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THERMAL PERFORMANCE OF SLAB ON GRADE WITH FLOOR HEATING IN A PASSIVE HOUSE

ZJAWISKA CIEPLNE W PŁYCIE NA GRUNCIE Z OGRZEWANIEM PODŁOGOWYM W DOMU PASYWNYM

A b s t r a c t

Extensive experimental investigations have been carried out in the passive house in Boruszowice for several years. The building foundation interface consists of a 25 cm reinforced concrete slab situated on a 40 cm layer of Styrofoam. The analysis of experimental results as well as theoretical calculations made it possible to determine the thermal performance of the applied slab on grade with floor heating during the whole yea.

Keywords: *slab on grade*, *floor heating*, *thermal performance*, *passive house*

S t r e s z c z e n i e

W ciągu kilku ostatnich lat w budynku pasywnym w Boruszowicach przeprowadzono obszerne badania eksperymentalne. Fundament przedmiotowego budynku stanowi płyta żelbetowa o grubości 25 cm położona na 40 cm warstwie styropianu utwardzonego. Analiza wyników pomiarowych oraz obliczenia teoretyczne pozwoliły określić zjawiska cieplne występujące w płycie z ogrzewaniem podłogowym w skali całego roku.

Słowa kluczowe: *płyta na gruncie*, *ogrzewanie podłogowe*, *zjawiska cieplne*, *dom pasywny*

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1. Introduction

The detached, single-family house in Boruszowice was constructed in 2010 using pre-fabricated, lightweight technology. It has a floor area of approximately 120 m^2 located on two stories and approximately 311 m^3 of internal volume. The length of the building is 10.58 m, its width is 7.77 m and its height is about 8 m. After the verification process, the building was granted the passive house standard certificate by the end of 2011. Since April 2011, it has been inhabited by a four-person family (parents + 2 children). Starting from the 1st May 2011, extensive experimental investigations are being carried out in the building. Passive, hygrothermal performance of outer partitions as well as energy use in active systems is continuously monitored [1, 2].

The foundation interface of the building consists of a 25 cm reinforced concrete slab situated on a 40 cm layer of Styrofoam. This reduces thermal-bridge effect while enabling even mechanical load distribution from load-bearing walls. Integration of floor heating with the concrete slab makes thermal insulation crucial for heat losses to the ground. Floor heating pipes were put at the bottom of the slab for better use of heat accumulation. Fig. 1 shows the passive house in Boruszowice and slab on grade during construction.

Fig. 1. Passive house in Boruszowice (left) and slab on grade during construction (right)

The reinforced concrete slab has the largest heat capacity in the building. This property is very important in terms of better use of internal and external heat gains and mitigation of air temperature fluctuation in the building.

The presented structural and functional solution of foundation and flooring has not yet been tested in Poland under real operating conditions. Measurement results and overall calculations were used to determine thermal performance of the applied slab on grade with floor heating during the whole year.

2. Experimental investigation

To get a full picture of the development of thermal conditions in the floor area, the temperature was measured at 21 points located along 7 vertical lines. One vertical is located in the middle of the building and two each at the outer edge of two rooms and the outer corner (Fig. 2). Floor structure with location of measurements points is presented in Fig. 3.

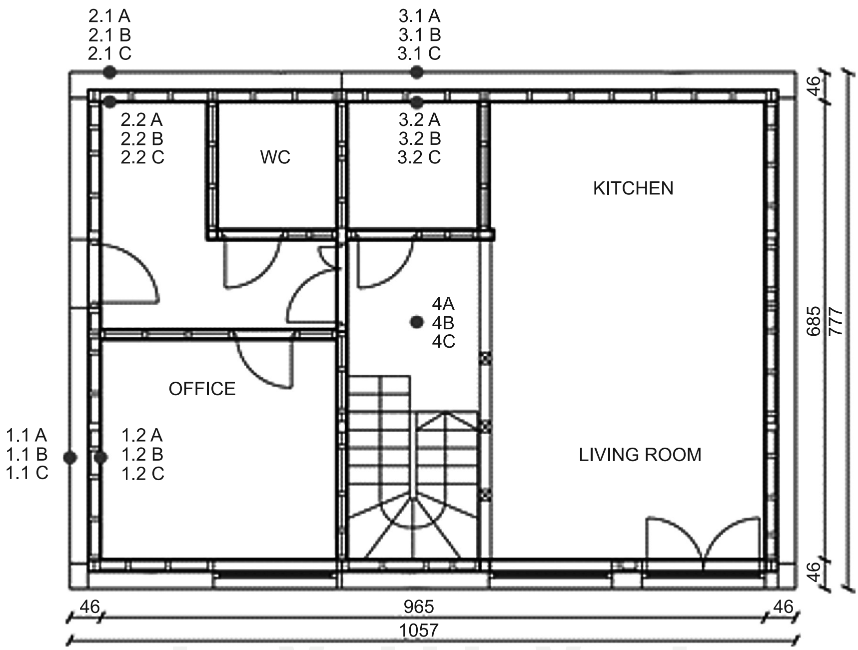

Fig. 2. Location of temperature measurement sections (dimensions in cm)

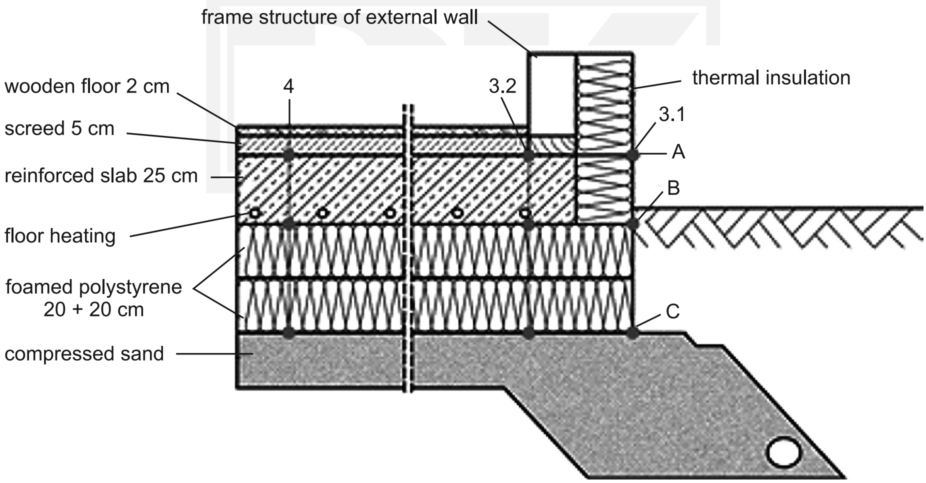

Fig. 3. Vertical section of foundation interface with measurement points

The PT100 sensors (TOP1068 class) with an accuracy of 0.1°C were used (together 21 measurement points).

The energy demand for space-heating of the building and domestic hot water is covered by a ground source heat pump. The heat is stored in a 500-litre water storage tank, from which hot water is supplied to the air heater and the floor heating system (Fig. 4).

Both supply and return water temperature as well as water flow for floor heating were measured. TP100 sensors for temperature and JS90-06_NC flow meter (accuracy above 95%) for water flow were used. The results allow for calculating the energy provided to the slab by the heating system.

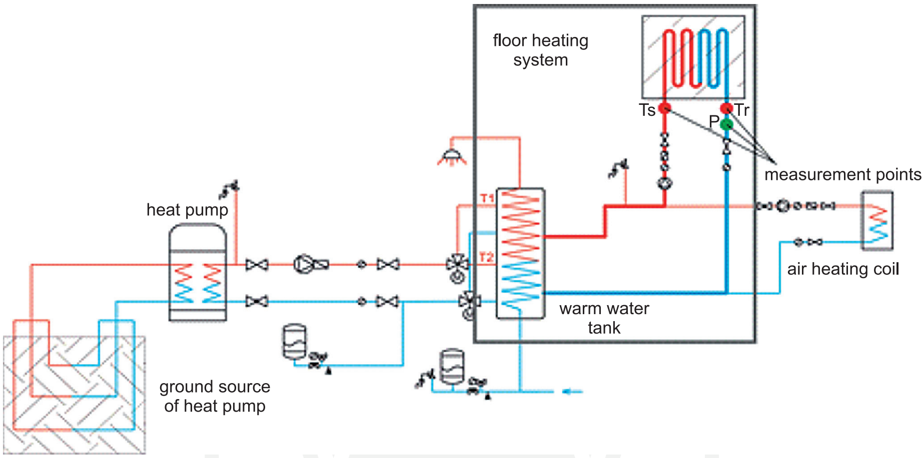

Fig. 4. Heating system with measurement points of supply (Ts), return temperature (Tr) and water flow (P) for floor heating

In order to maintain a continuous record of the outer climate, a local meteorological station was built next to the building. Outdoor air temperature and relative humidity, solar radiation, wind velocity and direction were also measured.

All measurements were carried out with the time step of 1 minute. Short time step is necessary for the monitoring of energy flow into floor heating. For temperature measurements, 1h would have been enough, but applied measurement techniques required the same time step for all channels.

At present, the results for more than two years are available. However, due to gap-free data set (no breaks caused by failure of measurement system), an analysis was carried out for the year 2012. Fig. 5 presents measurement results for outer and inner air temperature as well as temperature at the top of the concrete slab at the edge (section 3.2) and in the center of the building (section 4), for 90 days (from 1st January to 30th March 2012).

The winter of 2012 started with mild outer temperature gradually dropping at the end of January. The first half of February was very cold with temperatures reaching almost –30°C. Floor heating operated intermittently till the end of February. Based on the measured supply and return temperature as well as water flow, heat supply into the slab was calculated (Fig. 5).

The indoor air temperature oscillated mostly between 20°C and 22°C (to a maximum of 24°C during sunny days). The temperature at the slab top was about 20°C with small

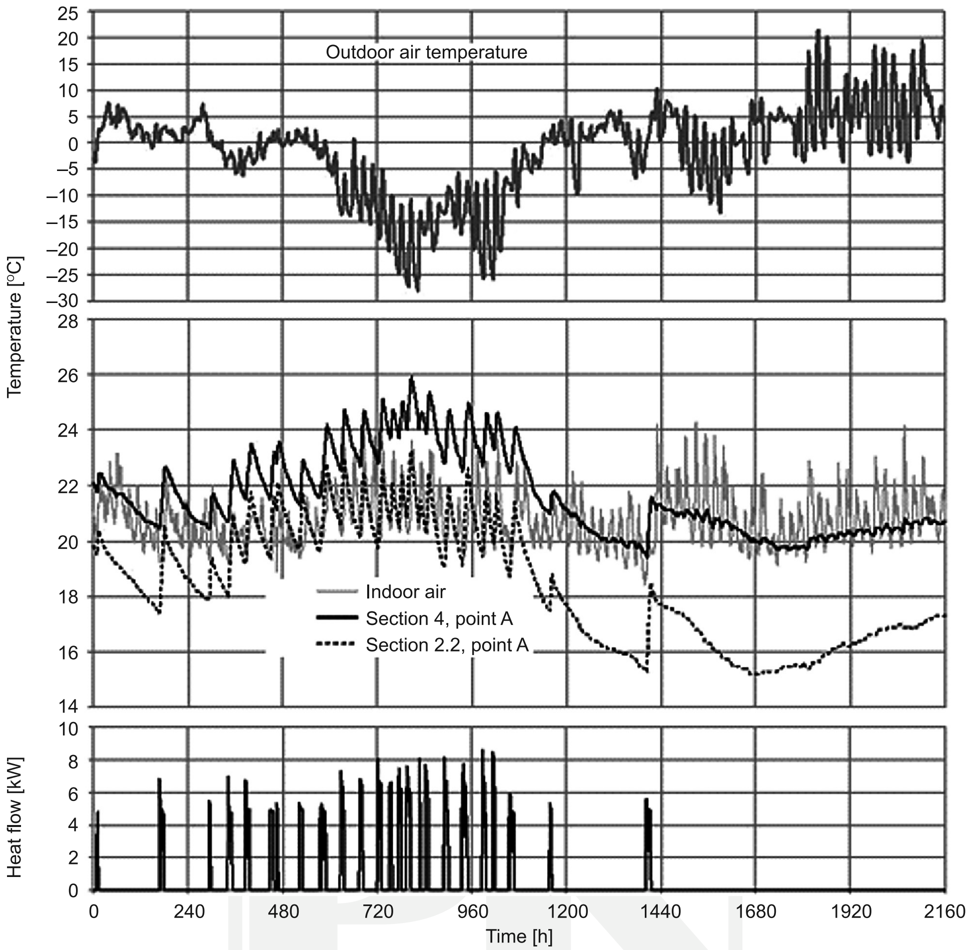

Fig. 5. Pattern of outdoor (top diagram) and indoor temperature, temperature measured at points 4A, 2.2A (lower diagram), and heat supply to floor, 1st Jan.–30th March, 2012 (measurement points location shown on Figs. 2, 3)

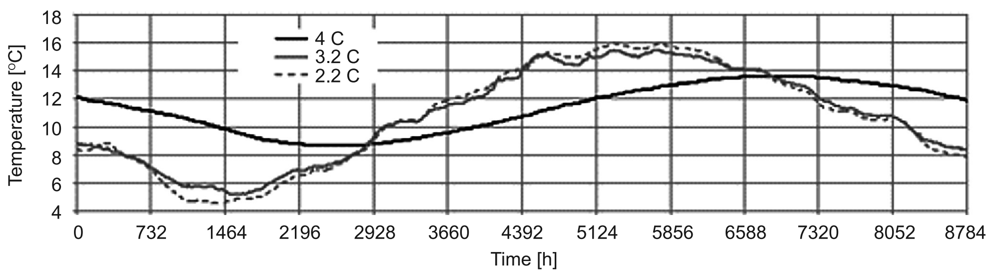

Fig. 6. Measured, yearly temperature pattern at the bottom of thermal insulation (measurement points location shown on Figs. 2, 3)

changes following the indoor temperature. The temperature at the corner (section 2.2) was lower than in the middle of the building by about 3–4°C. No significant temperature difference between the slab top and bottom (points A and B, see Fig. 3) was observed during the measurement period.

Over the course of the heating period, slab temperature rose to 2–3°C above indoor temperature. Despite intermittent heating, floor temperature also remained higher than air temperature during the cut off time. Due to a relatively high heat capacity, temperature drop was about 1°C during a 1 day break. Along with floor heating, air heaters were also used during most cold periods.

Measurements below the insulation layer showed a very stable temperature pattern during the whole year (Fig. 6). In the middle of the building, an almost ideal sinusoidal course (mean value 11.3°C, amplitude 5°C) was observed. At the edge and corner, a similar pattern with about 10.5°C mean value and 11°C amplitude occurred.

3. Numerical analysis

Numerical analysis of transient 3D heat flow in the system with measured boundary conditions was carried out using the hygrothermal whole building simulation software WUFI®Plus [3]. To account for 2 and 3 dimensional thermal bridges in thermal coupling with the building, the software was supplemented with the so-called 3D-objects. Transient heat flow is calculated using the finite balance method. The calculation method was recently validated against DIN EN ISO 10211 standard (DIN 2008) and cross-validated with ZUB Argos® software [4, 5]. WUFI®Plus software was also used for calculation of heat exchange between building and ground [6, 7].

The latest software development concentrates on the integration of active systems within a building [8]. This includes wall and underfloor heating. The modelling of integrated heating pipes would require the application of advanced calculation methods, which is still limited by the capability of contemporary PCs. Therefore, simplified methods, possibly not compromising calculation accuracy, are tested and validated.

The applied algorithm does not reflect the exact arrangement of heating pipes in the slab. Instead of modelling liquid flow and heat exchange in the slab, the model assumes a heat source at certain places of assembly. In the case of floor heating, it is the plane of piping. This assumption can only be made by spiral pattern piping arrangements where the heat source can be regarded as even across the horizontal plane (mean flow and return temperature are constant in the nearby pipes. In the analyzed floor, 3 loops with a spiral pattern are used. Material data used for calculation are collated in Table 1.

Based on the assumed calculation model, the calculation of yearly heat flow in the floor and ground was carried out. The measured indoor and outdoor temperature and heat supplied into the system were used as boundary conditions. Results, for section 4, point A, are presented in Fig. 7 (upper diagram). After about 10 days, quite a good match between calculated and measured temperature could be achieved. The impact of the initial conditions (initial temperature assumed 12°C) can be seen in a relatively short time (about 10 days), this is due to high thermal insulation of the slab from the ground. Similar accuracy was obtained for the remaining measurement points.

Table 1

Assumed material data for calculation

Material	Thermal conductivity [W/mK]	Heat capacity [kJ/m³]
Concrete slab and screed	2.0	1887
Floor (panels)	0.6	600
Styrofoam	0.04	22.5
Compressed sand	1.3	1530
Ground	1.6	1600

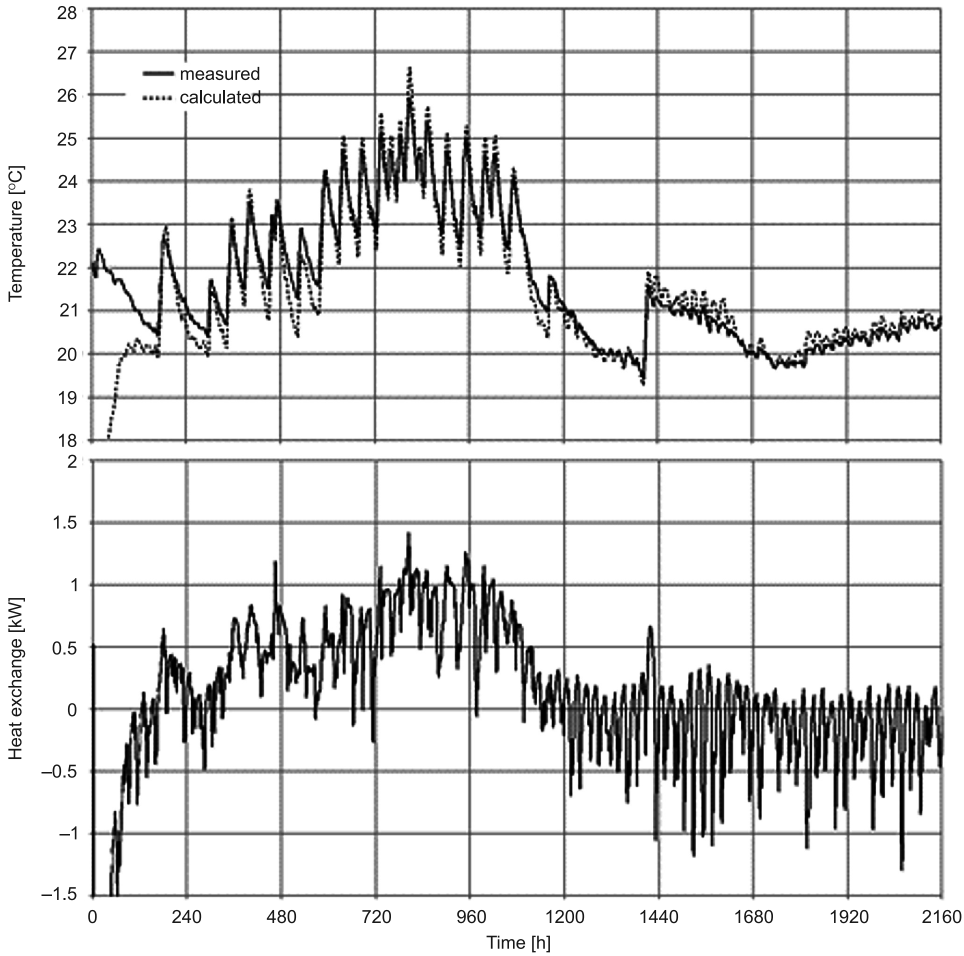

Fig. 7. Measured and calculated temperature pattern at section 4, point A (measurement points location shown on Fig. 2, 3) and total heat exchange between inner air and floor, 1st January–30th March, 2012

Inner air temperature is determined dynamically by heat balance of the analyzed zones. One of the significant factors is heat exchange between inner air and the floor. The results for 90 days are presented in Fig. 7 (lower diagram). As presented, inner diurnal temperature changes of 2–4°C cause more than 1 kW heat exchange in the whole building. This is the contribution of the massive concrete slab to the stabilization of inner air fluctuations. The obtained pattern of heat flux also allows for the assessment of the thermal efficiency of the system. Taking into consideration the time period between 480 and 1000 h (about a 3-week heating period), the energy consumed by floor heating (538 kWh) and the sum of heat gained by inner air from the floor (376 kWh), it could be estimated that efficiency of floor heating was about 70%. For most of the time, outside heating periods, heat loss into the ground was about 250 W (~3 W/m^{2}K).

4. Conclusions

The paper presents results of whole year measurements of a foundation interface in a passive house, including concrete slab with floor heating. Beside valuable, objective information about the thermal performance of the system, the results were used for the validation of a simplified calculation model of floor heating. Overall, calculations supplemented results by heat exchange and led to more general conclusions.

During the measurement time, excluding the heating period, indoor air temperature oscillated between 20°C and 22°C (to a maximum of 24°C). The temperature at the slab top was about 20°C in the middle of the building and lower by 3–4°C in the corners. No significant temperature difference at the slab top and bottom was observed. Below the thermal insulation, the ground temperature remained very stable revealing a sinusoidal pattern.

Diurnal fluctuations of inner air caused heat exchange with floor of about 1 kW for the whole building. For most of the time, heat loss into the ground was about 250 W (~3 W/m^{2}K). The estimated thermal efficiency of floor heating was about 70%. However, this value was obtained under very cold weather conditions.

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