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Application of Pro-Ecological Building Technologies in Contemporary Architecture

Jerzy Górski[1], Joanna Klimowicz[2] and Anna Nowak[3]

[1] Warsaw University of Technology, Faculty of Architecture, Department of Structure Design, Construction and Technical Infrastructure, Koszykowa 55, 00-661 Warsaw, Poland, jerzy.gorski@pw.edu.pl

[2] Warsaw University of Technology, Faculty of Architecture, Department of Urban Design and Spatial Planning, Koszykowa 55, 00-661 Warsaw, Poland, joanna.klimowicz@pw.edu.pl klijo@poczta.onet.pl

[3] Warsaw University of Technology, Faculty of Architecture, Department of Structure Design, Construction and Technical Infrastructure, Koszykowa 55, 00-661 Warsaw, Poland, anna.patrycja.nowak@gmail.com

Abstract. *Structural and material solutions of modern buildings are an important element of considerations in accordance with the idea of sustainable design, in which the aim is to minimize their negative impact on the environment. These searches turn towards low-tech technology, which uses natural and low-processed materials, which are possible to obtain in selected locations. Construction in the raw earth technology is a modernization of the traditional technology, in which it is possible to apply pro-ecological values associated with the used material. The paper presents research on insulation properties of walls in an experimental earth building located in Pasłęk in Poland. The aim of the research was to determine the potential of the applied raw earth technology in a local climate. The accepted design assumptions were verified due to the effects achieved in the empirical research on the thermo-humidity conditions in an experimental building. On the basis of the conducted research with the use of specialized tools, the positive and negative sides of the selected technology and building material were determined.*

Keywords: *Raw Earth Technology, Sustainable Design, Energy Efficiency.*

1 Introduction

In modern pro-ecological architecture, many trends can be identified, which lead to the design of architecture in accordance with the idea of sustainable development. One of them is circular design. The main assumption in this design approach is to use materials that can be obtained in close proximity to the design area, with the possibility of their reuse, or using bio-materials. According to this, structural and material solutions of modern buildings are an important element of considerations in accordance with the idea of sustainable design, in which the aim is to minimize their negative impact on the environment. These searches turn towards low-tech technology, which uses natural and low-processed materials, which are possible to obtain in selected locations. Construction in the raw earth technology is a modernization of the traditional technology, in which it is possible to apply pro-ecological values associated with the used material. The use of earth as "waste" from the excavated material after excavation of the foundations of the building, for the construction of external and internal walls of the designed object is an important element inscribing the project in the idea of circular design. The paper presents research on insulation properties of walls in an experimental earth building located in

Pasłęk in Poland. The aim of the research was to determine the potential of the applied raw earth technology in a local climate. The accepted design assumptions for the veranda design were verified due to the effects achieved in the empirical research on the thermo-humidity conditions in an experimental building. On the basis of the conducted research with the use of specialized tools, the positive and negative sides of the selected technology and building material were determined within the scope of a veranda designed as a heat accumulating element.

One of the trends of contemporary architecture is the use of traditional technologies and among them diverse raw earth solutions, wooden structures supplemented with straw bale walls, and use of various recycled materials.

In an experimental building described below located in the Ecological Park in Paslek in Poland the following types of raw earth technologies were used: rammed earth in formwork, earth pressed blocks, strew clay blocks and clay render. The project was carried out at the Faculty of Architecture of the Warsaw University of Technology by the team: prof. Teresa Kelm, arch. Jerzy Górski PhD, arch. Marek Kołłątaj, Dorota Długosz-Nowicka PhD, who cooperated on technological issues and carried out laboratory tests. Structures and installations designers participated in the preparation of the Construction Design.

Preparation of the project and construction of the building became possible thanks to the grant from the Ministry of Science and Higher Education in the years 2005 – 2008, involvement of the city authorities of Pasłęk and with the help of sponsors. The municipality of Pasłęk, had been interested in ecology for many years, made the plot available for construction to promote the idea of ecological construction in its area. The building was commissioned in 2012. and handed to the city. The building is administered by the management of the Ecological Park and used as an information, educational and exhibition centre.

The construction of the building was used for didactic programme on ecological construction with the use of raw earth technology, carried out in the form of seminars, practical classes, workshops and local inspections on the construction site. Also finished building is an object of further research and observation on the behavior of the structure during its exploitation. The results of such examinations will be shown in this paper.

2 Design Assumptions and Implementation Details

2.1 Spatial and Functional Characteristics of the Building

The building is detached, one-storey, without basement and is roofed by a single pitched, north-facing roof covered with extensive greenery. It is located in the south-eastern corner of a plot of land with an area of about 1 ha. It is flat meadow at a side of local lake, used by the Ecological Park to organize in summer outdoor events. In order to achieve the energy-optimal surface area of the facades, the longer axis of the building is located in the east-west direction. The facade with the largest surface area and the largest number of glazing is on the southern side, the facade on the northern side is smaller and has no openings. The main entrance to the building is located on the western side. It leads through the vestibule to the one-spatial didactic and exhibition hall located in the eastern part of the building and connected through two glass doors with a large fully glazed veranda located within the southern facade. The main room is connected with the external terrace located along the eastern elevation of the building and with the utility part (kitchenette, toilet) located in the western part. The development area of the whole building is 105 m^2, usable area 75.5 m^2 and cubic capacity 250 m^3.

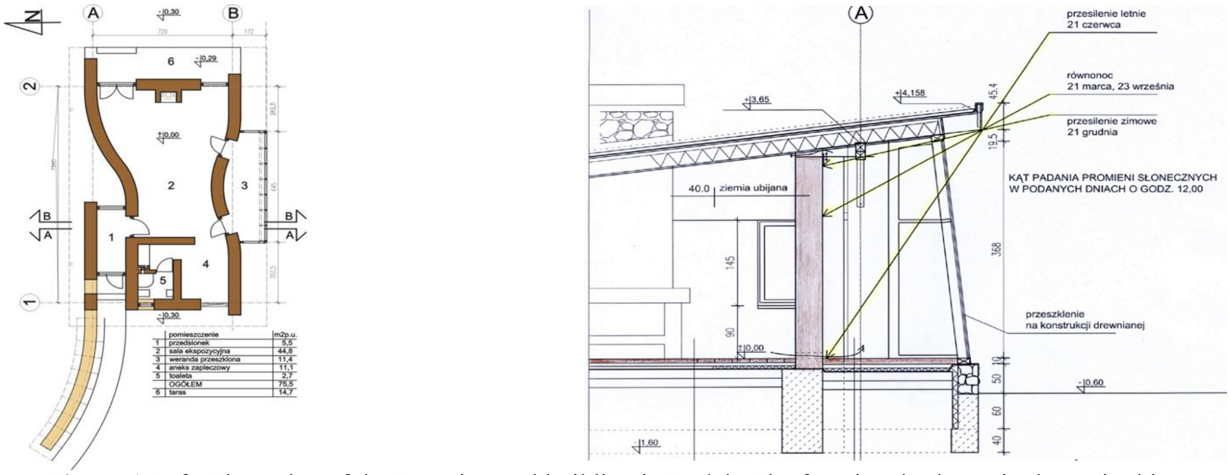

Figure 1. Left: Floor plan of the Experimental building in Pasłęk. The functional scheme is shown in this drawing 1. Vestibule, 2. Exhibition hall, 3. Veranda, 4. Back room annex, 5. Toilet, 6. Terrace; Right: Section through the veranda and the accumulation wall. The eaves is designed to shade the accumulation wall in summer. (accumulation wall not thermally insulated).

2.2 Construction Solutions

In the project, energy-efficient solutions were applied during both the implementation and the operational phases. The technology of rammed earth in the formwork was applied to the structural and external walls using the soil from the excavations on the plot (reduction of the costs of transport of construction materials). They are supplemented with an internal layer built of straw-clay blocks and thermal insulation. The partition walls are made of pressed earth blocks.

The foundations of the building are benches and foundation walls made of reinforced concrete and thermally insulated with foamed polystyrene inserts, and damp-proof with bitumen membrane. Taking into account the necessity of protecting the earth mass of the walls against water and ground dampness, the aboveground wall is elevated about 50 cm above the ground level and supported by a concrete foundation finished with natural stone.

The external walls are designed and constructed as three-layer partitions. The load-bearing layer is situated outside in form of rammed earth monolithic walls compacted in formwork using a pneumatic compactor. The raw material (soil from site) was supplemented - in order to obtain a mixture meeting the technical requirements for this type of elements - with modification additives like sand or gravel. Moreover, due to the contact of the walls with the air moisture, a stabiliser - 6 to 8 % by weight of cement - was added to the earth's mass. The load-bearing layer is topped off with a reinforced concrete ring beam with anchors for fixing the wall plates (roof structure). The internal layer of the partition was made of blocks made of clay and straw compacted mass, and the gap between the layers was to be filled with cellulose backfill (Ecofiber) replaced by mineral wool due to the price. Mineral wool is also used to insulate the roof. The inner blocks are finished with earth plaster to regulate the humidity of the interior or have a natural surface impregnated with varnish in order to stop the material from chipping. Partition walls are made of blocks made of pressed earth without any additional finishing. The floors on the ground were damp insulated with bitumen membrane laid on the underlay concrete and thermally with polystyrene. A broken stone slab floor with concrete subfloor is a thermal accumulation mass.

The unconventional order of external wall layers (rammed earth load-bearing layer as external one) was dictated by research considerations - verification of the influence of climatic factors (humidity from the air) on the earth mass and of water vapour permeation through the partition layers, determination of the dew-point, etc. It was assumed that the external surface of the compacted earth wall would be left without any finishing, as a natural illustration of an unusual technology. External walls above the window openings are made as wooden frame walls, insulated with mineral wool with internal vapour-barrier insulation, external wind-barrier insulation and wooden boarding on both sides. The roof is a single pitched, with wooden wall plates, purlins and rafters. A layer of weather-resistant tundra greenery was laid on the roof. In order to protect the rammed earth walls from direct rainwater, the roof eaves were extended from the wall line at a distance of not less than 80 cm.

The fully glazed veranda with wooden construction has a southern sloping wall. It is separated from the main room by a thick, non-thermally insulated accumulation wall made of rammed earth and room is connected with veranda by two glass doors. The windows and exterior doors are made of wood. The building has a sewerage system, cold and hot water, and electricity. The main source of heating is a freestanding wood-burning cast iron fireplace.

Figure 2. Left and in middle: View of the experimental earth building located in the Ecological Park in Pasłęk. Right: The inside of the veranda. Wooden structure glazed with low-emission composite panes. On the right there is an accumulation wall made of compacted raw earth and a door connecting with the main hall.

2.3 Energy Performance of Building Components Using Raw Earth Technologies

The experimental building in Pasłęk was designed in terms of space and materials so that the assumed construction solutions could be used for later analysis and research. At the design stage, theoretical calculations were carried out, which can later be compared with the achieved effects .

The characteristics of the basic earth and insulating materials of external walls are presented below.

The thermal conductivity coefficients of λ [W/mK] of the materials used in the walls were as follows:

- Heavy earth (for rammed earth in formwork) – 0,870
- Light weight (straw and clay blocks) – 0,350

- Cellulose insulation (Eco-fibre)/(Mineral wool) -0,040

Building material solutions of the other elements (ceilings, floor, glazing) complement the design's assumptions concerning energy efficiency. The coefficient of heat transfer through the partition for the external wall - U0 (1/Rt) - was 0.34 W/m^{2}K. The designed building was classified as a public utility building, so the expected heat transfer coefficient through the partition complied with the regulations of that time. A significant role in the energy management of the object is the passive use of solar energy. This is achieved by using a glass veranda on the south side, glazed terrace doors and windows. The amount of solar energy penetrating into the room in the form of short wave radiation depends on the size of the glazing and the type of glass in the set, especially the type of external glass. Solar energy is stored in the compacted earth wall (without thermal insulation) between the veranda and the main room and in floors made of materials that well store heat - stone and in partition walls made of pressed blocks. The stored heat is retained in the interior by the use of double glazing with low-emission internal glazing and insulating properties of the external partitions.

2.4 Inspections and Technical Examinations

The building was subject to local inspections during its execution and operation by the design team and other persons from the Faculty of Architecture of the Warsaw University of Technology.

The building has been used in various ways for over 7 years and direct feedback from users was important and it shows that the internal climate is very comfortable. During the heating period, a wood-burning stove was sufficient as a source of heat. Solid walls and flooring were a good heat accumulator and the heat buffer in the glass veranda accumulated heat on sunny days in cold period and supplemented the overall heat balance. Multi-layered external walls and roof containing thermal insulation assured even internal temperature both in hot and cold periods.

During inspections also the structural and construction problems were observed. There are no signs of uneven settling, i.e. the dimensions and structure of the foundations are correct. The visible, stone-covered plinth is in a very good condition. Above the plinth a wall made of compacted earth does not show any negative effects of climatic factors. The principle of protecting the rammed earth from moisture by raising the walls above the stone plinth and protecting them from direct rainfall by roof eaves has proved its worth.

Site inspections in 2018 apart from construction problems, also took into account the issues of internal microclimate, insulating quality of partitions and energy management. In 2019 we repeat measurements incorporating some modifications as the result of previous experiences.

The measurements were carried out at different times of the year (spring, summer, late autumn). Field tests were carried out in the following methods:

- examination of heat transfer through external partitions with thermal imagine camera for identification of possible thermal bridges,
- outside the building, measuring air temperature, wall surface temperature, humidity, insolation, wind speed,
- inside - measuring air temperature and humidity, wall surface temperature and humidity.

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Researches were divided into three parts: measurement of wall moisture (using TROTEC BM 22) in summer and in autumn, measurements of room temperature and humidity (using Testo 410-2) in summer and in autumn, and research with thermal camera (using SeeK Thermal) in autumn.

2.4.1 Measurements of Wall Moisture Using TROTEC BM 22

The first research of moisture took place on 1st August 2018. The temperature outside was 30°C and humidity outside the building was 45%. In the case of a veranda, the humidity of the partition wall from the outside decreased for 0,1%, which is caused by the relation between the southern exhibition and the positions of the points inside the veranda, which is heated by the sun during the summer period. Since the differences between the individual measurement points outside and inside the building are of the order of several decimals, it can be concluded that the walls will retain their stability.

The second research of moisture took place on 29 October 2018. The temperature outside was 5,46°C and humidity outside the building was 75%. In the case of a veranda, the humidity of partition wall from outside decreased for 0,2-0,3%. The wall moisture was higher in summer than in autumn. The amplitude of the moisture behind the accumulating wall inside the building about 0,1% and in veranda 0,2-0,3%. The difference probably depends on heating system in autumn.

2.4.2 Measurements of Room Temperature and Humidity Using Testo 410-2

The first research of temperature and humidity took place on 1st August 2018. The temperature outside was 30°C and humidity outside was 45%. The collected measurement results show higher humidity values inside than outside the building. Using this device, the humidity on the veranda was analysed, where the lowest percentage values of humidity were noted. The humidity in point 7 on the veranda was even up to 19.8% lower than in other points inside the building. It follows that a veranda with a glass wall reduces the humidity inside the building. The veranda also recorded the highest temperatures of 39°C and 40.5°C, while in other rooms the temperature ranged from 28.5°C to 29.8°C.

The second research of temperature and humidity took place on 29 October 2019. The temperature outside was 5,46°C and humidity outside the building was 75%. The humidity in veranda was the same or lower (about 1,3%) than in inside the building behind the partition wall. The temperature in veranda was lower than in inside of the building about 0,4-0,6°C.

The amplitude of temperature in summer and in autumn in veranda was 23,6°C, but delta of humidity was 5,5%. The amplitude of temperature behind the partition wall (accumulating wall) was 12,3°C and delta of humidity was 11,4%.

2.4.3 Research with Using Thermal Camera SeeK Thermal

During the visit on 29 November 2018 the SeeK Thermal thermal camera was used. Temperature measurements with the thermographic camera were taken between 14:00-15:00. During the analysis, the object was heated by a fireplace for about 2 hours.

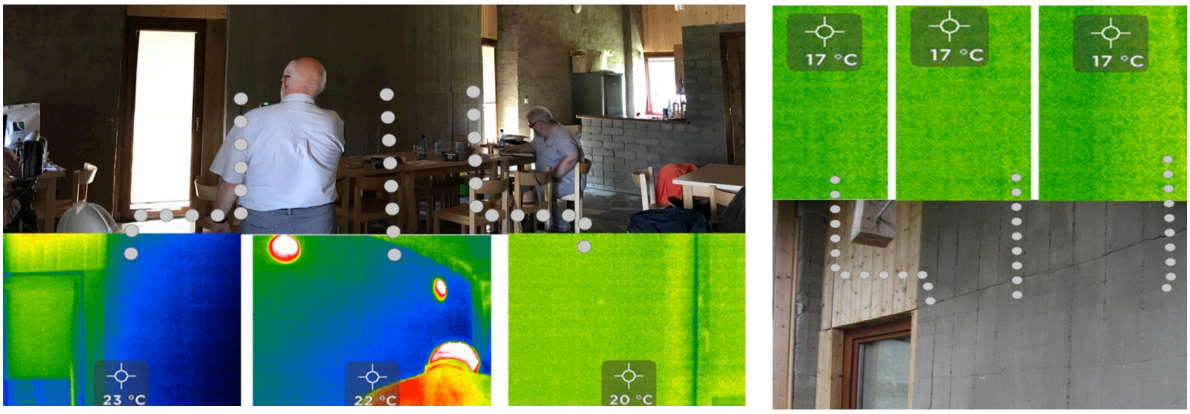

Figure 3. Measurements with a thermal camera in the interior near the accumulation wall and the glass part of the southern wall.

The wall accumulation analysis from the inside showed the temperature difference depending on the finishing materials used. On the veranda side, in three measurement points of the wall, the same result of 17°C was obtained. From the main room side the temperature varies from 23°C towards the eastern elevation, through 22°C to 20°C from the western elevation side. In case of covering the wall with wooden cladding, the temperature was higher and constant, regardless of the measurement point, and it was 25°C.

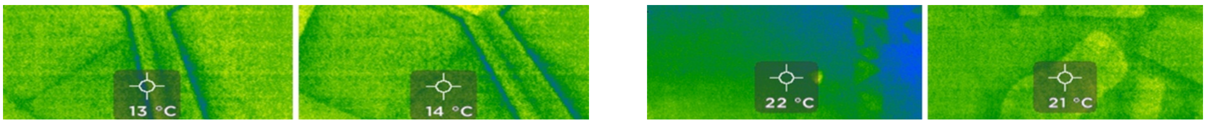

Figure 4. Measurements with a thermal camera of a glazed curtain wall on a veranda and a floor in the interior of the main utility part and veranda.

The difference in temperature in the veranda room and the main utility room is noticeable, which is caused by the adopted technical and material solutions of the external partitions. Measurements with a thermal camera show lower thermal insulation of the veranda external partitions made as a glazed curtain wall. The glazing temperature was 14°C, and the structural elements were 13°C. The temperature of the floor, finished with stone, in the part of the veranda and the main utility room was comparable. The temperature of the floor on the veranda was 21°C. The purpose of this floor is to accumulate heat generated by solar radiation penetrating through the glass wall of the veranda. The temperature of the floor in the main heated usable part was higher and amounted to 22°C. Despite the temperature difference in the rooms and external partitions, the floor temperature is similar in both rooms. It can be assumed that the stone flooring accumulates the heat generated by solar radiation, as assumed at the design concept stage.

3 Conclusions

Research has shown that there is no significant heat transfer from the veranda space, because no openings were introduced to allow ventilation and the doors, which were proposed in the design to perform this function, were closed during the use by users. Due to financial reasons external shading roller shutters, which were proposed in design, were abandoned. The research has shown that despite the fact that the object is located at the border of the forest at the southern orientation, the height of the trees crowns does not provide adequate shade. As a result, the veranda is overheated. The introduction of external roller shutters would improve the quality of the microclimate inside. At the same time, it should be emphasized that the designed accumulation wall fulfils its function and constitutes a barrier that stores heat and constitutes a thermal barrier between the veranda and other rooms. Openings in the accumulation wall should be added to allow for a correct flow of heated air from the veranda to the inside of the building. The wall made with the use of rammed earth technology meets the conditions of thermal insulation, maintaining proper temperature both in winter and in summer. The material is characterized by appropriate thermal capacity, ensuring thermal and humidity stability of the building. The rammed earth technology can be implemented in Poland in the temperate climate zone. The construction of the experimental building in Pasłęk met with interest in the scientific and architectural environment related to ecological construction. The building was awarded by an international jury of the European Union's Terra (In)cognita programme for design and innovative implementation and received the Outstanding Earthen Architecture in Europe Award in the year 2011.

ORCID

Jerzy Górski: http://orcid.org/0000-0002-4583-8144
Joanna Klimowicz: http://orcid.org/0000-0003-4950-3250
Anna Nowak: http://orcid.org/0000-0003-2952-904X

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