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Parametric Study: Impact of Selected Factors on the Energy Demand of a Family House

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Abstract. Results of a parametric study, which deals with energy demand of family house with different shape factors and thermal properties of the building envelopes will be presented. Basic shape is a single-floored bungalow. Partly two-story and complete two-story house with flat roof are alternatives. Different building envelopes are considered, from the project, upgraded to low-energy house up to nearly-zero energy house. Air change ratio respects required indoor air quality. The natural ventilation and mechanical ventilation with heat recovery were analyzed. Pellets, wood, electric, gas and heat pump were considered as heat sources. Also a combination with solar collectors to decrease energy for hot water preparation was considered. Presented results are in form of delivered energy and primary energy.

1. Introduction

This parametric study deals with a family house and its characteristics related to actual requirements of Slovak standards and Acts for the energy buildings performance. 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 the European Union's energy consumption by 20 % until 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 have to be nearly zero-energy by 2018. This should be done individually by the EU member countries according to the National plan [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 (change 1) [5] and another change is in preparation. This standard creates three steps towards 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. To gain building permit in Slovakia nowadays, it is necessary in the design phase to meet the requirements. After construction, energy certificate with energy class B and in primary energy A1 is necessary [7].

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, represented with ratio between building



envelope area and the enclosed volume is of great importance, hence another two variants of the starting house are calculated. Also various heating sources were taken into account.

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. To calculate this energy need, U-values for all individual fragments, such as wall, roof, windows etc. are needed. Calculation of energy need in this case was done with simple season method using 3422 day degrees. The calculation methodology is described in STN EN 13790 [8] and in STN EN 13790/NA [9]. The other requirements are: U-value for the individual fragments creating the building envelope, minimum surface temperature, hygienic criterion based on the air change ratio. The building itself usually do not meet the energy for heating requirements even though all the fragments meet the U-value requirements. In the design stage, for this calculation the use of renewable sources is not taken into account. The biggest opportunity to lower the energy need is trying to justify the air change ratio with assistance of mechanical ventilation.

Required energy for heating values are stated in STN 73 0540 Z1 [5]. The values are stated as a specific energy need for heating per square meter (m^2) or cubic meter (m^3), divided into four classes depending on the year of building design. Last parameter is the shape factor, which is a ratio between the sums of building envelope fragments (m^2) to enclosed heated volume (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.

2. Case study house description

The analyzed family house is based on the single-floored house (bungalow). This type is very popular in Slovakia in the last decade. With the requirements for low-energy buildings, problems with this type of houses arise. The problem is caused by high shape factor and little floor area. There is often problem with energy certification even though the fragments reach much lower U-values than it is required. This is also the case of analyzed house. To analyze the difference deeper, two more variants were developed. The 3D models of these three variants are shown in figure 1 also with their shape factors.

This parametric study began with the project of building: architecture, structures etc. It was taken from the catalogue which consist of dozens of different houses.

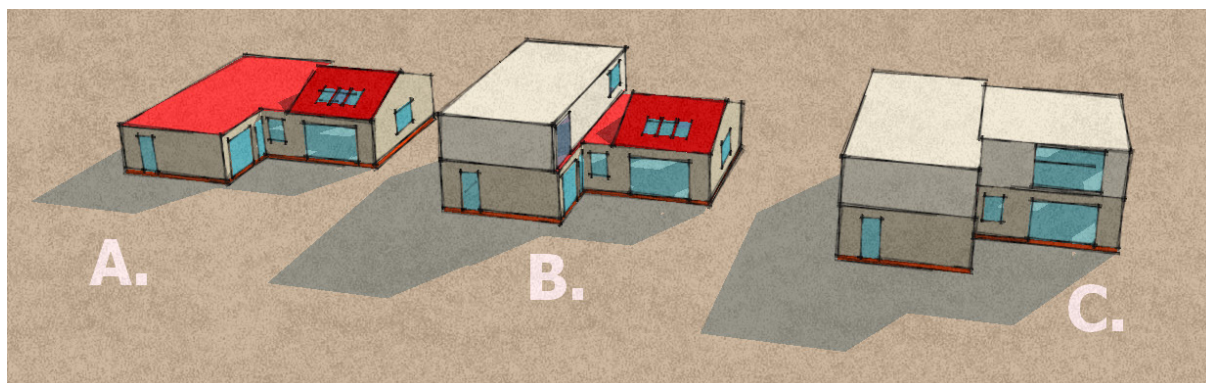


Figure 1. Three different investigated houses. Starting with A and evolved to C. Building shape factors: a) 0.973, b) 0.8, c) 0.672.

The basic variant is from the project. The building envelope consists of several fragments, more than usual. This is based on the fact, that the living room has pitched 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 and nearly zero energy buildings, the mechanical ventilation is needed, because the heat loss from ventilation in order to meet the minimum air change is crucial.

3. Building envelope fragments and its variants

Starting structure of the building enclosure wall consists of masonry with ETICS. Also the masonry itself is built from clay bricks (th. 380 mm), which have integrated thermal insulation from mineral wool (later insulated brick - IB). Thermal insulation of ETICS is based on the graphite expanded polystyrene (GEPS) with thickness of 200 mm. This structure with the coating and plaster has total thickness of 605 mm. This structure of wall has very low U- value, much lower than is required nowadays and also for the nearly zero-energy buildings (from 2021). This structure is compared to different possible solutions, in which the ratio between the load carrying part of the wall (masonry brick) and thermal insulation is changed. In this paper 4 different variants, stated in table 1 are described. Two of them consist of insulated bricks, which gain some popularity since start of production. Another variant is a use of classic aerated clay brick. The producers do not recommend less than 300 mm thickness for load carrying walls. Last version is based on timber frame, which has the possibility to use almost the whole wall thickness as effective thermal insulation.

Table 1. Used variants for the wall - thickness and thermal conductance coefficient for used materials.

Th. (mm)	Insulated Brick (IB) + ETICS (W/(m.K))	Th. (mm)	IB + ETICS (W/(m.K))	Th. (mm)	Brick + ETICS (W/(m.K))	Th. (mm)	Wooden column wall (WCW) (W/(m.K))
380	0.079	300	0.067	300	0.155	220	0.034
200	0.031	210	0.031	290	0.031	160	0.034
605		555		590		400	

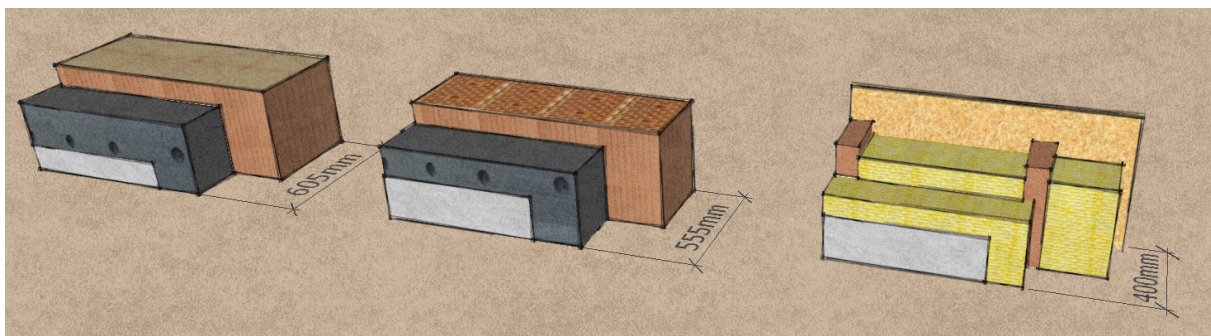


Figure 2. Graphic comparison of three different walls. Project based wall (left), enhanced wall (middle) and timber-framed wooden wall (right).

Graphic comparison of three further used variants is shown in figure 2. These consist of project based wall (IB + GEPS, th. 605 mm), enhanced wall with 50 mm decrease of thickness. This is done by use of narrower brick and to obtain the same thermal resistance by thicken the GEPS. The change of ratio between thickness and thermal resistance and increased effectivity is shown in figures 3 and 4. Last variant is a lightweight wooden wall with insulation placed between wooden columns (th. 220 mm) and another continuous layer (th. 160 mm). Mineral wool has higher thermal conductance coefficient compared to the GEPS. With its use, the thermal insulation thickness can be even reduced.

The biggest benefit caused by the decrease of thickness (in case of getting the same thermal resistance) is increase of gross internal area (GIA). Comparison for the three houses (A, B, C) and three different walls (same as in figure 2) are in table 2. The outside dimensions of the houses are constant, so only the usable inside floor area is increasing with decrease of wall thickness (inside walls are not taken into account). The decrease of thickness by 50 mm adds more than 2 m², use of timber-framed wall adds more than 10 m², which is a size of an average room. In two other house variants, the increase is even bigger because of gross floor area increase. The structure of the roof does not influence the use

of gross floor area as the walls, but it has an influence on the building volume. In all houses structures based on the project were used, as shown in figures 5 and 6. The only change is that in the variant C, there is not used a pitched roof because the house is two story.

Table 2. Comparison of usable floor is based on the difference wall thickness and constant outside dimensions of house

[m ²]	A - bungalow	B - partly two story house	C - two story house
Gross floor area	165.86	261.76	331.72
Gross internal area (GIA), th. 605 mm	133	205.26	266.00
IM + ETICS, th. 555 mm	135.12	208.88	270.24
WCW, th. 400 mm	143.46	223.16	286.92

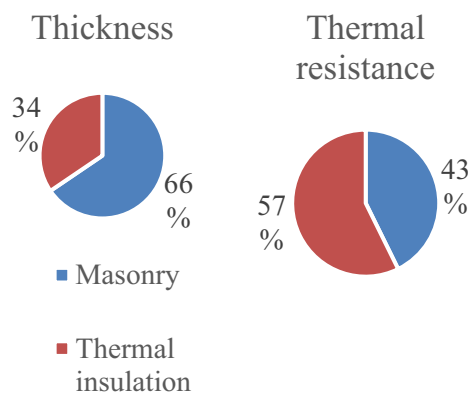


Figure 3. Project based wall (th. 605 mm). Ratios are based on the total thickness and thermal resistance

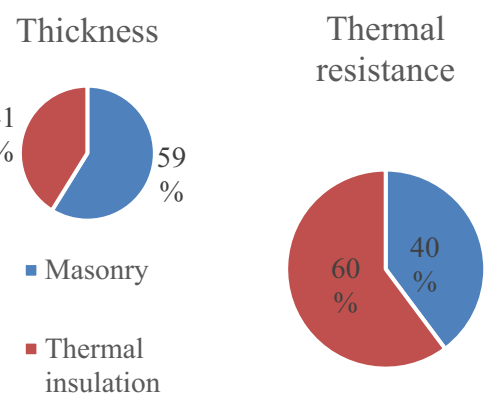


Figure 4. Enhanced wall (th. 555mm). Ratios are based on the total thickness and thermal resistance

4. Energy need for heating, primary energy and energy for hot water preparation calculations

U-values of the fragments and calculated energy need for heating are summarized in table 3. Project-based variants have more fragments than usually, with development of the B and C variant of the house some of them were removed. Previous chapter results do not influence these results because the calculated U-value remains the same by the variations of the wall structures (valid for project based values).

Totally 36 combinations were calculated (table 3), which differ from each other by the shape and U-value of the individual fragments (every time for all fragments). Four types in each variant were calculated:

- 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.

For each individual variant were also considered different air change ratio, starting with natural ventilation, local mechanical ventilation and finally with very effective heat recuperation. To show current situation in Slovakia, several heat source were used for primary energy, also with help of renewable sources, solar boiler for hot water preparation. Choose of heat source is the key factor nowadays for the energy classes comparison. National conversion factor based on the heat source, can simple lowered or doubled the energy need. Delivered energy, which is sum for energy for heating and for hot water preparation. This total sum is multiplied by the conversion factor.

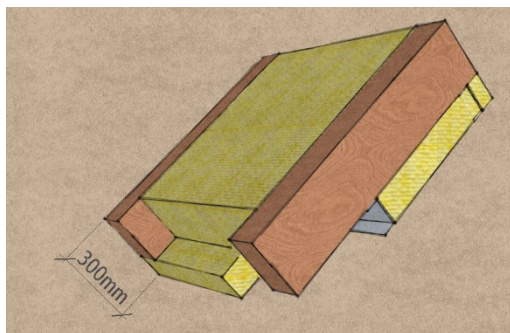


Figure 5. Pitched roof structure based on the project. Thermal insulation between the rafters and underneath with gypsum boards ceiling.

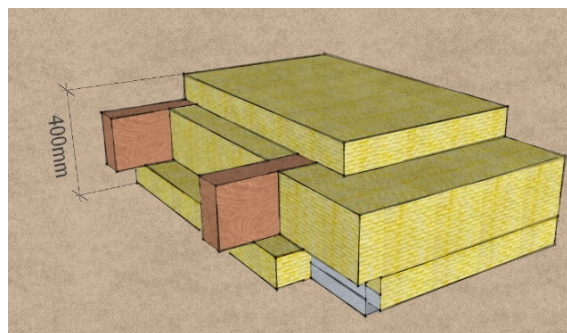


Figure 6. Insulated ceiling based on the project. Thermal insulation between floor beams, continuous layer on the upper side, another layer within suspended gypsum board ceiling.

5. Results and discussion

Starting with the basic house - A type, without mechanical ventilation does not comply the required value, so, the project should not get the planning permission nowadays. Even with the much lower (and thus not very economical) U-values for all fragments than required from 2021.

Required values for energy need for heating based on [4] for calculated shape factor of three variants are shown in figure 7. Figure 8 shows the dependency of calculated energy need on the U-value for the wall for different values from the Standard. Comparing the three variants (figure 9 and 10) 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 so not such low U-values are required. 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 heat recuperation. The variant C complies the nowadays required value without mechanical ventilation while the variant A does not, which confirms that for this variant is not possible to comply the final values for nearly zero energy building. Also with mechanical ventilation with high efficiency, highly insulated walls and roof is very problematic to reach that limit.

In terms of delivered energy, influence of conversion factor is shown in figure 10, where for example the wood boiler changed from the worst alternative by the delivered energy (figure 11) to the best in primary energy. Nowadays, electricity has the highest conversion factor. This influences also the use of a heat pump (powered by electricity). Use of solar for hot water preparation can reduce this energy need. 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]. For energy certificate, to the delivered energy is also taken into account energy for lighting and cooling (if AC is used).

Table 3. Calculated energy for heating for three variants of the house and four different types based on the U -values.

A bungalow													
Shape factor	0.973	Wall th. 250	Wall th.115	Wall plinth	Insulated ceiling	Pitched roof	Floor on the terrain	Window	Roof window	Avg U _{e,m}	Q calculated (kWh/(m².a))		
Recommended value	49										n = 0.50	n = 0.21 n = 0.17	
Final value	24.1	(W/(m².K))											
1	Design values from project												
2	U _{r,1} - standard	1.1.2016	0.22	0.22	0.22	0.15	0.18	1.00	1.40	0.275	73	52.27 49.41	
3	U _{r,2} - standard	1.1.2021	0.15	0.15	0.15	0.10	0.18	0.60	1.00	0.206	54.78	34.05 31.19	
4	U-value to meet the standard	1.1.2021	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	0.8	Wall th. 250	Wall th.115	Wall plinth	Insulated ceiling	Pitched roof	Floor on the terrain	Window	Roof window	Avg U _{e,m}	Q calculated (kWh/(m².a))		
Recommended value	42.85										n = 0.50	n = 0.21 n = 0.17	
Final value	21.43	(W/(m².K))											
1	Design values from project												
2	U _{r,1} - standard	1.1.2016	0.22	0.22	0.22	0.15	0.18	1.00	1.40	0.286	58.48	21.55 36.46	
3	U _{r,2} - standard	1.1.2021	0.15	0.15	0.15	0.10	0.18	0.60	1.00	0.209	42.99	39.13 20.97	
4	U-value to meet the standard	1.1.2021	0.09	0.12	0.10	0.09	0.16	0.60	1.00	0.178	36.63	17.29 14.62	
C two story house													
Shape factor	0.672	Wall th. 250	Wall th.115	Wall plinth	Insulated ceiling	Pitched roof	Floor on the terrain	Window	Roof window	Avg U _{e,m}	Q calculated (kWh/(m².a))		
Recommended value	38.5										n = 0.50	n = 0.21 n = 0.17	
Final value	19.2	(W/(m².K))											
1	Design values from project												
2	U _{r,1} - standard	1.1.2016	0.22		0.22	0.15	0.18	1.00		0.196	34.97	16.11 13.51	
3	U _{r,2} - standard	1.1.2021	0.15	-	0.15	0.10	-	0.60	-	0.208	49.91	31.05 28.45	
4	U-value to meet the standard	1.1.2021	0.10		0.10	0.10	0.18	0.60		0.188	36.88	18.02 15.42	
variant does not meet the standard											33.69	14.83	12.22
variant meets the required values since 1.1.2016											variant meets the required values from 1.1.2021		

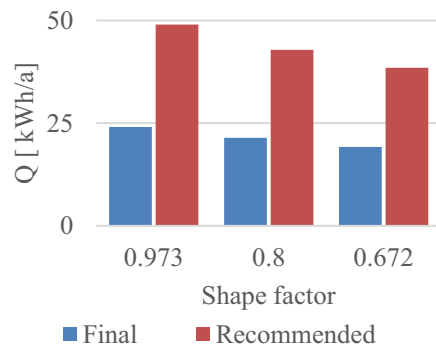


Figure 7. Energy need for heating values based on building shape factor from the standard STN 73 0540.

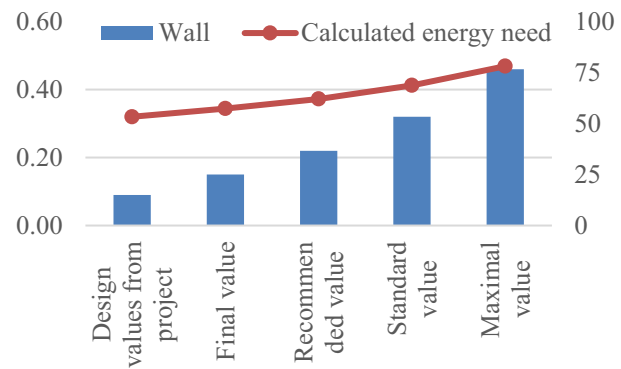


Figure 8. Energy need for heating dependency based on the U -value for wall.

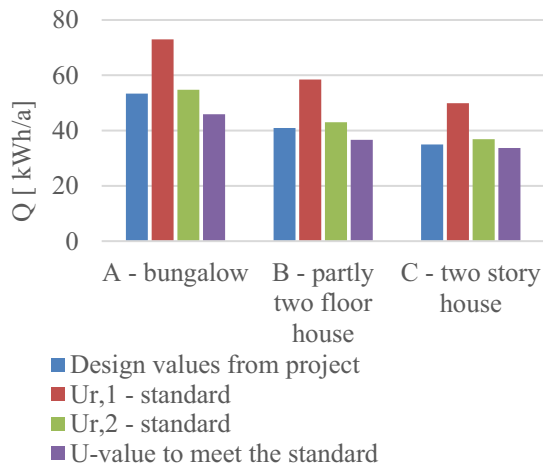


Figure 9. Energy need for heating depend on the U -value meeting the required values for individual fragments and air change ratio 0.5.

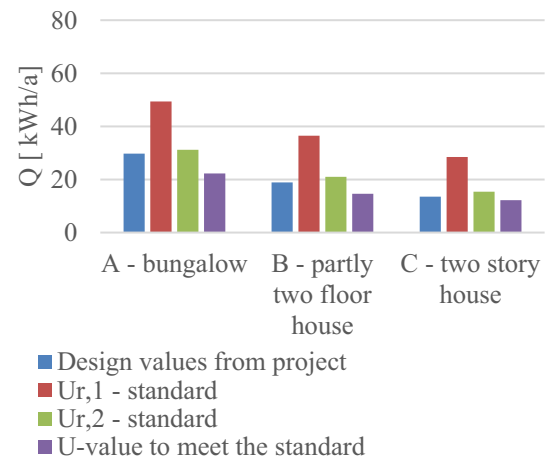


Figure 10. Energy need for heating depend on the U -value meeting the required values for individual fragments and air change ratio 0.17.

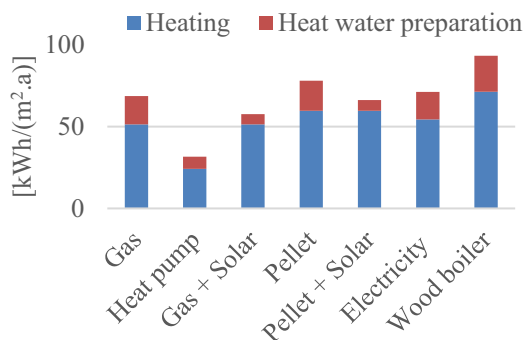


Figure 11. Delivered energy for A1 variant and air change ratio 0.5.

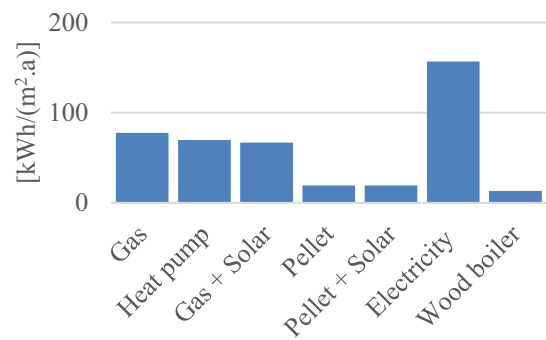


Figure 12. Primary energy for A1 variant and air change rate 0.5.

6. Conclusion

Influence of building shape factor, U -values for the building envelope fragments and the air change ratio based on the natural or mechanical ventilation were analyzed in the parametric study. Due to the lack of space, not all possibilities are described as it would be necessary.

Nowadays, with implementing the mandatory Energy performance of building directive it 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. This study confirms that for the bungalow type of family house it is not very easy to meet the requirements although with a well-insulated building envelope. During the design phase for obtaining building permit, use of renewable sources cannot be taken into account. Only the use of mechanical ventilation can be considered and used to decrease energy need for heating.

In terms of global indicator - primary energy, the results are based on the source of energy, best sources in Slovakia are represented by the conversion factors 0.2 for renewable energy sources, such as wood or pellets. The worst source is the electricity. The gas is still a good alternative. The use of additional solar system can reduce the energy demand for water heating. This paper deals only with simple calculations, which are required. No advanced model simulations for calculation are used or allowed nowadays.

Acknowledgments

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