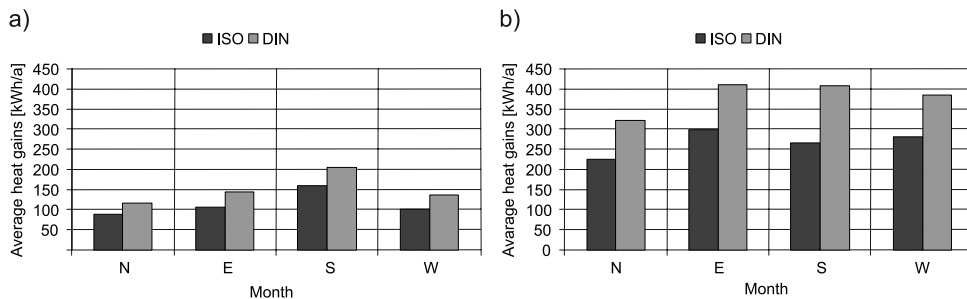


Fig. 3. Average monthly heat gains during: a) heating season, b) cooling seasons

The differences in the results obtained are mainly caused by the values of total solar energy transmittance of TI. The ISO method assumes that these values depend on the orientation and are different for specific months, while a constant value is used in the DIN calculation method (Fig. 4).

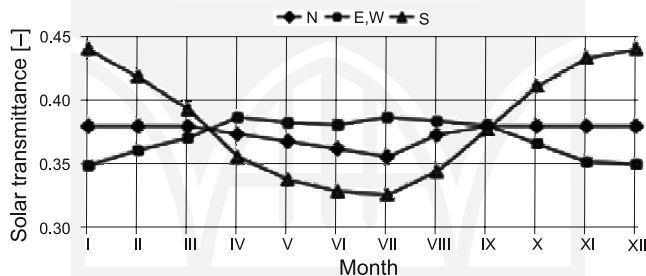


Fig. 4. Values of total solar energy transmittance used in the ISO calculation method

5. Conclusions

The analysis demonstrates that calculations for the energy balance for the partition with the transparent insulation varies depending on the method used. Despite some similarities in heat gain calculations and in the means of determining heat loss in results obtained, differences are apparent and significant. Both methods take into account the thermal resistance of the insulation, shading and frame area coefficients. Nevertheless, the ISO method separately includes diffuse and direct solar energy transmittance and absorption coefficient of the materials. On the other hand, the DIN method includes the heat loss share by thermal radiation (due to the emission) by the introduction of the h_r and $\Delta\theta_{er}$ parameters.

For all the months in question, heat gains recorded using the Polish Standard calculation method are lower than those recorded using the German Standard. Nevertheless, it is noted that heat gains are only desirable at certain times of the year and during the summer months effective insulation should provide protection from overheating. Therefore, it is not possible to make a clear declaration as to which method allows for more precise calculations. Therefore, more complex and dynamic analysis, including experimental tests, should be undertaken [5].

References

- [1] DIN 4108-6:2000-11: Wärmeschutz und Energie-Einsparung in Gebäuden – Teil 6: Berechnung des Jahresheizwärme- und des Jahresheizenergiebedarfs.
- [2] Dudko K., *Izolacje transparentne w systemach pasywnego ogrzewania słonecznego*, Izolacje, 1/2004.
- [3] Kaushika N.D., Sumathy K., *Solar transparent insulation materials: a review*, Renewable&Sustainable Energy Reviews, Vol. 7, 2003, 317-351.
- [4] Kisilewicz T., *Computer Simulation in Solar Architecture Design*, Architectural Engineering and Design Management, Vol. 3/2007.
- [5] Kisilewicz T., *Experimental field testing of transparent insulation*, Archives of Civil Engineering, Vol. 54, 2008, 493-508.
- [6] Lewandowski W.M., Lewandowska-Iwaniak W., *The external walls of a passive building: A classification and description of their thermal and optical properties*, Energy and Buildings, Vol. 69, 2014, 93-102.
- [7] Platzer W.J., *Total heat transport data for plastic honeycomb-type structures*, Solar Energy, Vol. 49, 1992, 351-358.
- [8] PN-EN ISO 13790: Energy performance of buildings – Calculation of energy use for space heating and cooling.
- [9] Polish Ministry of Infrastructure and Development (<http://www.mir.gov.pl>).
- [10] Sick F., Kummer J.P., *Simulation of transparently insulated buildings*, Solar Energy, Vol. 49, 1992, 429-434.
- [11] Strachan P.A., Johnstone C.M., *Solar Residences with transparent insulation: predictions from a calibrated model*, Proc. North Sun '94, Glasgow, 1994, 347-353.
- [12] Suehrcke H., Daldehog D., Harris J.A., Lowe R.W., *Heat transfer across corrugated sheets and honeycomb transparent insulation*, Solar Energy, Vol. 76, 2004, 351-358.
- [13] Verbeeck G., Hens H., *Radiative and Conductive Heat Transfer through Transparent Insulation Material and the Effect on the λ -value*, Building Physics '96 – 4th Nordic Symposium.
- [14] Wallner G.M., Hausner R., Hegedys H., Schobermayr H., Lang R.W., *Application demonstration and performance of a cellulose triacetate polymer film based transparent insulation wall heating system*, Solar Energy, Vol. 80, 2006, 1410-1416.
- [15] Wittchen K.B., *Simulation Solar Walls with tsbi3*, Building Physics '93 – 3th Nordic Symposium.
- [16] Wong I.L., Eames P.C., Perera R.S., *A review of transparent insulation systems and the evaluation of payback period for building applications*, Solar Energy, Vol. 81, 2007, 1058-1071.
- [17] Yang H., Zhu Z., Burnett J., *Simulation of the behaviour of transparent insulation materials in buildings in northern China*, Applied Energy, Vol. 67, 2000, 293-306.
- [18] Zanghirella F., Perino M., Serra V., *A numerical model to evaluate the thermal behaviour of active transparent facades*, Energy and Buildings, Vol. 43, 2011, 1123-1138.