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MEASUREMENTS AND CALCULATIONS OF TEMPERATURE IN THE GROUND AND IN ASSEMBLIES ADJACENT TO AN INTERMITTENTLY HEATED BASEMENT

POMIARY I OBLICZENIA TEMPERATURY W GRUNCIE I PRZEGRODACH W PIWNICY OGRZEWANEJ OKRESOWO

Abstract

Cellars of the main building of the University of Agriculture in Krakow are used as storage areas, laboratories and as classrooms. This article presents the results of many years of temperature measurements in one cellar room; internal and external air temperature as well as temperatures of the walls, the floor and adjacent ground were recorded. In the winter season, the examined room was intermittently heated. Using measured boundary conditions, transient, three-dimensional heat flow in the basement foundation interface was calculated. WUFI®Plus software was used for calculation. By means of statistical analysis, the calculated temperature distribution in assemblies and the ground was then compared with the measurement results. The analysis allowed for the determination of the accuracy of theoretical calculations of thermal conditions in the environment of the periodically heated cellar room.

Keywords: *ground*, *heat flow*, *measurements and calculations*, *intermittent heating*

Streszczenie

Piwnice w budynku głównym Uniwersytetu Rolniczego w Krakowie są używane jako magazyny, laboratoria oraz sale lekcyjne. Artykuł prezentuje wyniki wieloletnich pomiarów w pomieszczeniu piwnicznym; temperatury powietrza wewnętrznego i zewnętrznego, ścian, podłogi oraz w gruncie. W zimie piwnica była ogrzewana z przerwami. Obliczenia trójwymiarowego, niestacjonarnego przepływu ciepła wykonano, wykorzystując pomierzone warunki brzegowe. Do obliczeń zastosowano program WUFI®Plus. Wyniki pomiarów i obliczeń temperatury w przegrodach i gruncie porównano statystycznie. Wyniki pozwoliły określić dokładność obliczeń warunków termicznych wokół piwnicy okresowo ogrzewanej.

Słowa kluczowe: *piwnica*, *grunt*, *przepływ ciepła*, *pomiary i obliczenia*, *ogrzewanie okresowe*

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1. Introduction

In addition to active heating systems, the ground and the external climate are factors affecting heat and moisture phenomena in buildings. Most of the external partitions are in contact with the outside air; however, some of the rooms have partitions adjacent to the ground – these can be not only floors, but also, external walls if the building is recessed in the ground. If the room has more than 70% of the walls adjacent to the ground, it is defined as a basement.

If the ground and water conditions allowed, cellars were usually included in buildings. Initially, these were for the purpose of storing fuel and keeping food products, mainly due to their favourable hygrothermal parameters. Cellars in modernised buildings are now often adapted for use as storage rooms, offices, service rooms, commercial rooms or even for residential purposes. New buildings are often designed as partially recessed in the ground.

The ground is an additional kind of barrier between the internal and external environment of the building and to some extent, reduces heat loss. The large heat capacity of the ground environment stabilises the temporary heat balance of the room by taking heat in times of internal air temperature increase and by releasing it back during periods of lower temperature. These phenomena, to some extent, lead to a reduction of the room's demand for heating and cooling energy. An additional effect is a positive impact on the microclimate. In summer, the temperature of ground surrounding the building is lower and in winter, it is higher than the external air temperature.

Today, in order to reduce energy consumption, intermittent heating and/or variable heating power is commonly used. The switching on and off of heating systems causes fluctuations in the internal air temperature of the room – this results in a significant, temporary heat exchange between partitions and the ground. The heat flow in partitions and the ground is transient and due to the geometry, three-dimensional; therefore, in most cases, it cannot be analysed in stationary terms.

The aim of the experimental measurements and calculations was the recognition of temperature in the environment of cellar rooms being periodically heated over the period of the whole year. Ground surface near to the building ascents 1.5m embankment like and becomes flat at a distance of about 5m.

Experimental measurements were constantly performed in the years from 2007 to 2015. Results from the period from 2007−2009 were used to evaluate the thermal comfort of the room, as well as to analyse the thermal and humidity conditions in the basement [2, 3]. This paper presents the results of comparative calculations made by means of the WUFI®plus software. Calculations include the period from 2010−2014. The article provides detailed measurement and calculation results for the years 2010 and 2011 and the results of the statistical, comparative analysis for this period. The aim of the study was the determination of the possibilities of using the model and the WUFI®Plus software to calculate the thermal conditions in the room and the ground. The program was previously validated in terms of standards [1] for thermal bridges and by the analysis of the passive house foundation interface [4]. However, the case of the floor below grade and inclination of the near ground surface, has not yet been analysed.

2. Methodology of experimental measurements and calculations

The object of the research is a basement room of the main building of the Agricultural University, built in the nineteen-sixties, used today as laboratory and teaching space. The basement walls are made of solid brick with plaster on both sides with a total thickness of 0,55 m. The floor is made of PVC tiles lying on a concrete slab with a thickness of 10 cm. Thermal insulation of basement walls or floor has not been applied. A horizontal section of the basement and investigated room is shown in Fig. 1.

On the partition surfaces of the tested room and in the surrounding ground, 20 PT 100 resistive sensors of TOP 106 type [5] (accuracy ±0.15 K) were located. Additionally, the same sensors were installed to measure the inside and outside air temperature. The results were recorded at 15 minute intervals in the memory of a MPS-1 recorder [6], linked to two 8-channel loggers. The basement geometry and the arrangement of measurement points are shown in Fig. 2.
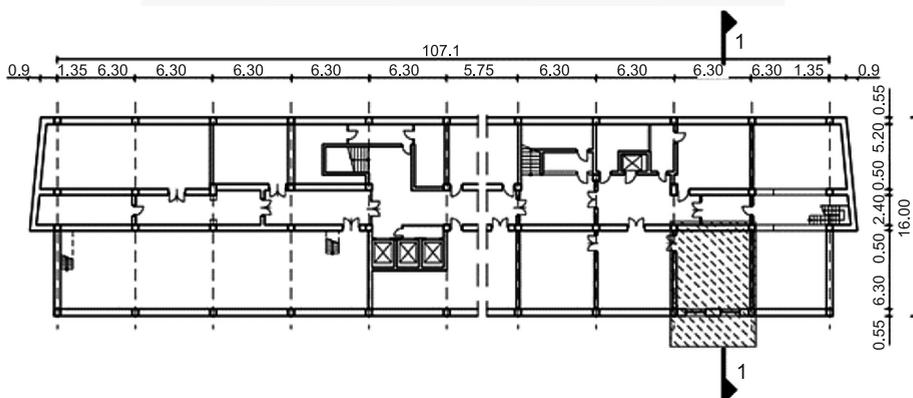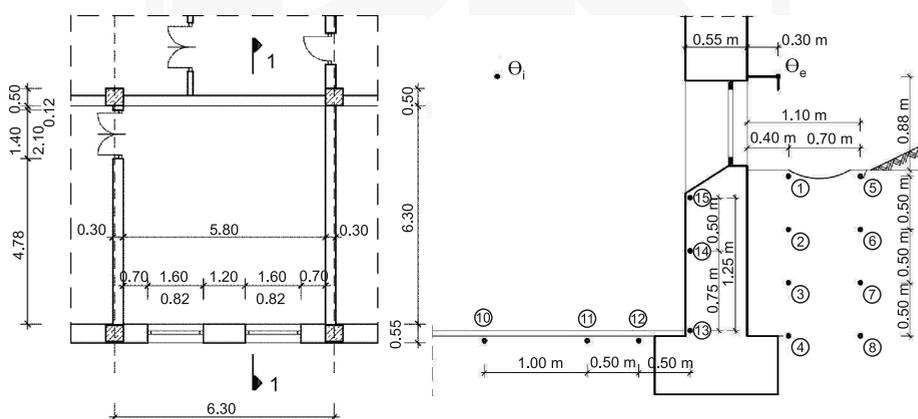

Fig. 1. Investigated cellar room

Fig. 2. Basement geometry and location of measurement points

The WUFI®Plus software [7] was used for the calculations – this allowed performing the thermal and energy analysis of the building in transient conditions. The program allowed the calculation of the transient heat balance (heated area) with full thermal coupling with the ground. Visualisation of the examined room, heat conducting space and boundary conditions is shown in Fig. 3, this was made with WUFI®Plus software.
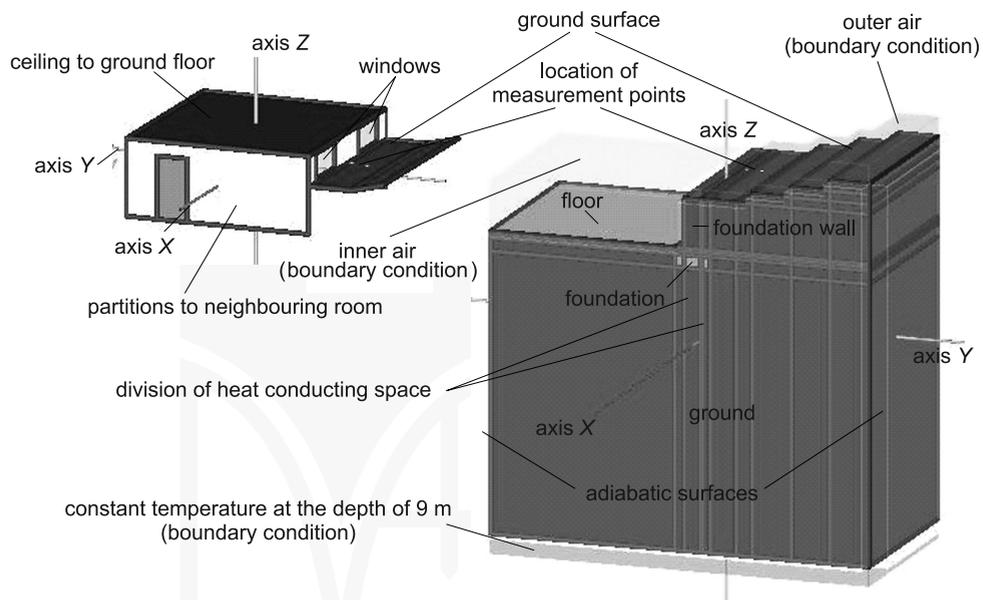

Fig. 3. Calculation room and ground model

It was assumed that within the particular assembly (wall, floor, ground), the thermal properties of the material continuum are homogeneous and isotropic. Ground surface inclination was modelled geometrically with steps. The basic data of the room is summarised in Table 1. Construction of partitions and adopted material parameters are shown in Table 2. The window parameters in the tested room are summarised in Table 3.

The calculation of heat flow in the partitions and the ground was made for the entire measurement period. Air temperature measured inside and outside the room was used as a boundary condition. Heat exchange coefficients were assumed according to PN-EN ISO 6946 standard. Other factors, such as wind and solar radiation, were omitted – these parameters were not measured. However, it should be noted, that the ground surface outside the tested room is shaded from sunlight and to some extent, sheltered from the wind.

The results of calculations of the temperature in the walls and the ground were compared with the results of measurements and analysed statistically. The following measures were used: the arithmetic mean, minimum, maximum, quartiles and also standard deviation as a measure of differentiation.

In order to determine the correlation, a Pearson test was used when the variables were normally distributed, and a Spearman test, when the variables were not normally distributed.

For all conducted tests, a level of significance of α = 0.05 was adopted. Normality of distribution of the variables was checked by means of a Kolmogorov-Smirnov test. For statistical calculations, the STATISTICA program, version 10, was used.

T a b l e 1

Room parameters used in the calculation

Specification	Unit	Value
Net volume	[m³]	89.52
Floor area	[m²]	36.54
Wall surface adjacent to the ground	[m²]	11.59
Exterior wall area (to outer air)	[m²]	3.43
Window area	[m²]	2.62
Internal walls: – wall adjacent to the library – wall adjacent to the corridor – wall adjacent to the teaching room	[m²]	15.44 14.21 12.50
Inner door	[m²]	2.94
Internal heat source (1 adult working 8^{00}–16^{00})	[W]	80/41*
Maximum power of the radiators in the room	[kW]	2.6
Computational internal temperature	[°C]	20

* Convection part/radiation part

T a b l e 2

Arrangement of layers (from inside to outside) and material parameters

Specification material/layer	Thermal conductivity λ [W·m⁻¹·K⁻¹]	Heat capacity c [J·kg⁻¹·K⁻¹]	Bulk density ρ [kg·m⁻³]	Thickness [m]
Outer wall				
Cement-lime plaster	0.85	840	1850	0.02
Solid brick	0.8	870	1770	0.51
Cement-lime plaster	0.85	840	1850	0.02
Moisture insulation on glue	0.18	1460	1000	0.003
Floor				
PCV floor covering	0.2	1460	1300	0.004
Concrete	1.8	850	2200	0.1
Other				
Ground	1.6	1430*	1950	–

* Includes 15% of the ground moisture in the natural state

Window parameters in the test room

Parameter	Unit	Value
The heat transfer coefficient U	$W \cdot m^{-2} \cdot K^{-1}$	2.6
Framework coefficient f_R	–	0.7
Average coefficient of solar radiation transmission T_R	–	0.65

3. Measurement and calculation results

As already mentioned (Introduction), calculations were performed for the years 2010 and 2011. Fig. 4 shows the example results of the calculation of the temperature pattern at two measuring points against the measurement results.
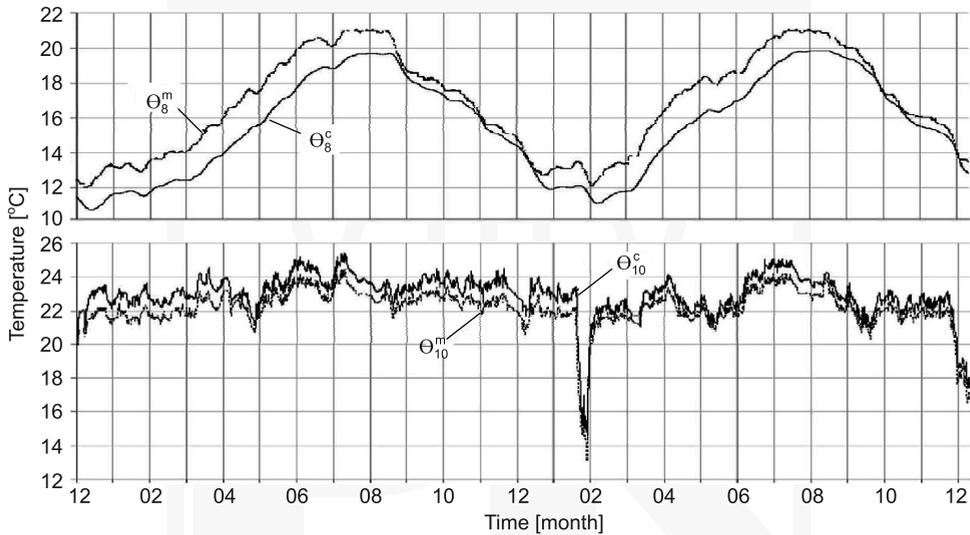

Fig. 4. The course of the temperature measured and calculated at measuring points 10 and 8 in 2010 and 2011. Upper indicators m and c indicate the temperature as measured and calculated, respectively

Point number 10 is in the middle of the floor of the room (Fig. 2). It can be seen that in this case, the influence of the boundary condition is stronger. Whereas, point number 8 is significantly further away from both the room and from the ground surface (outside air). Agreement of calculation and measurement results is usually stronger for points which are located 'closer' to boundary conditions. This is also confirmed in the case of other measurement points.

It can be seen (Fig. 4) that in February 2011, there was a fall in temperature for approximately 2 weeks – this was caused by switching off the heating in the room during

the winter holidays. If no heating is available, the temperature in the room is shaped passively as a result of the instantaneous heat balance (heat exchange with partitions and ventilation). Figure 5 shows the course of the internal air temperature and the temperature at measuring points 8 and 10 against the outside air temperature with particular emphasis put on the cut-off period.
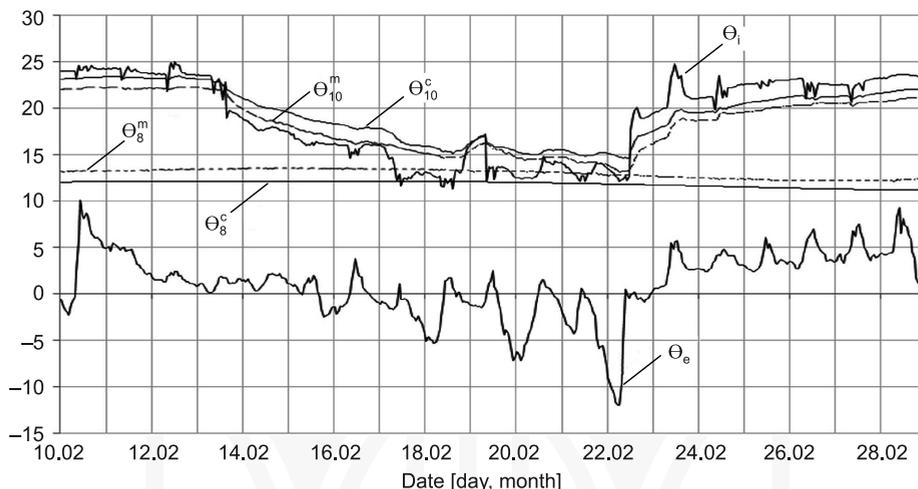

Fig. 5. The pattern of the temperature measured and calculated at measuring points 10 and 8 in February 2011. Θ_i – inside air temperature, Θ^m – temperature measured in the ground and the floor, Θ^c – temperature calculated in the ground and the floor, Θ_e – outside air temperature

A large thermal inertia causes a slow decrease of the air and ground temperature. At the beginning, heat flowed from the partitions and the ground to the internal air; within two weeks, the air temperature decreased from above 20°C to about 12°C. The floor temperature (measuring point 10) decreased along with the air temperature, but it remained higher by approx. 2°C. The dynamics of the temperature decrease diminished with time. After turning on the heating, there was a rapid increase in air temperature. This time, the floor temperature was lower than the air temperature by approx. 2.5°C. After turning on the heating, the floor and the ground take heat from the indoor air. At measuring point number 8 (1.65 m away from the room) no effect of switching off the heating was observed. Analysis of the temperature in the remaining sections allows us to state that the spatial scope of the thermal effect caused by the two weeks switching off is about 1 m.

The coincidence of calculations and measurements results was determined by statistical analysis of value pairs (see section 2). The results in terms of the average value, minimum, maximum, lower and upper quartile are illustrated in the so-called box diagram (Fig. 6). The correlation is shown in Table 4.

Figure 6 reveals that the results for the measurements and calculations are very similar both in terms of value and amplitude. Maximum differences do not exceed 5°C. Deviations in terms of the lower and upper quartiles are less than 2°C. The correlation is highly
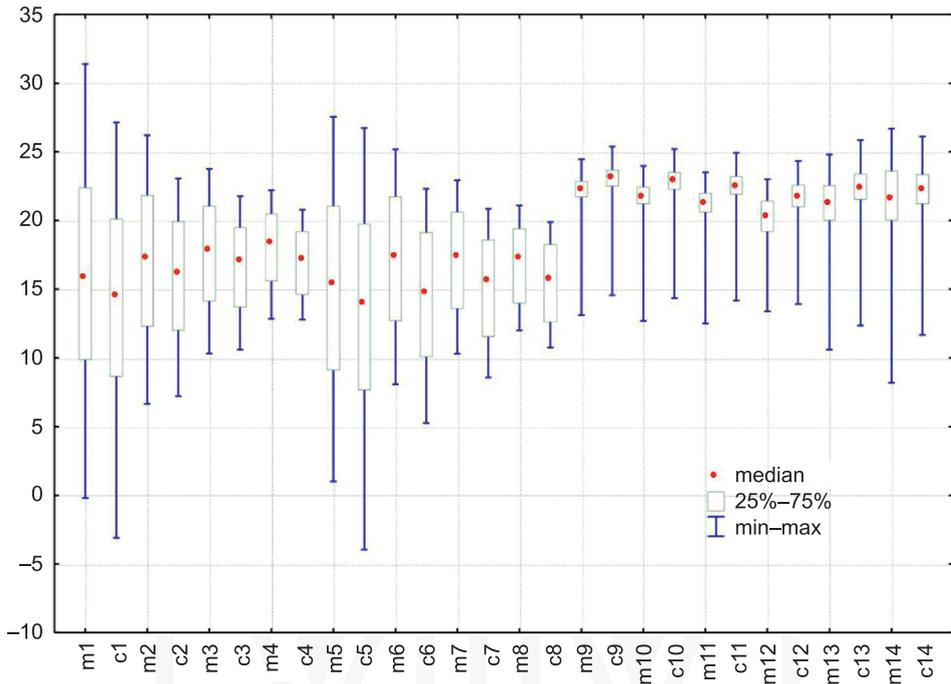
Fig. 6. Statistics of the results of calculated (c) and measured (m) temperature at particular measurement points

Table 4

Correlation between measured and calculated patterns

Measurement point	Correlation coefficient
1	0.9906
2	0.9853
3	0.9826
4	0.9690
5	0.9953
6	0.9951
7	0.9870
8	0.9753
10	0.9753
11	0.9691
12	0.9612
13	0.9235
14	0.9529
15	0.9491

significant at all measurement points. This means that the calculated courses of temperature are closely related to the measurement. At measuring points 3, 4, 7 and 8, the differences between calculation and experimental results are slightly greater than those at other measurement points. These points are further away from the boundary conditions, which are internal and external air temperature. The calculation results at these points are more dependent on physical properties of the ground such as conductivity and heat capacity.

The accuracy of calculations, in terms of coincidence can be improved by the so-called model calibration, which includes adaptation of material parameters and boundary conditions. However, the purpose of this article is to show the accuracy which can be obtained by assuming simplified boundary conditions (omission of radiation and the effect of wind on the exchange of air) and homogeneous, consistency over time, and estimated thermal properties of partitions and the ground.

4. Conclusions

This paper presents results of long term measurements and calculations of temperature and heat flow in the assemblies and ground in the vicinity of an intermittently heated cellar. Measurements were made under real operating and climate conditions. During the whole measurement period, a great thermal stabilising effect caused by the ground was observed.

During 2 weeks heating cut off, inner air temperature dropped from 20 to 12°C, whereas set point temperature was reached within 1−2 days after heating was switched on. The floor temperature remained higher (by approx. 2°C) during cut off and lower (by approx. 2.5°C) than the air temperature. It could be estimated that approximately 1m ground thickness exchanged heat with inner air during this period.

Results of comparative calculations with measured air temperatures as boundary conditions showed strong agreement with measurements. Maximum, absolute differences did not exceed 5°C. The correlation was highly significant at all measurement points. Calculation accuracy was slightly better in points located geometrically nearer to the boundary conditions. However, calculation results, obtained with estimated material properties of assemblies and the ground, correctly reflect the thermal performance of a cellar room and heat exchange with the surrounding soil.

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