HEAT PUMPS A VIABLE ALTERNATIVE FOR PASSIVE HOUSES

S. Ruud, M.Sc, SP Technical Research Institute of Sweden, Borås, Sweden

Abstract: There is today a clear trend towards low energy houses. Several passive houses have been built in Sweden. However heat pumps are not installed in any of these houses. The standard system solution is a high efficiency air-to-air heat recovery system with an electric reheater in the supply air. About half of the domestic hot water is produced by thermal solar panels, mostly during the summer time. The rest is produced by electricity. In winter the heating system therefore mainly uses direct electric heating. A theoretical comparison has been made between this solution and two heat pump solutions. These solutions have also been evaluated for a less well insulated house. The calculations show that in most cases the heat pump solutions give a lower total energy use and life cycle cost than the standard solution. The ground source heat pump also has a lower peak power demand and in addition offers the benefit of free cooling. The conclusion is that heat pumps are a viable alternative for passive houses and also for other types of low energy houses.

Key Words: ***heat pumps, passive houses, low energy houses***

1 INTRODUCTION

In large parts of Europe so called passive houses have almost became synonymous with low energy houses. The passive houses have evolved from well insulated houses with efficient ventilation heat recovery that were exported from Sweden to Germany around 1990. The principle of passive houses is that the needed power supply for heating is so low it can be supplied through a small reheater in the supply air and distributed only by the ordinary air flow rate in the ventilation system. Thereby the increased cost for the higher insulation standard can be almost equaled by the decreased cost not needing to install a rather expensive separate heating system. To decrease the initial cost and minimize the complexity of the small heating system, the standard solution for passive houses has been to install a very cheap and simple electric reheater. The maximum specific power output of the reheater is in Germany set to 10 W/m^2. For reduction of bought energy for domestic hot water solar panels are normally installed, although it's not necessary for the passive house concept. In Sweden the contribution from the solar panels are almost negligible in the midst of the winter. This means that the peak power needed in the wintertime is still rather high and for the standard solution it is all electricity. To decrease the peak electric power demand, some of the recently built passive houses in Sweden have been connected to a local district heating plant using biofuel. District heating is then used both for domestic hot water and for the hydronic reheater. Another possibility to decrease both the total energy use and the peak power demand might be to use heat pumps. Although heat pumps are very common both in new built and older houses, this far none of the passive houses built in Sweden are using heat pumps. The aim of this paper is to theoretically evaluate both the technical and the economic feasibility of using heat pumps as an alternative to the standard solution for passive houses.

2 METHOD

2.1 Overall method

An energy calculation method has been calibrated to match the average measured energy use for the passive houses at Lindås Park (Ruud et al 2004, 2005). The actual energy system solution has then been replaced and compared with two heat pump system solutions. The heat pump solutions have also been combined with a less heavily insulated building envelope. Bought energy in the form of electricity and power demands has been calculated. Energy costs, initial investment costs for the heating system, life time of main components and reinvestment costs have been estimated. Interest rates and inflation rates for energy and components have also been estimated. From this, life cycle costs have been calculated.

2.2 Energy calculations

The energy calculations are made with an energy calculation method originally developed by SP for a Swedish association for producers of timber framed single family houses, TMF. It is used to make a preliminary energy declaration of specific energy use in new built single family houses according to the new Swedish building code of year 2006. Due to the implementation of the European Energy Performance of Building Directive (EPBD), the Swedish National board of Housing and planning has in the new regulations set maximum values on specific energy use for space heating and domestic hot water in new buildings. The calculation method is based on the European standard EN ISO 13790:2004, but with national parameters for usage (Levin et al 2007). In this paper the calculation method had been slightly modified to suite the purpose of the study.

2.3 Description of the building

The calculations are made on a whole terrace house block consisting of four apartments and having a total heated floor area of 484 m^2 and a total external envelope area of 920 m^2. The specific heat loss through the building envelope (U_m), excluding ventilation and infiltration but including thermal bridges, is for the for passive houses set to 14 W/(K m^2). For the more normally insulated houses the specific heat loss is set to 28 W/(K m^2). The air tightness of the building envelope is in all cases set to a quite low value; 0.4 l/(s m^2) at a pressure difference of ±50 Pa. This together with a rather wind shielded position gives for a balanced ventilation system a mean infiltration of 7.4 l/s. The house is equipped with a mechanical supply and exhaust air ventilation system having a high efficient air-to-air heat recovery unit. The temperature ratio of the heat recovery is 90 %, including heat emitted from the fans. The house is situated close to Gothenburg, having a mean outdoor air temperature of 8°C. The indoor air temperature is during the heating season set to +20 °C. The house is inhabited by 16 persons having a mean heat output of 80 W when present, and on an average present in the house 14 hours a day. The total use of household electricity is 16 000 kWh/year and the total use of domestic hot water, excluding storage heat losses, is 6 400 kWh/year.

2.4 Description of the heating system solutions

2.4.1 Distribution of space heating

In the passive houses the space heating is distributed throughout the house with a central high temperature reheater placed in the supply air of the air handling unit. In the less heavily insulated houses the space heating is distributed by a low temperature floor heating system and that the possibility to increase the COP of the heat pump is connected to a low temperature system is utilized. The increased investment cost for a floor heating system is assumed to be equal to the decreased investment costs for a more moderately insulated building envelope.

2.4.2 Standard Passive house solution

The standard system solution is a high efficiency air-to-air heat recovery system with an electric reheater in the supply air. About 40-50 % of the domestic hot water is produced by thermal solar panels, mostly during the summer time. The rest is produced by an electric heater placed in the domestic hot water boiler. In the winter time heating and domestic hot water is therefore mainly produced by direct electric heating. Domestic hot water can either be produced (and stored) centrally or individually in each flat. A common storage tank is likely to increase the percentage of solar contribution. In the calculations individual systems is assumed, just as in the passive houses at Lindås Park. The standard heating system solution is estimated to have an initial investment cost of 13 000 EURO and a reinvestment cost of 10 000 EURO every 30 year (3 times during a house life time of 120 years).

2.4.3 Air-to-water heat pump solution

The heat pump takes heat from the outside air. Values of performance used in the calculations are based on data sheets from one of the larger Swedish manufacturer. At high outdoor temperatures both the heat output and the coefficient of performance (COP) are rather high; 8.3 kW and a COP of 2.5 at +15°C for a high temperature system (and domestic hot water production), and 4.6 kW and a COP of 4.8 at +15°C for a low temperature system. At low outdoor temperatures both the heat output and the coefficient of performance are rather low; 3.9 kW and a COP of 1.3 at a minimum operating temperature of -10°C for a high temperature system (and domestic hot water production), and 3.0 kW and a COP of 1.7 at a minimum operating temperature of -20°C for a low temperature system. As there are no air-to-water heat pumps on the Swedish market suitable for individual installation in each apartment, it is assumed that the whole house block of four apartments is sharing one heat pump. The COP values are given excluding the influence of power input to circulation pumps and fans in the outdoor unit. The air-to-water heat pump system solution is estimated to have an initial investment cost of 12 000 EURO and a reinvestment cost of 8 000 EURO every 15 year (7 times during a house life time of 120 years).

2.4.4 Ground source heat pumps solution

The heat pump takes heat from a well bored down into the ground. Also here values of performance used in the calculations are based on data sheets from one of the larger Swedish manufacturer. The heat output and the coefficient of performance are relatively insensitive to the variations in the outdoor temperature. The heat pump has a maximum heat output of 8.1 kW and an average COP of 3.4 for a high temperature system (and domestic hot water production), and 8.9 kW and an average COP of 4.7 at +15°C for a low temperature system. As there are no ground source heat pumps on the Swedish market suitable for individual installation in each apartment, it is assumed that the whole house block of four apartments is sharing one heat pump. The COP values are given excluding the influence of power input to circulation pumps. The ground source heat pump system solution is estimated to have an initial investment cost of 15 000 EURO and a reinvestment cost of 6 500 EURO every 20 year (5 times during a house life time of 120 years).

2.5 Calculation of life cycle costs

The life cycle costs are for each heating system solution calculated as the present value of initial investment cost, reinvestment costs and energy costs during an estimated lifetime for the whole house of 120 years. The discount rate for energy costs is assumed to be 1% lower than the discount rate for other costs involved in the calculations, i.e. reinvestment costs. A discount rate of 3% for energy costs and a discount rate of 4% for other costs are therefore assumed in the calculations.

3 RESULTS AND DISCUSSION

3.1 Summary of results

A summary of the results from the calculations is given in table 1 below. The results concerning specific energy use for the heating system, peak electric power demand and life cycle costs for the different heating system solutions have been highlighted with boldface letters. The best results have also been indicated by green letters and the least good results have been indicated with red letters. The reason that it is the values excluding household electricity that is highlighted is that it is the heating system that is of interest. The additional cost for household electricity will be the same for all solutions.

Table 1: Summary of results for the different energy system solutions

	unit	**HI+EL +HR+SOL**	**HI+AirHP +HR**	**HI+GrHP +HR**	**SI+AirHP +HR**	**SI+GrHP +HR**
Total energy use (electricity) per year	kWh/year	31773	29466	25818	34212	27921
Energy use, excluding household electricity	kWh/year	15773	13466	9818	18212	11921
Specific energy use, incl. household electricity	kWh/ (m^2 year)	66	61	53	71	58
Specific energy use, excl. household electricity	kWh/ (m^2 year)	**33**	**28**	**20**	**38**	**25**
Peak electric power, excl. household electricity	W	**9018**	**9118**	**3702**	**10942**	**8620**
Energy cost per year, excl. household electricity *	EURO	1987	1695	1239	2294	1501
Total energy cost per year, incl. household electricity *	EURO	4003	3711	3255	4310	3517
Initial investment cost "heating system" **	EURO	13000	12000	15000	12000	15000
Cost for each reinvestment in the "heating system"	EURO	10000	8000	6500	8000	6500
Intervals for reinvestments in the "heating system"	years	30	15	20	15	20
Present cost of reinvestments ***	EURO	4327	9826	5349	9826	5349
Present cost of heating energy (120 years) ***	EURO	66246	56499	41304	76474	50049
Present life cycle cost "heating system"	EURO	**83573**	**78325**	**61653**	**98300**	**70398**

*) Swedish average electricity price winter 2008, excluding fixed costs, is set to 0,126 EURO/kWh
**) Less costs for insulation and frame timber is assumed to equal the increased costs for a floor heating system in houses with standard insulation
***) The discount rate (internal rate minus inflation rate) for reinvestment costs for the “heating system” is set to 4 %
****) The discount rate (internal rate minus inflation rate) for energy costs are set to 3 %

HI = **H**igh **I**nsulation standard according to the passive house standard
SI = **S**tandard **I**nsulation according to “normal Swedish building standard”
EL = Direct **EL**ectric heating (both for space heating and domestic hot water)
HR = High efficient air-to-air ventilation **H**eat **R**ecovery
SOL = Thermal **SOL**ar panels for heating of domestic hot water
AirHP = **Air**-to-water **H**eat **P**ump
GrHP = **Gr**ound source **H**eat **P**ump

3.2 Specific energy use

The specific energy use for the different energy system solutions are presented in figure 1 below. It shows that a ground source heat pump has a significantly lower energy use for the heating system in a passive house than the standard solution. What is even more interesting is that a ground source heat pump installed in a less insulated but still very airtight house and with the same efficient heat recovery as in a passive house also has a lower energy use for the heating system. The increased heat losses through the building envelope have in this case been more than fully compensated with a more efficient heating system. The air-to-water heat pump installed in a passive house has only a slightly lower energy use than the standard solution, and if installed in a normally insulated house it is somewhat higher.

For the passive house the ground source heat pump covers the whole heating demand without the need for any additional heating. In the case with a less well insulated house the ground source heat pump do not fully cover the whole heating demand. Additional heating is then needed during the coldest periods of the year. This is made by an electric resistance heater in the central boiler. A larger heat pump would however only have decreased the specific energy use of the heating system to 24 kWh/(m^2 year).

The household electricity is assumed to be the same in all cases. It therefore gives a common baseline 33 kWh/(m^2 year) for all the system solutions. Historically the use of household electricity has increased quite much during the last decades. In the future this increase might be stopped and hopefully even decreased. In the present study changes in the household electricity use is assumed to have the same effect on the baseline for all system solutions studied. For the standard solution a reduction will partly lead to an increase in the energy use of the heating system. This will of course also happen with the heat pump solutions, but as the heats pumps are producing the heat much more efficient the increase in energy use for the heating system will be much smaller for these system solutions. This also means that a decrease in household electricity has a better “pay off” for the heat pump solutions than for the standard solution.

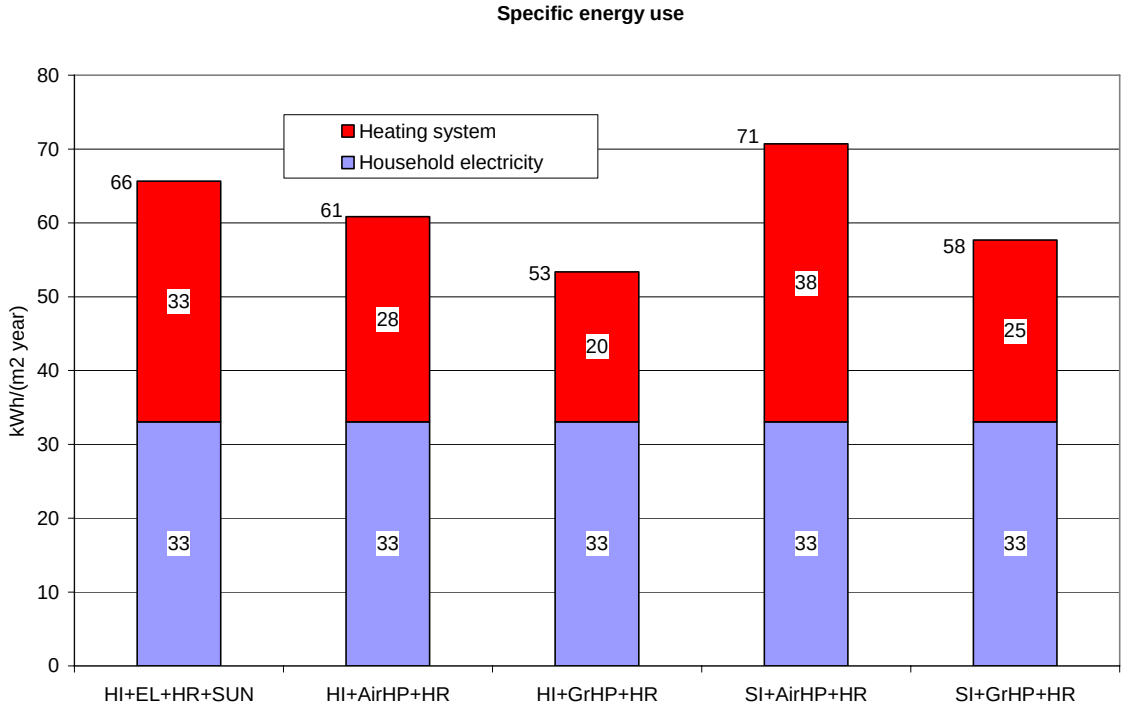


Figure 1: Specific energy use for the different energy system solutions

3.3 Specific peak power demand

The specific peak power demand for the different energy system solutions are presented in figure 2 below.

The specific peak power demand is about the same for the passive house with the standard solution and the passive house with the air-to-water heat pump. The reason is that the air-to-water heat pump can not give any contribution to a high temperature system at the lowest outdoor air temperatures.

The passive house with the ground source heat pump has a significantly lower specific peak power demand for the heating system than the other solutions. The reason is that the ground source heat pump covers the whole heating demand, both for domestic hot water and space heating, without the need for any additional heating.

The less well insulated house with the air-to-water heat pump has a somewhat higher specific peak power demand due to increased heat losses, and even if the heat pump still is contributing to the low temperature system at the lowest outdoor air temperatures the COP is then rather low.

The less well insulated house with the ground source heat pump has a slightly lower peak power demand than the standard solution. The increased thermal losses through the envelope have in this case been fully compensated with a more efficient heating system. It should be noted that in this case the heat pump do not fully cover the whole heating demand. Additional heating is then needed during the coldest periods of the year. If a larger heat pump had been chosen, covering the whole heating demand also for the less well insulated house, then the total peak power demand of the heating system would have decreased to about 10 W/m^2 (3,3 W/m^2 for domestic hot water and 5 W/m^2 for space heating).

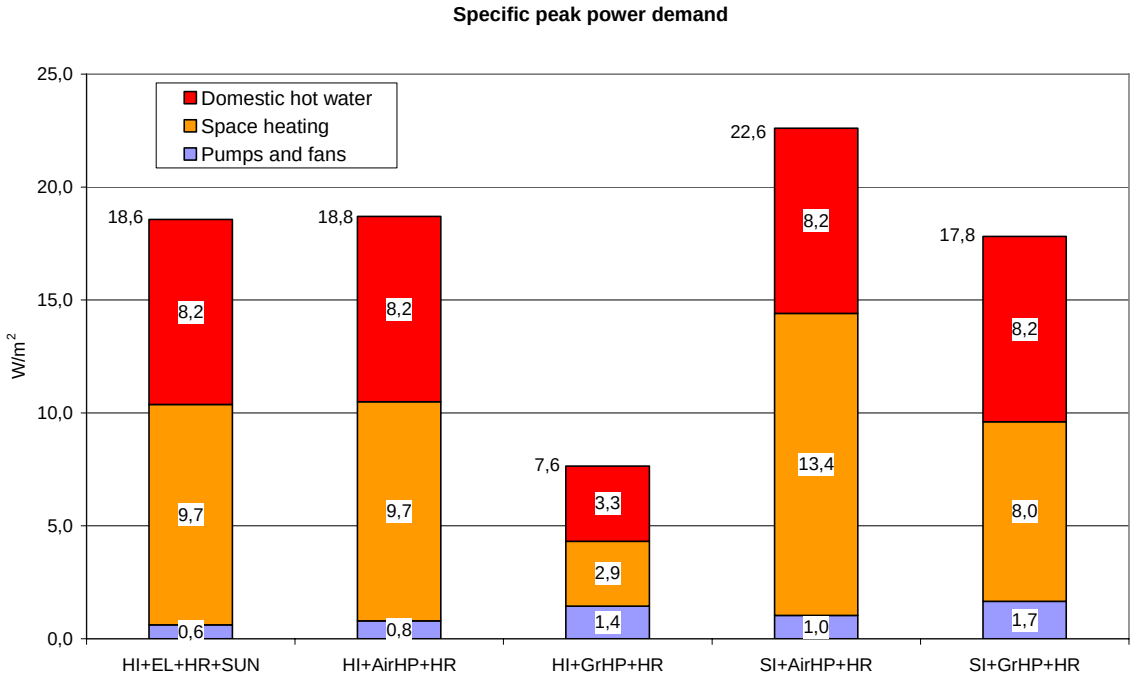


Figure 2: Specific peak power demand for the different energy system solutions

3.4 Life cycle costs

The life cycle costs for the different energy system solutions are presented in figure 3 below. It shows that a ground source heat pump is a considerably better solution for a passive house than the standard solution. What is even more interesting is that a ground source heat pump installed in a less insulated but still very airtight house and with the same efficient heat recovery as in a passive house is also a better solution. The air-to-water heat pump installed in a passive house is however only slightly better than the standard solution, and if installed in a normally insulated house it is a considerably worse solution.

With increasing electricity prices and more efficient appliances available on the market it is not unlikely that the use of household electricity will decrease in the decades to come. In this scenario, referring to the discussion in paragraph 3.3, the heat pump solutions would come out even better compared to the standard solution.

If the discount rates were doubled, the present energy costs would be halved, the present reinvestment costs only one third and the differences between the systems less that shown in figure 3. Still the present value of the energy costs would be larger than the investment costs and the relationship between the different solutions would also be the same. However, high interest rates correlate historically with high inflation rates. The values given in figure 3 are therefore considered to be a more realistic assumption. A halving of the life time of the house would give almost the same consequence as doubling the discount rate. But a well built timber framed house is more likely to last for more than 100 years than less. The values given in figure 3 are therefore also from this point of view considered as relevant.

One conclusion is that from an LCC point of view the ground source heat pump solution, even though it has the highest initial investment cost, is the solution of those compared.

Another conclusion is that a well built standard house with a ground source heat pump can also be a better solution than the standard passive house solution.

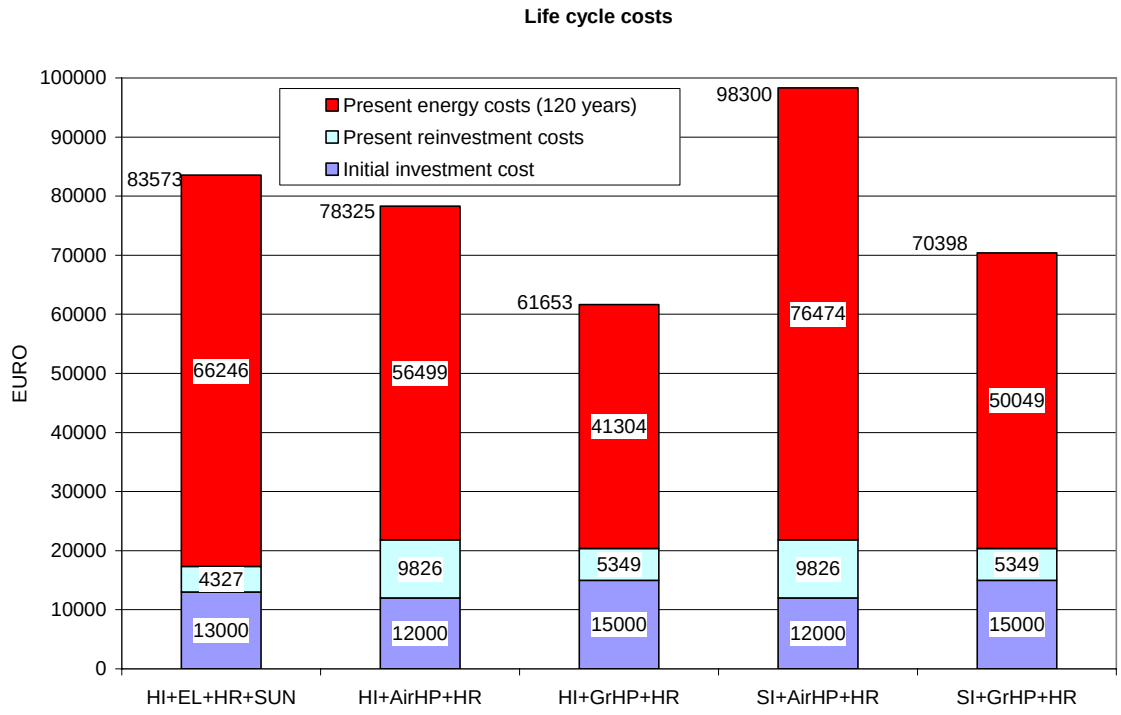


Figure 3: Life cycle costs for the different energy system solutions

4 CONCLUSIONS

The heating system of a passive house combined with a ground source heat pump has a significantly lower specific energy use, a considerably lower peak power demand and also a much lower life cycle cost than the standard solution for passive houses. I.e. it is from all these points of view a better solution than the standard solution.

A ground source heat pump installed in a less insulated but still very airtight house and with the same efficient heat recovery as in a passive house can also be a better solution than the standard solution for passive houses. Lower specific energy use, equivalent or lower specific peak power demand and lower LCC. The reason is that increased heat losses through the building envelope can be more than fully compensated with a more efficient heating system.

The heating system of a passive house combined with an air-to-water heat pump has a somewhat lower specific energy, the same peak power demand and a somewhat lower life cycle cost (LCC) than the standard solution for passive houses. I.e. it is almost equivalent to the standard solution.

An air-to-water heat pump installed in a less insulated but still very airtight house and with the same efficient heat recovery as in a passive house is a less good solution compared to the standard solution for passive houses. Specific energy use, specific peak power demand and LCC are all higher than for the standard solution.

An additional benefit of the ground source heat pump solution is that it can utilize free cooling in the summertime. In a passive house the hydronic reheater used for heating in the wintertime can then also be used for cooling in the summertime. This has however not been further evaluated in this study.

5 REFERENCES

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