Paradigm ŚRODOWISKO MIESZKANIOWE/ HOUSING ENVIRONMENT 53/2025 WYZWANIA STOJĄCE PRZED ZRÓWNOWAŻONĄ ARCHITEKTURĄ ŚRODOWISKA MIESZKANIOWEGO/ CHALLENGES TO SUSTAINABLE HOUSING ENVIRONMENT ARCHITECTURE e-ISSN 2543-8700 https://doi.org/10.2478/he-2025-0032

Received: June 30, 2025; **Received in revised form:** July 4, 2025; **Accepted:** November 13, 2025

Citation: Mika, P., Jing, Y., (2025). Impact of structural system type and thermal insulation material on the internal floor area of residential buildings.. Środowisko Mieszkaniowe/ Housing Environment, e2025032. https://doi.org/10.2478/he-2025-0032

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Impact of structural system type and thermal insulation material on the internal floor area of residential buildings.

Streszczenie

Budownictwo mieszkalne w Polsce zdominowane jest przez technologię zwaną tradycyjną udoskonaloną. W poszczególnych rejonach świata stosowane są jednak inne, które z powodzeniem mogłyby przyjąć się na polskim rynku budowlanym. Opisane w artykule badania koncentrują się na wpływie rodzaju konstrukcji oraz materiału termoizolacyjnego na grubość przegrody zewnętrznej, typowej dla budynków mieszkalnych, a co za tym idzie na powierzchnię zabudowy lub wewnętrzną budynku oraz jego funkcjonalność. Badania przeprowadzono na trzech rodzajach konstrukcji ścian zewnętrznych oraz ponad dwudziestu rodzajach dostępnych na rynku materiałów termoizolacyjnych. Wyniki badań, mimo że dotyczą tylko wybranego fragmentu zagadnienia, obrazują w jakim stopniu rodzaj konstrukcji i izolacji mogą wpłynąć na powierzchnię, funkcjonalność oraz na komfort użytkowania budynku.

Abstract

In Poland, residential architecture is dominated by so-called improved traditional technology. However, other technologies are used in different parts of the world, and they can be successfully adopted on the Polish construction market. The research described in this paper focuses on the influence of the type of structural system and thermal insulation material on the thickness of the envelope, typically for residential buildings, and consequently on the footprint or usable area of the building and its functionality. The study focused on three types of external wall systems: a two-layer masonry wall with rigid thermal insulation, a CLT wall with thermal insulation and a timber-frame wall with thermal insulation material. There were over twenty market-available thermal insulation materials chosen for the research. Our findings, although they apply to only a fragment of the subject matter, demonstrate the degree to which the type of structural system and insulation material can affect a building's floor area, functionality and comfort of use..

Słowa kluczowe: technologie budowlane, budownictwo energooszczędne, ściana zewnętrzna, materiał termoizolacyjny

Keywords: construction technology, energy-efficient construction, external wall, thermal insulation material

1. INTRODUCTION

This paper discusses the design of external load-bearing walls commonly used in residential architecture. The aim of this research was to determine which technology could be considered the most advantageous in terms of its impact on building envelope thickness, i.e., allowed a larger usable floor area to be achieved with a constant footprint and the same U-value. An increased usable floor area can be interpreted as leading to an interior being more functional and providing a higher comfort of use. The right choice of materials and technology also helps to reduce the environmental impact throughout a building's life cycle. The carbon footprint, i.e., the sum of greenhouse gas emissions caused by a planned project, can be reduced by taking an informed approach to the successive stages of design, construction or operation of a building. A building's fate after its service life has come to an end is also essential. Reducing CO_2 emissions in architecture is therefore linked to the implementation of sustainable design principles and the use of energy-efficient technologies, renewable energy sources and as few processed materials as possible.

An analysis of data by Statistics Poland (Główny Urząd Statystyczny, 2024) showed that currently in Poland, the most commonly used construction technology for the erection of residential buildings is the so-called improved traditional technology (TU) (Ill. 1), which is a method of erecting a residential building in which the load-bearing structure consists of walls made of bricks or either solid or cavity blocks of a weight and size that allows them to be used by hand (Główny Urząd Statystyczny, *Techologia tradycyjna udoskonalona*). The reason this technology has become so widespread is mainly because there is no need for heavy equipment during construction (the situation may be similar in timber frame construction if entire walls are not prefabricated). However, the remaining, completely marginalised technologies have a number of advantages that few project owners pay attention to and can be associated with a significant reduction in carbon footprint or project execution time. For TU technology, the time to erect a residential building is by far the longest, with data for 2024 showing an average of 45 months. Meanwhile, 28 months were reported for big-block technology and about 27.3 months for large-panel and 33.2 for

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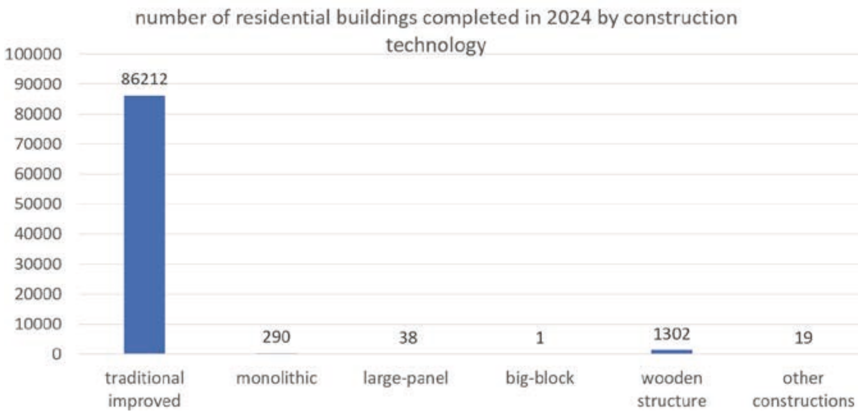
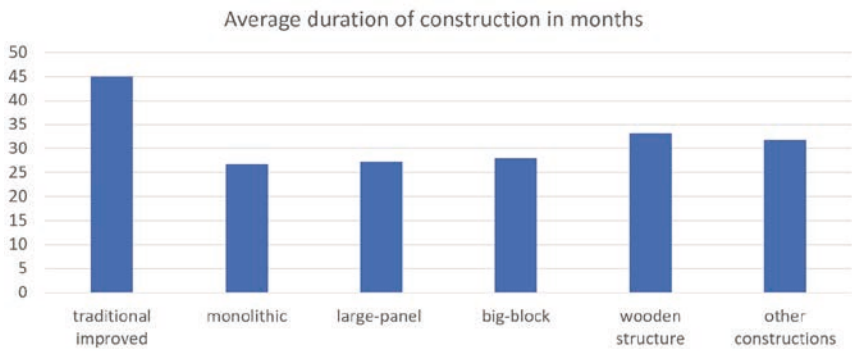


Ill. 1. Number of residential buildings completed in 2024 by construction technology (by Mika P., source of data: Główny Urząd Statystyczny, 2024)



Ill. 2. Average duration of construction time in months by construction technology (by Mika P., source of data: Statistics Poland, 2024)

timber frame technology (Ill. 2). Project execution time is highly essential. This is so not only because the project owner or buyer of a house/apartment can move in earlier, but because the entire construction process becomes shorter, and it is tied to the use of energy-consuming construction equipment that emits pollutants (particulate matter, dust, engine exhaust) and noise, leading to a lower comfort of living in the project's general area.

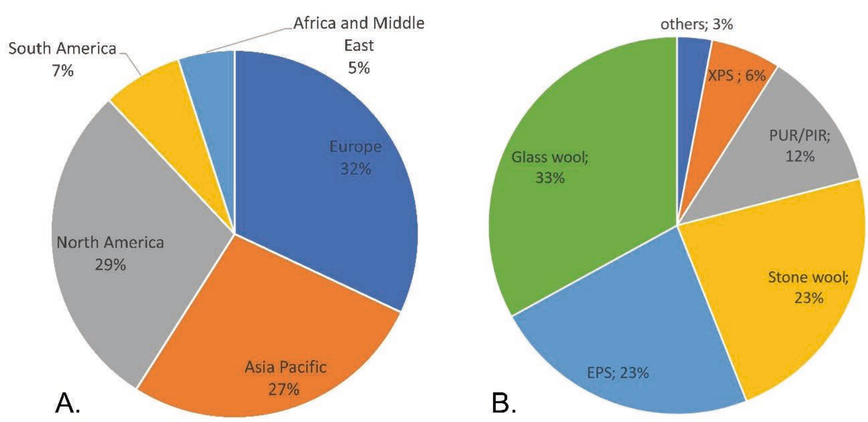
Prefabrication, so characteristic of large panel and large block buildings, but currently also of wooden buildings (both from Cross Laminated Timber, CLT, panels and timber frames), allows a shorter construction process. The entire prefabrication process takes place in dedicated plants, under controlled conditions and constant supervision. Much of the work is carried out by CNC equipment. When constructing a building using contemporary prefabrication methods, we can be certain that it is going to be built to a higher standard in comparison to building it fully at the construction site. The number of possible mistakes or inaccuracies is largely minimised. The elements can be prepared regardless of weather conditions and installed quickly, which does not generate as much noise as fully on-site projects. There will also be significantly less waste and unused material, which translates, among other things, into reduced CO_2 emissions (Orchowska 2020).

Thermal insulation is an essential part of any envelope assembly. The main purpose of insulation materials is to reduce heat transfer between the interior and the exterior, which translates into energy savings, maintaining the right temperature inside the building and increasing the thermal comfort of the occupants. Thermal insulation materials also reduce greenhouse gas emissions and the environmental impact of buildings. The performance of thermal insulation materials is based on their ability to retard heat flow (conduction, convection and radiation) through walls, roofs, floors and other building elements.

In contemporary construction, there is a very broad spectrum of materials for the thermal protection of buildings. Thermal insulation is widely used throughout the world, especially in areas with harsh climatic conditions with low temperatures. This is confirmed by the market shares in each region (Ill. 3A) (Building Thermal Insulation Market). Europe is the largest market here. This is influenced not only by development density or climate but also by a high awareness of sustainability, energy efficiency and the need to protect the environment. New buildings are being insulated increasingly effectively and existing buildings are having their performance systematically improved.

Of the thermal insulation materials available on the market, mineral wools (glass or rock) are by far the most common choice.

Ill. 3. A. Building thermal insulation market share by region 2023. B. Share of the material on the European market in 2023, (by Mika P., sources of data: A: Building Thermal Insulation Market; B: Zerari et al., 2024)



Expanded (EPS) and extruded polystyrene (XPS) comes second, and polyisocyanurate (PIR) polyurethane (PUR) foams third. These three types of material account for approximately 97% of the market. The remaining 3% are materials such as innovative vacuum insulating panels (VIP) (Zerari et al., 2024), aerogels, and also organic materials of plant or animal origin, in which the future of sustainable construction should be seen (Ill. 3B).

2. STATE OF THE ART

There is a wide range of publications that present findings of research on the properties of different types of thermal insulation. Such studies include those on the influence of thermal insulation or structural system choice on envelope thickness (Biała, 2023; Major, Różycka 2014; Danielski et al., 2012). One study investigated the thickness of the thermal insulation itself (Abdelgadir et al., 2019) and found "that the optimum insulation thickness was greatly affected by the wall structure, degree-days, and the insulation material" (Abdelgadir, et al., 2019). These studies, are often narrowed down to specific climatic conditions, in one location, (Ozel, 2011), or several (Abdelgadir et al., 2019). They address the topic of selected, usually most commonly used thermal insulation materials (EPS, XPS, mineral wool) (Abdelgadir et al., 2019; Ozel, 2011). Other studies (Mangkuto, Fela, Utami, 2019) present the results of analyses of the relationship between wall thickness and interior lighting in buildings. Eliza Szczepańska-Rosiak and Dariusz Heim (Szczepańska-Rosiak, Heim, 2015) demonstrated that changes in wall thickness (25 and 50 cm, without taking into account the choice of materials or type of construction) and window geometry significantly affect the amount of daylight entering an office space. Their findings showed that wall thickness plays a very important role in shaping the quality of usable space.

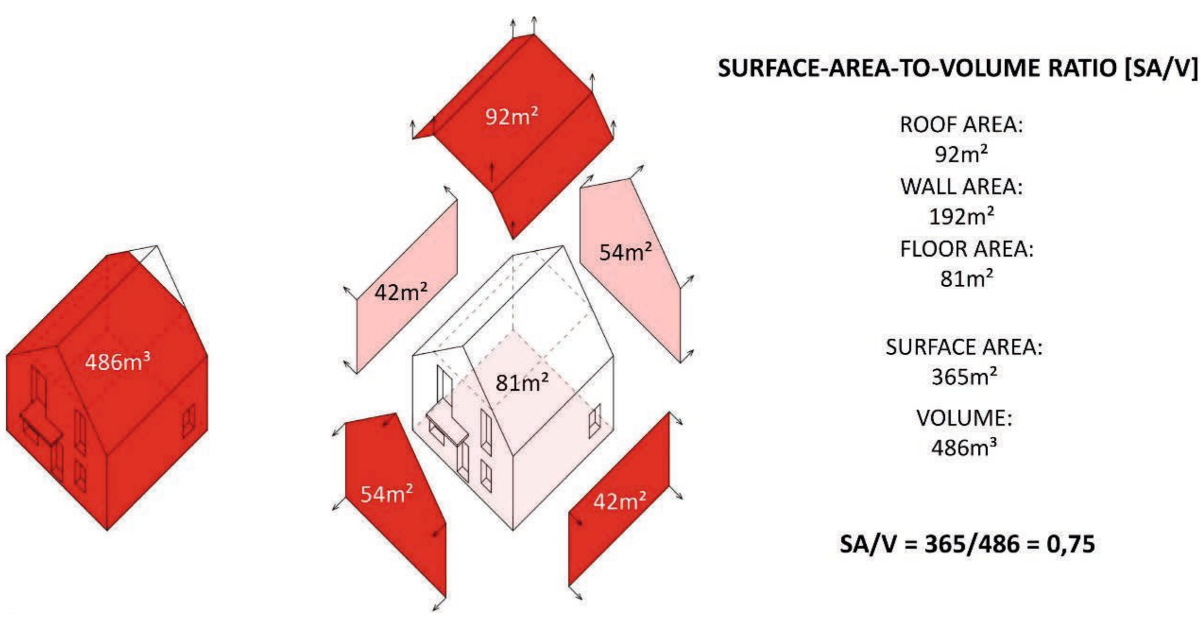
New studies extend this issue to include life cycle assessment and environmental impact. Silvestre et al. (2016) conducted an ecological analysis of cork insulation, indicating that its use reduces the carbon footprint of buildings throughout their life cycle. Similarly, Nucci and Iraldo (2016) compared four types of insulation made from natural and recycled materials, proving that sheep's wool or hemp can have a lower environmental impact than traditional synthetic insulation.

Another important issue is the impact of insulation on the economically optimal thickness of partitions. Research by Al-Sanea and Zedan (2012) shows that the choice of insulation material should be considered not only in terms of thermal properties, but also in terms of life cycle costs and local climatic conditions.

This study presented an analysis of the relation between the technology of erecting load-bearing external wall assemblies and the necessary thermal insulation thickness (and that of the entire assembly) and the impact of this decision on daylighting and how the wall edges of the building block daylight admission. The consequences of the adopted solutions for daylighting and interior shading were also analysed, which allows for a more comprehensive view of the issue,

Ill. 4. Plans and section schemes of the house analysed, with a 46.5 cm thick external wall assembly (by Mika P.)

Ill. 5. Surface area to volume ratio of the house under study (by Mika P.)



combining technical, functional, and environmental aspects (Lylykangas, 2009).

The study was conducted on three types of external wall assemblies – one built using the improved traditional method, one built using CLT panels, and a timber frame wall. Insulating materials were compared, both those with dominant shares on the construction market and those that are rarely used but have significant potential due to their limited negative impact on the environment – plant- and animal-based.

3. METHODOLOGY

The methodology was developed to verify the research hypothesis that the choice of wall construction technology and thermal insulation materials affects not only the thickness of the partition and the usable area of the building, but also functional and environmental aspects. The study is therefore comparative in nature, and its results can serve as a reference point for further empirical research (Creswell, 2014; Yin, 2018).

A small single-family house with a usable attic was designed (Ill. 4). The building has a simple form, with a 9 × 9 m plan, with a gable roof with a 40° incline. The floor-to-floor storey height is 3.0 m and a ridge height of 8.5 m. The external walls were constructed using TU technology. Cellular concrete blocks with a thickness of 24 cm and a thermal conductivity coefficient of λ = 0.09 W/mK were assumed as the reference structure. EPS with a thickness of 20 cm and λ = 0.031 W/mK was used as thermal insulation. The U-value adopted was 0.11 W/(m²K), which is slightly less than the value assumed for passive buildings (Kaczkowska, 2023).

The total thickness of the assembly, using the materials listed, was 44 cm and 46.5 cm when plaster was accounted for. The footprint of the building was 81 m² and the internal floor area, calculated according to building standard (PN-ISO 9836:1997), was 130.0 m².

When designing the building for the study, the A/V ratio (shape factor, form factor, area-to-volume ratio) i.e., the respective ratio of the building envelope to the volume of the house, was also taken into account (Ill. 5). According to various sources, this value should be within the range of 0.70 and 1.25 (*Co to jest współczynnik kształtu budynku*?; Apollo, Miszewska-Urbańska, 2018; Lylykangas, 2009; Danielski et al., 2012)

As a rule, it has a significant impact on the amount of heat loss, although, in the case of passive, highly insulated buildings, its importance decreases (Kaczmarzyk, 2017). The larger the building to be designed, the more favourable the ratio. With such a small detached house, however, it was possible to achieve a score in the lower limit – 0.75.

To investigate how technology affects the use characteristics of a building, four different wall assembly types were compared (Ill. 6), each with different structural and insulation materials.

A. External, two-layer wall assembly (Ill. 6A). This is the solution that is the most common in Poland, and consists of a load-bearing layer in the form of ceramic masonry, aerated concrete, or silicate masonry units. They have similar strength characteristics, making them around 25 cm thick. The insulation material in this solution is usually in the form of a panel, which is glued and studded to the supporting layer.

B. Structural wall consisting of a CLT panel with insulating material (Ill. 6B). This solution is rarely used in Poland at the moment. It is only in recent years that the first residential and public or commercial buildings using it have begun to appear.

C. Timber frame wall with thermal insulation material between structural elements (Ill. 6C).

In addition to the variation in structure type, the study investigated four categories of insulation materials:

- of mineral inorganic origin (rock wool, glass wool, foam glass),
- of organic origin, derived from fossil fuels (EPS, XPS, PUR foam, PIR foam),
- of organic origin, plant- or animal-based (wood wool, cork, cellulose, hemp insulation, seagrass insulation, straw insulation, flax insulation, sheep wool insulation),
- innovative (aerogel-based, VIP vacuum insulation panels, recycled plastic insulation).

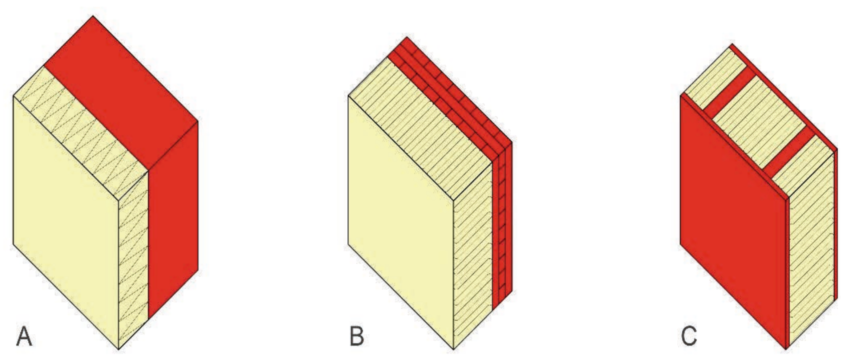
The study was based on the parameters declared by the manufacturers. All products were available on the market at the time of the study. The thermal conductivity coefficient λ W/mK was crucial from the perspective of this analysis. From among the materials collected, in each category, those with the lowest coefficient were selected. U-value calculations were performed for each wall assembly version, taking into account the heat transfer coefficient on the external and internal surfaces (Rse = 0.13 m²K/W; Rsi = 0.04 m²K/W), but ignoring the wall finish layers on the inside and outside. The insulation values of these layers are usually so small that they do not play a significant role in the overall calculation.

4. RESULTS

4.1. Two-layer wall assembly with rigid thermal insulation material (A)

In the first instance, thermal insulation materials were examined that could combine with the structural layer technology used (aerated concrete), i.e., in the form of panels. Of those surveyed, VIP panels had the best performance. According to the parameters declared by their manufacturers, a panel thickness of only 3.6 cm was sufficient to achieve the desired U-value when combined with aerated concrete. The total wall thickness in this case was 27.6 cm. However, their price, complicated installation, durability (performance can deteriorate over time, possibility of damage) and availability significantly limit their use in common single-family housing. They are used in exceptional situations, such as cold storage envelopes. Of the commonly available materials, closed-cell PUR foam achieved the best result. The total wall thickness here was just under 38 cm, which is more than 5 cm less than in the case of EPS.

Ill. 6. Types of wall assemblies analysed in the study (by Mika P.)



Type of Thermal Insulation	TI thickness [cm]	Wall thickness [cm]
Stone wool	20.7	44.7
Glass wool	18.0	42.8
Glass foam	23.8	47.8
EPS	18.9	44.0
XPS	18.1	42.1
PUR/PIR	13.8	37.8
Wood wool	22.6	46.6
Cork (board)	22.6	46.6
Hemp	25.0	49.0
Seagrass	23.2	47.2
Flax	22.5	46.5
Aerogel	8.0	32.0
VIP (Vacuum ins. panel)	3.6	27.6

Ill. 7. Thickness of thermal insulation for a Type A wall with U = 0.11 W/(m²K) (by Yifan J.)

4.2. Two-layer CLT wall assembly with rigid thermal insulation material (B)

The second type of wall is a CLT-type structure with a thermal insulation layer. It is widely used in Austria, but in Poland is largely unknown (Wesołowski, 2022; Chrzanowska, 2025). CLT allows large timber panels to be created in dedicated plants from square timbers with small cross-sections. The thickness of such a structural panel is usually around 10–12 cm. The thermal conductivity coefficient is assumed to be 0.12 W/mK (CLT by Stora Enso, 2020). The technology allows for partial and full prefabrication (including joinery and trim) and is considered sustainable due to the use of timber as the main construction material. Wood is a fully renewable raw material and, if sourced from sustainable plantations, should be certified.

Ill. 8. Thickness of thermal insulation for a Type B wall with U = 0.11 W/(m²K) (by Yifan J.)

Type of Thermal Insulation	TI thickness [cm]	Wall thickness [cm]
Stone wool	27.0	39.0
Glass wool	23.7	35.7
Glass foam	28.5	40.5
EPS	27.0	39.0
XPS	23.0	35.0
PUR	17.5	29.5
Wood wool	28.5	40.5
Cork	28.5	40.5
Cellulose	29.3	41.3
Hemp	31.0	43.0
Seagrass	29.3	41.3
Straw	51.5	63.5
Flax	28.5	40.5
Sheep wool	27.7	39.5
Aerogel	11.0	23.0
VIP	4.5	16.5
Recycled PET	27.7	39.5

In the case of this structure, due to the low thermal conductivity coefficient, again the thinnest partition was achieved using PUR foam – 29.5 cm. Although solutions such as aerogel and VIP panels make it possible to significantly reduce this value, they are not widely used due to the specific nature of these products. However, the closed-cell PUR foam included in the study is not the best choice for this type of structure. The high diffusion resistance of the insulation can, under certain climatic conditions, result in moisture build-up in the wood which, over time, would lead to irreversible damage. The situation will be similar for extruded polystyrene (XPS). From the point of view of building physics, glass wool (wall thickness of 36 cm) and insulating materials of organic plant or animal origin seem to be the best solution, in this version. Of the latter, the results for wood wool, cork and sheep's wool were the most promising. The total wall thickness can oscillate around 40–41 cm. Thanks to the wide variety of these materials, partitions can be designed from locally sourced raw materials. This will reduce, to some extent, the carbon footprint resulting from transport and also minimise the problem of disposing of material during demolition. However, these materials can come in variants with chemical additives to improve hydrophobic parameters, protection against moisture, fungi and fire.

4.3. Timber-frame wall with thermal insulation material (C)

The third wall type to be investigated was timber frame. It is a technology that is widely used in the United States, Canada, and Scandinavian countries. It is now apparent that there is an increase in investor interest and a growing number of companies involved in the design and construction of this type of building (Malesza, Miedziałowski, Jarosław, 2015). Its advantages include, but are not limited to, a short construction time, no need to use heavy equipment and the potential for complete prefabrication. This study found that it allows for significantly thinner walls while maintaining similar thermal performance to other assemblies.

Of the commonly used thermal insulation materials, PUR foam is again the best. The thickness of the wall, which achieves the intended coefficient, is 22.5 cm, which is about 15 cm less than with previous technologies. However, it should be noted here that PUR foam comes in two variants – closed-cell and open-cell. Closed-cell PUR foam has significantly better insulating properties and

Ill. 9. Thickness of thermal insulation for a Type C wall with U = 0.11 W/(m²K) (by Yifan J.)

Type of Thermal Insulation	TI thickness [cm]	Wall thickness [cm]
Stone wool	28.8	31.2
Glass wool	26.2	29.4
Glass foam	33.2	36.3
EPS (granulate)	26.2	29.4
PUR	19.2	22.5
Wood wool	31.5	34.1
Cork (granulate)	33.5	36.1
Cellulose	32.3	35.7
Hemp	35.0	38.5
Seagrass	32.3	35.7
Straw	42.0	45.4
Flax	31.5	34.1
Sheep wool	30.6	33.4
Recycled PET	30.6	33.4

Ill. 10. Plan and section diagram of the analysed house with 26.0 cm thick external walls. The dashed line shows the outline of the reference building with walls 46.5 cm thick, (by Mika P.)

was considered in the study. However, it is a vapour-proof material and should be used on dry structural elements.

With glass wool, the wall thickness increased to 29.5 cm, an increase of 7 cm. Again, by far the thickest assembly was obtained by using straw as thermal insulation material – around 45 cm.

Thermal bridges were not considered in this study. However, they can be expected to occur in every case – at the point of contact of different structural materials (a wall with a lintel, a wall with a tie beam), around window and door openings, in places with structural posts in a timber frame. However, there are ways to minimise or completely eliminate these bridges.

Sections of load-bearing walls made of materials with a higher thermal conductivity coefficient (e.g., reinforced concrete lintels, columns in knee walls, tie beams) can be made slightly thinner and additionally insulated. According to current standards, door and window frames should be extended into the thermal insulation layer using suitable supports and secured with vapour-proof tapes designed for this purpose. In the case of frame walls, part of the thermal insulation can be placed between the grid added on the inside and a continuous cladding of hard insulation board (e.g., wood fibre board) can be made on the outside. It is also effective to replace solid timber posts with I-beams whose flanges consists of boards of glue-laminated veneer and its web is hardboard (System budowlany STEICO, 2018).

5. SUMMARY

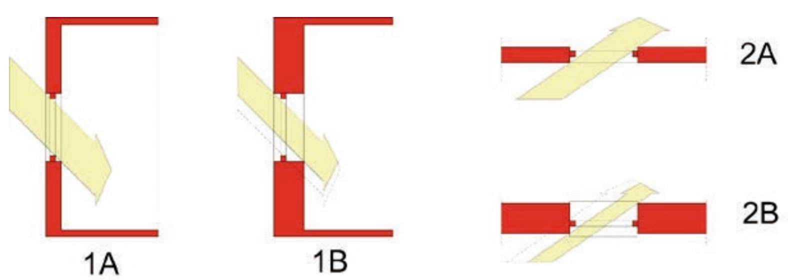
This study found that the thinnest wall assembly, composed of commonly available materials, can be achieved in a frame structure filled with closed-cell PUR foam. The thickness of the envelope, with a thermal transmittance of 0.11 W/(m²K), was 22.5 cm and, with cladding and internal and external render, 26.0 cm (Ill. 10). Such an external envelope, applied to the designed single-family building, allowed a total internal floor area of 144 m² for both floors. This is 14 m² higher than the TU technology, with the same building footprint. Compared to the reference building, the area increased by 10.76%. This is an area that can correspond to, for example, a bedroom for one person.

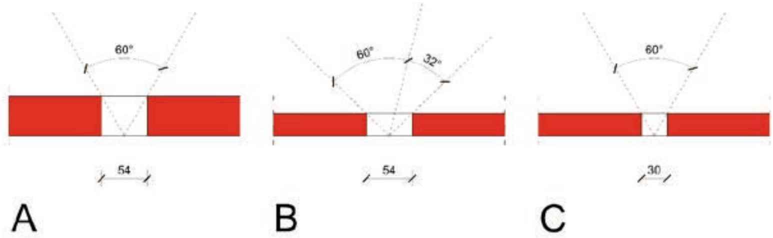
One of the disadvantages of a timber-frame house is its low thermal inertia, i.e., its inability to store thermal energy (Major, Różycka, 2014). This property allows the building to be heated but also cooled quickly. In certain circumstances, it should be considered an advantage – for example, if the building is used periodically. For continuous use, it may be more economically advantageous to accumulate energy, especially that from solar radiation. The energy stored during a sunny day (heated walls, ceilings) is released at night, reducing the need for heating. The opposite situation will occur in summer, during a heatwave – a ventilated, night-cooled interior will provide comfort during the day (Bać, Michalski, 2022). In timber-framed buildings, this property does not occur, but energy accumulation can be partially ensured by making the foundation slab and floor of concrete and, for example, the partition walls of brick or concrete. They will be of similar thickness (so there will be no significant difference in floor area) and can have a positive impact on comfort.

Interior daylighting is also an important factor for comfort. It involves aspects such as ensuring adequate natural light levels indoors, providing the necessary visual stimuli, allowing occupants to feel the circadian rhythm, and positively influencing wellbeing and psychological comfort (Kuczia, 2009). In addition, sunlight eliminates microorganisms, influences the perception of the interior, colours, etc. A thinner wall allows more sunlight to penetrate into the building (Ill. 11) – a window aperture with a thicker partition needs to be designed with a larger area to provide the same comfort of use. Not only will this involve a higher cost, but there will also be an increase in the length of linear thermal bridges, around the window frames, at the point of installation. The window itself can also be considered as a thermal bridge, especially when it faces northwards – it does not generate thermal gains and its heat transfer coefficient is usually 4–5 times higher than that of a wall. Therefore, the larger its surface area, the greater the heat loss.

The situation is similar for view obstruction. According to §13 of the Regulation on the technical conditions to be met by buildings and their placement, 'Daylighting', interior daylighting is considered sufficient if, among others 'there is no obscuring part of the same building or other obscuring building within the arms of a 60° angle developed on a horizontal plane, whose tip

Ill. 11. Difference in interior insolation with a wall thickness of 26 cm (A) and 46.5 cm (B). Vertical sections (1) and plans (2). (by Mika P.)





Ill. 12. The difference in the angle of manoeuvre and the width of the window aperture to meet the daylighting requirement with a wall thickness of 46.5 cm (A) and 26 cm (B and C), (by Mika P.).

is situated at the internal face of the wall with the window of the indoor space whose view is being obstructed...' (Rozporządzenie Ministra Infrastruktury, 2002). By reducing the thickness of the wall from 46.5 cm to 26 cm, a greater angle manoeuvre area of 32° can be achieved (Ill. 12B) to avoid a possible obscuring building or, in the absence of a building, this condition can be met with a much smaller window aperture (Ill. 12C). This not only reduces thermal bridges, but also gives designers more options in terms of facade composition (size and location of windows).

6. CONCLUSIONS

The following conclusions can be drawn from the analysis:

- Advanced insulation materials, such as VIP vacuum panels and aerogels, enable a significant reduction in the thickness of partitions, but their cost, limited durability, and technological issues limit their use in residential construction.
- The choice of not only the insulation material but also the wall construction technology has a significant impact on the thickness of the envelope. Relative to the prevailing material and technology solutions, the gain of internal floor area was more than 10% which aligns with the results of similar studies (Major, Różycka, 2014).
- Organic plant- and animal-based insulation proves to be an interesting alternative to the dominant insulation materials. Their thermal conductivity coefficient is sometimes close to that of materials such as EPS or mineral wool. However, they have the added advantage of being possible to produce locally and having a small carbon footprint, as most of them can be made from waste (e.g., straw, cork).
- A wall with less thickness allows for a window aperture with a smaller surface area, while providing the same degree of interior insolation. A smaller window aperture means a reduction in linear thermal bridges at the window frames and jambs.
- With a pitched roof and a low knee wall in the attic, we will not benefit from a thinner external wall.
- The choice of wall structure technology and the choice of thermal insulation material have a significant impact on the function of residential buildings, their degree of environmental impact and comfort of use.

When choosing technology and building materials, other factors should be taken into account, such as, for example, the strength of the elements, their price, availability, fire resistance and aesthetics.

The results of the research and the conclusions drawn from it served as reference material supporting the implementation of student projects at the Faculty of Architecture of the Cracow University of Technology as part of facultative classes. These projects focused on the development of buildings using sustainable, local, and traditional building materials, which enabled the practical application of theoretical knowledge in the context of environmental, functional, and technological aspects of construction (Ills. 13–16).

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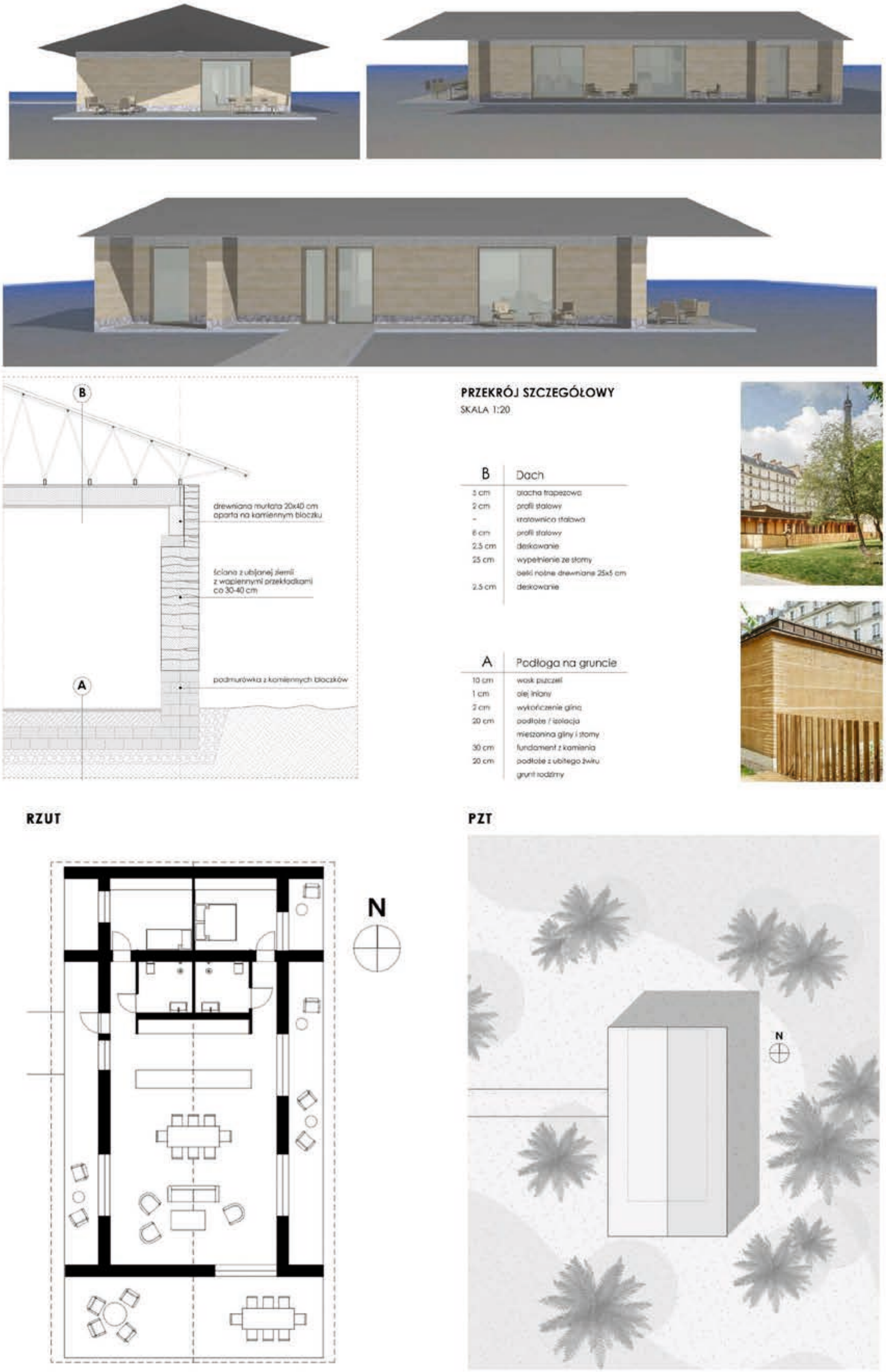
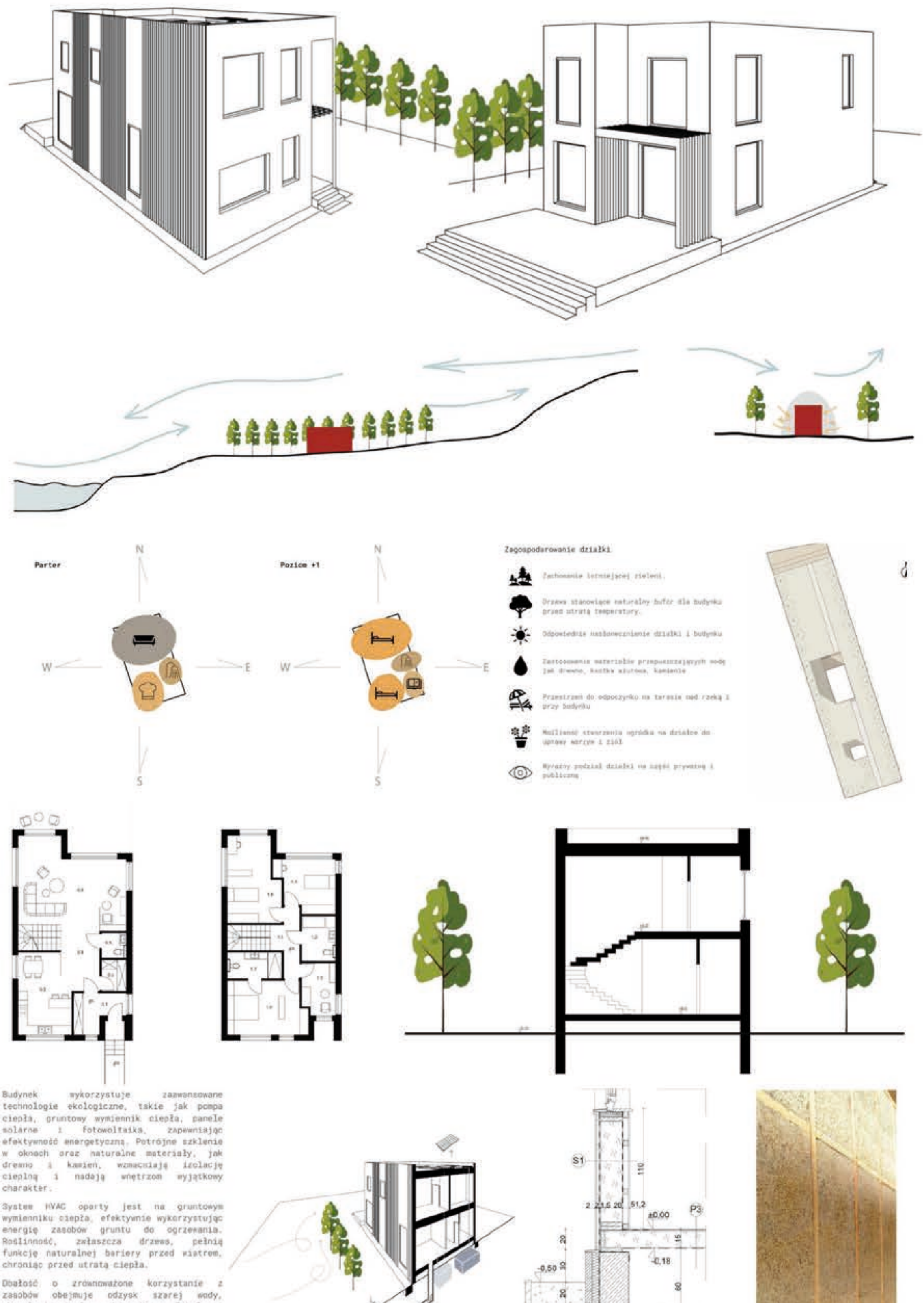
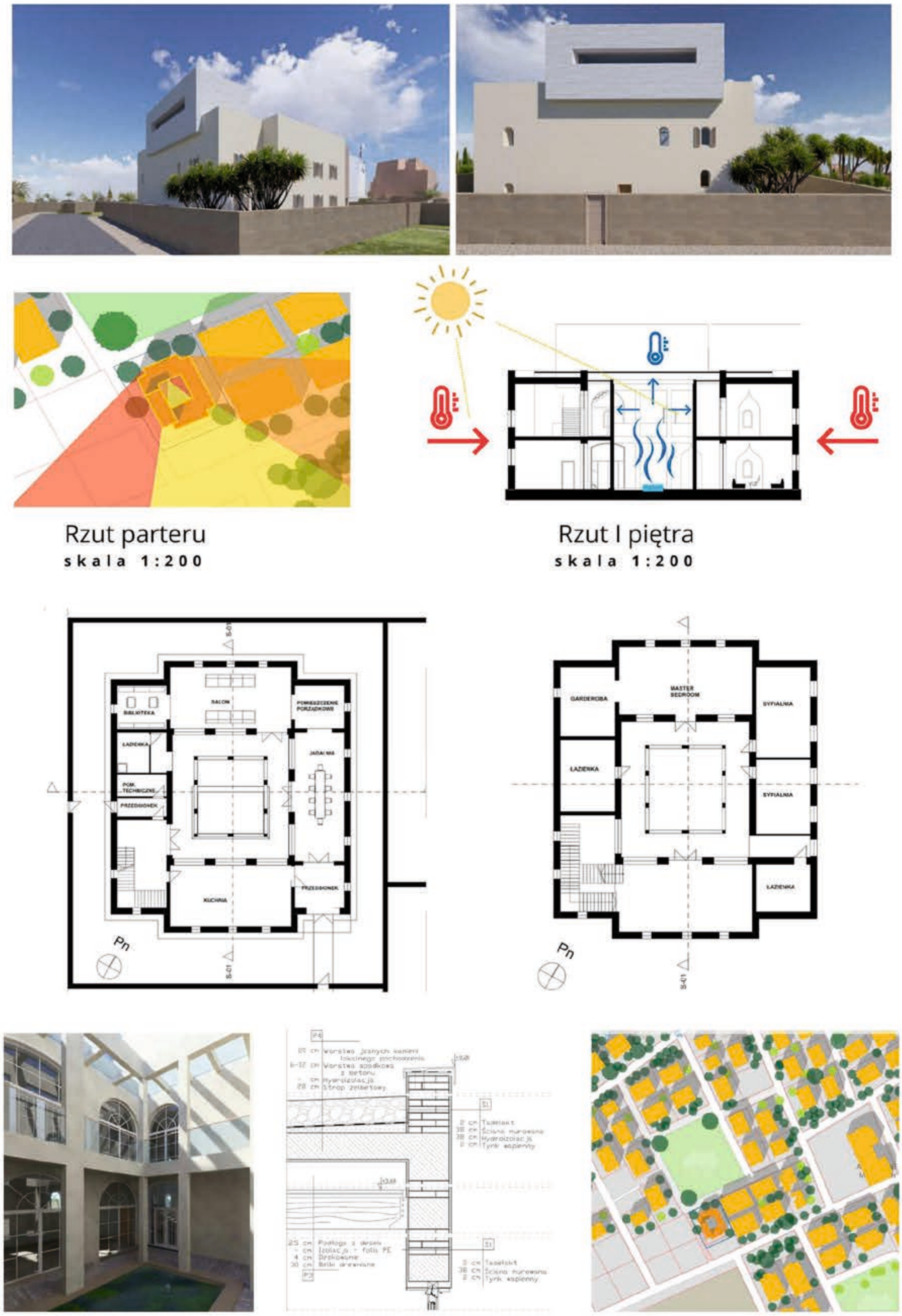


Ill. 13. K. Jarczok, R. Machura: concept of a single-family house, made of sustainable, local, traditional building materials.



Ill. 14. W. Boroń, W. Chłopek: concept of a single-family house, made of sustainable, local, traditional building materials by Rożnowskie Lake.



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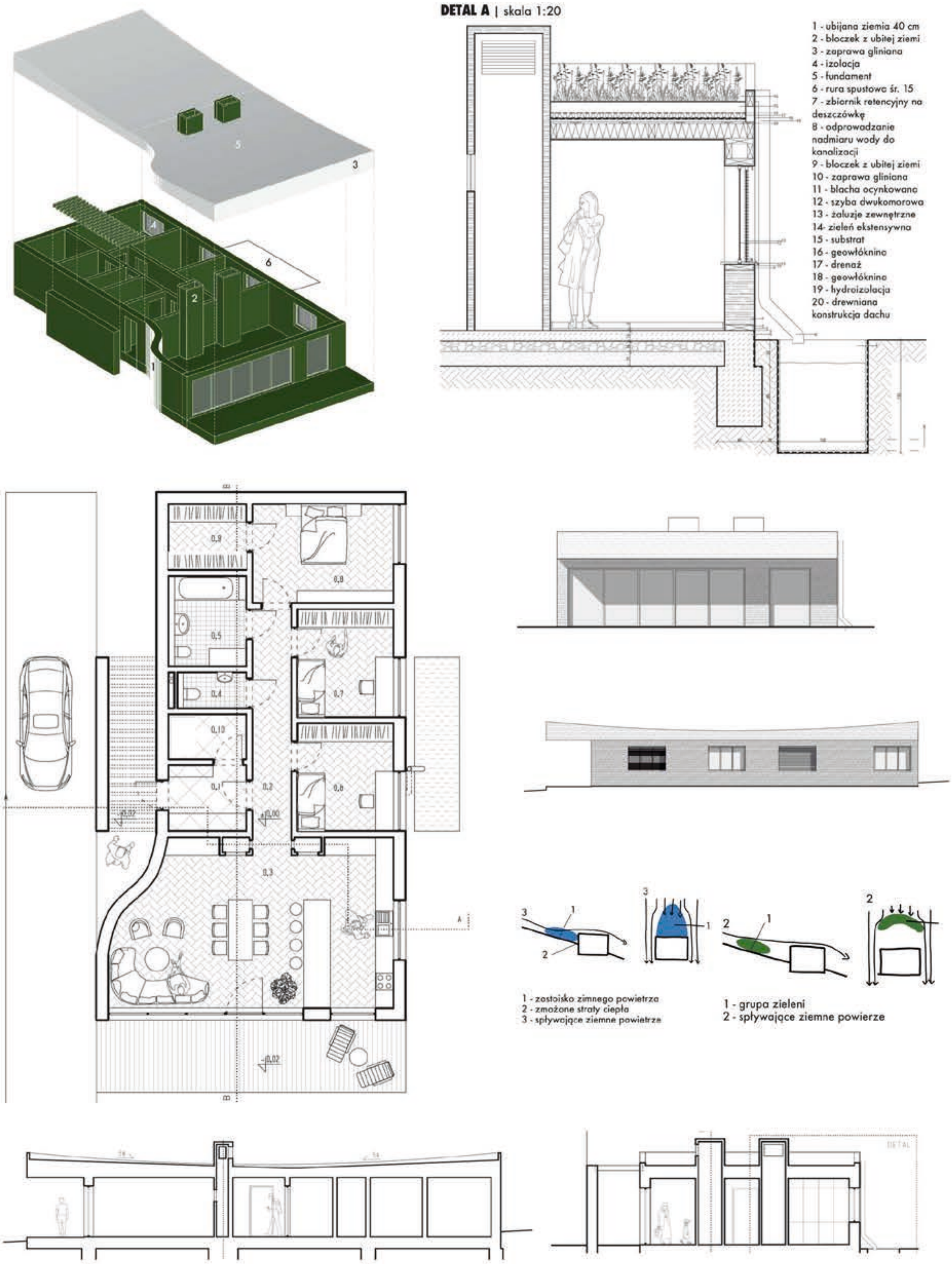

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