Net Zero Energy House with Direct Electric Heating

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Abstracts

This project demonstrates that it is possible to build "net Zero Energy Houses" (nZEH) with solar power system and electric floor heating in Denmark by utilizing the power grid for seasonal energy storage. A 196 m^2 low energy house with a heat pump and water based floor heating system has been used as a starting point and then modified into a nZEH. The heat pump and the water based floor heating system was replaced by a 7.2 kW solar power system, a 4.9 m^2 solar thermal system for domestic hot water production, and electric floor heating system. The Danish Energy Performance of Buildings calculation tool Be10 has been used to verify the official energy performance at 20°C indoor temperature. Be10 has also been used to calculate the energy consumption at 22°C indoor temperature, which was expected to be a realistic estimate for the energy consumption in practice. The nZEH has been built, and the energy performance has been monitored for 9 months and will continue to be monitored for 24 months in total. The collected data indicates that the nZEH ends up being an energy-plus house, which produces 17% more energy than it consumes for space heating and DHW. The financial attractiveness of this type of nZEH has also been estimated and compared with the original low energy house. The initial cost is about 90,000 DKK (12,000 EUR) higher for this type of nZEH compared to the original house, but in a 30 years "global cost" analysis, the nZEH ends up being 75,000 DKK (10,000 EUR) cheaper (2010 prices).

Keywords: Net Zero Energy House, Energy-plus House, Electrical Floor Heating

Introduction

For a long time, electrical heating was banned in Denmark for primary heating of new buildings. The ban was removed in 2006 where a new calculation methodology was introduced as required by the Energy Performance of Buildings Directive. The calculation methodology is based on primary energy with a 2.5 primary energy factor on electricity. The high primary energy factor on electricity has made it very difficult to fulfil the energy performance of building requirement with electrical heating, but with the lower and lower heat demand of new buildings and the increased share of renewable energy production, electrical heating could, in the near future, become attractive for space heating in very low energy houses in Denmark and elsewhere. In 2020, the primary energy factor for electricity in Denmark will be 1.8, and by 31 December 2020, all new buildings in the EU must be "near zero energy buildings" [EPBD 2010]. When this project started in 2011, house owners in Denmark were allowed to connect solar power systems up to 6 kW to the power grid and "store" the energy in the grid. The electricity sold to and bought from the grid was handled with same price over a yearly period, making it financially attractive to build an nZEH. "Zero Energy House" in this project means a house that produces (exports) as much energy as it consumes (imports) for space heating and domestic hot water production. The wording “net” emphasizes that the house uses the electrical power grid for seasonal energy storage to balance export and import of electricity over a yearly period.

Objective

The purpose of this project is to demonstrate that it is possible to build nZEHs with electrical floor heating in Denmark and to investigate and compare the financial attractiveness of such a solution against a low energy house with a heat pump. The objective is therefore to convert a low energy house with a ground source heat pump into an nZEH with electric floor heating and a solar power system, verify by calculation that it fulfils the Danish energy performance of building requirements and afterwards verify the energy performance in practice by actually building the house and monitoring the energy production and energy consumption for 24 months, while it is occupied by a family. A second objective is to investigate the financial attractiveness of the nZEH by comparing initial investment and 30 years global cost with the original low energy house with a heat pump.

Method

The energy performance of a building in Denmark is verified by an official and mandatory calculation tool called “Be10” [SBI 2013]. Be10 calculates the annual energy consumption in primary energy and takes into account the contribution from a local solar power system and solar thermal system in the energy performance result. In this project, Be10 has been used to verify the official energy performance at 20°C indoor temperature and to estimate the energy consumption at 22°C indoor temperature, which was expected to be a realistic estimate of the energy consumption in practice. The estimated power production from solar power system has been calculated with LynxPlanner [Danfoss 2013].

Electricity consumption is measured by three standard electricity meters (total energy consumption, hot water production and space heating). These meters are manually read every month. The energy production of the solar power system is measured by the solar inverter and also read manually every month. Temperature measurements and thermostat set points in every room are logged by the heating system.

The financial attractiveness has been investigated by means of EN 15459:2007 - a European standard for economic evaluation of energy systems in buildings.

Figure 1. The “net zero energy house” (nZEH).

The starting point for this project was a low energy house with a structural wood-frame inner wall and a brick siding outer wall. This house is normally equipped with a ground source heat pump, a water based floor heating system and a heat recovery ventilation system. The ventilation rate is 0.325 l/s m^2 and the efficiency of the heat recovery is 82.5 %. Infiltration has been tested by blower door test to 0.08 l/s m^2. The cooker exhaust hood is not connected to the ventilation system.

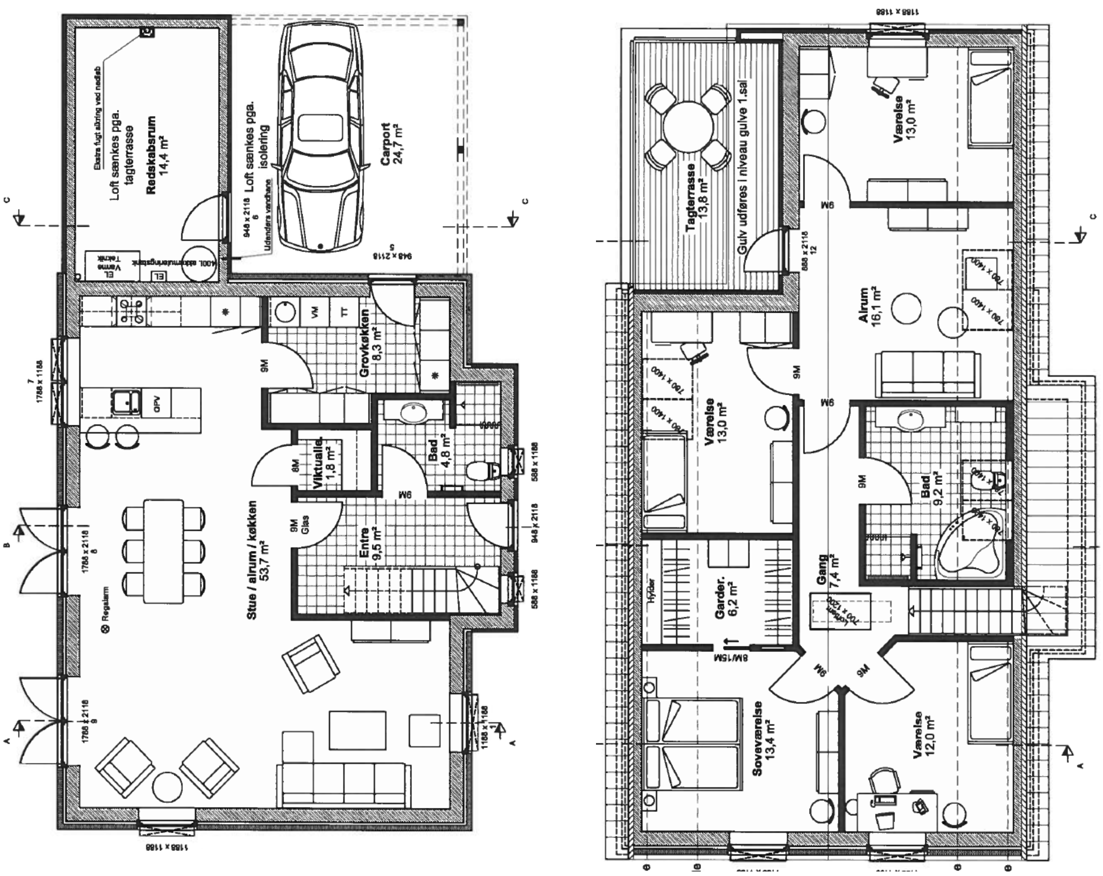

Figure 2 Layout of the house

Building part	W/m^2K
Outer walls (walls facing utility room)	0.13 (0,15)
Ceiling (slope ceiling)	0.08 (0.15)
Ground deck	0.09
Windows (roof windows)	0.83 (1.00)
Outer doors (Terrace doors)	1.14 (1.16)

Table 1 U-values of the building parts

Building part	W/mK
Foundation	0.1

Table 2. Thermal bridges

The nZEH is equipped with electrical floor heating in all rooms. On the ground floor, the electrical heating cables are embedded into 10 cm concrete slab (wet system). On the first floor, electrical heating mats are installed directly under the wooden floor (dry system).

The solar power system has Mono Crystalline PV Solar Panels. The solar power used in the calculation is 6 kW, which is the maximum solar power allowed to be connect to the grid. During the construction of the house it was decided to install 7.2 kW solar power system with a 6 kW limitation to the grid, handled by the inverter. The solar thermal collector panel is 4.93 m^2 with a 300 l buffer tank. A supplementary electric heater is installed in the tank. The orientation of the solar thermal collector and the solar power system is SSW and the slope of the roof is 45 degrees.

The dishwasher and the washing machine are connected to the hot water storage tank from the solar thermal system to minimize the energy for water heating.

Apart from these changes, the two houses are identical.

The nZEH is owned and occupied by a family with two adults and two small children.

Results

The Danish requirements for energy performance of a 196 m^2 building are shown in Table 3.

DK Building Code Requirements for 196 m2	Primary Energy kWh/ m2 year (Factor 2.5)
Standard House	60.9
Low energy building 2015	35.1
Low energy building 2020	20.0

Table 3 Danish energy performance requirements for a 196 m^2 house

The energy performance of the original low energy house with a heat pump is calculated by Be10 to be 31.1 kWh/m2 per year (measured in primary energy), which fulfils the “Low energy building 2015” requirements. When the heat pump is replaced with direct electrical floor heating, the primary energy demand increases to 87.7 kWh/m^2. By adding a 6 kW solar power system, the primary energy demand is reduced to 19.4 kWh/m^2. To reduce the primary energy even further, a 4.9 m^2 solar thermal system for the domestic hot water production is added. The primary energy now ends up being negative, which indicates that the energy produced by solar power system and solar thermal system is higher than the energy demand for space heating and DHW (Table 4).

Be10 calculations for 196 m2 kWh/ m2 year @ 20 C indoor temp.	**Heat**	**DHW**	**PV**	**Solar thermal system**	**Primary Energy (Factor 2.5)**
The standard low energy house	16.5	16.2	0	0	31.1
HP replaced with electrical heating	16.5	16.0	0	0	87.7
and added 6 kW solar power system	16.5	16.0	27.3	0	19.4
and 4.9 m2 solar thermal system	16.5	16.2	27,3	10.4	-5.0
With **22°C** indoor temperature	21.5	16.2	27,3	10.4	7.5

Table 4 Be10 calculations on net zero energy house

The official energy performance must be calculated with 20°C indoor temperature and at this temperature the house is an "energy-plus house". In practice, the energy consumption is expected to be higher and a more realistic estimate of the energy consumption of the house is calculated at 22°C indoor temperature, which results in 7.5 kWh/m^2 per year. This is primary energy and the actual energy consumption is found by dividing with the primary energy factor: 7.5 / 2.5 = 3 kWh/m^2. The total energy consumption for 196 m^2 with 22°C indoor temperature is 588 kWh per year.

6 kW solar power system was used in the calculations but 7.2 kW solar power system is installed on the house. The maximum power delivered to the grid is still limited to 6 kW by the inverter, but the extra solar power panels will enhance the chance of reaching the goal of "net zero energy" in practice, because the larger system will produce more energy in periods where the produced power is lower than the 6kW limit (for example in cloudy weather).

Empirical Findings

The energy production from the 7.2 kW solar power system has been measured for 12 months and the energy consumption for space heating and domestic hot water has been measured for 9 months. The results are illustrated in Figure 3.

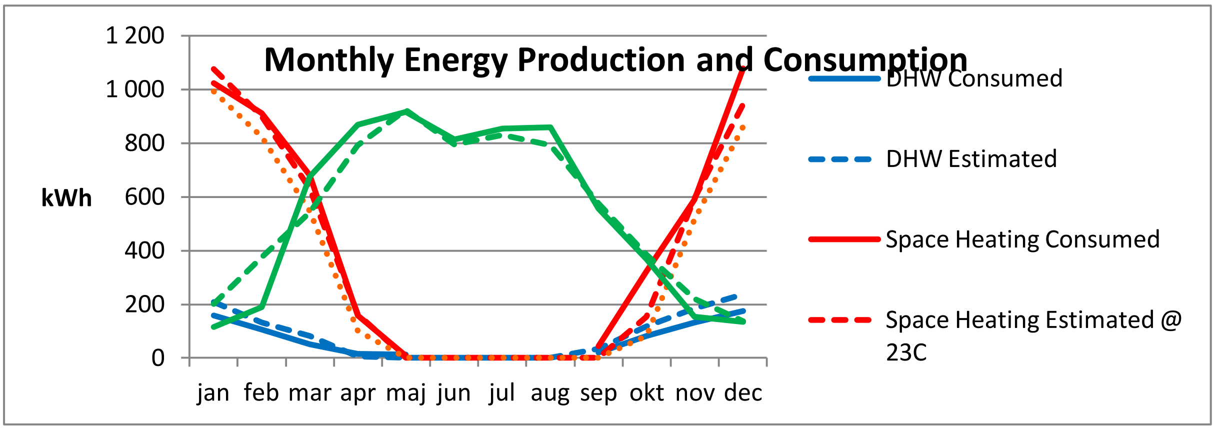

Figure 3. Estimated and measured consumption and production Sept-Dec (2012) and Jan-May (2013).

The energy consumption was high in October due to commissioning and setup of the system, and December was a very cold month. The thermostats are set to 20°C or 21°C with a 3°C night setback.

The measured energy consumption for space heating is higher than what is calculated in Be10 with 22°C indoor temperature and seems to be closer to what is calculated with 23°C indoor temperature. A building's heating requirement depends on the construction of the building. The heating requirement increases when a construction's thermal mass is reduced, as its ability to store heat in periods with e.g. high solar radiation is reduced [Larsen 2012]. A possible explanation could be that the heat capacity of the building used in Be10 was too high. This could explain why the measured energy consumption is higher than the calculated. 80 Wh/K m^2 has been used, which is what Be10 recommends for a building with just a single heavy building part, in this case, the concrete floor. The measured energy consumption for DHW is lower than calculated. The reason could be that the house is occupied by a small family with two adults and two small children. Be10 calculates energy for DHW per m^2 and since this is a large house the energy for DHW is also equivalently higher. It is beyond the scope of this project to investigate and further explain the deviation between the calculated and measured energy consumptions.

The energy consumption has been measured for 9 months (Sep to May), which is the heating season, and the Be10 calculation indicates that there should not be any heat demand from June to September (see Figure 3). If this is assumed to be the case in practice, the annual energy consumption (import) should be 4,814 kWh for space heating and 748 kWh for DHW. The annual solar power production has been measured to be 6,503 kWh for the last 12 months. With these numbers, the result is a surplus export of 942 kWh (thanks to the larger solar power system). This indicates that the house in practice could be an "energy-plus House".

The house owners are very pleased with the system and the comfort in the nZEH. They have not experienced any discomfort with insufficient heating and no significant overheating problems. They perceive the house to be less troubled with overheating compared to their neighbours' more traditional houses with heavier inner walls. The owners explain that it is easy to ventilate the heat away and the house does not build up high temperatures in the construction during summer time. This is also confirmed by other observation of houses with different wall constructions [Larsen 2012].

Financial Attractiveness

The only difference between the original low energy house and the nZEH is that the low energy house has a heat pump and a water-based heating system and the nZEH has solar power system, solar thermal system and an electric floor heating system. Besides that, the two houses are identical. To determine the financial attractiveness, one thus only needs to take the mentioned equipment into account. Two financial calculations have been made. The first one shows the initial investment of the two different systems (equipment).

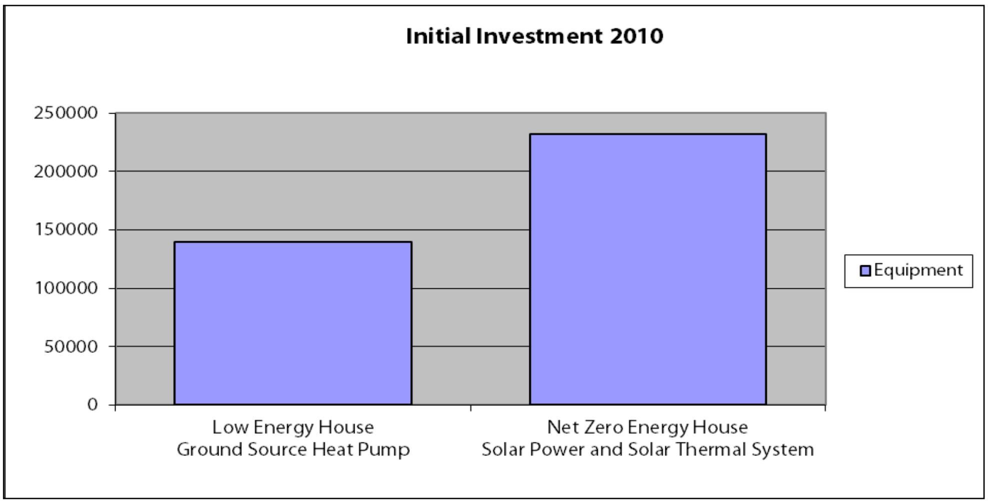

Figure 4. Initial investment of the two systems (2010 prices).

The initial investment of the solar power system is still more expensive than a ground source heat pump. The nZEH with an electrical heating system, a solar power system and a solar thermal system therefore results in about 90,000 DKK (12,000 EUR) higher initial costs. The price of solar power systems, however, is expected to drop by 50 % every 5 years, which would significantly decrease the initial costs.

The second financial calculation is a 30 years global cost analysis [EN 15459 2007], which takes into account the initial investment, annual costs and the final value. In this calculation, the nZEB with a solar power system and a solar thermal system is 75,000 DKK (10,000 EUR) cheaper due to the longer lifetime of a solar power system (30 years) compared to a heat pump unit (20 years), lower energy cost and lower service and maintenance costs.

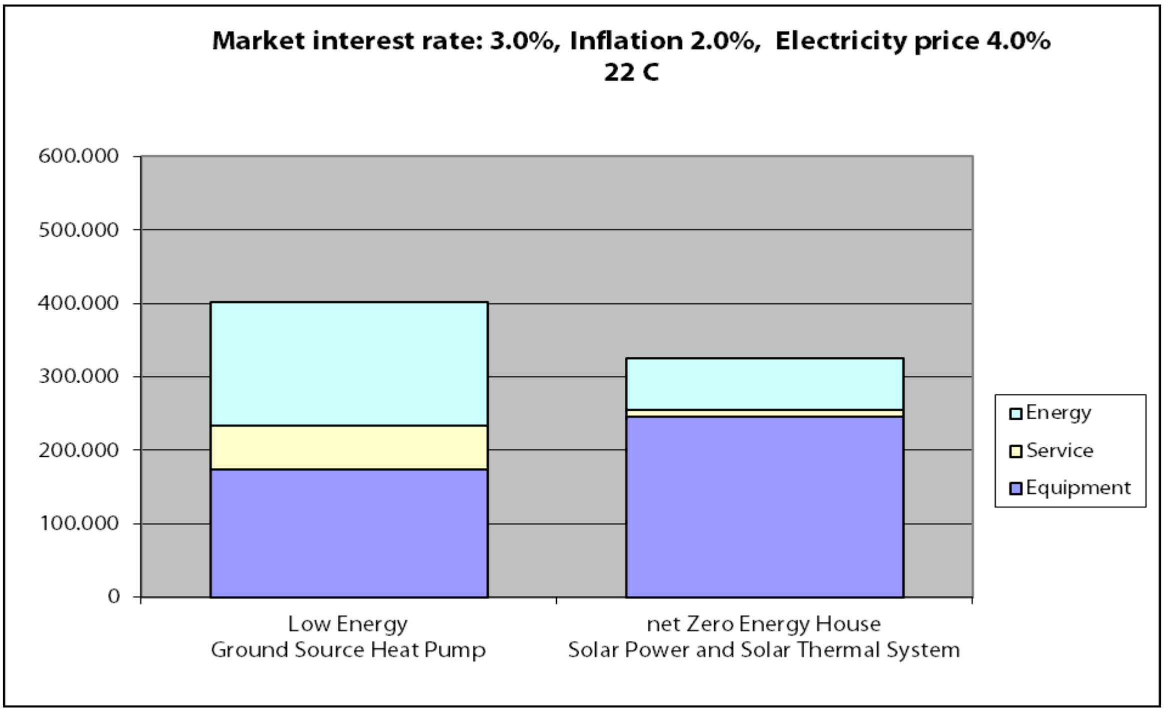

Figure 5. 30 years global cost analysis with 22°C indoor temperature.

Discussion

The Be10 calculations and the practical measurement demonstrate that it is possible to build an nZEH that produces (exports) as much and even more energy as it uses (imports) for space heating and hot water production on an annual basis. The precondition for this nZEH concept and for the deployment of nZEHs, is that house owners are allowed to store (sell) the energy generated in the summertime in the grid and get (buy) it back again in the wintertime in an attractive way.

The financial attractiveness depends first of all, as mentioned above, on the possibility to store the energy in the grid. Secondly, the financial attractiveness depends on whether the house owners focus is on the initial investment or the long-term investment and third, the price development of solar power systems and electricity in the future. The financial calculations are based on 2010 prices and the price development of solar power systems within the last 3 years may turn out to make solar power system even more attractive than indicated in this paper. When the initial investment of a 6 kW solar power system becomes equal to or lower than a ground source heat pump, then the nZEH concept in this paper is the most attractive, with the precondition that the energy can be stored in the grid or elsewhere from summer to wintertime.

Conclusion

This project has demonstrated that a standard Danish low energy house (2015) can easily be converted into a “net zero energy houses” (nZEH) with electric floor heating and maybe even a “net energy-plus house”. The low energy house was modified; the heat pump and water based floor heating were replaced with a 6 kW solar power system, a 4.9 m^2 solar thermal system and electrical floor heating system. No other modifications were needed on the house in order to reach a primary energy performance of -5.0 kWh/ m^2 year in Be10. In practice, the energy consumption was estimated to be higher and during the construction of the house it was decided to install a 7.2 kW solar power system to compensate for that.

The energy consumption has been measured in 9 months and the measured energy consumption is higher than expected and close to what is calculated with 23°C. The solar power production has been measured in 12 months and the measured power production is very close to the predicted production (6,503 and 6,566 kWh). By assuming there will be no heat demand in June-August as indicated by the calculations it was possible to predict the annual energy consumption for space heating and DHW: 5,562 kWh. The house is therefore expected to be an "energy-plus house" in practice with 17% surplus energy.

The financial attractiveness and the deployment of this type of nZEH depend first of all on the opportunity to store and balance energy in the grid in a financially attractive way. Secondly, on the price development of solar power system, the price development on electricity, and whether house owners focus on initial investment or on long term cost. The financial attractiveness was calculated with 2010 prices and with a 6 kW solar power system. In this case the nZEH requires about 90,000 DKK (12,000 EUR) more in initial investment but in a 30 years global cost analysis, the zero energy house is, at current energy and installation cost prices, about 75,000 DKK (10,000 EUR) cheaper.

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