Using the ground as a heat sink in residential buildings during heat waves

A Staszczuk, T Kuczyński
Faculty of Civil Engineering, Architecture and Environmental Engineering, University of Zielona Góra, Prof. Z. Szafrana 1 st, 65-516 Zielona Góra, Poland

E-mail: A.Staszczuk@ib.uz.zgora.pl; T.Kuczynski@iis.uz.zgora.pl

Abstract. Heat waves that are the result of climate changes have become an increasingly intense and therefore dangerous for human health and life. In the countries of moderate climate such as Poland, which have never before been experienced by such phenomena, residential buildings are usually free of overheating systems. In this paper authors propose a passive cooling method using the ground under thermally uninsulated floor slab as a heat sink for cooling the inside air during hot summer. The paper presents current knowledge of the authors gained as a result of theoretical analysis, fully confirmed by experimental research in two terraced rooms differing from each other only by the type of floor construction. Authors additionally presented the simulation results obtained for detached houses, which took also into account the effect of blinds in windows and increased night ventilation. The lack of ground floor thermal insulation significantly decreases the indoor air temperatures in the room with negligible “cold floor” effect. The duration of heat wave did not affect the effect of temperature reduction. Despite of the significantly difference in energy demands, it can be compensated by renewable energy sources.

1. Introduction
Climate change seems to be one of the biggest threats for human. Persistent heat waves became a serious threat, sustaining for long time, affecting the climate in buildings and human health and life.

In the last decade heat waves affected Europe repeatedly [1] often causing mortality because of heat stress [2], [3], [4]. It was particularly felt in western and central Europe in 2003 [5], [6] and during the extremely hot summer of 2015 [7]. At that time Poland was one of the hottest countries in Europe. In such country, located in the region of moderate climate, residential buildings are usually free of overheating systems. Therefore, to improve thermal comfort in building during hot summer, authors suggest utilizing the ground underneath as a heat sink. Applying uninsulated floor is a novel method among other passive cooling techniques for residential buildings presented in [8], [9], [10].

The method proposed by the authors has not been officially recognized as an efficient one [11], [12], [13]. Therefore, in the paper they focused on presenting current knowledge gained as a result of theoretical analysis [14] and experimental research [15] to show, that installing a thermally uninsulated floor can be an effective method for one-storey residential buildings in moderate climate area.
2. Materials and methods

2.1. Assumptions
In the paper results of theoretical considerations carried out on two similar, terraced experimental rooms differing by the type of floor construction were presented. Except for occurrence or lack of thermal insulation, any other actions preventing high indoor temperatures during heat waves weren’t included during research. The results of numerical simulations were fully confirmed by experimental research carried out by authors in above mentioned rooms in 2015 and widely presented and discussed in [15]. Detailed statistical analysis including significance tests as well as time series analysis showed high accuracy of the theoretical results.

To further expand the discussion including additional actions such as: blinds in windows and increased night ventilation as well as type of the building, results of numerical simulations referring to one-storey residential building were presented in the paper.

Despite of two different objects, time period and weather data, there was the same main goal: the assessment of possibilities of using the ground underneath thermally uninsulated floor as a heat sink to avoid building’s overheating.

2.1.1. Objects. Two kind of objects were considered in the paper: low-energy terraced, experimental rooms located at the ground floor in the three-storey building located in central-western Poland and passive, one-storey residential building.

First of them was used for experimental investigation. The second one was used in theoretical analysis to simulate the effect of different kind of floor construction on the indoor air temperature and energy demand in building, simultaneously considering above mentioned others actions preventing high indoor temperatures during heat waves.

Basic dimensions of the objects: terraced rooms and one-storey building were respectively: floor area - 18 m² and 108 m², net volume - 63 m³ and 300 m³, and A/V factor - 0.671/m and 0.85 1/m. Average temperature in building - 20°C and ventilation - 0.5 ACH during heating season were assumed in both objects. Detailed information on their technical parameters, construction of opaque assemblies, windows, ground characteristic and their thermal properties were presented in [14], [15].

2.1.2. Cases. In the Table 1 different cases including floor construction and actions against overheating in analyzed objects were characterized.

| Symbol | Floor construction | Action preventing high indoor air temperatures |
|--------|--------------------|-----------------------------------------------|
| **Object 1: terraced rooms in three-storey building** |
| 1 A-1  | Figure 1a         | Lack                                          |
| 1 B-1  | Figure 1b         | Lack                                          |
| **Object 2: one-storey building** |
| 2 A-1  | Figure 1c         | Lack                                          |
| 2 A-2  | Figure 1c         | BW                                            |
| 2 A-3  | Figure 1c         | BW, INV                                       |
| 2 B-1  | Figure 1d         | Lack                                          |
| 2 B-2  | Figure 1d         | BW                                            |
| 2 B-3  | Figure 1d         | BW, INV                                       |

BW – blinds in windows; INV – increased night ventilation (0.5 ACH from 6 a.m. to midnight; 2.0 ACH from midnight to 6 a.m.)

Details of floor construction were presented in Figures 1a-d.
2.1.3. Meteorological data. An analysis of air temperatures in Object 1 (terraced experimental rooms located at the ground floor in three-storey building) during heat waves in summer was carried out for 14 consecutive days in August (from 3rd to 16th August 2015). Uniquely August 2015 in Poland hasn’t remained so warm over such a long period of time. Temperatures in Nowy Kisielin exceeded 30°C for 15 days and 33°C for 7 days. Analysis in Object 2 (one-storey building) included weather data for Słubice. The period selected for analysis assumed 9 consecutive days of extremely hot, which took place in July 2006. For 19 days temperatures exceeded 30°C and for 7 days – 33°C.

2.2. Numerical simulations
To assess the possibilities of using the ground below an uninsulated floor as a heat sink, the numerical simulations performed by WUFI® plus software were carried out for both theoretical analysis in Object 1 and Object 2. Detailed assumptions of 3D model of analyzed building and surrounding ground, it’s structure and boundary conditions of heat flow were presented respectively in [15] and [14].
3. Results and discussion
In the paper the results of numerical simulations for terraced experimental rooms (fully confirmed by experimental research) were presented and the simulation results obtained for detached houses which take into account additionally the effect of blinds in windows and increased night ventilation.

In Figure 2 the courses of indoor air temperatures calculated with WUFI® plus software are presented for two cases of floor construction in Object 1 including occurrence (Case 1 B-1) and lack of thermal insulation (Case 1 A-1).

![Figure 2](image)

**Figure 2.** Pattern of temperature during heat wave in August, 2015 in Nowy Kisielin, Poland. Object 1. Cases A-1, B-1.

Similarly for Object 2, the courses of indoor air temperatures calculated with WUFI® plus software are presented in Figures 3. The impact of additional action preventing of overheating in building e.g. blinds in windows (cases A-2, B-2) and increased night ventilation (cases A-3, B-3) are presented in Figures 4-5.

![Figure 3](image)

**Figure 3.** Pattern of air temperature during heat wave in July, 2006 in Słubice, Poland. Object 2. Cases A-1, B-1.
Figure 4. Pattern of temperature during heat wave in July, 2006 in Ślubice, Poland. Object 1. Cases A-2, B-2.

Figure 5. Pattern of temperature during heat wave in July, 2006 in Ślubice, Poland. Object 2. Cases A-3, B-3.

In the Table 2 temperatures \( \bar{t}_{av} \) differences \( \Delta \bar{t}_{av} \) from Figures 2-5 from 10 a.m. to 10 p.m. in building during heat waves including occurrence (B) or lack (A) of thermal floor insulation for all cases are shown. Furthermore differences in yearly energy demand for heating and cooling \( \Delta Q_{A,B} \) are presented (assuming cooling demand to maintain temperature \( t_{max} = 25^\circ C \) during hot season).

The difference between these two floor solutions was 3.9 K in terraced rooms in Object 1 while difference between the same floor solutions obtained by simulation for one-storey residential building (Object 2) reached 7.5 K. It is most likely that the cause of such high differences obtained in both simulations was the ratio of the outside wall area to the floor area. In the Object 1 it was as low as 0.58 whereas in the Object 2 it was as high as 1.09. It seems obvious that the higher ratio, the stronger the effect of ambient temperature inside the building. In addition it should be taken into account slightly lower level of thermal insulation of the opaque assemblies of the Object 1 (including floor thermal insulation) and weather data (slightly higher average temperature outside during heat wave in 2006 compare to 2015 it is respectively 25.8°C and 24.8).
Table 2. Average air temperatures $t_{av}$, differences $\Delta t_{av}$ in building during heat waves and in yearly energy demand for heating and cooling $\Delta Q_{A,B}$ including occurrence (B) or lack (A) of thermal floor insulation for all cases.

| Case | $t_{av}$ [°C] | $\sigma$ [°C] | $\Delta t_{av}$ [K] | $\Delta Q_{A,B}$ [kWh] | $\Delta Q_{A,B}$ [kWh/m$^2$]* |
|------|----------------|---------------|----------------------|----------------------|--------------------------------|
| 1 A-1 | 25.0           | 1.1           | 3.9                  | 98                   | 5.5                            |
| 1 B-1 | 28.9           | 1.5           | 7.5                  | 1041                 | 9.6                            |
| 2 A-1 | 26.8           | 0.8           | 7.5                  | 1041                 | 9.6                            |
| 2 B-1 | 34.3           | 1.6           | 1602                 | 14.8                 |                                |
| 2 A-2 | 26.5           | 0.4           | 4.7                  | 1602                 | 14.8                            |
| 2 B-2 | 31.2           | 1.1           | 1602                 | 14.8                 |                                |
| 2 A-3 | 25.8           | 0.7           | 3.7                  | 1784                 | 16.5                            |
| 2 B-3 | 29.5           | 1.1           | 1784                 | 16.5                 |                                |

*The value applies to the floor area.

The average indoor air temperature in the time of the day between 10 a.m. to 10 p.m. was reduced by 3.1°C for case B-2 by the introduction of blinds in windows, and lowered by another 1.7°C using increased night ventilation.

Introduction additional action preventing overheating in building gives the best results in the case of slab with thermal insulation comparing with their lack, when it is only slight lowering of the temperature in building. The differences $\Delta t_{av}$ for this two kinds of floor construction decrease from 7.5 K (with cooling effect caused only by the ground thermal capacity) to 3.7 K (including all actions preventing overheating) while increasing difference in yearly energy demand for heating and cooling $\Delta Q_{A,B}$ almost 1.7 times more from 9.6 kWh/m$^2$ to 16.5 kWh/m$^2$. Energy demand for cooling is growing while energy demand for heating remains at the same level. Therefore, using the ground as a heat sink seems to be economically justified, without any other action preventing overheating in building.

Although reduction in cooling energy demand for building with thermally uninsulated floor doesn’t compensate additional energy demand for heating season for building with fully insulated floor in both analysed kinds of objects, the difference in energy demand is 5.5 kWh/m$^2$/year for Object 1 and proportionally more 9.6 kWh/m$^2$/year for Object 2. Since the different is relatively small, it’s worth considering solar collectors to compensate for heat losses for uninsulated floors in winter. The difference in measured average surface floor temperature didn’t exceed 0.5 K, therefore there was no a “cold floor” effect identified in the solution without thermal insulation.

4. Conclusions

- Sustaining for long time extreme heat waves become a serious threat, affecting the climate in building and human health and life in the way, that it should appropriately affect floor building design.
- Calculated and measured cooling potential of removing floor insulation in terraced rooms was as high as 0.2 MJ/m$^2$/day.
- Using additional methods of passive cooling i.e. blinds or night ventilation combining with the strategy of using ground as a heat sink in residential building is less efficient than in the one with fully insulated floor. However the combined effect of all actions provides significant reduction of internal temperature during extremely hot periods.
- The difference in yearly electrical consumption for uninsulated building’s floor comparing to fully insulated was relatively small and could be easily compensated by applying solar collectors.
- The duration of heat wave did not affect the effect of temperature reduction.
- There was no a “cold floor” effect identified in the solution without thermal insulation.
5. References

[1] Russo S, Sillmann J, Fischer E 2015 Top ten European heat waves since 1950 and their occurrence in the coming decades Environ. Res. Lett. 10 124003.

[2] Steul K, Schade M, Heudorf U 2018 Mortality during heat waves 2003–2015 in Frankfurt-Main – the 2003 heat wave and its implications Int. J Hyg. Environ. Heal. 221 81-86.

[3] Alcoforado M, Marques D, Garcia R, Canário P, Nunes M, Nogueira H, Cravosa A 2015 Weather and climate versus mortality in Lisbon (Portugal) since the 19th century Appl. Geogr. 57 133-141.

[4] Urban A, Hanzliková H, Kyslej J, Plavcová 2017 Impacts of the 2015 Heat Waves on Mortality in the Czech Republic—A Comparison with Previous Heat Waves International Journal of Int. J Environ. Res. Public Health 14 1562.

[5] Schär C, Jendritzky G 2004 Hot news from summer 2003 Nature 432 559–560.

[6] De Bono A, Giuliani G, Kluser S, Peduzzi P 2004 Impacts of summer 2003 heat wave in Europe UNEP/DEWA/GRID-Europe Environment Alert Bulletin 2 1-4.

[7] Di Liberto T 2015 Summer heat wave arrives in Europe https://www.climate.gov/print/682891.

[8] Santamouris M, Kolokotsa D 2013 Passive cooling dissipation techniques for buildings and other structures Energ. Buildings 57 74-94.

[9] Goudarzi H, Mostafaeipour A 2017 Energy saving evaluation of passive systems for residential buildings in hot and dry regions Renew. Sust. Energ. Rev. 68 432-46.

[10] Ascione F 2017 Energy conservation and renewable technologies for buildings to face the impact of the climate change and minimize the use of cooling Solar Energy 154 34-100.

[11] Porritt S, Cropper P, Shao L, Goodier C 2012 Ranking of interventions to reduce dwelling overheating during heat waves Energ. Buildings 55 16-27.

[12] Sakkas A, Santamouris M, Livadai I, Nicolb F, Wilsonb M 2012 On the thermal performance of low income housing during heat waves Energ. Buildings 49 69–77.

[13] Santamouris M, Pavlou K, Synnefa A, Niachor K, Kolokotsa D2007 Recent progress on passive cooling techniques. Advanced technological developments to improve survivability levels in low-income households Energ. Buildings 39 859–66.

[14] Staszczuk A, Kuczyński T 2016 Effect of extending hot weather periods on approach to floor construction in moderate climate residential buildings Civil and Environmental Engineering Reports 20 159-70.

[15] Staszczuk A, Wojciech M, Kuczyński T 2017 The effect of floor insulation on indoor air temperature and energy consumption of residential buildings in moderate climates Energy 138 139-46.