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Optimization of thermal insulation of external walls of wooden frame constructions

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Abstract. The article deals with the optimisations of external structures and points to energy-savings and requirements of low energy construction. It defines and evaluates the problems of required thermal-technical characteristics achievement set by standard for external structures of low energy and energy passive houses. At the same time, it describes in detail different variants of their optimisation.

1. Introduction

Work goal is to optimise chosen external wall composition of wooden frame construction from the viewpoint of thermal insulation. There was compared most used mineral wool with additional thermal insulation and without additional thermal insulation in the partition. The parameters and specific characteristics were modified by optimisation, and that exposed the behaviour of such external structure to the ordinary user [1].

Concerning the thermal-technical characteristics, the external structure optimization can improve its parameters, and at the same time reduce the built-up area. Material optimisation of wood-based walls from the viewpoint of thermal technical characteristics (heat conductivity coefficient (C-value), phase displacement and condensation) for low-energy houses (LEH) and energy-passive houses (EPH) [2].

Optimisation criteria are:

- Minimal value of heat conductivity coefficient \( U \) for LEH = 0.22 W/m\(^2\)K.
- Minimal value of heat conductivity coefficient \( U \) for EPH = 0.15 W/m\(^2\)K.
- Diffuse open structure (without vapour barrier) for natural transfer of vapour, so-called, structure breathing.
- Phase displacement if is the bigger, the better the structure is (recommended value is 14 hours).
- Critical surface temperature for the formation of \( T_{\text{sl,80}} \) (the formation of molds) and \( T_{\text{sl,100}} \) (the formation of condensation) - corresponding to 80% or 100% relative humidity in close to the surface of the building structure, depends on the temperature and relative humidity of the interior the air [3].
- Thriftiness to human and environment with using of natural materials, that can be recycled or easy disposable.
- Production and usage of carbon dioxide during construction must be more produced than consumed.
- Sustainable usage of raw materials – favour the ecological and renewable materials, recycle the waste and re-use it during construction [4].
2. Methods

The simulation software “Teplo 2010” [5], that evaluates and optimises the final thermal-technical parameters in accordance with Standard STN 730540-2, was applied for the optimisation of external wall composition from the viewpoint of thermal-technical characteristics.

3. Achieved results of optimization

Optimisation of designed EW (external wall) composition is mainly focused on usage main and additional TI (thermal insulation) on the interior side (EKO 2A – EKO 2 B) and their combination to achieve minimal values of thermal-technical characteristics in accordance with STN 730540-2 for LEH and EPH [4].

By optimisation of particular EW composition were improved foremost the values of heat conductivity coefficient $U$ (see table 1 from standard), phase displacement and water vapour condensation in the structure. The bigger the phase displacement is, the longer structure withstands the high temperatures and prevents overheating.

Recommended value of phase displacement is 14 hours. Recommended value of condensed vapour in the structure per year is maximum 0.5 kg.m$^{-2}$ year$^{-1}$ [4].

4. Mineral TI ISOVER Uni – properties

Table 2. Thermal-technical characteristics of used TI.

| Material          | Bulk density $\rho$ [kg.m$^{-3}$] | $K$ value $\lambda$ [W.m$^{-1}$.K$^{-1}$] | Specific thermal capacity $c$ [J.kg$^{-1}$.K$^{-1}$] | Diffuse resistance factor $\mu$ [-] |
|-------------------|----------------------------------|------------------------------------------|-------------------------------------------------|---------------------------------|
| Mineral Wool      | 45                               | 0.033                                    | 940                                             | 1                               |
| ISOVER Uni        |                                  |                                          |                                                 |                                 |

4.1. EW Composition – EKO 2 A EKO 2

A is external wall, having ISOVER Uni as main TI, while the EW have no any additional TI in the partition what you can see in table 3.

Table 3. Structure composition (from the interior side).

| Nr. | Name          | $T$ [m] | $\lambda$ [W.m$^{-1}$.K$^{-1}$] | $c$ [J.kg$^{-1}$.K$^{-1}$] | $\rho$ [kg.m$^{-3}$] | $\mu$ [-] |
|-----|---------------|---------|---------------------------------|---------------------------|---------------------|----------|
| 1   | Plasterboard  | 0.0125  | 0.2200                          | 1060.0                    | 750.0               | 9.0      |
| 2   | Closed air pocket | 0.0500  | 0.2940                          | 1010.0                    | 1.2                 | 0.2      |
| 3   | OSB 3 EKO     | 0.0150  | 0.1400                          | 1700.0                    | 650.0               | 150.0    |
| 4   | ISOVER Uni    | 0.1400  | 0.0390                          | 940.0                     | 17.0                | 1.0      |
| 5   | STEICO PRO    | 0.0600  | 0.0480                          | 2100.0                    | 230.0               | 5.0      |
| 6   | Mineral adhesive | 0.0060  | 0.8400                          | 920.0                     | 500.0               | 18.0     |
| 7   | Weber         | 0.0030  | 0.8600                          | 920.0                     | 1700.0              | 50.0     |

By evaluation, it is important to care about the minimal required and calculated interior surface temperatures shown in the figure 1. The calculated values related critical surface temperature for the formation of $T_{si,80}$ (the formation of molds) and $T_{si,100}$ (the formation of condensation) - corresponding
to 80% or 100% relative humidity in close to the surface of the building structure, depends on the temperature and relative humidity of the interior air [3].

**Figure 1.** Temperature distribution in the standard section in the EW structure – EKO 2 A [5].

**Figure 2.** Minimal required and calculated interior surface temperature of the EW – EKO 2 A [5].

**Table 4.** Final values of the EW structure optimisation – EKO 2 A [5].

| Used TI material                          | ISOVER UNI |
|------------------------------------------|------------|
| Main TI thickness [mm]                   | 120 140 200 240 |
| Total structure thickness [mm]           | 266.5 286.5 346.5 386.5 |
| Structure surface temperature [°C]       | 18.7 18.23 18.58 18.74 |
| Heat conductivity coefficient $U$ [W.m$^{-2}$.K$^{-1}$] | 0.227 0.207 0.165 0.146 |
| Structure resistance $R$ [m$^2$.K.W$^{-1}$] | 4.24 4.67 5.89 6.67 |
| Phase displacement $\Psi$ [h]            | 6.4 6.5 7.2 7.6 |
| Vapour condensation in the structure [kg.m$^{-2}$ .rok$^{-1}$] | $G_x$ 0.050 0.050 0.050 0.049 |
|                                           | $G_v$ 7.585 7.569 7.533 7.516 |
| Structure suitability concerning the $U$ value according to STN 730540-2:Z1/2016 | EPH $U_{\text{min}}=0.15$ fail fail fail fulfil |
|                                           | LEH $U_{\text{min}}=0.22$ fail fulfil fulfil fulfil |
Designed basic composition of external structure with overall thickness of 286.5mm and main thermal insulation ISOVER UNI thickness of 140mm, has been optimised in main insulation thicknesses of 120mm, 200mm and 240mm to achieve required values of heat conductivity coefficient U for LEH and EPH in accordance with standard STN 730540-2. Minimal required values are defined in table 1. By using main TI of 140mm thickness in the EW composition, the final values of heat conductivity coefficient U are not sufficient for construction of LEH or EPH [6].

Main TI of 140mm thickness in the EW composition has sufficient values of heat conductivity coefficient U for construction of LEH, however insufficient for the construction of EPH. By using the main insulation of 200mm thickness in the EW composition, the final values of heat conductivity coefficient U are favourable for the LEH, however still insufficient for the construction of EPH. Main TI of 240mm thickness in the EW composition causes the fulfilment of required values of heat conductivity coefficient U both for construction of LEH as well as EPH.

By using the main insulation of 240mm thickness in the EPH structure, the phase displacement in the structure has the value of 7.6 hours. Concerning the LEH structure with the main TI thickness of 140mm, it has 6.5 hours. With the thickness of 200mm, phase displacement value is 7.2 hours and with the thickness of 240mm, it is 7.6 hours [4].

4.2. EW Composition

EKO 2 B is external wall, having ISOVER Uni as main TI, while the EW have additional TI in the partition what you can see in table 5.

Table 5. Structure composition (from the interior side).

| Nr. | Name        | T [m] | \( \lambda \) [W.m\(^{-1}\).K\(^{-1}\)] | C [J.kg\(^{-1}\).K\(^{-1}\)] | \( \rho \) [kg.m\(^{-3}\)] | \( \mu \) [-] |
|-----|-------------|-------|--------------------------------------|---------------------------|-----------------|-------------|
| 1   | Plasterboard| 0.0125| 0.2200                                | 1060.0                    | 750.0           | 9.0         |
| 2   | ISOVER Uni  | 0.0400| 0.0390                                | 940.0                     | 17.0            | 1.0         |
| 3   | OSB 3 EKO   | 0.0150| 0.1400                                | 1700.0                    | 650.0           | 150.0       |
| 4   | ISOVER Uni  | 0.1400| 0.0390                                | 940.0                     | 17.0            | 1.0         |
| 5   | STEICO PRO  | 0.0600| 0.0480                                | 2100.0                    | 230.0           | 5.0         |
| 6   | Mineral adhesive | 0.0060| 0.8400                                | 920.0                     | 500.0           | 18.0        |
| 7   | Weber       | 0.0030| 0.8600                                | 920.0                     | 1700.0          | 50.0        |

Figure 3. Temperature distribution in the standard section in the EW structure – EKO 2 B [5].
Figure 4. Minimal required and calculated interior surface temperature of the EW – EKO 2 B [5].

Minimal required values are defined in table 1 [4]. By using main TI of 120mm thickness in the EW composition, the final values of heat conductivity coefficient U are not sufficient for construction of EPH, but favourable for construction of LEH.

Main TI of 140mm thickness in the EW composition also has sufficient values of heat conductivity coefficient U for construction of LEH, however still insufficient for the construction of EPH. However, by using the main insulation of 200mm thickness in the EW composition, the final values of heat conductivity coefficient U are favourable for both construction types, the LEH and the EPH.

Increasing the thickness of main insulation up to 240mm in the EW composition causes the improvement of required values of heat conductivity coefficient U compared with previous results, and are favourable for both construction types LEH as well as EPH [5].

Table 6. Final values of the EW structure optimisation – EKO 2 B [5].

| Used TI material | ISOVER UNI |
|------------------|------------|
| Main TI thickness [ mm] | 120 | 140 | 200 | 240 |
| Total structure thickness [ mm] | 256.5 | 276.5 | 336.5 | 376.5 |
| Structure surface temperature [°C] | 18.33 | 18.45 | 18.72 | 18.85 |
| Heat conductivity coefficient U [W.m⁻².K⁻¹] | 0.196 | 0.181 | 0.149 | 0.134 |
| Structure resistance R [m².K.W⁻¹] | 4.94 | 4.35 | 6.54 | 7.29 |
| Phase displacement Ψ [h] | 8.1 | 8.4 | 9.0 | 9.5 |
| Vapour condensation in the structure [kg.m⁻².rok⁻¹] | \( G_\lambda \) | 0.050 | 0.050 | 0.049 | 0.049 |
| | \( G_V \) | 7.560 | 7.547 | 7.519 | 7.505 |
| Structure suitability concerning the U value according to STN 730540-2:Z1/2016 | EPH \( U_{\text{min}} = 0.15 \) | fail | fail | fulfil | fulfil |
| | LEH \( U_{\text{min}} = 0.22 \) | fulfil | fulfil | fulfil | fulfil |
By using the main insulation of 200mm thickness in the EPH structure, the phase displacement in the structure reaches value 9.0 hours and increasing the main insulation to the thickness of 240mm raises the phase displacement in the structure to 9.5 hours.

For LEH constructions and at the main insulation thickness of 120mm, the phase displacement in the structure reaches value 8.1 hours, at the thickness of 140mm, the phase displacement in the structure is 8.4 hours. At the thickness of 200mm, the phase displacement in the structure is 9.0 hours and at the thickness of 240mm, the phase displacement value in the structure reaches up to 9.5 hours [5].

5. Results and Discussion
Optimising the designed composition of external structure for the construction of LEH and EPH imposed a gradual improvement of monitored thermal-technical values. Final parameters can be compared reciprocally, either by using only one type of TI material or various TI types.

Optimisations ran same in all cases concerning the thickness of main thermal insulation of 120mm, 200mm and 240mm.

In the EW composition EKO 2 A and EKO 2 B, the mineral insulation ISOVER Uni was used. In case A, it was applied solely as main TI within the structure and the structure contained 50mm thick air pocket under the plasterboard on the interior side. Values of heat conductivity coefficient U for all optimisations were favourable for EPH at TI thickness of 240mm with value of 0.149 W/m²K, and for LEH at thicknesses from 140 to 200mm with values from 0.210 to 0.149 W/m²K.

Optimising the TI to 140mm, 200mm and 240mm in the structure caused the change of thermal-technical characteristics and improvement of required values. Values of heat conductivity coefficient U were favourable for EPH only at TI thickness of 240mm (U=0.146 W/m²K). Also the values of heat conductivity coefficient U were favourable for LEH only at higher TI thicknesses 200mm (U = 0.165 W/m²K) and 240mm (U = 0.134 W/m²K).

In case B, ISOVER Uni was applied as main TI, but the air pocket was filled with same TI material of 40mm thickness. Final parameters achieve better values of heat conductivity coefficient U in connection with the increase of main TI thickness. Parameters of heat conductivity coefficient U for EPH are favourable for thicker TI, specifically for 200mm thickness (U = 0.149 W/m²K) and 240mm thickness (U = 0.134 W/m²K). Parameters for LEH are fulfilled in all cases of optimisation for all thicknesses with U values varying from 0.134 to 0.196 W/m²K [5].

6. Conclusion
Optimisation consisted from the thicknesses and use of additional TI in plasterboard partition walls on the interior side of structure. By comparing the observed thermal-technical characteristics of the external structure, we can estimate specific behaviour of particular structure compositions in connection to the required thermal-technical characteristics set in standard STN 730540-2. From achieved results, it is clear that every TI material acts different in the same structure composition. Fulfilling the required thermal-technical values for LEH and EPH, it is necessary to choose well the TI material type and thickness. Low energy construction demands a high quality of construction works as well as high quality of used materials. For these constructions, it is important to choose suitable TI material, that fulfils the required thermal-technical parameters, has impact on reduction of built-up area material consumption and is environmentally friendly.

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