Impact of heating concept on the energy demand of family house

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Abstract. This paper presents results of a parametric study, which analyses the energy demand of a family house. Assessed house has various shape factors and the thermal-technical properties of the building envelope. Also the recuperation unit and the heat source is taken into account. The house in the first case is a one story bungalow, the next version is a partly two story house and in the third case it is a complete two story house. Each of these geometric variants is calculated for four various building envelopes, which are considered for different energy performance standards including low energy and passive standard. Air exchange rate is considered according to the Slovak standard as natural or mechanical with use of recuperation. As heat sources are considered gas, heat pump, pellets, electricity and wood. Also two combined sources are analyzed: gas and pellets with solar collectors for preparing the hot water. The results are analyzed according to the Slovak standard and directives, which are in terms of delivered energy, primary energy and CO2 emissions.

1. Introduction

According to the European Directive 2010/31/EU [1], the building sector is the largest single energy consumer in Europe, which is absorbing 40 % of final energy. About 75 % of buildings are energy inefficient [2]. The outcome of the directive is to reduce 20 % the Union’s energy consumption by 2020.

The Energy Performance of Buildings Directive requires all new buildings to be nearly zero-energy by the end of 2020. All new public buildings must be nearly zero-energy by 2018. This should be done individually by the EU member countries according to the National plans [3]. In Slovakia, this was done by the new standard dealing with the thermal protection of buildings, STN 73 0540:2012 [4]. Last year it was updated to Z1 version [5]. This standard creates three steps to the nearly zero energy buildings. These were mandatory since 2013 to 2016, since 2016 and finally will be from 2021. The act No. 555/2002 [6] and 364/2012 [7] made this Standard and its requirement mandatory and also created classification depending on the primary energy need, which depends mostly on the heating source.

In this article a family house is analyzed in terms of meeting the Standard, which is valid now (ultralow-energy) and the future for the nearly zero building. This family house was analyzed from the point of view of building envelope, which consists of fragments such as wall, roof, floor etc., shape of the building and ratio between building envelope and the enclosed volume and also various heating sources were taken into account.
2. Slovak standard requirements
Slovak standard describes five requirements, which new or refurbished building have to comply. In this paper, only the energy need for heating, which is the one most complicated to reach, was analyzed. The others is the $U$-value for the individual fragments creating the building envelope, minimum surface temperature, natural or mechanical ventilation. The building itself usually do not meet the energy for heating requirements even though all the fragments meet the $U$-value requirements.

Required energy for heating according STN 73 0540 Z1 [5] is stated in the Table 1. The values are stated as a specific energy need for heating per square meter ($\text{m}^2$) or cubic meter ($\text{m}^3$), divided into four classes depending on the year of designing of the building. Last parameter is the shape factor, which is ratio between the sums of building envelope fragments ($\text{m}^2$) to enclosed heated volume ($\text{m}^3$). Nowadays the Recommended values, which differ from 25 to 50 ($\text{kWh} / (\text{m}^2\cdot\text{a})$) depending on the shape factor, are valid.

| Building Shape factor (1/m) | Maximal energy need for heating from STN 73 0540:2012 Z1 | Standard value $Q_{H,nd,N}$ valid since 1.1.2013 | Recommended (ultra-low building) $Q_{H,nd,r1}$ valid since 1.1.2016 | Final value (nearly zero building) $Q_{H,nd,r2}$ valid from 1.1.2021 |
|-----------------------------|-------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                             | $Q_{H,nd,max1}$ ($\text{kWh} / (\text{m}^2\cdot\text{a})$) | $Q_{H,nd,max2}$ ($\text{kWh} / (\text{m}^3\cdot\text{a})$) | $Q_{H,nd,N1}$ ($\text{kWh} / (\text{m}^2\cdot\text{a})$) | $Q_{H,nd,N2}$ ($\text{kWh} / (\text{m}^3\cdot\text{a})$) | $Q_{H,nd,r1,1}$ ($\text{kWh} / (\text{m}^2\cdot\text{a})$) | $Q_{H,nd,r1,2}$ ($\text{kWh} / (\text{m}^3\cdot\text{a})$) | $Q_{H,nd,r2,1}$ ($\text{kWh} / (\text{m}^2\cdot\text{a})$) | $Q_{H,nd,r2,2}$ ($\text{kWh} / (\text{m}^3\cdot\text{a})$) |
| $\leq 0.3$                 | 70.00                                          | 25.00                              | 50.00                           | 17.90                           | 25.00                                          | 8.93                             | 12.50                                          | 4.47 |
| 0.4                        | 78.60                                          | 28.10                              | 57.10                           | 20.40                           | 28.55                                          | 10.20                            | 14.28                                          | 5.10 |
| 0.5                        | 87.10                                          | 31.10                              | 64.30                           | 23.00                           | 32.15                                          | 11.49                            | 16.08                                          | 5.75 |
| 0.6                        | 95.70                                          | 34.20                              | 71.40                           | 25.50                           | 35.70                                          | 12.75                            | 17.85                                          | 6.38 |
| 0.7                        | 104.30                                         | 37.50                              | 78.60                           | 28.10                           | 39.30                                          | 14.04                            | 19.65                                          | 7.02 |
| 0.8                        | 112.90                                         | 40.30                              | 85.70                           | 30.60                           | 42.85                                          | 15.31                            | 21.43                                          | 7.66 |
| 0.9                        | 121.40                                         | 43.40                              | 92.90                           | 33.20                           | 46.45                                          | 16.60                            | 23.23                                          | 8.30 |
| $\geq 1.0$                 | 130.00                                         | 46.50                              | 100.0                           | 35.70                           | 50.00                                          | 17.86                            | 25.00                                          | 8.93 |

3. Analyzed house description
The analyzed family house is based on the single floored house (bungalow). This type is in the last decade very popular in Slovakia. But nowadays it has a problem to meet the standard requirements, because of a not suitable shape factor. Many types have problem with energy certification even though the fragments have much lower $U$-values for fragments than required. That’s why a partly two floored house and complete two story house with flat roof was created from the single floor house. The 3D models of these three variants are shown in Figure 1 also with its shape factors.
Figure 1. Three variants of analysed house: building shape factor a) 0.973, b) 0.8, c) 0.672.

U-values of the fragments and calculated energy need for heating are summarized in Table 2. The basic variant is from the project, which has several fragments, more than usual based on the fact, that the living room has sloped roof without ceiling, visible from Figure 1 a), this feature is kept also in the variant b).

The not suitable shape factor (lower number – better use of enclosed volume) and well insulated walls cannot meet the required objectives. For the highly insulated buildings and nearly zero energy building, the mechanical ventilation is needed, because the heat loss from ventilation in order to meet the minimal air change is crucial.
Table 2. Calculated energy for heating for three variants of the house and four different types based on the $U$-values.

|   | Shanf | Wall | Wall th. | Wall plinth | Insulated ceiling | Shaped roof | Floor on the terrain | Window | Roof window | Avg $U_{e,m}$ | Q calculated |
|---|-------|------|----------|-------------|-------------------|-------------|----------------------|--------|-------------|--------------|--------------|
| A | bungalow | | | | | | | | | | |
|   | Shape factor | | | | | | | | | | |
|   | Recommended value | | | | | | | | | | |
|   | Final value | | | | | | | | | | |
|   | 0.973 | 49 | 24.1 | | | | | | | | |
| 1 | Design values from project | | | | | | | | | | |
|   | $U_{r,1}$ - standard | 1.1.2016 | 0.09 | 0.13 | 0.14 | 0.11 | 0.09 | 0.11 | 0.18 | 0.76 | 1.10 | 0.201 | 53.34 | 32.61 | 29.75 |
|   | $U_{r,2}$ - standard | 1.1.2021 | 0.15 | 0.15 | 0.15 | 0.10 | 0.10 | 0.18 | 0.60 | 1.00 | 0.206 | 54.78 | 34.05 | 31.19 |
| 2 | U-value to meet the standard | 1.1.2021 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.14 | 0.60 | 1.00 | 0.172 | 45.88 | 25.15 | 22.29 |
| B | partly two story house | | | | | | | | | | |
|   | Shape factor | | | | | | | | | | |
|   | Recommended value | | | | | | | | | | |
|   | Final value | | | | | | | | | | |
|   | 0.8 | 42.85 | 21.43 | | | | | | | | |
| 1 | Design values from project | | | | | | | | | | |
|   | $U_{r,1}$ - standard | 1.1.2016 | 0.09 | 0.13 | 0.14 | 0.11 | 0.09 | 0.11 | 0.18 | 0.76 | 1.10 | 0.199 | 40.9 | 21.55 | 18.88 |
|   | $U_{r,2}$ - standard | 1.1.2021 | 0.15 | 0.15 | 0.15 | 0.10 | 0.10 | 0.18 | 0.60 | 1.00 | 0.209 | 42.99 | 23.64 | 20.97 |
| 2 | U-value to meet the standard | 1.1.2021 | 0.09 | 0.12 | 0.12 | 0.10 | 0.09 | 0.09 | 0.16 | 0.60 | 1.00 | 0.178 | 36.63 | 17.29 | 14.62 |
| C | two story house | | | | | | | | | | |
|   | Shape factor | | | | | | | | | | |
|   | Recommended value | | | | | | | | | | |
|   | Final value | | | | | | | | | | |
|   | 0.672 | 38.5 | 19.2 | | | | | | | | |
| 1 | Design values from project | | | | | | | | | | |
|   | $U_{r,1}$ - standard | 1.1.2016 | 0.09 | 0.11 | 0.09 | 0.18 | 0.76 | 0.196 | 43.47 | 16.11 | 13.51 |
|   | $U_{r,2}$ - standard | 1.1.2021 | 0.15 | 0.15 | 0.10 | 0.18 | 0.60 | 0.208 | 36.88 | 18.02 | 15.42 |
| 2 | U-value to meet the standard | 1.1.2021 | 0.10 | 0.15 | 0.10 | 0.18 | 0.60 | 0.188 | 33.69 | 14.83 | 12.22 |

variant does not meet the standard
variant meets the required values since 1.1.2016
variant meets the required values from 1.1.2021
Totally 36 combinations were calculated (Table 2), which differ from each other by the shape and $U$-value of the individual fragments (every time for all fragments). The four types were calculated in each variant:

- based on the project - design values,
- individual $U$-values meet the standard required values (since 2016) and accordingly the energy need for heating is stated and compared to the standard - ultra low energy level,
- individual $U$-values meet the standard final values and accordingly energy need for heating is stated and compared to the standard – nearly-zero energy level,
- $U$-values are calculated so the type comply the standard requirements.

4. Results and discussion

The energy need with different air change rate is also calculated for each type. As can be seen, the A-variant, without mechanical ventilation does not comply the required value, so, the project should not get the planning permission.

Required values for energy need for heating based on Table 1 for calculated shape factor of three variants are shown in Figure 2. Figure 3 shows the dependency of calculated energy need on the $U$-value for the wall for different values from the Standard. The decreased energy need for the better shape factor and air change ratio are showed in Figure 4.

With decreasing the shape factor, not so low $U$-values are needed to comply the standard. The variant C complies the nowadays required value without mechanical ventilation while the variant A does not. Even bigger problem has the variant A with the final values for nearly zero energy building. Also with mechanical ventilation with high efficiency, highly insulated walls and roof does not comply the final values.

Comparing the three variants (Figure 5 - 7) with same $U$-values (type 2 or 3), the energy need is reduced from 73 to 58 (variant B) to 50. This is based on the floor area and caused by the better utilizing shape.

As stated before, the heat loss created by the ventilation is crucial by the low energy houses. By the mechanical ventilation, the energy need can be reduced to half, depending on the effectiveness of the mechanical ventilation and energy recuperation (Figure 6 and 7).

In terms of primary energy, where is taken into account the heat source and its influence on the environment by using the national conversion factors. Also heating of the hot water is added. All variants and all four types for each variant with air change ratio 0.5 are summarized in Figure 8.

**Figure 2.** Energy need for heating values based on building shape factor from the standard STN 73 0540.  
**Figure 3.** Energy need for heating dependency based on the $U$-value for wall.
Figure 4. Energy need for heating for three different variants with different air change rates.

Figure 5. Energy need for heating depend on the $U$-value meeting the required values for individual fragments and different air change rates.

Figure 6. Energy need for heating depend on the $U$-value meeting the required values for individual fragments and air change ratio 0.5.

Figure 7. Energy need for heating depend on the $U$-value meeting the required values for individual fragments and air change ratio 0.17.
CO₂ emissions for all variants also with air change rate 0.5 are summarized in Figure 9. Presented results showed that the national conversion factor for each energy source is the key factor. This is shown in the Figure 10, where the electricity boiler has the worst results (conversion factor 2.2), gas boiler is in the middle (conversion factor 1.1) and the lowest primary energy has the wood and pellet heating (conversion factor 0.2). In the future there is accepted to lower the conversion factor for gas.
Finally, the delivered energy, which is sum for energy for heating and for hot water preparation and influence of air change ratio are in Figure 11 and 12. In real project, there will be also added energy for cooling and energy for lighting. This total sum is multiplied by the conversion factor and that’s why for example the wood boiler changed from the worst alternative by the delivered energy to the best in primary energy. Every building had to be put in the building energy performance classes. Nowadays, the building need to get in the class A1 or A0 in global indicator - primary energy, table F [7].

5. Conclusion
This presented heating study shows the influence of building shape factor, $U$-values for the building envelope fragments and air change ratio based on the natural or mechanical ventilation. Nowadays, with implementing the mandatory Energy performance of building directive is hardly possible to meet the designing assessment without mechanical ventilation for ultra-low energy buildings. The criteria, which will be valid from 2021 was possible to comply only with variants with better building shape factor and mechanical ventilation.

In term of global indicator - primary energy, the results is based on the source of energy, best sources are today in Slovakia representing by the conversion factors 0.2 for renewable energy sources, such as wood or pellets. The worst is electricity. The gas is still a good alternative. The use of additional solar system can reduce the energy demand for water heating. In the future, more detailed comparison will be conducted.

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References
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