BUDOWNICTWO
CZASOPISMO TECHNICZNE
TECHNICAL TRANSACTIONS
CIVIL ENGINEERING
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ
1-B/2009
ZESZYT 5
ROK 106
ISSUE 5
YEAR 106

MAJA STANIEC, HENRYK NOWAK*

ANALYSIS OF ENERGY CONSUMPTION IN EARTH-SHELTERED BUILDING WITH SOUTHERN ELEVATION EXPOSED

ANALIZA ZUŻYCIA ENERGII CIEPLNEJ W BUDYNKU ZAGŁĘBIONYM W GRUNCIE Z EKSPONOWANĄ ELEWACJĄ POŁUDNIOWĄ

A b s t r a c t

In the article, the authors present the results of heat balance simulations for the earth-sheltered house (with southern elevation exposed) with different thickness of the soil covering the roof and different insulation thickness. Then, the results are compared with heat balance of a traditional above-ground building. As the simulations show, earth-sheltered buildings require less energy loads for heating and cooling than above-ground ones.

Keywords: *earth-sheltered buildings, heating and cooling, energy balance, energy performance*

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

W artykule autorzy analizują zapotrzebowanie na energię do ogrzewania i chłodzenia budynku typu „earth-sheltered”, czyli zagłębionego w ziemi, z eksponowaną elewacją południową, z różną grubością gruntu pokrywającego budynek oraz różną grubością izolacji termicznej na ścianach, stropie i płycie na gruncie. Jak wskazują na to wyniki przeprowadzonych symulacji, budynki przysypane gruntem wymagają mniejszych nakładów energii na ogrzewanie i chłodzenie niż budynki tradycyjne – naziemne.

Słowa kluczowe: *budynki podziemne, zapotrzebowanie na energię do ogrzewania i chłodzenia, bilans energetyczny*

* Mgr inż. Maja Staniec, dr hab. inż. Henryk Nowak, prof. PWr., Instytut Budownictwa, Wydział Budownictwa Lądowego i Wodnego, Politechnika Wrocławska.

1. Introduction

The idea of sheltering buildings in the ground is not a contemporary invention. The ancients were the first to benefit from stable thermal conditions of caves and later all cities were built under the ground, like Matmata, the ancient city in Tunisia [1]. Nowadays earth--sheltered buildings have been evolving into many different designs and layouts, as the one presented in this article – elevational design, in which windows are grouped on one side of the structure; the three remaining walls and the roof are earth covered. In the northern hemi-sphere, it is usually the southern elevation that is exposed, which ensures obtaining the maximum solar gains. Such buildings are mainly used as single-family dwellings, detached houses or hotels and the room placement is very carefully done. The rooms which are intended to be used most frequently and need natural solar lightning, are placed along the window wall. The remaining rooms (bathroom, kitchen, storage rooms, stairs, etc.) are placed along the opposite – soil-covered, wall.

The most significant advantage of such buildings is their heat energy efficiency, due to the large thermal inertia of the soil cover, which causes the temperature in the surrounding soil to be higher/lower than the air temperature during winter/summer [2]. In such a way the temperature differences between the interior and exterior are minimised, which means that the heat transmission is smaller compared to conventional above-ground houses. Thus, the application of soil cover potentially reduces the required heating and cooling loads.

2. Case study – the physical model

The analysed earth-sheltered building is simply a concrete construction built on the ground level, whose three external walls and the roof are covered with soil. The southern elevation is exposed. For the simulation purpose, the following assumptions were taken: floor space 144 m^2, glazing space on southern wall – 30 m^2, the ceiling thickness – 0.30 m, the walls thickness – 0.30 m, the slab thickness – 0.15 m, two thermal insulation thicknesses – 0.10, 0.20 m (the building is thermally insulated with the same insulation thickness on all external partitions, including slab), variable ceiling soil cover thickness – 0.5, 1.0, 1.5 m, length of overhang on glazed wall – 1.0 m. The inside air temperatures were set: 19–1/20–25 in winter/summer. The picture below shows the analysed buildings.

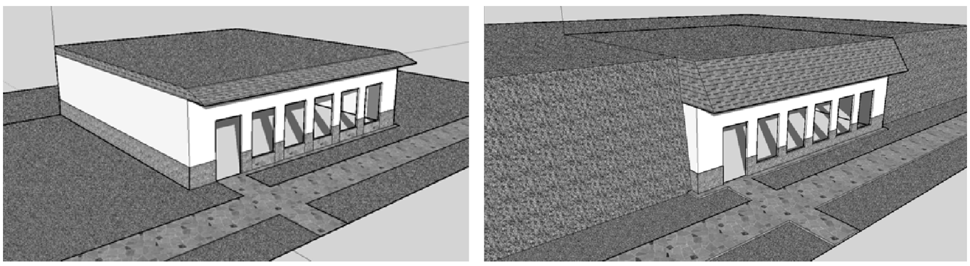

Fig. 1. Schemes of analysed buildings: a) above-ground, b) earth-sheltered (roof imitation)
Rys. 1. Schematy analizowanych budynków: a) naziemny, b) podziemny (imitacja dachu)

3. Case study – the mathematical model

The calculations were done with the use of two programs: FlexPDE for soil temperature distribution and EnergyPlus for energy consumption. The simulations were done for the Polish climate conditions (EnergyPlus EPW weather file for Poznan city). Fig. 2 illustrates the heat balance relation between the environment and the building [3] and other boundary conditions. The governing equation for the ground inside a domain is a 3D transient heat equation (1)

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}=\frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

The soil surface, both horizontal and vertical, the boundary conditions are set as the energy balance on the soil surface, where the energy absorbed by the soil is equal to the sum of absorbed incoming short-wave sun radiation and long-wave sky radiation, outgoing long-wave soil surface radiation, energy due to convection and latent evaporation plus long--wave radiation between both horizontal and vertical surfaces. This is expressed with (2).

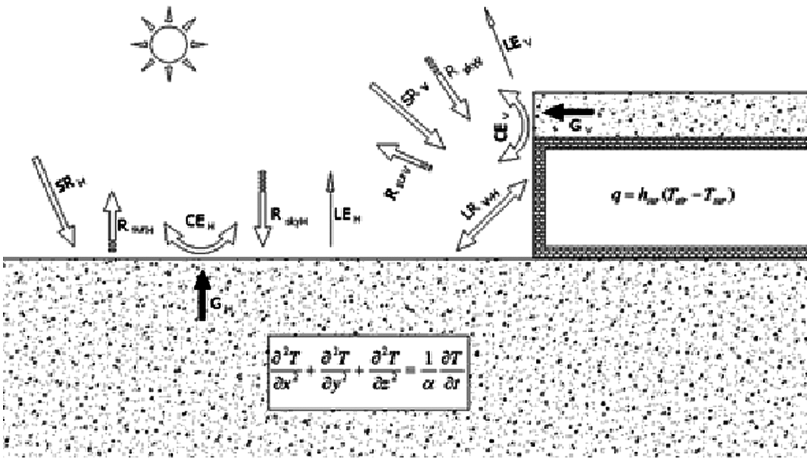

Fig. 2. Heat balance on the soil surfaces and boundary conditions
Rys. 2. Bilans cieplny na powierzchniach gruntu i warunki brzegowe

$$G_{H(V)}=SR_{H(V)}+R_{\mathrm{sky}H(V)}-R_{\mathrm{sur}H(V)}+CE_{H(V)}-LE_{H(V)}+LR_{H-V} \tag{2}$$

where:

- $G_{H(V)}$ – energy absorbed by horizontal (vertical) soil surface [W/m^2],
- $SR_{H(V)}$ – short-wave sun radiation energy absorbed by horizontal (vertical) soil surface [W/m^2],
- $R_{\mathrm{sky}H(V)}$ – long-wave sky radiation energy on horizontal (vertical) soil surface [W/m^2],
- $R_{\mathrm{sur}H(V)}$ – long-wave horizontal (vertical) soil surface radiation [W/m^2],
- $CE_{H(V)}$ – energy due to convection on horizontal (vertical) surface [W/m^2],
- $LE_{H(V)}$ – energy due to latent evaporation of horizontal (vertical) surface [W/m^2],
- LR_{H-V} – long-wave radiation between both horizontal and vertical surfaces [W/m^2].

Bottom and vertical domain boundary conditions are assumed to be perfect insulators, thus heat flux is equal to zero. Boundary conditions inside a building are equal to [4]

$$q = h_{\mathrm{sur}}(T_{\mathrm{air}} - T_{\mathrm{sur}}) \tag{2}$$

depending on the heat flow direction, where:

q – heat flux on the inside face surface [W/m^2],
h_{sur} – heat transfer coefficient of a surface [W/m^2 K],
T_{air} – inside air temperature [K],
T_{sur} – surface temperature [K].

4. Analysis of simulation results

Figure 3 shows the simulated heat gains and Fig. 4 heat loss through: four walls (a), roof (b) and slab (c). The sum of total heat gains/loss through external partitions (walls, roof and slab) are presented in Fig. 3d)/Fig. 4d). Heat gains and loss for windows are not shown, as they are comparable for all cases. Fig. 5a) shows total annual heating loads and Fig. 5b) gives values for cooling loads.

Due to the fact that in the wintertime the temperature of the soil surrounding an earth--sheltered house is higher than the air surrounding an above-ground building, the heat loss through walls is higher by 20–50% compared to the earth-sheltered one (Fig. 4a)). During the summertime, the heat loss is about 45% smaller since the temperature of the soil surrounding the building is lower than this of the external air, which causes not only bigger heat loss but also heat gains smaller by nearly 75%, which makes the loads of energy needed to cool down the building smaller comparing to the traditional building. The same reaction can be observed for the roof (Fig. 4b)). Heat gains through the roof are 40% smaller during the wintertime comparing to the above-ground building, which prevents the building from overheating. Heat loss is smaller during the wintertime, but larger for summer, which may be explained by the lower soil temperature than this of the external air. Heat losses and gains through the slab are comparable for the cases with the same thermal insulation thickness. It is explained by the fact that the soil temperature is mainly affected by the internal temperature inside a building, which for all cases has the same temperature points set. Thus heat flow through the slab is mainly influenced with thermal insulation thickness.

Figures 3d)/Fig. 4d) show a sum of heat gains/losses through the walls, slab and floor. It is clearly seen that for the wintertime (months 1–4, 9–12) heat gains (for the same thermal insulation thickness) are quite comparable (about 15%), while during the summer heat gains are nearly 50–60% higher for the above-ground house, which causes larger cooling energy loads. For the earth-sheltered building, as compared to the above-ground ones, heat losses through external partitions (excluding windows) are about 20–30% smaller during the winter and 15–20% bigger during the winter.

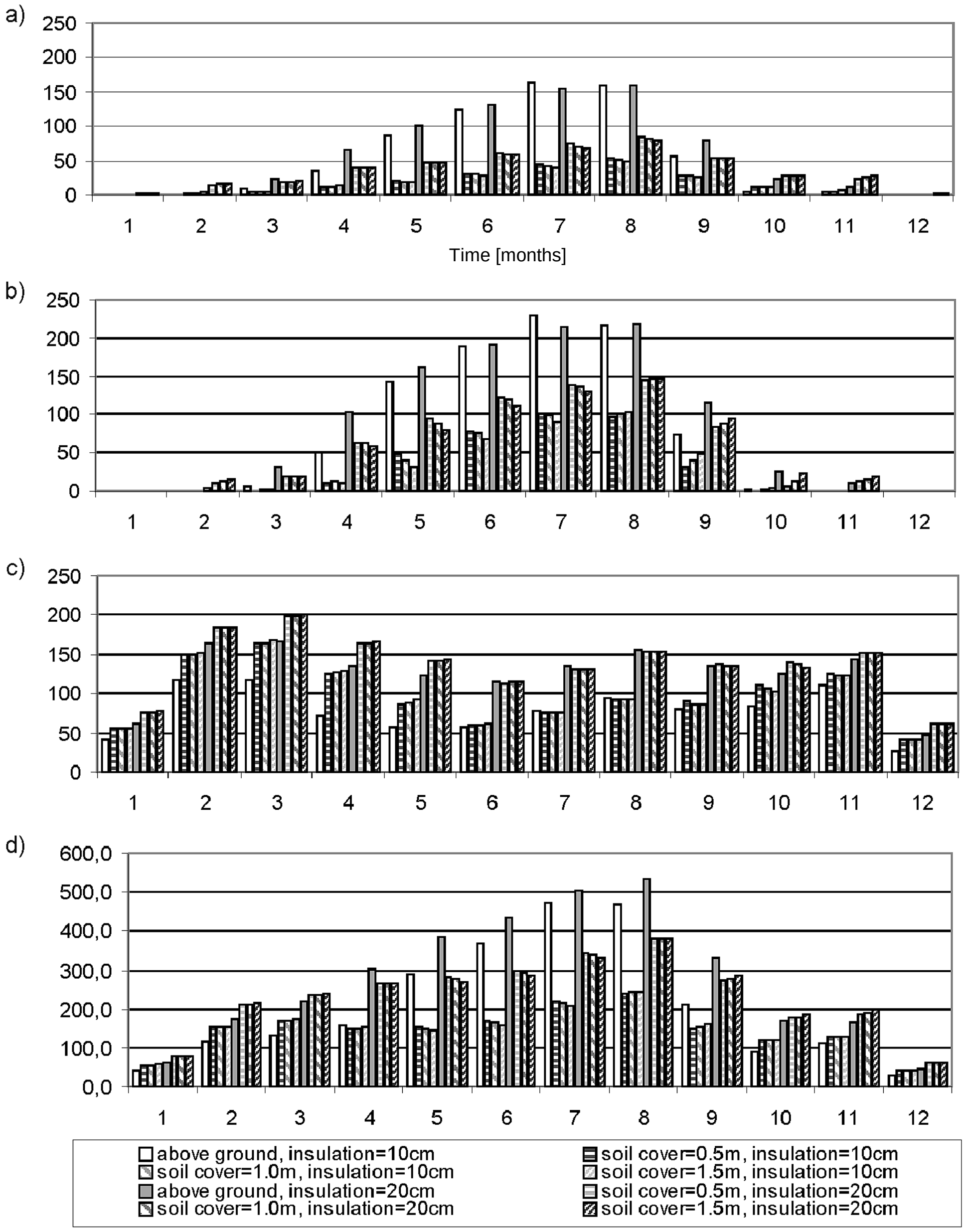

Fig. 3. Heat gains for external building partitions: a) walls, b) roof, c) slab, d) sum for: walls + roof + slab

Rys. 3. Zyski ciepła przez zewnętrzne przegrody budynku: a) ściany, b) strop, c) podłogę, d) sumaryczne dla: ściany + strop + podłoga

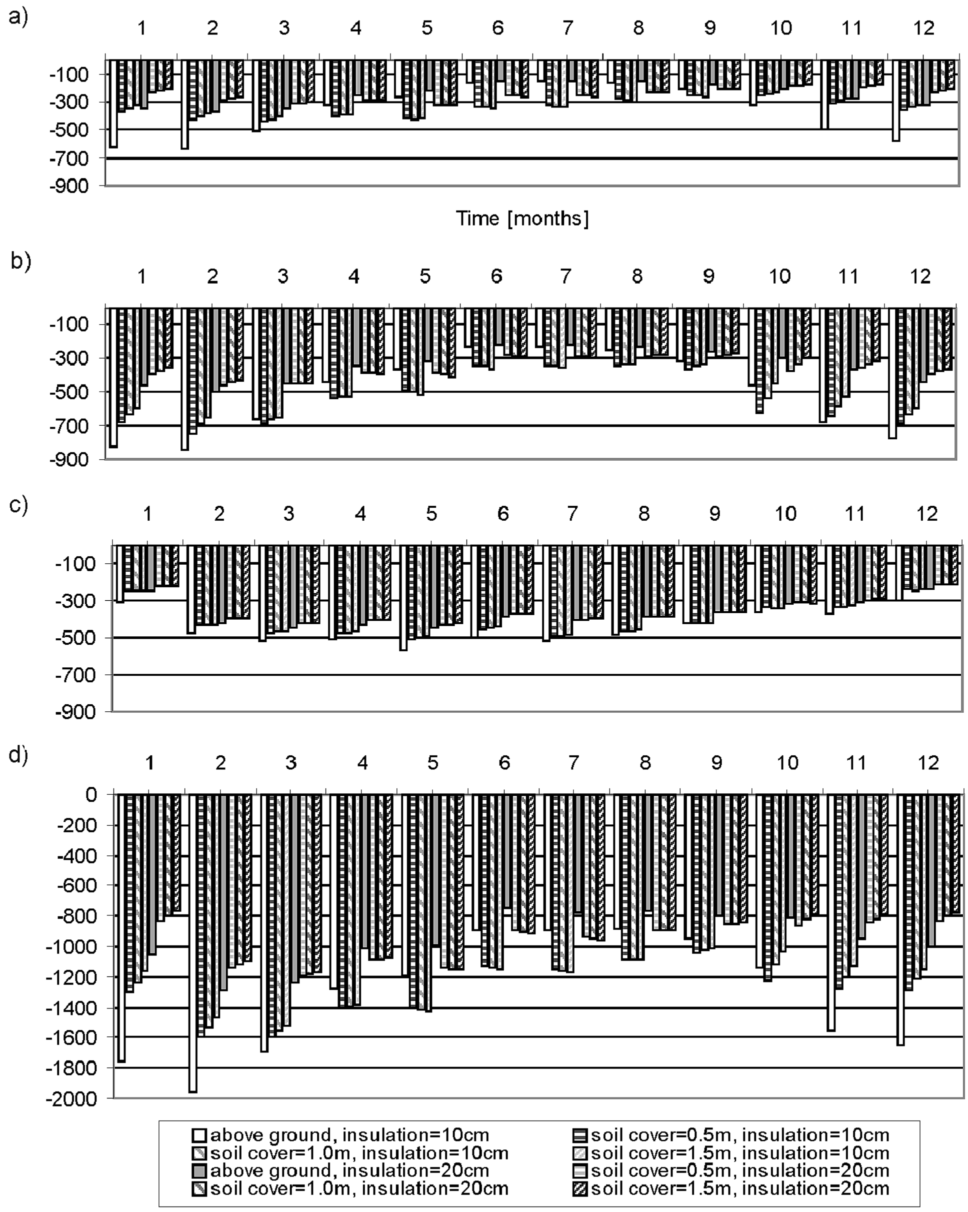

Fig. 4. Heat loss through external building partitions: a) walls, b) roof, c) slab, d) sum for: walls + roof + slab

Rys. 4. Straty ciepła przez zewnętrzne przegrody budynku: a) ściany, b) strop, c) podłogę, d) sumaryczne dla: ściany + strop + podłoga

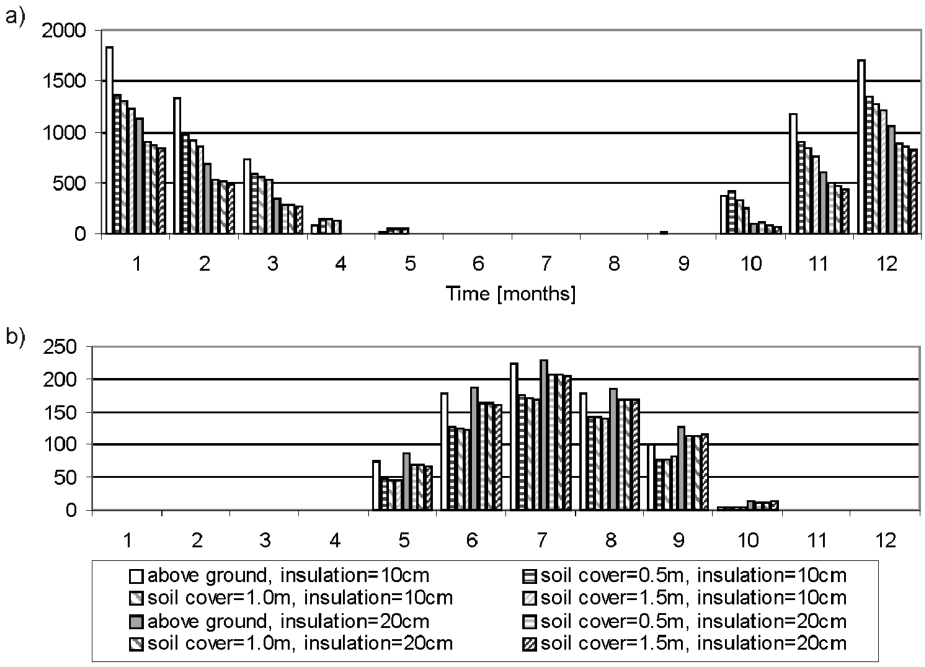

Fig. 5. Total annual energy consumption for: a) heating, b) cooling
Rys. 5. Roczne zapotrzebowanie na energię do: a) ogrzewania, b) chłodzenia budynków

Table 1

Values of annual heating and cooling energy consumption and their savings as compared to the above-ground building

Type of building, soil cover thickness [m], thermal insulation thickness [cm]	Annual heating energy [kWh]	Heating energy savings [%]	Annual cooling energy [kWh]	Cooling energy savings [%]
Above-ground, 10 cm	**7237**	–	**759**	–
Earth-sheltered, 0.5 m, 10 cm	5798	20	570	25
Earth-sheltered, 1.0 m, 10 cm	5390	25	567	25.2
Earth-sheltered, 1.5 m, 10 cm	5016	30	563	25.8
Above-ground, 20 cm	**3895**	–	**830**	–
Earth-sheltered, 0.5 m, 20 cm	3188	18	736	11
Earth-sheltered, 1.0 m, 20 cm	3040	22	734	11.5
Earth-sheltered, 1.5 m, 20 cm	2893	25	732	11.8

5. Conclusions

Covering a building with soil causes the heating energy loads to be smaller for the analysed earth-sheltered building than for a traditional one built on the soil surface (Fig. 5a)). It also requires less cooling energy loads during the summer (Fig. 5b)). The annual values are listed in Table 1. It may be noticed that the differences in heating and cooling energy savings are larger for the building with the ten-centimetre thermal insulation than for this with the twenty-centimetre one. It may be explained by the fact that in an above-ground building the thermal insulation does not allow heat to ‘go out’ from the building during the winter, where the external temperature (air) is lower, while in earth-sheltered buildings, in which the external temperature (soil) is higher during the winter than this of the external air, the thermal insulation does not allow to fully gain ‘warm’ energy accumulated in the soil. The opposite behaviour can be observed in the summertime. Since cooling loads depend mainly on solar gains, and the glazing area is the same for all cases, thus cooling loads are also comparable.

The research results indicate earth-sheltered buildings as a better solution than the above-ground ones regarding the energy efficiency. However, since the same thermal insulation thickness has been considered in all cases, more simulations and analyses need still to be done.

Nowadays, when energy demands are becoming stricter every year, this approach may become one of the ways of lowering the energy consumption in dwellings, regarding also higher costs of cooling than heating energy.

References

[1] Staniec M., Nowak H., *The future of earth-sheltered buildings* (in Polish) *Budownictwo o zoptymalizowanym potencjale energetycznym*, Wydawnictwo Politechniki Częstochowskiej, Częstochowa 2005, 381-390.

[2] Al-Temeemi A.A., Harris D.J., *The effect of earth-contact on heat transfer through a wall in Kuwait*, Energy and Buildings 35, 2003, 399-404.

[3] Xianting L., Zhen Yu, Zhao B., Ying L., *Numerical analysis of outdoor thermal environment around buildings*, Building and Environment 40, 2005, 853-866.

[4] Kumar R., Sachdeva S., Kaushik S.C., *Dynamic earth-contact building: A sustainable low-energy technology*, Building and Environment 42, 2007, 2450-2460.