Materials and technologies to achieve better energy efficiency of buildings

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Abstract. The article will discuss the aspects of the possibilities of improving the energy efficiency of buildings. In particular, the author will analyze innovative technologies in the field of improving the thermal insulation of external partitions and improving the efficiency of underfloor heating. The author will present the results of research on the thermal properties of metal and wooden frame structures, as well as innovative veneer floor panels. Frame structures are increasingly used in single-family housing, and veneer floor panels are used in underfloor heating. Innovative solutions of building partitions are to improve the energy efficiency of newly constructed buildings, and thus reduce the emission of greenhouse gases into the atmosphere.

1. Introduction
Energy efficiency in construction is very important from the point of view of improving air quality [1]–[7]. One of its elements is the development of new energy-saving technologies. Information on this subject can be found in the works of the authors [8]–[10]. The Małopolska Laboratory of Energy-Saving Construction (MLBE) conducts research on innovative solutions for external partitions, as well as solutions for underfloor heating. The thermal properties of external partitions were tested in an isothermal chamber (Figure 1). A skeleton structure with a steel supporting structure, two wooden skeleton structures and a structure made of glued timber were tested. Innovative veneer floor boards have also been tested [11]–[16].

Figure 1. Isothermal chamber (author’s archive)
2. Examination of a skeleton structure with a steel supporting structure

The thermal properties of the skeleton structure with a steel supporting structure and additional reinforcement of the skeleton were tested in the isothermal chamber. Figure 2 shows the load-bearing structure of the skeleton. The aim of the study was to determine the difference in heat transfer through the partition in the place of reinforcement and in the zone without reinforcement. The arrangement of the steel reinforcement is shown in Figure 3. The density of the heat flux flowing through the partition, in the place of the reinforcement and in the place without reinforcement, was measured using heat flux density sensors (heat flow meters). To measure the temperature on the surface of the sample, thermocouple temperature sensors were used, which were placed on the surfaces on the cold and the warm side. The distribution of temperature sensors is shown in Figure 4. Additional temperature sensors were used to measure the air temperature on the warm and cold side. Figure 5 shows the temperature distribution on the surface of the skeleton structure on the warm side, recorded with a thermal imaging camera. Test conditions, measured temperatures and test results are presented in tables 1-3.

![Figure 2. Bearing frame of the steel skeleton structure (author's archive)](image)

![Figure 3. Arranging the reinforcement of the steel frame structure (author's archive)](image)

![Figure 4. Location of temperature sensors on the tested frame structure (author's archive)](image)

![Figure 5. Temperature distribution on the surface of the skeleton structure on the warm side, recorded with a thermal imaging camera](image)
Figure 5. Temperature distribution on the surface of the skeleton structure on the hot side, recorded with a thermal imaging camera (author's archive)

Table 1. Test conditions

| Value                        | Cold side | Warm side | Difference |
|------------------------------|-----------|-----------|------------|
| Air temperature [°C]         | 0,61      | 23,55     | 22,94      |

Table 2. Temperatures measured on the surfaces of the frame structure

| Value                        | Reinforced section | Section without reinforcement | Reinforced section | Section without reinforcement |
|------------------------------|--------------------|------------------------------|--------------------|------------------------------|
| Surface temperature [°C]     | 0,27               | 0,25                         | 22,92              | 23,07                        |

Table 3. Study results

| Value                                | Reinforced section | Section without reinforcement | Difference |
|--------------------------------------|--------------------|------------------------------|------------|
| Heat flux density q [W/m²]           | 6,93               | 3,56                         | 3,37       |
| Temperature recorded on the surface of the heat flow meter [°C] | 22,8               | 23,16                        | -0,36      |
| Heat transfer coefficient U [W/m²K]  | 0,29               | 0,16                         | 0,13       |

3. Examination of frame structures with a wooden load-bearing structure.
Two such designs have been tested at MLBE. In one of them, the timber frame consisted of wooden battens and dried beams attached to the OSB board. There was a plasterboard on the inside, and the outer, elevation layer, was made of a fiber-cement board. The construction uses two air gaps, one non-ventilated, the other well ventilated. The remaining space was filled with mineral wool. On the outside, a vapor-permeable foil was placed on the mineral wool. A vapor barrier foil was placed on the OSB board from the inside. In one of the samples, the non-ventilated air gap was additionally separated with a multi-reflective foil. The layout of the partition layers is presented in Table 4.
Table 4. Layers of a skeleton structure partition with a wooden load-bearing structure (from the inside):

| Layer No. | Material                              | Thickness |
|-----------|---------------------------------------|-----------|
| 1         | Plasterboard                          | 18 [mm]   |
| 2         | Wooden battens 50x60 mm                | 60 [mm]   |
| 3         | Unventilated air gap                  | 60 [mm]   |
| 4         | Multi-reflective foil                 | 10 [mm]   |
| 5         | Vapor barrier foil                    |           |
| 6         | OSB                                   | 12 [mm]   |
| 7         | Mineral wool                          | 100 [mm]  |
| 8         | Wooden skeleton                        | 100 [mm]  |
| 9         | Breathable film                       |           |
| 10        | Dried logs 28x60 mm                   | 28 [mm]   |
| 11        | Air gap well ventilated               | 28 [mm]   |
| 12        | Cement-fiber board                    | 8 [mm]    |

Figure 6. Wooden skeleton structure with multi-reflective foil (author's archive)

The study of the thermal properties of these frame structures consisted in comparing the thermal properties of the frame structure additionally containing a multi-reflective foil (Figure 6) behind a non-ventilated air gap with the thermal properties of the frame structure without this foil. The values of the heat transfer coefficient $U$ (k) [W / m²K] obtained for these structures are presented in Table 5.

Table 5. Values of the heat transfer coefficient for a wooden frame structure with and without a multi-reflective foil

| Value                                      | Sample with multi-reflective foil | Sample without multi-reflective foil | Difference |
|--------------------------------------------|-----------------------------------|--------------------------------------|------------|
| Heat transfer coefficient $U$ (k) [W/m²K]  | 0.333                             | 0.497                                | 33%        |

The study of the thermal properties of the second wooden frame structure was combined with the study of the thermal properties of a barrier made in the CLT technology - made of glued wood with flexible joints. The skeleton structure with a thickness of 240 [mm] filled with Steico wool, with two Fermacell boards was supplemented from the outside with Frontrock wool. The CLT laminated timber partition was 200 [mm] thick. The tests were performed in an isothermal chamber using the covered hot
box method. Figure 7a. shows a timber frame structure, and Figure 7b. construction made of CLT glued timber. The values of the heat transfer coefficients obtained during these tests are presented in Table 6.

![Figure 7. a) Skeleton construction, b) Construction of glued laminated timber CLT (author's archive)](image)

**Table 6.** Values of the heat transfer coefficient for a wooden skeleton partition and a partition made of glued laminated timber CLT

| Material                                      | Thickness [mm] | Heat transfer coefficient [W/m²K] |
|-----------------------------------------------|----------------|----------------------------------|
| Skeleton construction                         | 240            | 0.257                            |
| Construction of glued laminated timber CLT    | 200            | 0.399                            |

4. Examination of veneer floor plates with heat sinks

Veneer floor panels are used in underfloor heating. The veneer boards tested at MLBE consisted of three layers. The outer and inner layers were oak or alder veneers, and between them there was a HDF board. Unlike ceramic tiles, which work well in the kitchen or bathroom, in the living room or in the bedroom wood-based floor panels provide better comfort. Oak veneer improves the mechanical properties of the board - it improves resistance to abrasion, scratches and other mechanical damage. The HDF board acts as a shock absorber, which allows the board to better adapt to the ground. The biggest problem, however, is the low thermal conductivity of veneer boards compared to ceramic tiles. Lower thermal conductivity causes slower heating of the air in the room, and thus lower efficiency of the heating system. To solve this problem, aluminum heat sinks passing through the plate material were used in the tested plates. These heat sinks improved the thermal conductivity of the plate. The aim of the study was to determine the optimal distribution and diameter of the heat sinks. In the isothermal chamber, measurements of the heat transfer coefficient for plates with heat sinks of different diameters were made and compared these values with the values of the heat transfer coefficient for plates without heat sinks. The test was carried out for the following temperatures: 0 [°C] and 15 [°C] on the cold side and 20 [°C], 23 [°C], 27 [°C] and 35 [°C] on the warm side. Due to the properties of veneers, the test was carried out at a temperature not exceeding 35 [°C]. The plates with heat sinks were tested by the shielded heating box method, and
the plates without heat sinks by the heat meter method. A thermovision study was also performed. Figure 8 shows a veneer board with heat sinks. The result of the thermovision examination is presented in Figure 9, 10. Tables 6 - 9 present the results of the examination of veneer floor panels with heat sinks. Table 10 present test results for a board with veneer and HDF layers without heat sinks.

Figure 8. Veneer board with heat sinks (author's archive)

![Figure 8](image)

Figure 9. The result of the thermographic examination. a) Warm side; b) Cold site (author's archive)

Table 7. Test results for a board with veneer and HDF layers with heat sinks Ø8 [mm]. Number of heatsinks in the board: 222 pcs

| Study number | Object surface temperature on the warm side [°C] | Object surface temperature on the cold side [°C] | Average object temperature [°C] | U factor [W/(m²K)] |
|--------------|--------------------------------------------------|--------------------------------------------------|---------------------------------|-------------------|
| Study 1      | 17,59                                            | 0,13                                             | 9,38                            | 4,082             |
| Study 2      | 21,50                                            | 15,10                                            | 18,53                           | 3,883             |
| Study 3      | 24,80                                            | 15,11                                            | 20,39                           | 4,110             |
| Study 4      | 35,86                                            | 15,13                                            | 24,15                           | 4,358             |
| Average value|                                                  |                                                  |                                 | 4,108             |
Table 8. Test results for a board with veneer and HDF layers with heat sinks Ø10 mm. Number of heatsinks in the board: 180 pcs.

| Study number | Object surface temperature on the warm side [°C] | Object surface temperature on the cold side [°C] | Average object temperature [°C] | U factor [W/(m²K)] |
|--------------|-------------------------------------------------|-------------------------------------------------|---------------------------------|-------------------|
| Study 1      | 18,62                                           | 0,12                                            | 9,37                            | 3,986             |
| Study 2      | 21,45                                           | 15,10                                           | 18,28                           | 3,721             |
| Study 3      | 24,74                                           | 15,10                                           | 19,92                           | 3,991             |
| Study 4      | 32,04                                           | 15,11                                           | 23,58                           | 4,171             |
| Average value|                                                |                                                 |                                 | 3,967             |

Table 9. Test results for a board with veneer and HDF layers with heat sinks Ø12 mm. Number of heatsinks in the board: 180 pcs.

| Study number | Object surface temperature on the warm side [°C] | Object surface temperature on the cold side [°C] | Average object temperature [°C] | U factor [W/(m²K)] |
|--------------|-------------------------------------------------|-------------------------------------------------|---------------------------------|-------------------|
| Study 1      | 18,61                                           | 0,12                                            | 9,37                            | 3,945             |
| Study 2      | 21,96                                           | 15,10                                           | 18,53                           | 3,883             |
| Study 3      | 25,68                                           | 15,10                                           | 20,39                           | 4,086             |
| Study 4      | 33,21                                           | 15,12                                           | 24,17                           | 4,213             |
| Average value|                                                |                                                 |                                 | 4,032             |

Table 10. Test results for a board with veneer and HDF layers without heat sinks

| Study number | Object surface temperature on the warm side [°C] | Object surface temperature on the cold side [°C] | Average object temperature [°C] | U factor [W/(m²K)] |
|--------------|-------------------------------------------------|-------------------------------------------------|---------------------------------|-------------------|
| Study 1      | 18,64                                           | 0,12                                            | 9,38                            | 3,979             |
| Study 2      | 21,97                                           | 15,09                                           | 18,53                           | 4,086             |
| Study 3      | 25,67                                           | 15,10                                           | 20,39                           | 4,167             |
| Study 4      | 33,18                                           | 15,12                                           | 24,15                           | 4,237             |
| Average value|                                                |                                                 |                                 | 4,117             |
5. Conclusions
The nearly zero-energy building standard introduced by the Energy Performance Directive requires the development of new technologies. Małopolskie Laboratorium Budownictwa Energooszczędnegd is the best place to develop and research innovations as presented in the article.

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