On some aspects of modernisation of a wooden house with special cultural value

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Abstract. This paper presents specification of the scope of modernization of a wooden house built in 1950 in the village of Nowoberezowo in the Podlaskie voivodship (eastern Poland). It was constructed in traditional technology that is specific for this area and which dates back to the 19th century. It was considered that due to special cultural values it is necessary to preserve the exterior appearance of the building. For this reason, the idea of insulating its external walls from the outside was abandoned. In connection with planned interior remodelling and the selected variant of insulation of external walls from the inside, a hydrothermal analysis was carried out. On this basis, the maximum acceptable thickness of the thermal insulation layer was determined given the need to protect wood against degradation resulting from long-lasting moisture. The necessity to ensure adequate air exchange in rooms was emphasized and a mechanical ventilation system was proposed. Next, the impact of the proposed treatments on the change of energy performance was evaluated. An economic assessment was also made and a simple payback time was determined.

1 Introduction

Standard thermal upgrade solutions, e.g. improvement of thermal insulation of external housing elements, improvement of air tightness of a building, replacement of heating installations and use of mechanical ventilation with heat recovery, are generally known. However, in the case of a house with a wooden structure, which can be qualified as having special cultural value, extraordinary care should be taken not to destroy the unique character of this building, and the proposed scope of modernization must guarantee maximum durability of wooden elements. Therefore, a heat and moisture analysis is extremely important.

2 Description of the existing building

The house (Figure 1) was built in 1950 in the village of Nowoberezowo (Hajnówka county, Podlaskie voivodship). It was built of wood in accordance with the tradition dating back to
the nineteenth century [4]. The building was erected on a foundation made of bricks arranged on a concrete screed. The floor is raised in relation to the ground, with a ventilated under-floor space: 6 ventilation holes with a diameter of 10 cm were made in the foundation walls. External walls were made of rectangular pine logs, about 8 cm thick. They are covered from the outside with a layer of roofing felt and timber board. All connections between wooden elements were sealed with linen tow. Hand-hewn beams were joined together using dovetail joints and additionally reinforced with wooden dowels [2]. In the 1980s, the gable wall, destroyed by a gusty wind, was repaired. A little later, the granary adjacent to the residential part was removed and a porch with steel doors was built. Original wooden casement windows were equipped with external shutters. Unfortunately, in 2004, all of them except one were replaced with PVC windows [2]. The ceiling over the first floor was insulated with sawdust. The roof truss is wooden with a collar beam construction. The roof is gabled. Currently, it is covered with galvanized trapezoidal sheet, but originally it was covered with asbestos boards.

Fig. 1. View of the house (photo taken in the late 1970s) [2].

Only one storey is residential and the attic is unusable. The house has five rooms, a kitchen and a hallway. The rooms were heated with two tiled stoves and a tiled kitchen with a hearth under a hob and with a bread oven. The air required for hygienic reasons and for combustion flows into the interior through leaks in the external envelope. If necessary, the interior was ventilated by opening the windows. In the 1980s the plumbing system was mounted only in the kitchen. For hot water preparation, a heat exchanger in the form of a coil installed in the kitchen stove is used. The tank has a capacity of 200 dm³. If necessary, water can be heated to the required temperature by means of an electric heater.
3 The purpose and scope of modernization of the house

Since the farm is planned to be transformed into an agritourism farm with a full-year rental of the house, the main goals of the modernization include:
- reconstructing the original exterior style,
- raising comfort of inhabitants and the standard of equipment,
- improving internal comfort in winter, mainly in terms of temperature and air quality,
- eliminating cumbersome service of tiled stoves,
- improving the energy performance of the building, and
- rationalisation of operating costs.

In order to achieve these goals, the following actions were proposed:
- reconstruction of an additional room, a so-called granary, intended for a boiler room,
- restoration of external decorations,
- renovation of external shutters,
- replacement of PVC windows with wooden casement windows,
- replacement of steel doors with wooden ones,
- creating a bathroom and a toilet by adapting one of the rooms,
- construction of a new heating system,
- installing a pellet boiler with an automatic feeder, and
- installation of window vents and mechanical ventilation controlled by air humidity in the bathroom.

As a result of the proposed changes, the house will be operated differently and it is necessary to take into account the increase of internal moisture emission, mainly from the bathroom.

It is worth underlining that the scope of thermomodernisation includes improvement of thermal insulation of the building elements and components, improvement of heating and hot water preparation installations as well as significant changes in ventilation.

Prior to the assessment of thermal protection and energy performance of the building in the current condition, a property condition survey was carried out; based on its outcome, it was decided that the scope of modernization works must be extended due to:
- dampness and damage to the house's foundation,
- a leak in the masonry smoke flue in the attic, and
- degradation of some rafters due to long-term moisture.

4 Hydrothermal analysis of wooden partitions

Heat transfer coefficients of partitions were determined in accordance with PN-EN ISO 6946: 2008 [8], PN-EN ISO 10077-1: 2007 [9], and PN-EN ISO 13370: 2008 [11]. Linear heat transfer coefficients were determined using the Therm software [15].

The evaluation of the humidity condition of partitions was carried out by J. Dojnikowska in her Bachelor's Diploma Thesis [2] using the WUFI® 2D simulation software [3]. In all layers, a decrease in moisture content was observed during operation (Figure 2).

According to the results of the simulation, there is no risk of fungi and mould growth on the internal contact surface of two internal walls, i.e. at the place of influence of the linear thermal bridge (Figure 3). Only in the initial simulation period (points marked in yellow) they are in the near area, but nevertheless below the limit value curve plotted for porous materials that are less resistant to moisture.
Fig. 2. Changes of relative humidity in the external wall in wooden logs (after termomodernisation) [2] (WUFI® 2D software [3]).

On the basis of the simulation results obtained, solutions chosen for termomodernisation of external walls and ceilings (Table 1) were such that they pose no threat of the wall structure degradation as a result of excessive moisture.

A simulation was performed assuming that the exterior wall surface is covered with facade paint which should be characterized by high vapour permeability and low water absorption.

It was shown that protecting the timber construction with building paper from the outside is a harmful solution, because it causes a rise in moisture during operation (Figure 4).

Comparison of thermal insulation of partitions before modernisation with that meeting current requirements clearly shows insufficient quality of partitions (Table 2), but the building was constructed in a rural area almost seventy years ago, i.e. when different standards applied.
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Table 1. Selected solutions for the external partitions.

| No. | Partition                          | Description of layers                                                                 |
|-----|-----------------------------------|---------------------------------------------------------------------------------------|
| 1   | External wall                     | - plasterboard,                                                                       |
|     |                                   | - vapour barrier foil,                                                                |
|     |                                   | - mineral wool (12 cm),                                                               |
|     |                                   | - windproof foil,                                                                    |
|     |                                   | - poorly ventilated air layer (3 cm),                                                |
|     |                                   | - original wooden logs,                                                               |
|     |                                   | - shuttering boards.                                                                 |
| 2   | Ceiling (heated space)            | - windproof foil,                                                                    |
|     |                                   | - mineral wool layer (10 cm),                                                        |
|     |                                   | - unventilated air layer (2 cm),                                                     |
|     |                                   | - vapour barrier foil,                                                                |
|     |                                   | - gypsum fibre board.                                                                 |
| 3   | Ceiling (unheated attic)          | - plasterboard,                                                                        |
|     |                                   | - unventilated air layer (3 cm),                                                     |
|     |                                   | - mineral wool in spaces between ceiling beams (10 cm),                               |
|     |                                   | - unventilated air layer (3 cm),                                                     |
|     |                                   | - OSB (Oriented Strand Boards).                                                      |

Table 2. Thermal insulation of partitions.

| No.   | Description                                                                 | Thermal transmittance, W m⁻² K⁻¹ |
|-------|----------------------------------------------------------------------------|---------------------------------|
|       |                                                                            | Before modernization | After modernization | Current requirements [14] |
| 1     | External wall                                                              | 1.63                | 0.30               | 0.23                      |
| 2     | Inner wall between the heated room and the unheated space                  | 1.63                | 0.30               | 0.30                      |
| 3     | Ceiling (unheated space)                                                   | 0.79                | 0.24               | 0.18                      |
| 4     | Floor (heated space)                                                       | 0.81                | 0.31               | 0.25                      |
| 5     | Wooden casement window                                                     | 2.55                | 1.10               | 1.10                      |
| 6     | PVC windows (modernisation in 2004)                                        | 2.00                | 1.10               | 1.10                      |
| 7     | Wooden casement window and external shutters                               | 1.60                | 1.05               | 1.10                      |
| 8     | Exterior doors                                                             | 2.00                | 1.50               | 1.30                      |
| 9     | Resultant heat transfer coefficient                                        | 0.95                | 0.30               | 0.26                      |

The quality of thermal insulation of the external envelope can be expressed by the value of the resultant thermal transmittance (Table 2, item 9) [6]:

$$U_B = \frac{\sum_i U_i A_i + \sum_j \Psi_j L_j}{\sum_i A_i}$$  (1)

where:
$U_i$ – thermal transmittance of the $i$-th external partition, W m⁻² K⁻¹,
$A_i$ – surface area of the $i$-th external partition, m²,
$\Psi_j$ – thermal transmittance of the $j$-th thermal bridge, W m⁻¹ K⁻¹,
$L_j$ – length of the $j$-th thermal bridge, m.
Fig. 3. Risk assessment of fungi and mould growth [2]:
Lim – limiting isopleths for building materials, below which no mould growth is usually to be expected:
Lim 1 – biodegradable materials, e.g. wall paper, plaster board; products made from easily degradable material, material for permanently elastic joints, etc.),
Lim 2 – non biodegradable materials (substrates with porous structure, e.g. plasters, mineral building materials, some woods, insulating materials not belonging to the above mentioned group,
Green dots – determined in each time step of calculation inner surface temperatures against the corresponding relative humidities (only one point above Lim 1 – practically the construction of the wall is appropriate) (WUFI® 2D [3]).
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Fig. 4. Water content in wooden logs (wall construction: plasterboard, plasterboard, wooden logs, building paper - incorrect solution) (WUFI® 2D [3]).

5 Energy performance of the house

The original state of the building was chosen only as a reference level against which a quantitative assessment of the proposed solutions was made.

It must be noticed that in the mid-twentieth century the house was operated in a completely different way, for example, the temperature of 20°C was not kept for the whole day and in periods with very low outside air temperature not all rooms were heated.

The heat demand for heating was calculated using the monthly balance method, according to PN-EN ISO 13790: 2009 [12]. The internal air temperature has been adopted in accordance with current requirements [14] as: in the rooms, kitchen, hall +20.0°C, and in the bathroom (planned) +24°C. As a result, the average temperature of the heated space was 20.3°C. The energy performance assessment of the building is based on [13].
Meteorological data for the building energy calculations were downloaded from the website of the Ministry of Investment and Development [7] for Białystok (IV climate zone, according to PN-EN 12831: 2004 [10]), i.e. the nearest meteorological station.

**Table 3.** Energy efficiency of the building.

| No. | Description                                              | Before modernization | After modernization |
|-----|----------------------------------------------------------|----------------------|---------------------|
| 1   | Indicator of the useful energy demand for heating, kWh m⁻² a⁻¹ | 489.5                | 122.2               |
| 2   | Indicator of the final energy demand for heating, kWh m⁻² a⁻¹ | 874.6                | 191.2               |
| 3   | Indicator of the primary energy demand for heating, kWh m⁻² a⁻¹ | 174.9                | 46.5                |

As a result of the proposed actions, the following factors were reduced: the demand for heating – by 4.0 times, the final energy demand for heating – by 4.6 times, and the demand for primary energy for heating – by 3.7 times.

6 Simplified economic assessment

The economic evaluation was carried out using the static method, based on the simple payback time:

\[
SPBT = \frac{I}{\Delta E_f}
\]

where:

\( I \) – investment costs, PLN,

\( \Delta E_f \) – obtained annual savings, PLN.

All costs listed below have been determined as a result of recognition on the local market and relate to the beginning of 2018. Investment costs amount to approximately PLN 45,000 and include the following costs:

- insulating materials (11,000 PLN),
- doors and windows (12,500 PLN),
- a pellet boiler with an automatic 12-kW feeder (12,000 PLN),
- heating installations (9,000 PLN), and
- auxiliary materials (500 PLN).

Annual savings result from the change in the amount of fuel burned, i.e. replacing wood (the annual cost of about 7,300 PLN) with pellet (the annual cost of about 3,200 PLN). After changing the heat source on the cost side, the cost of electricity required by the automatic feeder will appear (the annual cost of about 150 PLN). Thus, measurable annual savings obtained through the investment will amount to approximately 3,950 PLN.

As a result, the calculated simple payback time for the investment intended to improve thermal insulation of partitions and to upgrade ventilation and heating systems does not exceed 12 years and was accepted by the person who made the final decision.

However, it should be noted that the effectiveness of such an investment can be improved using home-grown methods and means, i.e. when the owner carries out renovation on his or her own.
7 Summary and conclusions

Based on the obtained values of the resultant thermal transmittance (Table 2), it can be concluded that heat losses due to heat transfer were reduced more than three times as a result of modernisation.

The necessity of protection of external partitions against moisture build-up in subsequent years as well as fungi and mould development made it impossible to achieve the level of thermal insulation quality that is currently required.

Nevertheless, the value of the resultant thermal transmittance meeting the current requirements is slightly lower—only by 5.2%.

The change of the heating method and the location of the heat source outside the residential area eliminated the risk of carbon monoxide poisoning. Moving the heat source outside the house to a new place with adequate fire resistance of the room will reduce the risk of fire. This room can take on the appearance of the granary that originally existed.

The need of supplying fresh air for combustion in tiled stoves and coal kitchens was also eliminated. That reduced heat losses associated with heating up the ventilation air.

As a result of a significant increase in air tightness of the house, diffusers should be installed in windows to ensure a proper fresh air stream.

Existing smoke ducts can play the role of ventilation ducts after cleaning, repairing and installation of ventilation grates in the upper part of the rooms.

As a result of the proposed scope of the house retrofitting, a significant improvement in energy performance was achieved: the values of all energy indicators were reduced by about 4 times.

The conducted hydrothermal analysis using the WUFI® 2D software [3] showed the correctness of the selected material solutions. At the same time, it should be pointed out that the issue of durability of such partitions is more complex due to wood swelling and shrinkage, cracking and warping as well as aging and freezing processes [1, 5].

The paper proposes a way of modernization of a wooden house with special cultural qualities that is rational in terms of economy and was accepted by the person who made the final decision.

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