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Original Research Article

COMPARISON OF THE CALCULATIONS RESULTS OF HEAT EXCHANGE BETWEEN A SINGLE-FAMILY BUILDING AND THE GROUND OBTAINED WITH THE QUASI-STATIONARY AND 3-D TRANSIENT MODELS. PART 2: INTERMITTENT AND REDUCED HEATING MODE

Anna STASZCZUK[1]
University of Zielona Gora, Zielona Góra, Poland

Abstract

The paper provides comparative results of calculations of heat exchange between ground and typical residential buildings using simplified (quasi-stationary) and more accurate (transient, three-dimensional) methods. Such characteristics as building's geometry, basement hollow and construction of ground touching assemblies were considered including intermittent and reduced heating mode. The calculations with simplified methods were conducted in accordance with currently valid norm: PN-EN ISO 13370:2008. *Thermal performance of buildings. Heat transfer via the ground. Calculation methods.* Comparative estimates concerning transient, 3-D, heat flow were performed with computer software WUFI®plus. The differences of heat exchange obtained using more exact and simplified methods have been specified as a result of the analysis.

Keywords: heat transfer via the ground, quasi-stationary calculations, transient 3-D calculations, intermittent heating mode, reduced heating mode

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[1] Corresponding author: University of Zielona Góra, Faculty of Civil and Environmental Engineering, Z. Szafrana st 1, 65-516 Zielona Góra, Poland, e-mail: a.staszczuk@ib.uz.zgora.pl, tel.+4868328 4784

1. INTRODUCTION

The heat flow process in the ground is generally transient, three-dimensional and boundary conditions are very complicated [1], [2], [6].

The main assumptions of recent methods up to the current standard [7] and their derivatives [8], [9] regarding heat exchange between a building and the ground are based on quasi-stationary method, presented in Part I of this article [12]. This method assumes harmonic boundary conditions and typical mean year pattern of outer air for European location can well be approximated by sine curve. If the real conditions, however, are not compatible with this assumption, calculations results may become not accurate and not adequate to heat flow between building and ground.

Previously not heated cellars are often adapted nowadays in Poland to variety of venues (shop, café, office or even residential). Since these rooms, after conversion, are in general not heated continuously then some approximation can be made when calculating energy use for heating using standard PN-EN ISO 13790:2009 [10] and heat loss via the ground according to PN-EN ISO 13370:2008 [9]. Similarly in the case of longer break in heating e.g. winter holiday.

In this paper the impact of two cases of heating mode: intermittent heating (cut off 10 p.m - 6 a.m) and reduced heating (assumes constant heating throughout a year and 2 weeks reduced heating in February) was considered to asses the possible error using quasi-stationary calculation methods for heat exchange with the ground, including different scenarios of building's geometry, basement hollow, construction of ground touching assemblies.

2. MATERIAL AND METHODS

2.1. Calculation tools and assumptions

Calculations according to PN-EN ISO 13370:2008 [9] were carried out using Microsoft®Excel®software. For calculations of transient, 3-D, heat flow through the ground the computer program WUFI®plus was used. Detailed assumptions of calculations obtaied with 3-D model of the surrounding ground and building as well as the parameters of statistical climate were presented in [12].

2.2. Cases

Three types of typical ground-floor residential buildings, characterized by different geometry (see Figure 1) were considered.

Observing tendency in the development of the modern single-family housing in Poland, small buildings about the footprints floor which area not exceeding 100 m^2 were chosen for the analysis. The shapes (footprints) and main dimensions are shown in Figure 1.

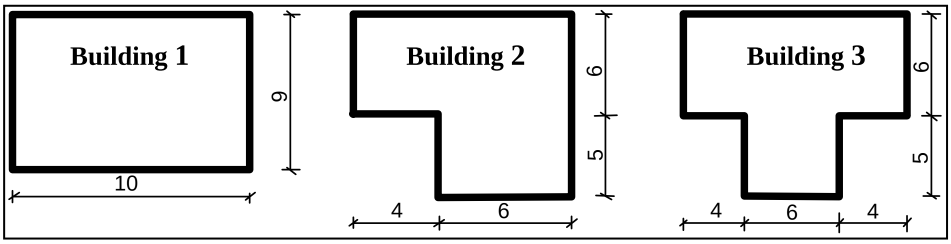

Fig. 1. Shapes of analyzed buildings

For each building three cases of basement hollow were considered:

- slab on ground (z = 0 m),
- basement (height 2,2 m, z = 1.0 m),
- basement (height 2,2 m, z = 1.5 m),

where “z” means the depth of cellar floor below ground level.

In addition every case includes two scenarios of earth-contact construction:

a. thermally not insulated,
b. thermally insulated (slab on ground insulated with 10 cm EPS, edge vertical insulation 10 cm EPS - 0.7 m depth, floor and basement walls thermally insulated with 5 cm EPS).

3. NUMERICAL ANALYSIS

3.1. Building and ground characteristics

In the Tables 1 and 2 the geometry and assembly construction of exemplary buildings are presented. The same assemblies and material data were assumed in each of the presented buildings.

According to PN-EN ISO 13370 standard recommendation thermal conductivity for ground λ=2.0 $W \cdot m^{-1} \cdot K^{-1}$ and thermal capacity $\rho \cdot c$=2.0·10^6 $J \cdot m^{-3} \cdot K^{-1}$ were used.

Table 1. Building geometry

Specification	Building 1 Rectangular	Building 2 „L-shaped”	Building 3 „T-shaped”
Floor area [m^2]	74	74	94
Net volume [m^3]:			
- building with floor on ground	252	252	319
- building with basement	447	447	605
Floor perimeter [m]	35	39	47
Characteristic dimension* B’	4.32	3.79	4.03
A/V coefficient:			
- building with floor on ground	1.14	1.18	1.15
- building with basement	0.80	0.84	0.82

*B’= floor area/(0,5·permieter lenght)

Table 2. Assemblies and materials

Building component	Material	U [W·m^{-2}· K^{-1}]
Outer wall	29 cm MAX hollow ceramic bricks + 10 cm EPS	0.29
Floor on ground	Concrete 10 cm	4.30
Foundation	Concrete 29 cm	3.13
Floor on ground thermally insulated	Concrete 10 cm + 10 cm EPS + Concrete 5 cm	0.36
	Concrete 29 cm + 10 cm EPS	0.35
Foundation thermally insulated		
Basement floor on ground	Concrete 10 cm	4.30
Basement floor on ground thermally insulated	Concrete 10 cm + 5 cm EPS + Concrete 5 cm	0.66

3.2. Calculations

Transient heat flow calculations were made for 2 years period. First year of simulation was used only to define proper initial condition (temperature distribution) in the ground and was not taken into account.

Hourly pattern of both internal and external air temperature obtained with WUFI®plus (transient 3-D) calculations was used to define mean year value and amplitude (sine curve for PN-EN ISO 13370 calculation) for every building type and case.

Due to summer overheating inner air temperature has no zero amplitude, even by constant heating throughout a year. Sometimes, however, inner air fluctuations are disregarded when calculating according to the PN-EN ISO 13370 standard. Therefore two kinds of comparative calculation were made, with and without considering the variation of monthly mean internal temperature, presented below.

4. RESULTS

To assess influence of the chosen factors on the calculations accuracy of heat exchange between the building and the ground, transient heat flow Φ [kW] obtained with WUFI®plus (transient 3-D method) was monthly averaged and compared with the results obtained according to the PN-EN ISO 13370 standard (quasi-stationary method) as well as heat exchange between the building and the ground *Q* [kWh] for the whole heating season (regarding 7 months).

In this paper as a results of analysis, relatives (percentage value of difference) between quasi-stationary and transient 3-D methods for particular month and for the whole heating season were presented. Percentage value of the difference between presented methods was calculated as:

$$\Delta\Phi_{1-3} = \frac{\Phi_1 - \Phi_3}{\Phi_3}, \ \Delta Q_{1-3} = \frac{Q_1 - Q_3}{Q_3}$$

and

$$\Delta\Phi_{2-3} = \frac{\Phi_2 - \Phi_3}{\Phi_3}, \ \Delta Q_{2-3} = \frac{Q_2 - Q_3}{Q_3}$$

where:

Φ_1, Q_1 - heat flow, heat exchange according to quasi-stationary method without variation of monthly mean internal air temperature, internal air temperature assumed constant [kWh],

Φ_2, Q_2 - heat flow, heat exchange according to quasi-stationary method with variation of monthly mean internal temperature adopted from WUFI®plus calculations [kWh],

Φ_3, Q_3 - heat flow, heat exchange according to transient 3-D method [kWh],

$\Delta\Phi_{1-3}$, ΔQ_{1-3} - relative between quasi-stationary (Q_1) and transient 3-D (Q_3) methods [%],

$\Delta\Phi_{2-3}$, ΔQ_{2-3} - relative between quasi-stationary (Q_2) and transient 3-D (Q_3) methods [%],

taking that into account transient 3-D method is more accurate.

Graphical interpretation of obtained results in statistical approach was presented in box-plots.

The relatives $\Delta\Phi_{1-3}$ and $\Delta\Phi_{2-3}$ between presented methods for Building 1 (Rectangular) for particular month obtained using PN-EN ISO 13370 method in comparison to results from WUFI®plus are figured out in Tables 3-4. Overall results for all building types are presented in Figures 1-2.

Table 3. Relatives between quasi-stationary and transient 3-D methods. Building 1. Intermittent heating mode

Month	Relatives between quasi-stationary and transient 3-D methods [%]					
	$\Delta\Phi_{1-3}$, ΔQ_{1-3} [%]			$\Delta\Phi_{2-3}$, ΔQ_{2-3} [%]		
	z = 0m	z = 1m	z =1.5m	z = 0m	z = 1m	z =1.5m
INTERMITTENT HEATING MODE - SCENARIO A						
1	43.53	20.61	14.53	28.10	6.38	0.16
2	39.60	18.64	12.64	26.43	6.09	-0.04
3	36.28	23.37	17.06	26.32	12.47	6.04
4	22.99	20.11	13.67	17.77	12.23	5.72
5	13.30	23.27	16.87	13.41	18.78	12.29
6	-8.64	14.68	9.03	-3.03	14.39	8.69
7	-34.90	-5.92	-10.14	-26.52	-3.61	-7.85
8	-37.68	-6.57	-11.21	-28.95	-5.21	-9.90
9	-2.44	6.56	0.54	2.09	2.30	-3.81
10	20.77	13.05	7.81	14.64	2.60	-2.86
11	21.96	7.02	1.44	10.08	-5.60	-11.32
12	33.19	12.67	6.96	18.42	-1.24	-7.10
INTERMITTENT HEATING MODE - SCENARIO B						
1	23.11	12.65	7.28	0.10	-0.87	-5.18
2	32.82	10.08	4.86	13.57	-1.65	-6.01
3	31.79	11.19	6.41	20.20	2.14	-2.16
4	21.51	5.89	1.89	19.28	1.16	-2.94
5	5.94	3.95	1.39	12.93	4.42	1.03
6	-19.80	-8.00	-7.88	-6.20	-2.15	-3.45
7	-42.61	-24.71	-23.00	-26.01	-16.12	-16.01
8	-53.36	-22.51	-20.80	-35.68	-13.75	-13.85
9	-43.90	-4.08	-6.54	-27.04	0.06	-4.14
10	-32.54	5.74	2.19	-29.78	1.35	-2.76
11	-14.78	3.16	-1.64	-27.21	-6.75	-11.09
12	7.13	7.51	2.30	-14.32	-5.27	-9.53

Table 4. Relatives between quasi-stationary and transient 3-D methods. Building 1. Reduced heating mode

Month	Relatives between quasi-stationary and transient 3-D methods [%]					
	$\Delta\Phi_{1-3}$, ΔQ_{1-3} [%]			$\Delta\Phi_{2-3}$, ΔQ_{2-3} [%]		
	z = 0m	z = 1m	z =1.5m	z = 0m	z = 1m	z =1.5m
REDUCED HEATING MODE - SCENARIO A						
1	25.75	5.29	-0.56	4.88	-14.16	-20.98
2	151.47	102.64	100.41	115.76	70.13	64.69
3	10.93	1.69	-4.32	0.48	-9.60	-16.14
4	14.27	10.38	3.85	12.08	6.48	-0.24
5	7.57	16.69	9.97	17.71	25.21	18.87

6	-10.41	10.15	4.22	12.96	33.99	29.28
7	-35.24	-8.56	-13.08	-5.23	24.50	21.90
8	-38.05	-10.53	-15.40	-4.85	24.21	21.21
9	-11.99	-3.45	-9.30	15.28	17.64	12.75
10	1.85	-4.11	-9.13	5.84	-3.50	-8.52
11	7.99	-5.72	-11.06	-3.51	-17.43	-23.37
12	17.90	-0.81	-6.27	-1.04	-18.50	-24.85
REDUCED HEATING MODE - SCENARIO B						
1	7.40	1.04	-3.46	-30.22	-20.64	-24.38
2	175.29	68.06	58.31	101.05	36.72	28.43
3	14.37	-1.98	-5.77	-3.47	-14.18	-17.74
4	12.85	-1.37	-4.86	11.18	-4.18	-7.88
5	1.55	-1.48	-3.62	17.71	8.87	6.01
6	-20.74	-10.87	-10.91	9.01	13.32	12.45
7	-42.84	-25.88	-24.46	-6.85	5.51	6.36
8	-53.34	-24.00	-22.94	-14.59	9.60	9.67
9	-47.44	-10.90	-12.77	-11.32	12.69	9.16
10	-40.43	-6.03	-8.83	-31.22	-3.05	-6.51
11	-25.06	-6.78	-10.71	-43.30	-18.66	-22.36
12	-6.70	-3.07	-7.35	-41.09	-22.56	-26.19

As expected. adjustment of the internal temperature provided better results. i.e. $\Delta\Phi_{2-3}$ and ΔQ_{2-3} deviations are generally smaller than $\Delta\Phi_{1-3}$ and ΔQ_{1-3} as opposed to continous heating mode [12]. It means that in the cases of intermittent and reduced heating internal temperature can not be set constant because of effect on the heat loss to the ground.

In case of both intermittent the relatives between quasi-stationary and transient 3-D methods are similar to continous heating [12] even though in the case of intermittent heating variations of inner temperature and heat flow are much higher. Therefore. the biggest difference between transient and simplified calculation for particular months is by thermally not insulated slab on ground and for rectangular building shape vary up to 28% (Table 3). In case of thermally insulated slab on ground. both thermally uninsulated and insulated basement during intermittent heating the results are more accurate.

Periods with reduced heating for longer time (February) mostly differ from “sin curve” assumption of PN-EN ISO 13370. Thus it is reflected in differences (Table 4). The maximal difference referred to insulated and uninsulated slab on ground exceeds 100%. Increase of basement hollow and thermal insulation of assemblies touching ground reduce this differences to 28%.

In all cases higher differences occur in summer. when the influence on energy for heating is not so significant.

In Figures 1-2 differences in heat exchange calculations $\Delta Q_{2\text{-}3}$ (indicated as ΔQ) in heating season and their statistical interpretation (*box-plots*) for all building types. scenarios and basement hollow are presented.

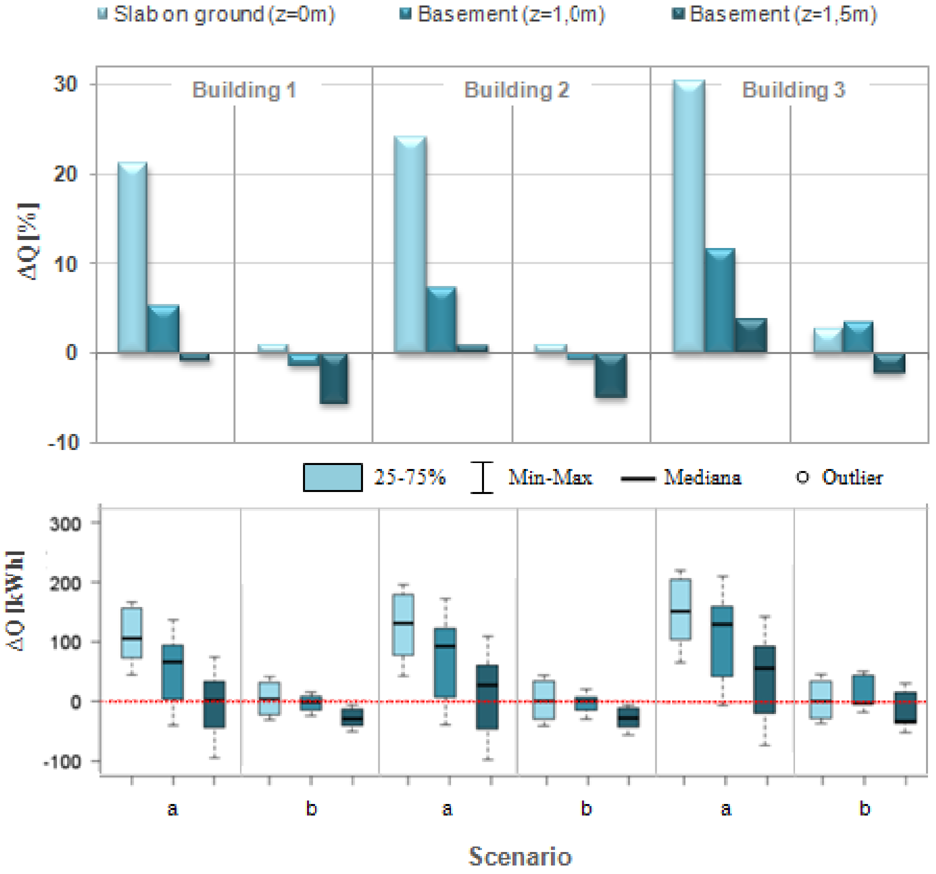

Fig. 1. Differences in heat exchange calculations ΔQ [%] in heating season and their statistical interpretation (*box-plots*). INTERMITTENT HEATING MODE

The most comparable results. similar to Hagentoft assumptions can be noticed in the case of intermittent heating mode. only if amplitude of inner air temperature. due to intermittent heating. isn't ignored. Differences ΔQ in heating season for thermally insulated slab on ground and both uninsulated and insulated basement are generally not greater than ±10%. except for uninsulated slab on ground in the all considered types of buildings and uninsulated basement (z=1m) in "T-shaped" building. Statistical analysis confirms above considerations (see box-plots in Figure 1). Distribution of differences between analyzed methods (quasi-stationary and transient) is approximately zero in the case of thermally insulated assemblies touching ground. similar to continous heating mode [12].

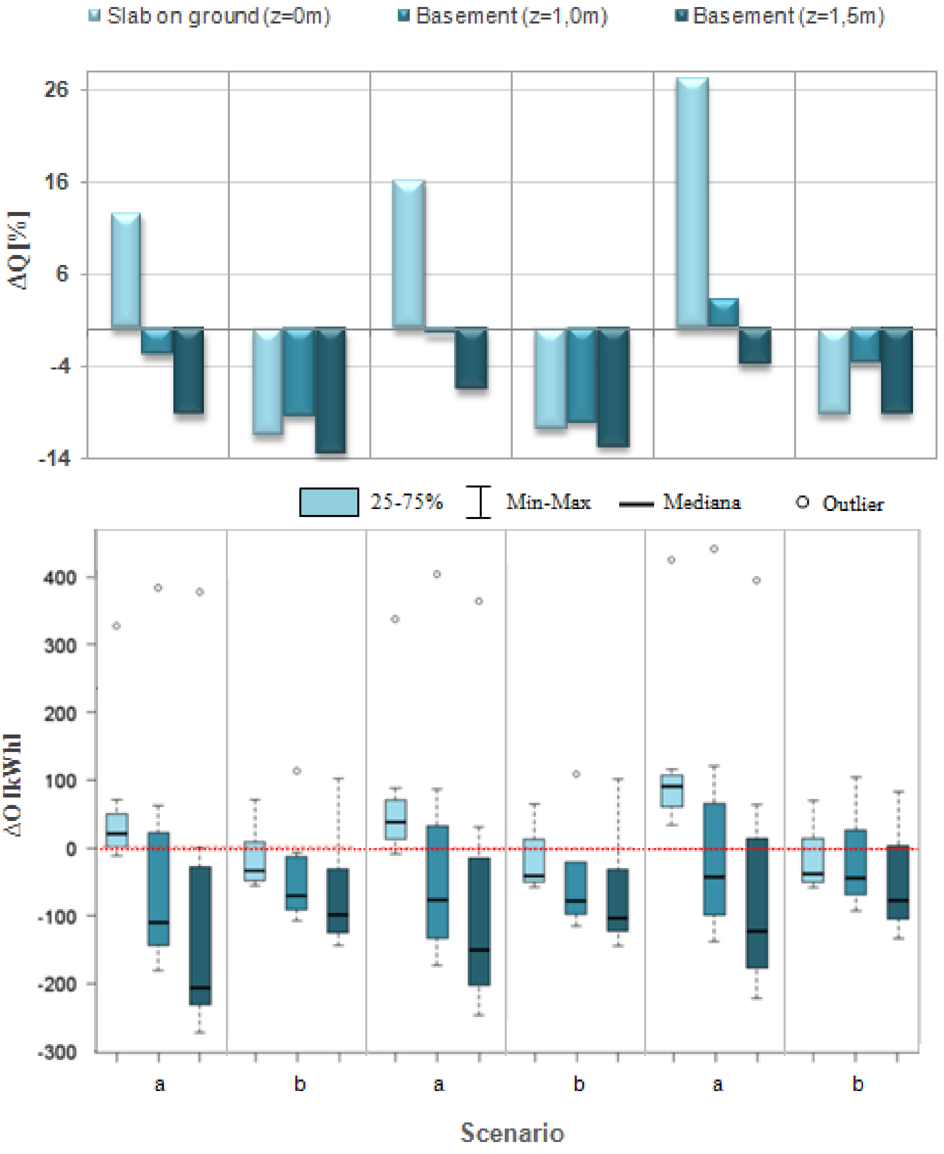

Fig. 2. Differences in heat exchange calculations ΔQ [%] in heating season and their statistical interpretation (*box-plots*). REDUCED HEATING MODE

Slightly higher deviations can be noticed in the case of reduced heating mode. although differences ΔQ for thermally insulated slab on ground and both thermally not insulated and insulated basement doesn't exceed ±10% in all considered types of building. except thermally uninsulated slab on ground as well as thermally insulated basement (z=1.5m) in Buildings 1 and 2. Longer heating break in February caused higher deviations in distribution of differences between analyzed calculations methods in comparsion to the case of intermittent heating e.g. occuring of outliers (see box-plots in Figure 2).

5. CONCLUSIONS

Two cases of heating modes: intermittent and reduced was considered in this paper to asses the possible error using quasi-stationary calculation methods for heat exchange with the ground. including different scenarios of building's geometry. basement hollow. construction of ground touching assemblies.

All factors considered in the paper have some (less or more) influence on calculation accuracy of quasi-stationary method including presented heating modes.

The highest differences in the calculation results independent of building type occur in the case of uninsulated slab on ground. Thermal insulation of assemblies touching ground and building hollow caused incresase of the quasi-stationary calculation accuracy. although in the case of reduced heating mode higher underestimating of calculation results comparing to the other cases. It is to be supposed that thermal insulation of slab on ground. foundations. basement floor and walls. and building hollow decrease influence of boundary conditions on heat exchange between building and the ground. reduce both 2-D heat flow at the floor perimeter and 3-D heat flow in the corners and decreases the impact of building's geometry on calculation accuracy.

Generally. calculations according to Hagentoft assumptions in two considered cases of heating mode may be useful in enginerring practice. but only if internal boundary condition i.e. yearly inner air course will be adjusted appropriately. However calculation can be made using simplified method in case of intermittent heating provided. that reduction time is less then 24 hours. Quasi-stationary methods aren't useful to calculations heat exchange between the building and the ground for a month with longer heating break. Some additional factors should be applied in the standard to correct the result.

Appropriate method and calculation tools for assessment of heat loss to the ground come into prominence in energy saving and proecological building design according to sustainable development paradigm. Therefore updating and developing calculation methods of heat exchange between the building and the ground [3, 4, 5, 11] remains a very important and contemporary problem.

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PORÓWNANIE WYNIKÓW OBLICZEŃ WYMIANY CIEPŁA JEDNORODZINNEGO BUDYNKU MIESZKALNEGO Z GRUNTEM UZYSKANYCH ZA POMOCĄ METODY QUASI-STACJONARNEJ ORAZ MODELU NIESTACJONARNEGO TRÓJWYMIAROWEGO. CZĘŚĆ II: OGRZEWANIE PRZERYWANE I PRZERWA W OGRZEWANIU

Streszczenie

W artykule przedstawiono porównanie wyników obliczeń wymiany ciepła typowego budynku mieszkalnego z gruntem z zastosowaniem metody quasi-stacjonarnej i metody uwzględniającej w pełni niestacjonarny. trójwymiarowy przepływ ciepła w gruncie. Celem analizy obliczeniowej było określenie wpływu wybranych czynników takich jak: geometria budynku. poziom zagłębienia budynku w gruncie oraz konstrukcja przegród stykających się z gruntem na dokładność obliczeń wymiany ciepła za pomocą metod quasi-stacjonarnych uwzględniając dwa tryby ogrzewania: ogrzewanie przerywane i przerwę w ogrzewaniu. Obliczenia z zastosowaniem metody uproszczonej przeprowadzono zgodnie z aktualnie obowiązującą normą: PN-EN ISO 13370:2008. W celu przeprowadzenia szczegółowych obliczeń numerycznych opracowano model wymiany ciepła budynku z termicznym sprzężeniem z gruntem. oparty na metodzie bilansów elementarnych i stanowiący integralną część programu komputerowego WUFI®plus. Rezultatem analizy porównawczej są różnice w wymianie ciepła określonej z zastosowaniem obu metod obliczeniowych.

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