Case Study Comparing the Efficiency of Wooden Buildings with Different Energy Standards

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This study compares the economic efficiency of wooden buildings from standard to low-energy, near-passive, and zero-energy homes. The comparison was carried out over the entire expected life cycle of the building (100 years), but due to the high uncertainty of the predictions of fuel and energy prices or discount rates and the clarity of the depiction of the subsequent results, a period of 30 years was also chosen. The most common and most suitable media and combinations for heating (gas, electricity, and wood) were selected. When calculating the entire life cycle of a building, it was found that the more stringent the energy standard, the lower the overall life cycle costs, and the share of heating costs also decreases with the highest costs being electricity heating alternatives. Adversely, the lowest costs were for the fictitious zero-energy home (ZEN) alternative with net metering followed, by some distance, by near zero-energy home alternatives and passive homes. With the chosen period of 30 years, initially after construction, it was shown that the cost is lowest to heat a standard home with gas, which is used by more than 60% of family homes for heating in the Czech Republic.

Keywords: Wooden homes; Zero-energy homes; Passive homes; Low-energy homes; Net metering; Economy

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Abbreviations

NZEH	Near zero-energy home
NPAH	Near-passive home
PVPP	Photovoltaic power plant
MRC	Mass remote control of high and low tariff
LCA	Life Cycle Assessment
ZEN	Zero-energy home
LEN	Low-energy home
HUW	Hot utility water
EN	European norm

INTRODUCTION

Costs for energy consumption are increasingly important for the decision-making of investors in the construction industry. Construction costs form only a minority of the total costs for the life cycle of a building. A large part of the costs consists of energy costs (heating, cooling, and appliances), where, at present, homes use about 40% of the energy costs, and, in the construction industry, about 31% of all energies are consumed (Dahlstrøm *et al*. 2012).

The importance of addressing this issue (Figueiredo *et al.* 2016) is based on Directive 2010/31/EC of the European Parliament and of the Council on the 19th of May, 2010 on the energy performance of buildings from 2010 (European Parliament 2010). This Directive requires Member States of the European Union to reduce the energy consumption of buildings and to ensure that new public buildings (from the end of 2018) or all newly-built buildings are to be almost zero-energy buildings by the end of 2020 (Colclough and McGrath 2015). Zero-energy buildings are those that receive as much renewable energy as they spend on their own in their operation each year, and buildings with positive energy generate more energy than they consume (Miller and Buys 2011).

Wooden buildings were chosen as the focus of this paper. Wooden buildings exist throughout the world in different forms, ranging from family homes to houseboats (De Araujo *et al.* 2016). Wood is the most common and most available renewable material. Because forests are a continually regenerating system, unlike fossil fuels, the wood used in wood buildings is a growing raw material (Frühwald and Wegener 2017). Furthermore, a forest accumulates carbon dioxide (CO_2) that carries carbon into its mass from the atmosphere during photosynthesis. There are 1948 gigatons of carbon dioxide (CO_2) accumulated in the forests on Earth, and an additional 2 gigatons of carbon dioxide are stored in forests annually (Wegener 1994). Their long-term attachment to buildings leads to a positive carbon balance (Blažek *et al*. 2016), as wood is bonded in a building over the long-term and is not released in decomposition or combustion, thereby helping to reduce the CO_2 in the atmosphere.

When building a home, the builder (investor) must accept limiting factors and the use of new technologies (Wang *et al.* 2017) that affect economic efficiency in their results in the building design. The climate of the location where homes are built (Badescu and Tudor 2015; Schnieders *et al.* 2015), where standards are adapted to local conditions (Georges *et al*. 2014), is also important. In the Czech Republic, these are primarily the following aspects and conditions:

- Legislative – Directive 2010/31/EU (European Parliament 2010) on the Energy Performance of Buildings and Regulations and Instructions to the Committee Regulation No. 244/2012;
- Social and political – ensuring sustainable development, reducing energy import dependence, and ensuring a friendly approach to the environment and climate protection;
- Technical – EN (European norm) set, the availability of building materials and energy equipment for construction, the properties of wood and the reaction to temperature and humidity (Liu and Wang 2016), and the efficiency of solar energy acquisition (Rekstad *et al.* 2015) and the inclusion of the impact of thermal comfort (Long *et al.* 2016) and air ventilation (Wang *et al*. 2017);
- Economic – the development of prices of energy, services prices, energy equipment prices, building construction prices, availability of funding sources, and possible subsidies.

The aim is to compare the efficiency of selected wooden building alternatives in different energy standards, ranging from standard to low energy (LEN), near zero-energy (NZEH), and passive homes (NPAH) to a zero-energy home alternative (ZEN), and the entire technology-related life cycle of the building and its consumption (100 years). Due to the high uncertainty of fuel and energy price predictions, or the clarity of the effect of energy changes, a shorter period of 30 years was also chosen. Thirty years is the common maximum period considered by most private investors. The effect of global warming, which could shorten the heating period, is not included in the calculations, as its effect on heating or solar power cannot be predicted more accurately.

Important costs for the construction and heating of a family home and the hot utility water, as well as the cost of technology, repairs, maintenance of consumption, and electricity, including other electrical household appliances, were included. The most common and most suitable media for heating (gas, electricity, and wood) were chosen, as well as such a combination thereof that, if possible, provides both comfort for the user and a potential aesthetic aspect, or possibilities of spatial placement in the home. For some home alternatives, this means an increase in the acquisition price (for example, when heating with wood, then the costs for a fireplace stove and chimney, including the subsequent costs for revisions, repairs, and maintenance and the cost associated with wood storage only after the purchase of a new heat source, after its expected lifetime recommended by the supplier), which are subsequently taken into account in the calculation.

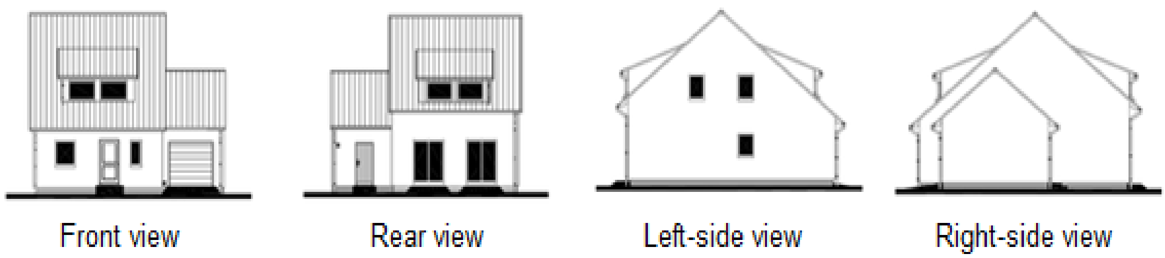

Fig. 1. Views of a two-story NOVA 101 home with five rooms and a kitchenette with garage

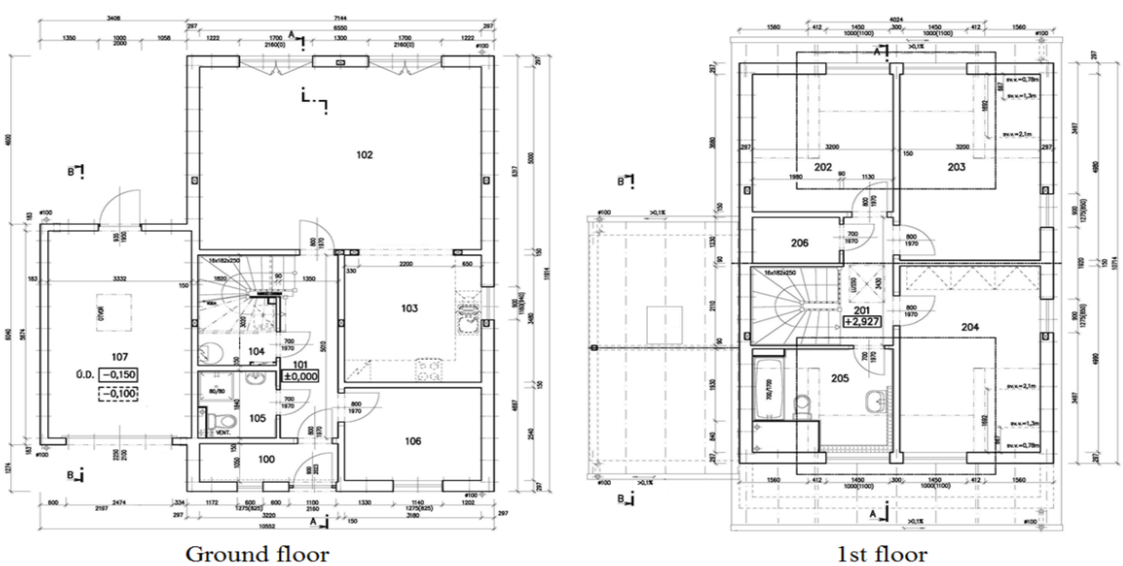

Fig. 2. Floor plans of the ground floor and first floor of the NOVA 101 home with five rooms and a kitchenette with garage

A home from RD Rýmařov s.r.o. was chosen for this case study and the subsequent comparison of the efficiency of wooden buildings. The Rýmařov s.r.o. family home has had an almost 50% share in the construction of wooden buildings in the Czech Republic. Specifically, this is the NOVA 101 family home, and its alternatives were built in Prague.

It is the best-selling wooden building in the Czech Republic. In total, more than 1000 of these homes were built in the last three years, which is a record in domestic construction in the sale of one home type (Pohloudek 2012). This is a family home with five rooms and a kitchenette. The home has two French windows in the living room with easy access to the garden. The two-story-type Nova 101 family home represents a compromise between the rational and generous requirement for spacious living. Without the garage, the built-up area was 85 m^2 and the floor area was 126.2 m^2. The alternative, which was offered as a basic with the garage, and which increased the utility value of the entire home, was evaluated.

As solar photovoltaic technology receives much attention (Yan *et al.* 2017), another alternative is the near-passive home (NOVA 101 EVO) with technologies producing electricity from solar radiation in two performance alternatives (4.9 kW and 7.35 kW) with a suitable location toward the cardinal direction, which is important for calculating the profits from solar thermal collectors and possible solar gains of the building. Passive houses with photovoltaic systems are effective solutions for minimizing the operating energy of buildings (Long *et al.* 2016). Under Act No. 318/2012 Coll. (Parliament of the Czech Republic 2012) which is based on the European Directives. Essentially, a building with near zero-energy consumption means a very low-energy building whose energy consumption is largely covered by renewable sources, as mentioned earlier. For Central European climates, the maximum space heating load corresponds to a space heat demand below 15 kWh/m^2 annually (Feist *et al.* 2005) and in the Czech Republic, this amounted to as much as 20 kWh/(m^2*year) with regards to the “green savings” subsidy.

There is a ZEN alternative also, where there is an alternative with net metering specified, *i.e.*, the electricity meter turns in both directions – electricity consumption and production (Ramírez *et al.* 2017). The electricity grid is used as a “battery”, but this was not yet in place in the Czech Republic. This is, for example, used in Australia, Canada, the Netherlands, Denmark, Italy, Spain, and most states in the USA. Its implementation would help to significantly expand renewable resources by motivating investors to expand them. The investors would be subsequently energy self-sufficient, which would help more than the non-systemic subsidies that have often caused solar power plants to be established on agricultural land.

The development of energy prices, especially for a long time ahead, is hard to predict, and many influences play a large role therein. It is based on current energy prices, which are also used in energy audits, but a so-called sensitivity analysis for fuel price changes was prepared. They were experimentally-adjusted according to their expected long-term development (year-on-year growth of 3% and 5%), and this was the range of these prices over the last 15 years. The consumption of electric appliances in a normal household was also calculated, where the use of energy-saving appliances (A+, A++, and A+++) was expected, as well as the use of LED light bulbs for lighting, which already standard today, including the choice of a suitable electricity tariff. A mortgage was not taken into consideration because the percentage of the mortgage on the price of the acquired home differed, as well as the payment period and the interest rate, which is usually fixed for several years only, and it would be necessary to propose a number of other alternatives.

The literature review and the above information show that the theme of this paper is highly up-to-date and that there is also no specific knowledge of the use of net metrics in family houses. Most studies have focused only on buildings in several standards without a detailed life cycle costing. The pressure to lower construction costs often occurs in practice also, and the subsequent costs associated with the next life cycle of the construction, such as energy costs, repairs, maintenance, *etc.* were also taken into account to a much lesser extent. Therefore, a real-life house with different heating options or combinations of them was selected for the case study, including the use of net metering and life cycle costing. The main novelty was the use of net metering as a suitable option to support the production of energy from renewable sources without the support of public budgets or at the expense of increasing the electricity costs to other consumers.

This option is not very widespread, even though it offers the opportunity to significantly reduce energy costs and also support renewable energy sources. Increasing the availability and introducing net metrics in other countries could have an impact on the future growth in the number of photovoltaic power plants in both family houses and other buildings. Another advantage is the complexity of this case study in the solutions used and the calculated details, from a standard house to a low energy house and a passive house to a zero energy house. In the case of the individual house variants, a combination of several heating options was also used, taking the energy standard of the house into account. It was also calculated with changes in energy prices and discount rates.

EXPERIMENTAL

When determining efficiency, the method of determining the present cost value was used, which was recommended as a basic method of evaluating the effectiveness of investments. This was a conversion of future costs to the present value. The calculated alternatives of net present value, including all costs (30 and 100 years) are based on the following model,

$$NPV = \frac{AC_0}{1.0p^0} + \sum_{t=0}^{n} \frac{HC_t}{1.0p^t} + \sum_{t=0}^{n} \frac{CRT_t}{1.0p^t} + \sum_{t=0}^{n} \frac{CRB_t}{1.0p^t} + \sum_{t=0}^{n} \frac{CD_t}{1.0p^t} \tag{1}$$

where *NPV* is the net present value of the costs of the life cycle of the building (in EUR), *AC* are the acquisition costs (in EUR), p is the discount interest rate (%), n is the period of lifetime of the investment (years), *HC* are the heating costs (in EUR), *CRT* are the costs for repairs and maintenance of technologies (in EUR), *CRB* are the costs for the repairs and maintenance of the building (in EUR), and *CD* are the costs for demolition.

To calculate the energy performance of the selected family home alternatives, the ENERGY 2013 programme was used, where a comprehensive energy performance assessment of the buildings was carried out. The average coefficient of heat transfer of the building, specific heat flows, heating needs, partial energy supplied (heating, cooling, forced ventilation, adjustment of humidity, preparation of hot water, and lighting), energy production (solar collectors, photovoltaics, and recuperation), total energy supplied, primary energy (total and non-renewable), and the CO_2 emissions were calculated. The calculation took the procedures and requirements of European standards into account. Consequently, the current tariffs and switching times of the MRC (mass remote control of high and low tariff) and the consumption ratios for individual tariffs for individual household consumption (heating, hot water, air conditioning, and other appliances including lighting) were also calculated; for example, heating with convector heaters and the tariff chosen for them allowed for using a low electricity tariff for 20 h a day for all of the appliances in the home (but there were higher costs for permanent monthly payments).

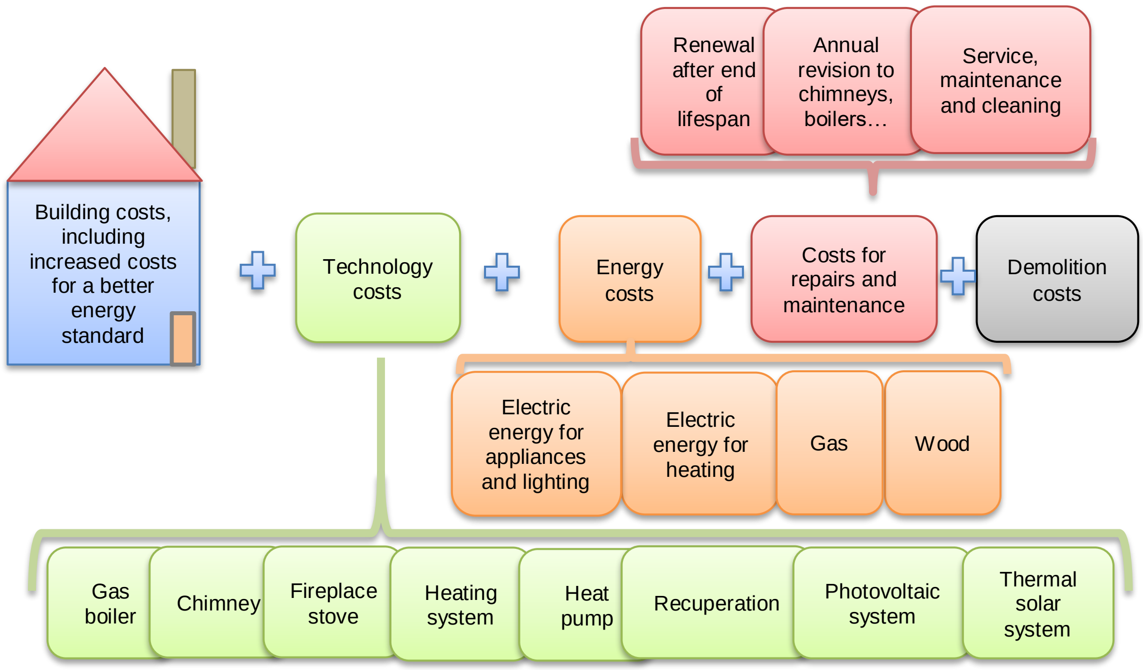

Fig. 3. Diagram of cost calculations of individual home alternatives

The calculated total annual energy supplied is the sum of the individual calculated partial supplied energy requirements for the heating, ventilation, cooling, air conditioning, preparation of hot water, and lighting in the prescribed quantity and quality, and this includes the efficiency of the technical equipment used in the building's energy systems, the losses incurred in these systems, part of heat losses usable to reduce the energy consumption, auxiliary energy, and usable heat and solar gains.

The results are presented in the form of break diagrams in several selected alternatives, where it is clear which alternative is best at what evaluated point in time with regards to the total costs incurred.

The above diagram shows the cost components that must be added to the basic building price. These are not only the costs of the selected technology, but, above all, in the subsequent years, the costs of energy, repairs, maintenance, and the cost of building demolition, which must be added to account for the expected final lifespan of the building (100 years).

RESULTS AND DISCUSSION

The first six alternatives are based on the NOVA 101 home and the other eight alternatives on the NOVA 101 EVO home (near-passive home), which is shown in Table 1. The LEN alternative was supplemented by windows with better thermal and technical parameters and the thermal insulation of the wall between the garage and the interior of the home. The near zero-energy home alternatives were supplemented by PVPP in two power alternatives (4.9 kW and 7.35 kW). For the first six alternatives, a heating alternative with heat utility water was selected, hot water heating using the OKCE 160 S2.2 boiler (similar to the NOVA 101 homes).

Table 1. Overview of the Individual Proposed Alternatives

Alternative	Alternative and Primary Source of Heating	Heating Technology (source, source efficiency in %)	Supplied Heating Energy *MWh/year*
1	Wood 40%, electro 60%	Tile stove with exchanger (ABX Bavaria, 68%), electric boiler (Cosmo THERM E kW 99%)	14.334
2	Gas 100%	Condensing boiler (Junkers ZSB 14-3 C CERAPUR SMART 99%)	12.146
3	Electric boiler 100%	Electric boiler (Cosmo THERM E kW 99%)	12.146
4	LEN wood 60%, electro 40%	Tile stove with exchanger (ABX Bavaria, 68%), electric boiler (Cosmo THERM E kW 99%)	10.856
5	LEN - gas 100%	Condensing boiler (Junkers ZSB 14-3 C CERAPUR SMART 99%)	10.856
6	LEN - electric boiler 100%	Electric boiler (Cosmo THERM E kW 99%)	10.856
7	NPAH - wood 30%, electro 70%	Fireplace stove (Thorma Skal II, 79%), VRJ (ATREA DUPLEX RB4-EC)	3.638
8	NPAH - solar, wood 30%, electro 70%	Fireplace stove (Thorma Skal II, 79%), VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors	3.637
9	NPAH - heat pump, solar	Heat pump (ATREA TCV 4.8), VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors	3.515
10	NPAH - solar, electro 100%	VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors	3.386
11	NZEH – solar, electro PVPP	VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors, PVPP (4.9 kW in peak)	3.386
12	NZEH - solar, wood 30% electro 70%, PVPP	Fireplace stove (Thorma Skal II, 79%), VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors, PVPP (4.9 kW in peak)	3.637
13	NZEH - electro, PVPP	VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors, PVPP 4.9 kW in peak	3.386
14	ZEN - electro, solar, PVPP, net metering	VRJ (ATREA DUPLEX RB4-EC), 3 solar collectors, PVPP 7.35 kW in peak, net metering	3.386

The other nine alternatives were equipped with the ATREA IZT U-TS400 storage tank (as comes with the NOVA 101 EVO alternative), which is normally supplied by the company. Table 1 also shows the required energy supply, including the calculated efficiency and losses associated with the individual technologies. The average heat transfer coefficient for a standard home was 0.22 W/(m^2 *K), LEN 0.2. W/(m^2*K) and 0.18 W/(m^2*K) for the others. Table 1 also lists the costs for energy supply, including the inclusion of the efficiency and losses of individual technologies.

Table 2 shows that the worst alternatives, in terms of cost of energy consumption, were the standard and LEN homes heated by an electric boiler, with annual energy costs of around 1900 EUR. Of course, the lowest cost of energy consumption would be for ZEN with net metering, but the acquisition cost would be almost 28% higher than the standard home with an electric boiler. When evaluating the construction costs and annual costs, when a comparison object (100%) was considered, the average of the total costs after the deduction of one's own consumption from the average of the near passive home alternatives and was compared with other types, the worst energy standard was, as expected, the standard home alternative (more expensive by 88%), followed by LEN (more expensive by 70%). Adversely, the NZEH alternative was less expensive by 25%.

Naturally, the lowest cost would be for ZEN with net metering, *i.e.*, 83%, but the acquisition costs would be 9% higher. This means that the efficiency of passive homes was higher than near zero-energy homes and standard homes when calculated at current prices. As can be seen from the following graphs, given the long evaluation period, discounting has a significant effect on the results. This was especially evident for the costs that would be spent in a more distant future. The individual jump in costs year-on-year increased, as shown in the following graphs, which was due to adding the costs of repairs and maintenance of the individual technologies and parts of the buildings, which were carried out according to the assumptions of individual manufacturers or suppliers.

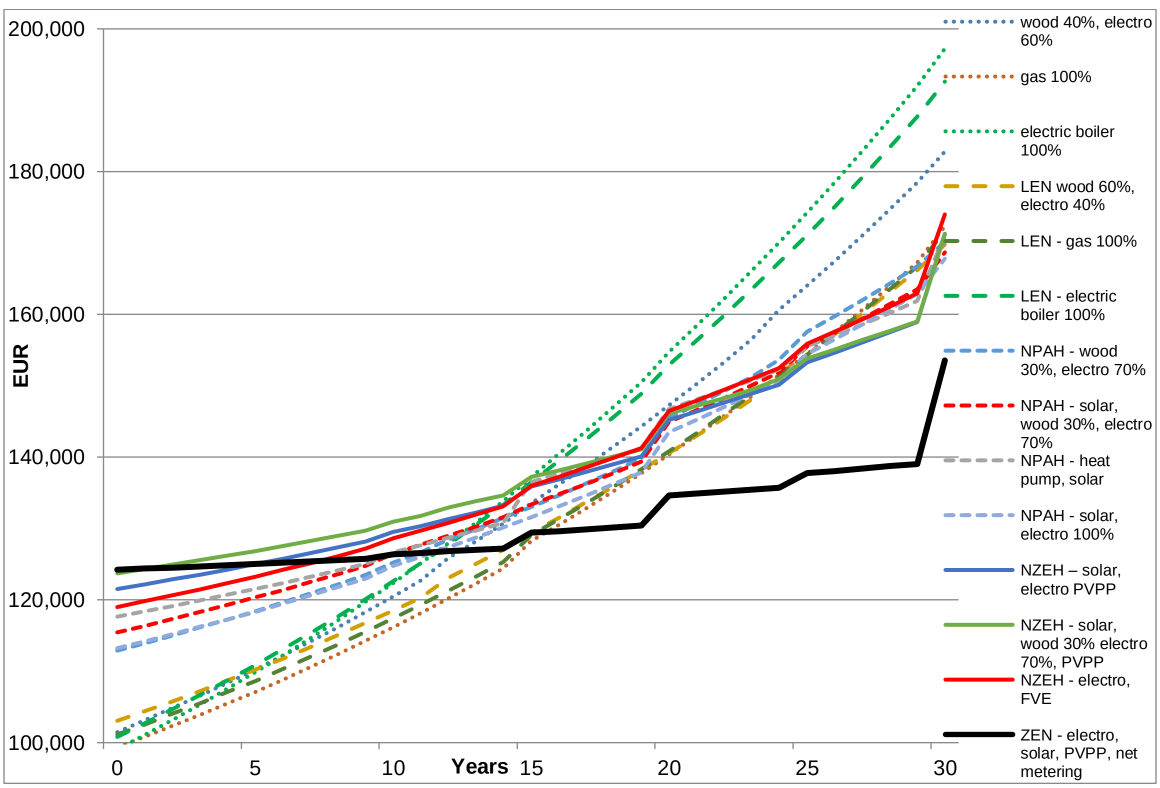

Fig. 4. Comparison of expenses of wooden buildings at a discount rate of 0% and an annual growth in energy prices by 3%

Table 2. Costs for the Acquisition of the Building, Heating, Ventilation, Hot Water, and Household Consumption at Current Prices for the Individually-Proposed Alternatives

Alternative and Heating Sources	Acquisition Costs for the Building	Costs for Heating and Ventilation	Costs for Hot Water	Costs for Household Consumption	Total (Heating, Ventilation, Hot Water, Consumption)	Total After Deducting Own Consumption from PVPP and ZB	Specific Heat Need for Heating
	EUR	EUR/year	EUR/year	EUR/year	EUR/year	EUR/year	kWh/(m^2*year)
Wood 40%, Electro 60%	100,789	1,098.9	188.7	334.2	1,621.8	1,621.8	56
Gas 100%	98,835	856.4	245.5	334.2	1,436.1	1,436.1	56
Electric Boiler 100%	97,974	1,422.9	303.6	265.9	1,992.3	1,992.3	56
LEN Wood 60%, electro 40%	102,692	798.0	188.7	334.2	1,321.0	1,321.0	50
LEN - Gas 100%	100,701	806.8	245.5	334.2	1,386.5	1,386.5	50
LEN - Electric boiler 100%	99,876	1,291.7	303.6	265.9	1,861.2	1,861.2	50
NPAH - Wood 30%, Electro 70%	112,920	471.8	216.2	334.2	1,022.2	1,022.2	17
NPAH - Solar, Wood 30%, Electro 70%	115,620	473.5	93.2	334.2	900.8	900.8	17
NPAH - Heat Pump, Solar	118,024	395.5	58.1	261.5	715.1	715.1	17
NPAH - Solar, Electro 100%	113,345	562.1	115.2	265.9	943.1	943.1	17
NZEH - Solar Electro PVPP	122,006	525.2	93.2	334.2	952.6	641.6	17
NZEH - Solar, Wood 30% Electro 70%, PVPP	124,281	463.8	93.2	334.2	891.2	580.2	17
NZEH - Electro, PVPP	119,307	534.9	230.0	334.2	1,099.1	788.1	17
ZEN - Electro, Solar, PVPP, Net Metering	125,231	809.3	239.9	540.6	1,589.7	145.7	17

With the assumption of growth in energy prices by 3%, Fig. 4 shows that, by the 16th year, the total costs are the lowest for the standard alternative heated by gas. This was caused by very low initial costs for the acquisition of a gas condensing boiler. From the 17th year it would be the fictitious ZEN alternative with net metering, which showed that with the increasing price of energy, it would be worthwhile to invest into one's own PVPP. However, if there was no net metering, an investment into LEN would only become the least expensive after 23 years of operation. If natural gas is not available or installed, after 6 years the best alternative would be LEN heated with wood, and only after 24 years would it be replaced by near zero-energy home alternatives.

Figure 5 shows a discount rate of 2% and a 3% growth in energy prices, after more than 18 years; given this, the best alternative became ZEN with net metering. Until such a time, and with the same applications as Fig. 4, the best alternative for heating a home was gas.

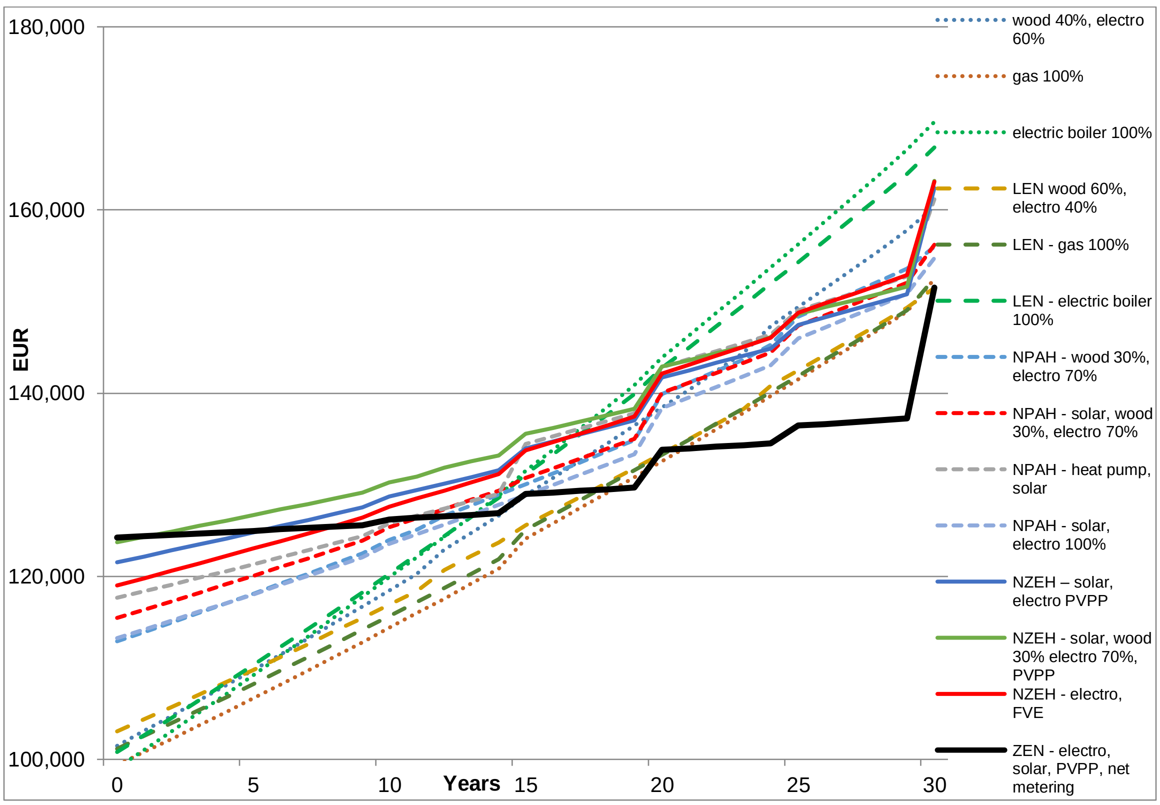

Fig. 5. Comparison of expenses of wooden buildings at a discount rate of 2% and an annual growth in energy prices by 3%

Figure 6 shows that with a rising energy price (5%), the return on the increased costs with regards to a better energy standard was shortened. Initially, the best alternative was, once again, heating with gas for the first 16 years, where the best alternative became the fictitious ZEN alternative with net metering. If net metering was not implemented, then the best alternative became LEN heated with gas, or a combination of wood and electricity after 21 years. After 24 years, the best alternative seemed to be NZEH.

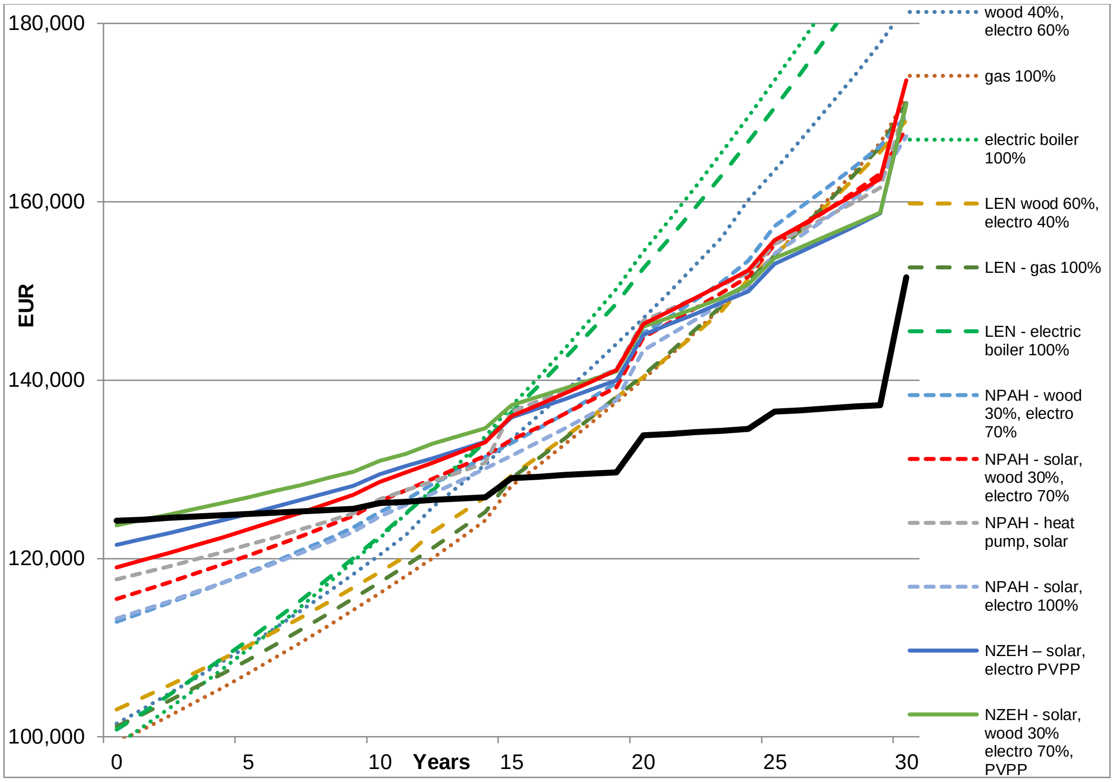

Fig. 6. Comparison of expenses of wooden buildings at a discount rate of 2% and an annual growth in energy prices by 5%

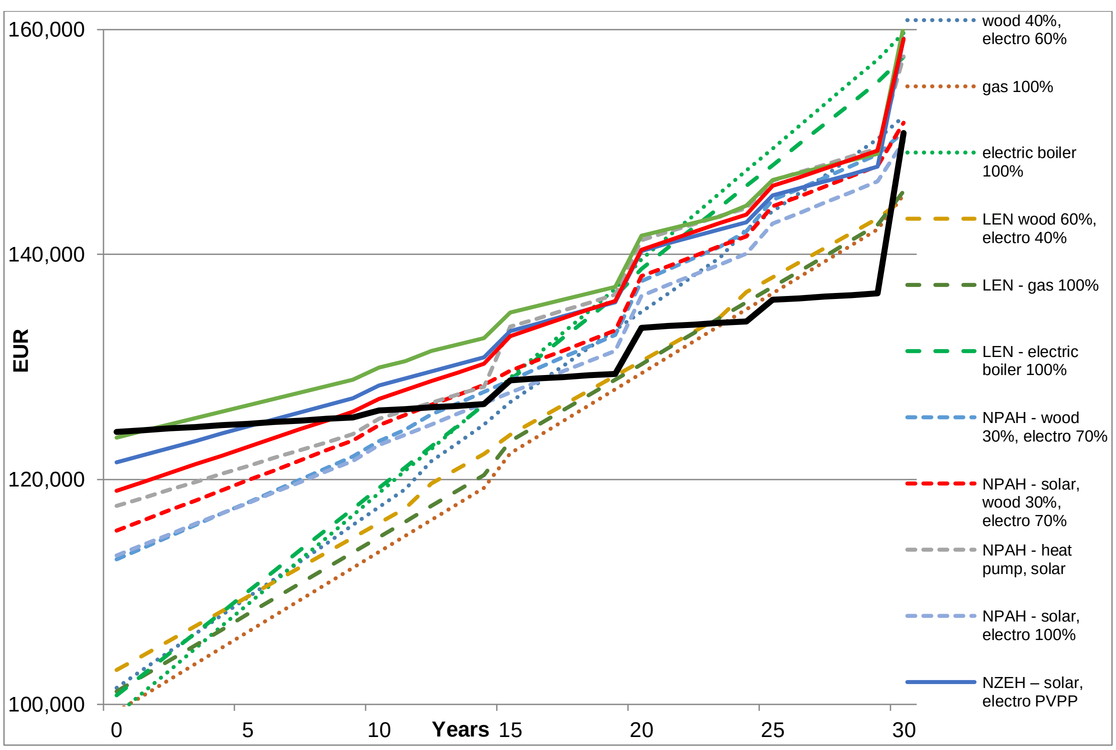

Fig. 7. Comparison of expenses of wooden buildings at a discount rate of 0% and an annual growth in energy prices by 0%

Figure 7 considers the solutions without a discount rate; with unchanged energy prices, the standard home alternative with gas was still the best alternative for up to almost 25 years. Afterward, the fictitious ZEN alternative with net metering became a better alternative. If net metering was not implemented, the best alternative was a standard home heated with gas for up to 30 years, followed by LEN heated with gas and wood. It was also apparent that the increased costs invested into NPAH would not be returned in the form of cost savings in wooden buildings up to 30 years old.

Figure 8 shows a graphical comparison of the total costs over the estimated lifespan of 100 years, including demolition costs. The share of energy and fuel costs compared to other costs was apparent. By far, the lowest energy and fuel costs alternative for the entire period was the ZEN alternative with net metering, where the costs for energy were 20% of the acquisition costs for completing the building compared to average the NZEH alternative, where the costs for energy consisted of 93% of the acquisition costs of the building, 131% for the average NPAH, 254% for the average LEN, and as much as 286% for the average standard home.

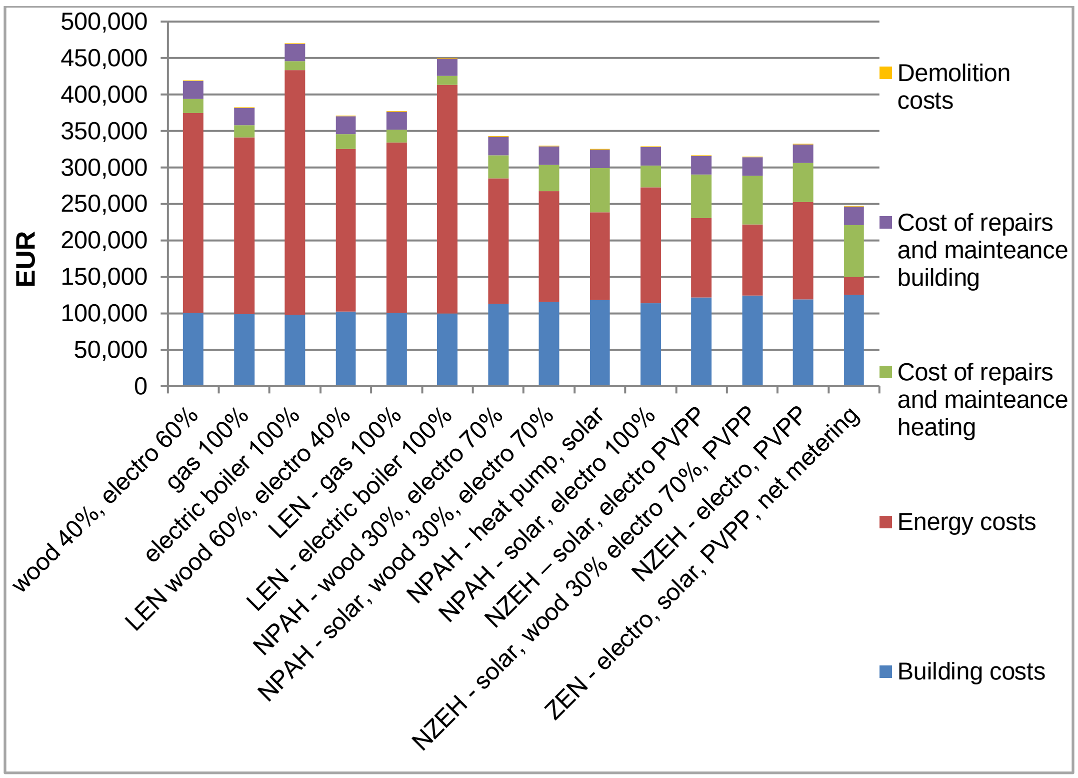

Fig. 8. Comparison of expenses of the total costs during the lifespan of wooden buildings (100 years) at a discount rate of 2% and an annual growth in energy prices by 3%

However, compared to other alternatives, in this case, the highest costs were for maintenance and repairs of heating and the production of hot water for the ZEN alternative, which were at the level of 57% of the acquisition costs of the building. The lowest costs for maintenance and repairs of heating were for the alternative with an electric boiler, but which was countered by the highest costs for energy and the highest total costs

For investors (builders), who are going to live in the house and not just build it for sale, it is important to compare the evaluated period of up to 30 years, once again in different alternatives, and the expected annual change in energy prices, or possibly a considered change in the discount rate, where it is possible to clearly choose from the graph which alternative is economically best (from the considered alternatives). Adversely, compared to the entire life cycle of the building, the results show that in some cases the passive home alternative may not become the best alternative within 30 years. The investor must decide what return time is required in relation to other possible alternatives. For the investor, the results show that the costs for a passive home may not be returned in cost savings during the investor's chosen period and alternative, which confirms that it is not always economically optimal to always seek the best energy standard, but to rather properly calculate everything and be energy efficient, as evidenced by the submitted contribution to the most frequently constructed wooden building alternative of a family home in the Czech Republic. It was confirmed that with rising energy prices, the period of return on investments into a better energy standard was reduced. For example, it was clear from the results that investing in a heat pump in a passive home does not pay off because most other energy sources will be economically more advantageous in a passive home (at least up to 30 years) due to the high acquisition cost and the maintenance cost of heat pumps.

Unlike the LCA (life-cycle assessment) method, wherein, for example, the produced CO_2 and bound energy demand, *etc.*, are calculated, in the proposed methodology, only the economic efficiency for the investor was evaluated, which, as the authors assumed, was the most important aspect for the majority of investors and it will likely remain as such for a long time. The lowest justifiable level of energy performance of buildings should correspond to the so-called cost optimum, and that is why it is necessary to look for an energy-efficient building that will bring its owner the lowest costs not only for heating but also for the purchase, repair, and maintenance of the building and the technologies used therein.

However, it is also important to have an indoor environment where there are differences in humidity, but mainly to retain CO_2 (exhaled) (Sviták *et al*. 2018), which here remains without sufficient ventilation or recuperation and thus reduces the well-being of living and quality of living. Sufficient ventilation or recovery is taken into account in our study.

It is expected that passive homes will be more comfortable for their inhabitants (Rodriguez-Ubinas *et al.* 2014; Mihai *et al.* 2017) and provide a healthier environment (Brimblecombe and Rosemeier 2017), which was also thanks to the regulated ventilation (Srba *et al.* 2016 with recuperative units with filters (Kinnane *et al.* 2016).

It was therefore obvious that passive homes were usually more expensive than low-energy standard homes, and it was up to the investor to decide which alternative was more interesting and appropriate. According to Berndgen-Kaiser (2008), the average cost of a passive home in Germany was 1338 EUR/m^2 of living space, which was higher than the price of the standard Rýmařov NOVA 101 family home (which already includes a heat pump), where the purchase price amounted to 1198 EUR/m^2 of living space. The company RD Rýmařov also supplies houses to the German market. Although the GDP is significantly higher in Germany, the prices of prefabricated buildings are often similar in both markets unless one considers the price of land.

At current energy prices, the expected return on investment into better thermal insulation and technologies of the NPAH or LEN homes was estimated to be within 10 to 15 years (Koloděj *et al.* 2012; Klobušník 2013). However, as the results show, this was not always the case, as it depended, very much, on what fuel will be used for heating a standard home. As far as natural gas is concerned, the return on investment into a better energy standard could be extended within 25 years for a passive home and 20 years for LEN. If considering only heating with electricity, then the above statement can be agreed with. Low energy or passive homes will achieve lower operating costs (up to 40% lower operating costs compared to a normal home built according to the requirements of the current Czech standards (ČSN 2011) that are associated with the usual use of a home (Liu and Wang 2016). Of course, for a home with solar panels, it is possible to choose whether, for example, hot water will be heated by solar collectors, or by the electric energy obtained from photovoltaic cells (Ochs *et al.* 2014), and how large batteries will be used to store energy (unless a net metering is used) from photovoltaic exportation during warm months and decrease the peak demand during cold months (Zhang *et al.* 2017).

According to the research of the Passive Home Institute in Germany (Passivhaus Institut) compared to standard construction, the costs for a passive home are higher by 8% (Srba *et al.* 2016), which was not confirmed in this work, and the costs for a passive home were approximately 15% higher (alternative with heat pump) compared to the standard home; however, this may concern an increase in the price by as much as 10.4% (Zhang *et al*. 2017). This price increase percentage could be significantly lower if the builder would do part of the work himself, which the authors can also confirm through experience.

There are also problems in the incorrect design of houses, which are specifically the thermal bridges. Not only the design, but the quality of the design is also important. Critical spots can be revealed by thermography in already finished buildings (Sviták *et al.* 2016).

The comparison does not include time-limited subsidies, which generally distort the situation on the market. For example, it is now possible to acquire a subsidy for a passive home in the Czech Republic in the amount of 16,637 EUR, and after this is included, a passive home would pay off from the beginning. However, such a high subsidy is not a system solution for building passive homes, as it will only support, over the short-term, a fraction of those interested in building family homes.

It can be stated that increased costs for a better energy standard are not always returned to the investor over a short-term period. However, another aspect to take into consideration is consumer behavior (Ridley *et al.* 2014 Ashouri *et al.* 2018). Yet, if the growth in energy prices is taken into consideration, then investments into passive homes, and possibly those that are even more energy-efficient, almost always pay off, and they may, therefore, constitute a certain social certainty for owners, as they will only have to spend a small amount of money on energy in the future.

CONCLUSIONS

1. For the determined period of 30 years, initially the lowest-cost alternative is always the standard home heated with gas for a standard-delivered home, which is not available in all localities, but more than 60% of family homes are heated with it in the Czech Republic.
2. The ZEN alternative with net metering would be the second-most economical option, which would significantly increase the ROI (return on investment), and this is the path that countries should take (implement net metering), which would also increase interest in ZEN as the return would be around 10 years at a 3% growth in energy prices and 0% discount rate. The ZEN alternative with net metering would, therefore, have a

significantly lower payback period than PAH and would likely be used by investors (builders) more often. Unfortunately, net metering has not yet been implemented in the Czech Republic. If implemented, there would be a significant increase in photovoltaic interest if the subsidies for renewable energy sources remained. Without this subsidy, due to higher acquisition costs, the increase in the use of photovoltaics would be slower. In many cases, increased investments into a better energy standard (NZEH and NPAH) would not be returned even within 30 years.

3. When calculating the entire life cycle of the building (100 years), it turns out that the better the energy standard, the lower the overall life cycle costs. The alternatives with the highest total costs are those where electric energy is used for heating, followed by an alternative with electric boilers and some wood used for heating. On the contrary, the alternative with the lowest cost is the fictitious ZEN alternative with net metering, followed by the NZEH alternatives by some distance.
4. However, the photovoltaic alternative with net metering is only available in some countries. If this alternative was also enabled in other countries, this would mean that end users would pay a great deal less for energy, in particular in the combination with ZEN, which was also proven by the ascertained results. This is also a way in which to increase the share of renewable energy resources without subsidies or state contributions, and, thereby, help decrease CO_2 emissions and increase the energy self-sufficiency of the population. At the same time, this will increase the proportion of renewable energy sources that individual countries (including the Czech Republic) have committed to.
5. Before deciding to build a family home, if the investor (the builder) assumes that he will live in the house for a long time, it is important to duly calculate the potential return of an increased investment into a higher energy standard. If possible, buildings should be energy efficient, *i.e.*, by providing the lowest costs for their owners for the acquisition, repair, and maintenance of a building and the technologies used inside it, including costs for heating and consumed energy. In such a case it is possible to ignore the costs for repairs and maintenance of the building, as throughout the lifetime of the building they will be almost the same or a very similar amount as for homes in various energy standards, and in most cases, they would affect the result of the comparison very little, or not at all.

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