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Orginal Article

The influence of sunspaces on the heating demand in living spaces – comparison of calculation methods according to ISO 13790

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Abstract: The calculation method presented in ISO 13790 was developed during the research project PASSYS. It aimed to work out the way of estimating energy demand while taking into account different passive solar systems. The standard includes two calculation methods for sunspaces – a full and simplified method. They differ in terms of basic assumptions and the treatment of solar gains in the sunspace and conditioned rooms. There are some doubts about the interpretation of equations presented in the standard, especially when it comes to modelling the solar radiation distribution within the solar space. The paper presents a discussion on the basic hypotheses applied in full and simplified methods, together with the author's suggestions regarding modifications to the ISO 13790 calculation methods. The modified methods allowed to satisfactorily predict the functioning of the exemplary sunspaces with a smaller area of glazed partitions and higher radiation absorptivity of the casing, that is spaces similar in terms of solar radiation utilisation to traditional living spaces. The phenomena typical for sunspaces with a high degree of glazing, such as the retransmission of reflected radiation, were not sufficiently taken into account in the calculation methods of the standard.

Keywords: passive sunspace systems, heating demand, ISO 13790, dynamic simulations

1. Introduction

The current version of the ISO 13790 [1] standard was accepted by The European Committee for Standardization in 2008, and its Polish version was approved one year later as PN-EN ISO 13790 standard "Energy performance of buildings. Calculation of energy consumption for heating and cooling". Although the policy regarding technical conditions that the buildings and their location should have [2] does not include the Polish version of the standard, the current methodology for preparing energy performance certificates for buildings [3] is based on it. The calculation method was developed during the PASSYS research project [4], aiming to work out a way of estimating the energy demand taking into account the influence of passive systems. The ISO 13790 norm was replaced by ISO 52016-1 [5] in 2017, also presenting calculation procedures for sunspaces. However, this method requires information about the direct and diffuse components of solar radiation. It may restrict its use in Poland because climatic data included in publicly available Typical Meteorological Years contain only total solar radiation incident on planes with different slopes.

Quasi-stationary methods of the standard [1] are based on the hypothesis of constant heat flow in building partitions. Calculations are performed by averaging climatic parameters for quite long periods (e.g. one month or the entire heating season). Phenomena related to the dynamic behaviour of the building, such as the accumulation and release of heat, are taken into account indirectly through the introduction of a heat gain utilization factor.

Appendix E of the standard [1] contains two calculation methods for non-conditioned sunspaces – a full and a simplified one, differing in fundamental concepts and the way of taking into account solar gains in the sunspace and the adjacent heated rooms. Equations included in the standard are formulated in a quite generalised way, and the interpretation of calculation methods raises certain doubts, especially in the area of modelling the distribution of solar radiation in the sunspace. These problems were discussed in the subject literature many times [6], [7], however, a comprehensive solution has yet to be found.

This article presents the author's suggestions for modifying both methods, as well as correcting the discrepancies of calculation algorithms. Results obtained with the use of the modified full and simplified methods of the quasi-steady state were compared with the results of more accurate dynamic simulations with an hourly step, which allowed to determine the recommended scope of the use of each method.

2. ISO 13790 methods

Heating demand in a monthly, quasi-stationary method is set out as in Eq. 1:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{H,gn} \tag{1}$$

where: $Q_{\mathrm{H,nd}}$ – energy demand for heating during the time step [MJ], $Q_{\mathrm{H,ht}}$ – total heat transfer, including heat losses through building partitions, and heat losses for heating ventilation air [MJ], $Q_{\mathrm{H,gn}}$ – total heat gains, including internal gains and gains from solar radiation [MJ], $\eta_{\mathrm{H,gn}}$ – gain utilisation factor, calculated as in Eqs 2 and 3:

$$\eta_{H,gn} = \frac{1-\gamma_H^{aH}}{1-\gamma_H^{aH+1}} \quad \text{for } \gamma_{\mathrm{H}} > 0 \text{ and } \gamma_{\mathrm{H}} \neq 1 \tag{2}$$

$$\eta_{H,gn} = \frac{a_H}{a_H + 1} \quad \text{for } \gamma_{\mathrm{H}} = 1 \tag{3}$$

γ_{H} – heat gains and losses relation (Eq. 4):

$$\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}} \tag{4}$$

a_{H} – dimensionless numerical parameter (Eq. 5),

$$a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}} \tag{5}$$

$a_{H,0}$ – referential numerical parameter set out on the national level, for a monthly method, $a_{H,0} = 1$ [–], $\tau_{H,0}$ – relative time constant, set out on the national level, for a monthly method, $\tau_{H,0} = 15$ hours, τ – time constant of the building zone characterising the internal thermal inertia [hours], (Eq. 6),

$$\tau = \frac{C_m / 3600}{H_{tr} + H_{ve}}, \tag{6}$$

C_m – the internal thermal volume of the zone [J/K], H_{tr} – total coefficient of heat loss through partitions [W/K], H_{ve} – total coefficient of heat loss through ventilation [W/K].

2.1. Heat gains from the sunspace – full method

The method presented in the standard can be used only for the evaluation of non-conditioned sunspaces, i.e. neither heated nor cooled. In the partition wall between the living space and the sunspace, the presence of permanent openings allowing airflow is excluded. If they do exist, the sunspace should be regarded as a part of conditioned space.

Heat losses through the partition wall between the conditioned space and sunspace are determined with the inclusion of temperature reduction factor $b_{tr} < 1$, which means that heat is transmitted into the environment of higher temperature than external conditions. The temperature reduction factor is determined as follows (Eqs 7 and 8):

$$b_{tr} = \frac{\theta_{int,H} - \theta_s}{\theta_{int,H} - \theta_e} = \frac{H_{se}}{H_{is} + H_{se}} \tag{7}$$

$$\theta_s = \frac{\theta_{int,H} H_{is} + \theta_e H_{se}}{H_{is} + H_{se}} \tag{8}$$

where: $\theta_{int,H}$ – set-point temperature for heating in the living space [ºC], θ_e – average external temperature in the given calculation step [ºC], θ_s – average internal temperature of the sunspace in the given calculation step [ºC], H_{is} – coefficient of heat transfer through the partition between the living space and sunspace [W/K], H_{se} – coefficient of heat transfer through sunspace casing to the outside [W/K].

In the calculation of the coefficient b_{tr} (Eq. 7), it is the heat transfer through the partition and the casing of the sunspace that is taken into account, rather than the influence of solar gains on the sunspace temperature $\theta_{i.}$ It is compensated for by including indirect gains from the sunspace Q_{si} in the energy balance of living spaces.

Heat gains in the building's heated zone obtained through a sunspace Q_{ss} [MJ] are treated as a sum of direct Q_{sd} and indirect Q_{si} gains (Eq. 9):

$$Q_{ss} = Q_{sd} + Q_{si} \tag{9}$$

Direct gains reach the conditioned zone through the partition wall between the sunspace and living space. These gains are derived from multiple transmissions (first through the sunspace glazing, and then through windows or doors in the partition wall) or from radiation absorbed on the partitions' surface. Indirect gains are determined by ISO 13790 as (Eq. 10):

$$Q_{sd} = F_{sh,e}\left(1 - F_{F,e}\right) g_e \left(\left(1 - F_{F,w}\right) g_w A_w + \alpha_p A_p \frac{H_{p,tot}}{H_{p,e}}\right) I_p t \tag{10}$$

where: $F_{sh,e}$ – reduction factor taking into account shading of the sunspace by external obstacles (buildings, trees, hills, elements of the same building) [–] (Eq. 11):

$$F_{sh,e} = F_{hor} F_{ov} F_{fin} \tag{11}$$

F_{hor} – reduction factor from horizon [–], F_{ov} – reduction factor from overhangs [–], F_{fin} – reduction factor from pilasters [–], $F_{F,e}$ – frame area fraction in the sunspace outer glazing area [–], $F_{F,w}$ – frame area fraction in the total area of the window in the partition wall [–], g_e – total solar energy transmittance of the sunspace glazing [–], g_w – total solar energy transmittance of window glazing in the partition wall [–], A_w – window area of the partition wall [m^2], A_p – opaque area of the partition wall [m^2], α_p – absorptivity of the partition wall [–], $H_{p,tot}$ – heat transfer coefficient from the internal environment through the opaque part of the partition wall and the sunspace to the external environment [W/K], $H_{p,e}$ – heat transfer coefficient from the absorbing (external) surface of the partition wall through the sunspace to the external environment [W/K], I_p – solar irradiance of the partition wall in a given calculation step [W/m^2], t – duration of the calculation step [Ms].

Indirect gains are released to the air in sunspace volume through convection, coming from the energy absorbed on the surface of the casing. They are treated as gains derived from non-conditioned space with the temperature reduction factor $(1 - b_{tr})$. They are calculated by summing up the gains from each opaque absorption area in the volume of the sunspace and subtracting the gains transmitted by conduction directly through the partition wall, included in Q_{sd} (Eq. 12):

$$Q_{si} = (1 - b_{tr}) F_{sh,e} (1 - F_{F,e}) g_e \sum_j (I_j \alpha_j A_j) - F_{sh,e} (1 - F_{F,e}) g_e \alpha_p A_p \frac{H_{p,tot}}{H_{p,e}} I_p t \tag{12}$$

where (the remaining nomenclature as above): b_{tr} – temperature reduction factor in the given month [–], I_j – solar irradiance on the "j" opaque interior surface of the sunspace in a given time step [W/m^2], α_j – absorptivity of the "j" opaque interior surface of the sunspace [–], A_j – area of the "j" opaque interior surface of the sunspace [m^2].

2.2. Heat gains from the sunspace – a simplified method

On the national level, the use of the simplified method is allowed, subject to the following modifications:

- in the living space, solar gains from the sunspace are ignored – direct gains "supplied" by opaque and glazed parts of the partition wall or indirect gains from the sunspace casing are not included in the heat balance,
- these gains are included as a substitute, through the use of the temperature reduction factor b_{tr}* while calculating heat transmission from the heated space to the sunspace; it is assumed then that temperature in the sunspace θ_s* is the result of not only inflow and outflow of heat through the casing (as in the full method), but also of solar gains in its volume (Eqs 13 and 14):

$$b_{tr}^* = \frac{\theta_{int,H} - \theta_s^*}{\theta_{int,H} - \theta_e} \neq b_{tr} = \frac{H_{se}}{H_{is} + H_{se}} \tag{13}$$

$$\theta_s^* = \frac{\Phi_u + \theta_{int,H} H_{is} + \theta_e H_{se}}{H_{is} + H_{se}} \tag{14}$$

where: Φ_u – average solar gains in sunspace volume in the calculation step [W].

2.3. Proposed modifications of both methods

The abovementioned methods require some kind of commentary because the equations provided in the standard are not entirely consistent. Firstly, in Eqs 10 and 12 the multiplier $F_{sh,e}(1 - F_{F,e})g_e$ is related to the exterior casing of the sunspace. It should be therefore related to the intensity of the radiation incident on the external casing, not with the intensity of the radiation reaching the partition wall I_p or the interior part of the casing I_j. Secondly, the subtraction of the element regarding direct gains by the casing in the Eq. 12 means that these gains are not at all taken into account in the calculations (it is shortened with the analogical element in the Eq. 10). The subtracted element should also be multiplied by $(1 - b_{tr})$, which can be physically interpreted as diminishing the indirect gains from the partition wall by a part conducted directly to the interior of the living space. Such notation was placed in the draft of the standard, which was made available by CEN in 2007 to submit comments before the final version was published [8]. Thirdly, the multiplier "t" meaning the duration of the calculation step occurs in Eqs 10 and 12 with the component I_p but is omitted in the component I_j. Moreover, the standard does not precise the way the radiation intensity in the sunspace should be specified.

Taking the above into account, it was proposed that the calculation of gains Q_{sd} and i is performed as follows (Eqs 15-19):

$$Q_{sd} = \left(\left(1 - F_{F,w}\right) g_w A_w + \alpha_p A_p \frac{H_{p,tot}}{H_{p,e}} \right) I_p t \tag{15}$$

where (remaining nomenclature is as above):

$$I_p = f_p \frac{1}{A_w + A_p} \sum_k F_{sh,ek} A_{sol,k} I_{sol,k} \tag{16}$$

f_p – the part of solar radiation that is transmitted into the sunspace, incident on the area of the partition wall [–], k – the number of collecting (glazed) surfaces of the external casing of the sunspace facing the given direction, $F_{sh,ek}$ – shading reduction factor of the collecting surface "k" of the sunspace, connected with external obstacles [–], $A_{sol,k}$ – an effective area of the sunspace's collecting surface "k" [m^2] (Eq. 17), $I_{sol,k}$ – the intensity of solar radiation on surface "k" of the sunspace's exterior casing [W/m^2],

$$A_{sol,k} = \left(1 - F_{F,ek}\right) g_{ek} A_{ek} \tag{17}$$

$F_{F,ek}$ – frame area fraction of the sunspace external glazing in the surface "k" [–], g_{ek} – total solar energy transmittance of the sunspace glazing on plane "k" [–], A_{ek} – the area of external glazing of the sunspace in surface "k" [m^2].

$$Q_{si} = \left(1 - b_{tr}\right) \left(\sum_j \left(I_j \alpha_j A_j \right) - \alpha_p A_p \frac{H_{p,tot}}{H_{p,e}} I_p \right) t \tag{18}$$

where (the remaining nomenclature is as above):

$$I_j = f_j \frac{1}{A_j} \sum_k F_{sh,ek} A_{sol,k} I_{sol,k} \tag{19}$$

f_j – the part of solar radiation transmitted into the sunspace, incident on the surface "j" of its internal wall [–].

Suggestions for the calculation of coefficients f_p and f_j were presented in part 4.

3. Dynamic simulations

More complex simulation methods are used to carry out computer calculations. The calculation step estimated here is much shorter than in quasi-stationary methods – it can be, for example, one hour or several minutes. This allows to include heat exchange processes that are dependent on temperature change and exposure to solar radiation as discreet dynamic processes [9], [10]. Dynamic simulations can also be used as validation methods for the less accurate procedures (such as quasi-stationary methods) [11], [12].

Postulates concerning the possibility of using the commonly available simulation tools for modelling sunspace systems formulated based on various research works ([13] – [15], among others) were included synthetically in work [16]. The main requirements that the computer programmes should meet to correctly calculate the solar gains in rooms with a high degree of glazing are as follows:

- the capability of defining the actual geometry of the room as well as glazed elements, considering their dimensions, placement in partitions, and orientation in terms of the direction they are facing,
- detailed analysis of solar radiation reaching the walls of the living space, taking into account the division into direct and diffuse components, and also relevantly accurate modelling of radiation incident onto leaning surfaces (e.g. using the models which are taking into account scattered radiation anisotropy),
- description of the radiation transmitted into the living spaces, considering the actual beam path through glazing; the distribution of direct radiation incident on individual internal partitions with the help of weighted proportionality coefficients (taking into account surface area and optic features of the partition, i.e. the ability to absorb and reflect the radiation) or configuration coefficients used for modelling radiative heat exchange is not sufficient,
- the capability of taking into account radiative heat exchange with the sky.

In this work, calculations are performed with the use of BSim simulation program, which meets the above requirements [17]. The algorithms of the program are based on the control volume method, in which building construction elements and air zones are represented by nodal points of specified physical properties, such as density, conduction, and heat capacity. For each of the air zones, there is a balance equation that takes into account the heat flux flowing through the casing, the transmission of solar radiation by transparent elements, heat fluxes generated by installation systems and carried through ventilation, infiltration, or interzonal mixing of air. Processes that are constant in time are modelled via the division into time steps of finite duration, usually lasting up to 1 hour.

The user's data (e.g. from own measurements) can be inputted into the program as climatic data, or data representing typical meteorological years prepared under the procedures binding in a given country. The essential input parameters include air temperature, the intensity of the direct and diffuse solar radiation, and the relative air humidity. Data regarding the direction and speed of the wind may also be desired, especially if more detailed modelling of the natural exchange of air is being planned. In this research, a Typical Metrological Year for

Warsaw created under the procedures described in [18], available on the https://dane.gov.pl website, was used.

4. The comparison of presented calculation methods

Below there is presented the energy demand obtained for an exemplary living space adjacent to the sunspace, calculated with the help of the proposed modification of algorithms of the full and simplified method. The results were compared with dynamic simulations of the same living space arrangements carried out with assumptions as close as possible to the assumptions of steady-state methods.

The living space has two exterior walls – the wall facing south is adjacent to the sunspace (glazed balcony), and the full, eastern wall is exposed to the external air (Fig. 1). Insulating properties of the partitions are quite high, which corresponds to constructions built after 2014 (Tab. 1). Apart from solar gains in the living space, internal gains on the 3.0 W/m^2 level (according to Appendix G ISO 13790) were assumed. The air exchange in the room equals 0.5 1/h, and the air is supplied from the outside to meet the requirement of the standard [1] of the lack of infiltration between the sunspace and conditioned space.

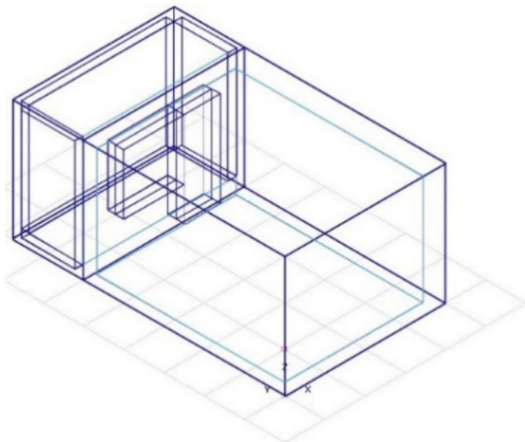

Fig. 1. A diagram of the living space and the sunspace in BSim program

Table 1. Chosen parameters of external partitions

Type of space	Heat transfer coefficient *U* [W/(m²·K)]		Total solar energy transmittance *g* [–]
	Full part	Window joinery	Glazing
Living space	0.24	1.20 – 1.23	0.63
Sunspace	0.50	1.66 – 1.69	0.62

All the balcony walls are glazed (Fig. 1). Two types of glazing were analysed:

- on the entire height of the balcony – variant 1,
- above the height of 1.1 m, with a full casing below – variant 2.

Absorptivity of the interior surfaces of the sunspace was assumed to be equal to 0.2, 0.5, or 0.8. In dynamic simulations, radiation losses caused by the retransmission to the outside were taken into account, which is consistent with the physical characteristics of these phenomena.

In the full method of the ISO 13790, it is assumed that the solar gains in a conditioned space are derived from the radiation absorbed on the surface of full partitions of the sunspace or let through the glazing in the partition wall, making them dependent on the optical properties of the surface. This means that only the radiation dose reaching the given surface before the first reflection is used and the remaining part of the radiation is lost. Phenomena related to multiple reflections in the sunspace are omitted, which causes the underestimation of air temperature in the sunspace.

In the calculations following the simplified method, the retransmission of the radiation on the outside of the sunspace was omitted. Such hypothesis is assumed in the literature of the subject [6] as consistent with the general methodology of the standard and compensating for the fact that the simplified method diminishes the effects of the exposure to solar radiation caused by omitting solar gains transmitted through the glazing of the partition wall of the living space.

In reality, the radiation on individual surfaces of the sunspace is not identical. Because of the sun's movement in the sky, it can be expected that the intensity of the direct radiation will be the highest on the partition wall and the floor. Accurate analytical methods determine these values by tracing the path of the sun's rays ("ray tracing"), as in [14], [19].

The distribution of diffuse solar radiation incident on the given surface can be determined in several ways:

- by assuming that radiation division is proportional to surface absorptivity and size; it is the simplest method described in the literature [6, 14, 15],
- using view factors, determining which part of radiation derived from one surface reaches the other surface, depending on their location and geometry; these factors are available in [20], for example.

In the example, the first method was used by deriving factors f_p and f_j from the general formula (Eq. 21)

$$f = \frac{\alpha \cdot A}{\sum_n (1-\rho_n) \cdot A_n} \tag{21}$$

where: n – the number of the opaque internal surfaces of the sunspace, α – absorptivity of a surface [–], ρ – reflectivity of a surface [–], A – surface area [m^2].

These factors were used in total radiation division, which is the sum of direct and diffuse radiation. It is not quite physically correct, however, such simplification was accepted because ISO 13790 methodology does not assume the division of the radiation into individual components. This assumption understates direct solar gains (through the partition wall) in the living space, and therefore it is on the "safe" side.

When comparing the chosen calculation methods below, basic parameters of the system functioning characteristics were presented: air temperature in the sunspace and energy demand in the living space (Tabs 2 and 3).

Table 2. Air temperature [ºC] in the sunspace during the heating season, SD – dynamic simulations, ISO p – full method, ISO u – simplified method

Air temperature in the sunspace [ºC]												MAPE
Month			IX	X	XI	XII	I	II	III	IV	V	[%]
Variant 1	α = 0.2	SD	17.9	12.5	7.2	5.1	4.2	4.8	10.2	12.2	18.0	
		ISO p	14.1	10.4	6.1	4.4	2.7	3.0	7.3	8.8	13.6	24.6
		ISO u	37.1	24.6	13.3	10.2	12.6	15.0	26.8	34.8	46.7	145.5
	α = 0.5	SD	20.8	14.3	8.1	5.7	5.3	6.0	12.5	14.8	21.5	
		ISO p	14.1	10.4	6.1	4.4	2.7	3.0	7.3	8.8	13.6	36.1
		ISO u	37.1	24.6	13.3	10.2	12.6	15.0	26.8	34.8	46.7	105.2
	α = 0.8	SD	22.2	15.2	8.5	6.0	6.0	6.7	13.7	16.2	23.4	
		ISO p	14.1	10.4	6.1	4.4	2.7	3.0	7.3	8.8	13.6	40.8
		ISO u	37.1	24.6	13.3	10.2	12.6	15.0	26.8	34.8	46.7	89.0
Variant 2	α = 0.2	SD	19.2	13.6	8.4	6.3	5.6	6.2	11.6	13.7	19.3	
		ISO p	14.2	10.4	6.2	4.5	2.8	3.1	7.4	8.9	13.7	34.0
		ISO u	27.3	18.6	10.3	7.8	8.5	10.0	18.5	23.7	32.6	48.8
	α = 0.5	SD	21.1	14.8	9.0	6.7	6.3	7.0	13.2	15.4	21.6	
		ISO p	14.2	10.4	6.2	4.5	2.8	3.1	7.4	8.9	13.7	40.2
		ISO u	27.3	18.6	10.3	7.8	8.5	10.0	18.5	23.7	32.6	34.2
	α = 0.8	SD	22.0	15.3	9.2	6.8	6.6	7.4	13.8	16.1	22.6	
		ISO p	14.2	10.4	6.2	4.5	2.8	3.1	7.4	8.9	13.7	42.0
		ISO u	27.3	18.6	10.3	7.8	8.5	10.0	18.5	23.7	32.6	29.0

Table 3. Heating demand in the living space [kWh] during the heating season. SD – dynamic simulations, ISO p – full method, ISO u – simplified method

Heating demand in the living space [kWh]												Sum	Change to SD*	MAPE
Month			IX	X	XI	XII	I	II	III	IV	V	[kWh]	[%]	[%]
Variant 1	α = 0.2	SD	1.3	62.8	135.4	169.5	177.1	155.5	96.2	66.3	18.2	882.3		
		ISO p	0.4	49.3	139.8	176.3	183.5	154.1	73.4	26.6	0.1	803.4	-8.9	32.2
		ISO u	0.0	35.1	133.0	170.6	173.9	143.4	54.0	1.6	0.0	711.6	-19.4	44.2
	α = 0.5	SD	0.0	36.0	124.5	161.4	163.7	140.7	66.8	36.0	0.4	729.4		
		ISO p	0.0	23.3	125.0	163.9	162.5	130.9	35.9	4.5	0.0	646.1	-11.4	30.9
		ISO u	0.0	35.1	133.0	170.6	173.9	143.4	54.0	1.6	0.0	711.6	-2.4	26.4
	α = 0.8	SD	0.0	22.7	117.7	156.4	155.5	131.6	49.1	24.0	0.0	657.1		
		ISO p	0.0	7.9	110.2	151.6	141.5	107.9	12.3	0.6	0.0	531.9	-19.0	30.4
		ISO u	0.0	35.1	133.0	170.6	173.9	143.4	54.0	1.6	0.0	711.6	8.3	22.3
Variant 2	α = 0.2	SD	0.4	59.5	130.8	164.6	171.4	150.4	92.3	63.9	17.1	850.4		
		ISO p	8.2	78.0	153.7	187.8	203.4	176.0	113.0	73.1	3.7	996.8	17.2	34.8
		ISO u	0.0	66.8	148.2	183.2	195.6	167.4	97.6	53.2	0.0	912.0	7.2	31.6
	α = 0.5	SD	0.0	42.1	124.2	159.8	163.3	141.5	74.2	43.6	6.1	754.7		
		ISO p	1.2	60.2	145.0	180.5	190.9	162.4	88.5	42.8	0.3	871.8	15.5	24.6
		ISO u	0.0	66.8	148.2	183.2	195.6	167.4	97.6	53.2	0.0	912.0	20.8	31.6
	α = 0.8	SD	0.0	35.0	121.1	157.5	159.4	137.3	65.7	36.0	1.1	713.0		
		ISO p	0.2	43.0	136.2	173.2	178.5	148.7	64.5	19.1	0.0	763.4	7.1	23.6
		ISO u	0.0	66.8	148.2	183.2	195.6	167.4	97.6	53.2	0.0	912.0	27.9	41.2

* The change of heating demand in the entire heating season under the ISO method compared to dynamic simulation results.

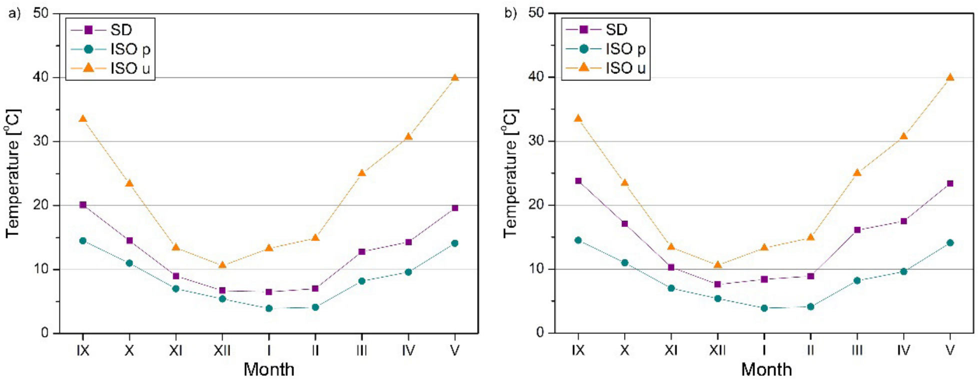

Fig. 2. Air temperature in the sunspace during the heating season: a) variant 1, α = 0.5, b) variant 2, α = 0.5

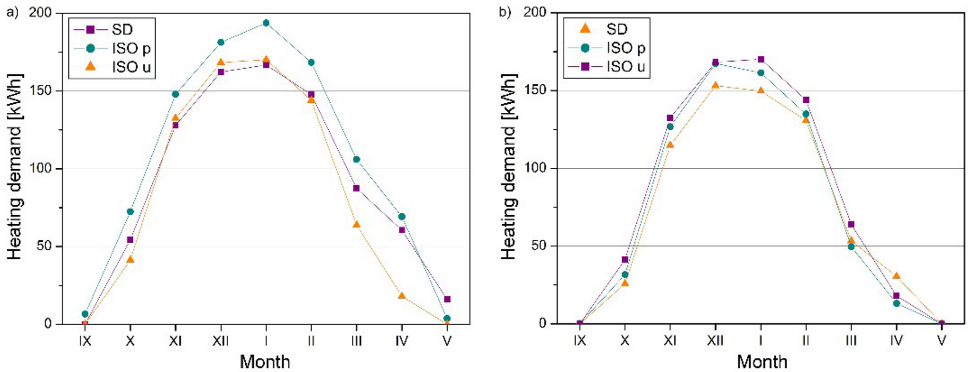

Fig. 3. Heating demand in the living space during the heating season: a) variant 1, α = 0.5, b) variant 2, α = 0.5

In ISO 13790 methods, both in full and simplified versions, the absorptivity of the interior surfaces of the sunspace does not influence its interior temperature. This temperature is determined as dependent only on inflow and outflow of heat through transmission (full method), or as a derivative of solar gains through glazing and thermal features of the construction (simplified method). As a result of these hypotheses, the full method understates, and the simplified method quite significantly overstates interior temperatures, which is especially noticeable in spring and autumn months (Fig. 2). The results of dynamic simulations indicate the increase of interior temperature along with the increase of surface absorbency. The temperature takes intermediate values between the results obtained for the full and simplified method, which can be regarded as a kind of upper and lower limit of the actual inside temperature

The course of average monthly temperatures and the heating demand in the subsequent months of the heating season were compared with the results of dynamic simulations, determining the Mean Absolute Percentage Error MAPE (Eq. 22):

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{P_i - S_i}{S_i}\right| \tag{22}$$

where: n – number of forecast values, P – forecast value (according to ISO 13790), S – accurate value (according to dynamic simulations).

If MAPE > 15% (which was the case in all instances), the forecasts are inaccurate, and they should not be accepted in the analysis of the phenomenon [21]. This does not disqualify the methods presented in the standard, because they are expected to produce a result of the seasonal heating demand that is merely close to the more accurate calculations.

In assumption, quasi-stationary methods ISO 13790 should be "on the safe side", overstating the seasonal heating demand compared with the calculations with the hourly step, whereas the full method (which is more accurate) should produce a lower heating demand. Such regularity is noticeable only in two calculation cases – variant 2, $\alpha = 0.5$, and 0.8 (Fig. 3, Tab. 3). In these instances, the differences between the full method and simulations, are 15.5% and 7.1%, and between simplified method and simulations – 20.8% and 27.9%. This sort of approximation in engineering calculations can be regarded as satisfactory.

The results obtained for the lowest surface absorptivity (in casing variant 2) can raise some doubts in terms of the correct mapping of the psychical processes by both methods of the standard [1], even though differences between them and dynamic simulations alone are, in the worst case, close to 17%. If the absorptivity of the sunspace casing is low, the full ISO method gives the highest heating demand, which is the result of joining smaller indirect solar gains with the incomplete consideration of the buffer effect of the sunspace as a result of lowered inside temperature and indirect gains. In this variant, the simplified ISO method, which overstates the buffer effect of the sunspace, turned out to be closer to dynamic simulations.

Modelling of solar spaces with a high degree of glazing (variant 1) according to the ISO 13790 standard should be regarded as unsatisfactory. The simplified method overstates energy gains when large, glazed surface areas are involved, which is a result of the omitting of radiation retransmission. The significance of this phenomenon diminishes only in the instances of the highest surface absorptivity. In the full method, in turn, omitting the retransmission causes the overstatement of direct and indirect gains, which causes a drop in the heating demand, which is particularly noticeable when the absorptivity increases.

5. Summary

Summing up, ISO 13790 methods (after proposed modifications were taken into account) allowed to satisfactorily predict the functioning of the exemplary sunspace with a smaller area of glazed partitions and higher radiation absorptivity inside of the casing, that is space similar in terms of solar radiation utilisation to traditional living spaces. The phenomena typical for sunspaces with a high degree of glazing, such as the retransmission of reflected radiation, were not sufficiently taken into account in the calculation method of the standard. This effects in bigger discrepancies in results obtained for the sunspace glazed on all surfaces, and for high reflectivity inside the casing.

It is important to remember that the above analyses were carried out for a specific radiation distribution in the sunspace. A better estimation of surface irradiation could affect the accuracy of calculations. However, a detailed analysis of the radiation path goes beyond the area of engineering calculations, which is to be used by the methods contained in ISO 13790.

Among the presented calculation methods, dynamic simulations are a tool that allows taking into account the largest number of factors determining the functioning of a sunspace, i.e. primarily:

- the spatial nature of solar radiation,
- optical properties of the glazing as a function of the angle of incidence,
- radiation retransmission due to reflections in the sunspace,
- varied surface absorptivity,
- ventilation of the sunspace and airflow between the greenhouse and the conditioned room.

Therefore, it is a method with the greatest research potential, if it is consciously used and, if possible, validated in the conditions of the actual operation of the tested objects.

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