Variations of Ground Temperature in Shallow Depths in the Silesian Region

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Abstract. Knowledge of temperature distribution in relation to time and depth is necessary in many applications. These include: designing GSHP (ground source heat pump) and EAHE (earth-air heat exchangers) systems, calculating heat loss in buildings, in determining foundation depth for buildings and structures with consideration of frost penetration depth, designing pavement of roads and airports or designing underground systems of energy transmission. Regular measurements and perfecting models describing temperature in the ground is therefore extremely valuable. This article presents authors’ own research on ground temperature changes in time and distribution of temperature at different depths, up to c. 2.0 m beneath ground level. The tests were performed in the Silesia region over a period of 6 months between May and October, using thermistors installed in the ground at various depths. The measurements were compared with temperature of the air, measured at test stations using a meteorological multisensor in order to find a correlation. Aside from readings of temperature over time and profiles of ground temperatures the paper contains selected elements of statistical analysis of the measurements. It was noted that the temperature distribution is closely related to depth below ground level, and the influence of outside temperatures decreases with depth.

1. Introduction
The idea of sustainable development is closely related to the need to obtain heat from renewable sources of energy. In Poland, the renewable energy source market began to develop in the 90s. It was then that first professional installations were created which used renewable wind, solar, geothermal and biomass energy [1]. They are currently subject to numerous research projects and analyses such as [2, 3]. Development in this area is connected to international obligations and the necessity to meet EU requirements related to boosting development of renewable energy market, implementing the rule of energy safety and the necessity to protect the environment (climate preservation, maintaining/improvement of environment quality, including air [4]) and most importantly diminishing supply of non-renewable energy sources.
One of potential energy sources is that obtained from the ground [5]. The ground temperature depends mostly on the structure and physical properties of the soil itself, on air temperature changes and other variables of the climate, i.e. sunlight radiation, rainfall, wind and to some degree on the shape of the terrain.

The ground surface temperature is the result of convection and radiation processes between it and its direct surroundings with temperature \( T_e \), radiation between it and further surroundings \( T_{\text{sky}} \), and energy loss resulting from evaporation and transfer of heat between the surface and deeper layers of the soil [6, 7] – figure 1. Therefore, the ground surface temperature is indirectly influenced by its covering; impact of deforestation on ground surface temperature is presented in [8]. Differences between air temperature at the surface, temperature of ground surface and ground temperature at a depth of 0÷5 cm has been analysed in [9]; higher ground surface temperatures were recorded in urban areas [10]. The relationship between air temperature or other variables of the climate and ground temperature were the subject of multiple papers, e.g. [11-14].

Analysing temperature distribution in relation to depth, general three ground temperature zones can be distinguished [9, 13, 15]. Other than the surface zone already mentioned, where the temperature depends strongly on daily fluctuations of surface temperatures, and therefore on the weather conditions, we need to distinguish the shallow zone, where the temperature depends on seasonal fluctuations, is more stable and close to annual average air temperature, and the deep zone, where the ground temperature is constant and increases by c. 2÷3 K per 100 m depending on the local geothermal gradient value [15, 16].

**Figure 1.** Main heat flux contributions at the surface of the ground, where: \( \alpha_s G \) – short-wave global solar radiation (radiant flux) absorbed by the ground surface; \( h_{\text{conv}} \) – convective heat transfer coefficient, \( \Phi_{\text{conv}} \) – heat flux exchanged between the air and the ground surface; \( \Phi \) – heat flux transferred by conduction across the ground surface, \( \Phi_{\text{evap}} \) – evaporation heat exchange flux, \( \Phi_{\text{sky}} \) – long-wave radiation (radiant flux) emitted by the ground surface to the sky, \( h_{\text{rad}} \) – radiation heat transfer coefficient [7]

Measurements of ground temperature are presented in papers [6-15, 17-32] among others. For example, authors of [9, 29] presented measurements of temperature of frozen soil.

In the past there have been multiple research projects and analyses aimed at assessing the ground profile. Most typical procedures found in literature are short term measurements of ground temperature – authors of [19, 20, 22, 30] have analysed the results of measurements which were accompanied by TRT (thermal response test [33, 34]). Long term temperature measurements are unfortunately much less common [13, 24, 26, 17]. This is related to the necessity to expand monitoring
systems with continuous monitoring stations, described e.g. in [35]. As an example we can bring up a complex measuring system under the Lesser Poland Province Laboratory of Energy-Efficient Construction [36]. That is why it should be emphasized that, despite ground temperature measurements being common, typical weather stations are usually not upgraded with equipment for measuring distribution of temperatures in the ground.

Measured values may be used to determine frost penetration depth [37] or preparing a numerical model of heat transfer and mass [29,38]. [6, 7, 17] present models of predicting changes in ground temperature as a function of depth and time, using meteorological data, verified using measured temperatures.

The most popular of them, called energy balance models, use energy balance equations as boundary condition. The precision of these models strongly depends on the precision of estimating input data, and availability is dependant on the availability of those data. It is therefore valuable to perform regular measurements and continue to perfect the models describing temperatures in the soil. Ground temperatures and its measurements and the designed and used models are also subject of this paper, which presents analyses for Silesia.

2. Methodology

Ground temperature was measured at different depths over six months in 2016. The temperature was measured simultaneously at 5 points at different depths (-0.15, -0.35, -0.75, -1.35, -1.95m) away from any buildings. The profile probe was set up according to [23] – figure 2b – and in a manner similar to measurements of soil strains [39,40].

![Figure 2. Ground profile: a) YSI 44005 thermistor [41], b) documentation from sensors installation](image)

Measurements of ground temperature were taken using a multi-channel, automatic measuring system. The temperature was measure by YSI 44005 thermistors (figure 2a) measuring temperatures in the range -40 to +105°C and with accuracy of 0.5 °C. The temperature sensors were connected to multi-channel recorders from Geokon type 8002. The value being measured is the sensor’s resistance, temperature is calculated from formula (1). Measurements were taken every hour, and data saved in the recorder’s memory.
\[ T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2 \]  

where:
- \( T \) – temperature, °C,
- \( LnR \) – natural logarithm of the sensor’s resistance,
- \( A = 1.4051 \times 10^{-3}, B = 2.369 \times 10^{-3}, C = 1.019 \times 10^{-3} \) (coefficients calculated for values in the range -50 do +150°C).

3. Results and discussions

Figure 3 presents the record of ground temperature measured at different depths over six months, i.e. from 1 May to 31 October 2017 [25].

![Figure 3. Hourly ground temperatures at various depths; May 1-October 31](image)

![Figure 4. a) Monthly average ground temperature profiles at various depths, b) Frame chart of median temperature at various depths; May 1-October 31](image)
Changes in monthly average ground temperature at different depths is presented in figure 4a, the temperature sensitivity on an annual scale corresponding to them is presented in figure 4b.

Figure 5 shows changes in average temperatures of ground at different depths for each day per month, labelled with different colours.

On spring and summer days the ground temperature at the surface is higher than that at greater depths; on autumn days it is the opposite.

Additionally a variability analysis (figure 6) was performed for a selected day in July and a day in October, i.e. average daily temperature, minimum, maximum, median and momentary temperature at two selected times of day.

![Figure 5. Daily average ground temperature profiles at various depths; May 1-October 31](image1)

![Figure 6. a) Daily average and hourly ground temperature profiles at various depths, b) Frame chart of median temperature at various depths; July 5 and October 5](image2)

Ground temperatures were compared to air temperatures measured at the workstation of Department of Building Engineering and Building Physics of the Silesian University of Technology.
in Gliwice, using a meteorological multisensor FMA510H from Ahlborn, with data recording using ALMEMO 5690-2M09 recorder [25]. Changes of air temperature are shown in figure 7.

![Figure 7. Air temperature; May 1-October 31](image)

Correlation of air temperature with ground temperature is shown in figure 8. The correlation coefficient for the linear relationship is 0.8587, which shows strong agreement between the results.

The amplitude of ground temperature changes decreases with depth (figure 6b), and the delay of ground temperature in comparison to air temperature increases. The strength of relationship between the air temperature and the temperature at each measurement point is described using the coefficient of determination (table 1). The results clearly show a decrease in strength of relationship between the variables following increase of measurement point depth. This means that with increasing depth the influence of air temperature decreases.

![Figure 8. Correlation of air temperature with ground temperature (-0.15 m); May 1-October 31](image)
Table 1. Correlation of air temperature with ground temperature; May 1-October 31

| Depth, m | Determination coefficient R^2 (Air-Ground) |
|---------|------------------------------------------|
| -0.15   | 0.737                                    |
| -0.35   | 0.482                                    |
| -0.75   | 0.353                                    |
| -1.35   | 0.194                                    |
| -1.95   | 0.080                                    |

4. Conclusions

The necessity to protect the environment and the diminishing of non-renewable energy sources drive the search for new solutions in the field of energy and optimising energy consumption throughout the service life of buildings. Optimisation of building foundation level based on frost penetration depth also fits this trend.

The above translates to a need for monitoring ground temperature with particular consideration of temperature relative to depth. Results of such measurements can be found in academic literature. They are typically taken over a short time, which does not allow to interpret their significance in time. Moreover, due to the fact that ground temperature depends on the structure and properties of the ground itself, there is a necessity to account for local conditions both in determining the frost penetration depth or designing geothermal heating, or designing innovative solutions considering transfer of heat [42], including usage of foam concrete [43] insulation e.g. under industrial floors [44-48].

Based on the above, this paper presents ground temperature variations in the Silesia Region, Poland. The following conclusions can be drawn from the above presentation of the results:

- distribution of temperature is closely related to depth; on spring and summer days the ground temperature at the surface is higher than that at greater depths; on autumn days it is the opposite.
- the amplitude of ground temperature decreases with depth,
- influence of air temperature decreases with depth,
- there is linear correlation between air temperature and ground temperature.

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