Ymere

Investigation on air source heat pumps for the residential area Almere Hout Noord

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HEAT
PUMP

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Summary

Ymere and the city Almere will in the next ten years develop the residential area Almere Hout Noord. The ambitious targets of this area is a CO_2 neutral and energy independent neighborhood with an EPC demand of 0,4. Because of the area's limitations an investigation into air source heat pumps was needed to establish if air source heat pump concepts are worth to consider as a residential heating option.

Air source heat pumps have the potential to reduce CO_2 emissions associated with domestic space and hot water requirements. The energy cost and CO_2 emissions reduction potential of these systems will only be achieved if they are designed properly. Efficient and reliable operation is required, not damaging fragile costumer confidence.

The carbon dioxide reduction potential for air source heat pumps is about 67% compared to natural gas boilers. However, the margins for saving annual energy costs are thin; approximately 10% compared to high efficiency natural gas heaters. Because of these thin margins, a proper optimal dimensioned heat pump system is needed. The highest potential is an inverter controlled air source heat pump with an electric auxiliary heater, extended with a solar collector and/or photo voltaic to further increase the reduction potential. The distribution system should consist of a floor heating systems with additional low temperature convectors.

The heat pumps market is still at the beginning of its potential. Further research and development of air source heat pumps is needed to reduce the risks involved with air source heat pump systems.

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Introduction

Just before the UN climate talks started in Cancun on November the 29th 2010, the established research institute Maplecroft published a study [1] rating 183 countries on their CO_2 emissions from energy use. The study indentified the Netherlands as the fifth worst performing nation in relation to CO_2 pollution per capita. The Netherlands is the only European country that's rated 'extreme risk'. This indicates the demand for energy efficiency and CO_2 reduction in the Netherlands.

Domestic hot water and heating accounts for nineteen percent of the Netherlands total CO_2 emission. To attain the European mandate on CO_2 reduction, the Dutch government introduced the EPC "Energieprestatiecoefficient" for newly built dwellings in 1995. The EPC is an index for the energetic efficiency of dwellings, taking into account the energy for heating, cooling, hot tap water and lightning in relation to the surface area of the dwelling. Since 2006 the EPC demand is 0,8, the following EPC demands have to be fulfilled in the near future:

	Standard requirements	Excellent
- 2006,	EPC = 0,8	NA
- 2011,	EPC = 0,6	EPC = 0,4
- 2015,	EPC = 0,4	EPC = 0,3
- 2020,	Energy neutral	Energy neutral

The high efficiency gas boiler has reached its maximum potential, therefore, innovative energy saving measures are required. Heat pumps are a technology which can contribute to low carbon heating and hot water provision in the domestic market.

In the next ten years, Ymere and the city Almere will develop the residential area Almere Hout Noord (figure 1). The target is building a CO_2 neutral and energy independent neighborhood. The project is also marked as an excellent area and therefore has an EPC demand of 0,4. These ambitious targets require the input of several sustainable measures. However, the area has some limitations:

- The building area's ground is used for making drinking water.
- Because of the energy independent target, no natural gas network is installed

These limitations exclude the use of local ground source heat pumps and natural gas boilers. In order to fulfill the sustainable targets, an energy concept with air source heat pumps is investigated. This report aims to establish if air source heat pump concepts are worth to consider as a residential heating option and how to maximize its potential. It also describes the risks and do's and don'ts that have to be taken into consideration when applying air source heat pumps to dwellings.

Figure 1 - Location of Almere Hout Noord (marked yellow)

The department “Gebieds en Projectontwikkeling” of Ymere has commissioned this report in order to reduce the change of unexpected costs and problems when installing air source heat pumps. A partnership with the Hogeschool Utrecht is formed to give a student the opportunity to research the topic. To structure the research a mind map (Annex 1) and time schedule is produced which shows the structure of the research. The accentuated area is the main focus of this report.

Section one describes the technology of air source heat pumps and its basic components. The operation of the heat pump is explained and the terms coefficient of performance (COP) and season performance (SPF) are introduced. A description of the CO_2 emission reduction potential and energy bill saving potential is given.

Section two attends the other components of the energy concept that affect the performance of the heat pump and the energy efficiency of the dwelling. The “trias energetica” is introduced as a guide to reduce energy consumption. A description of the model house is given and the assumptions for isolation are outlined. This information is valuable in the context of the simulations that are made later in the study. Furthermore, the potential of the use of solar energy is considered.

In section three the variables for comparing heat pumps with a simulation is explained and a basic simulation of heat pumps is made. The section starts with the weather files that are used and how variables like COP curves, heating curves and start/stops are used in the simulation. Then the optimal capacity dimension of the air source heat pump is determined by simulating different heat pump sizes. Based on the optimal heat pump capacity a comparison on energy use is made between heat pump brands and models.

Section four consists of the risks that come with using air source heat pumps for users, installers and developers. The risk of fluctuating energy bill is explained and how wrong usage or dimensioning leads to high energy use. Beside high energy use and energy bills, the risk of noise is explained and possibilities to control the risks are given. Also the impact on the electrical connection per dwelling and the area is considered.

In section five design directives are given for developers, architectures, advisors, building contractors and heat pump manufacturers. The section emphasizes the need for integrated design to guarantee the working of air source heat pump installations.

Finally section six will summarize the main findings from each section of the report and give recommendations for further research into the possibilities of air source heat pumps.

1 Air source heat pump technology

1.1 What is an air source heat pump?

Although an air temperature of -10 ℃ is cold, it still contains heat. Everything above the absolute minimum temperature of – 273,15 ℃ contains heat that can be extracted. A heat pump is an electrical heating device that moves heat from a lower temperature heat source to a higher temperature heat distributor. The heat distributor can be a radiator, floor heating or hot water device. The air source heat pump uses outside air and/or ventilation air as heat source.

A refrigerant (or any liquid/gas) changes phase at different temperatures depending on the pressure. This principle makes it possible to evaporate at low temperature at a low pressure and liquefy at high temperature at a high pressure. Evaporating extracts energy from a lower temperature heat source and liquefying supplies it to a warmer heat distributor. Shown below in figure 2 is the basic representation of a heat pump cycle.

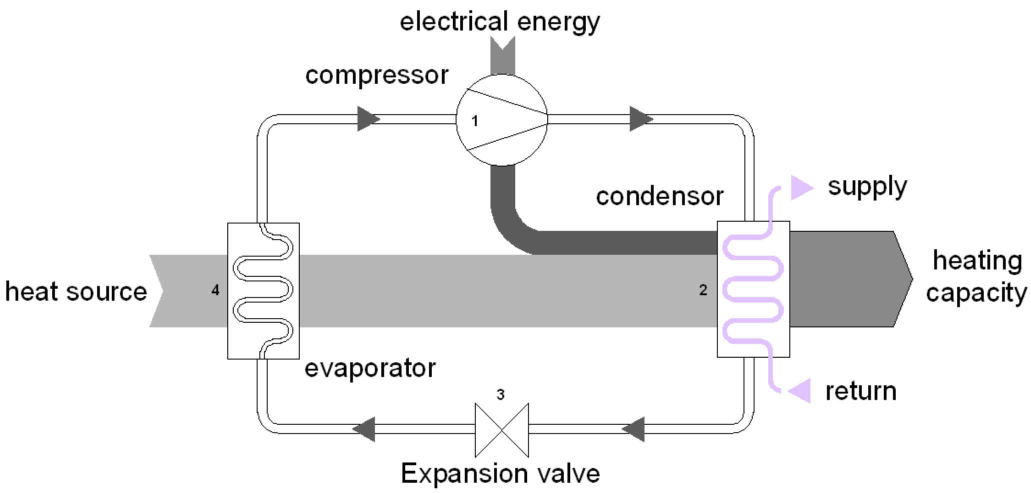

Figure 2 - Principle of a heat pump

The gas that enters the compressor (**1**) is compressed, which increases the pressure of the gas and the temperature of the gas. The hot gas then enters the condenser (**2**), which is basically a heat exchanger, where it releases its energy to the colder heat distributor. This makes the hot gas condense to a liquid. The liquid enters the expansion valve (**3**) where the pressure is decreased, and thereby decreasing the temperature and boiling point of the fluid. In the evaporator (**4**) the cold liquid absorbs energy from the warmer heat source, making it evaporate. Then the cycle starts again by compressing the gas with the compressor. The heating capacity is the energy extracted from the heat source plus the energy put into the refrigerant by the compressor.

1.2 The difference between COP and SPF

The compression cycle as described in figure 2 is usually represented on a pressure-enthalpy diagram (figure 3 below) since it is composed of two constant pressure process and one constant enthalpy process.

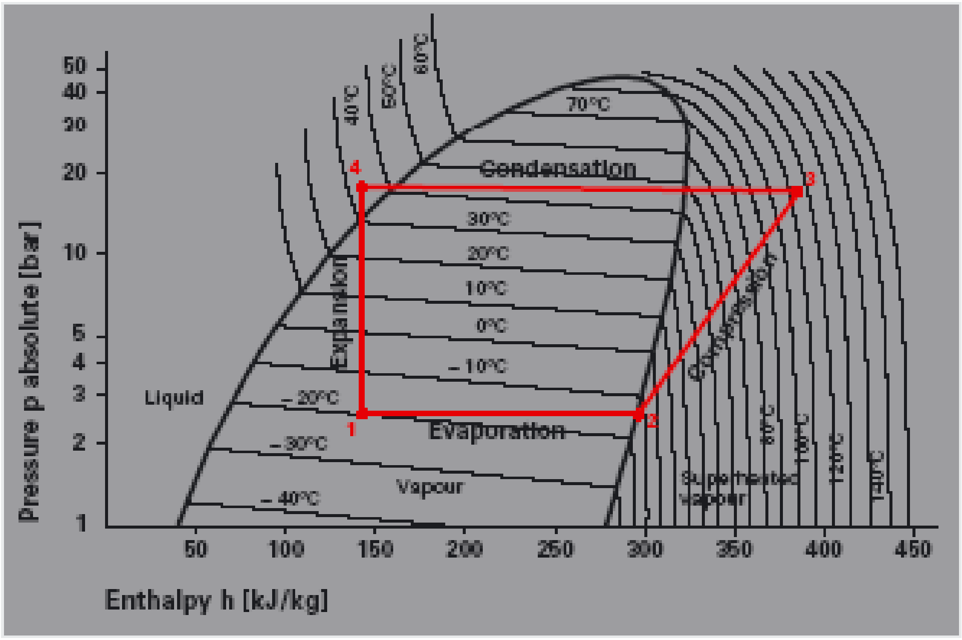

Figure 3 - Pressure enthalpy diagram with compression cycle

The main benefit of a heat pump can be shown through calculation.

Tc = Work in compression = h3 – h2 = 390 – 300 = 90 kJ/kg
Th= Heating effect from condenser = h3 – h4 = 390 – 140 = 250 kJ/kg
COP = Useful Heat (Th)/ Work Expended (Tc) = 250 / 90 = 2.77

Therefore for every one kW of energy used by the compressor 2.77 kW of heat is generated. The efficiency of this process is called the coefficient of performance (COP). A more realistic COP however is the heat output divided by the total amount of electric energy consumed by the compressor and other electric components.

$$COP = \frac{Q_h}{P_{el}}$$

Q_h: Heat supplied
P_{el}: Electric energy consumed

When calculating heat pump performance it is more important to consider its efficiency over time or Seasonal Performance Factor (SPF). Calculating this factor requires knowledge of the variable loads and source temperatures over time.

$$SPF = \frac{Annual\ heat\ supplied}{Annual\ electricity\ consumed}$$

1.3 Types of operation modes

There are different types of operation used by air source heat pumps.

- **Monovalent**: The total amount of heat is generated by the heat pump.
- **Bivalent**: The heat pump has an additional heater such as an electric heater or a high efficiency gas heater. The additional heater delivers heat when the capacity of the heat pump is insufficient or the efficiency of the gas heater is higher than the efficiency of the heat pump.

Because of the Almere Hout Noord restrictions, the only option is a monovalent heat pump (figure 4 right) or a bivalent heat pump using an additional electric heater (bivalent mono-energy) (figure 4 left).

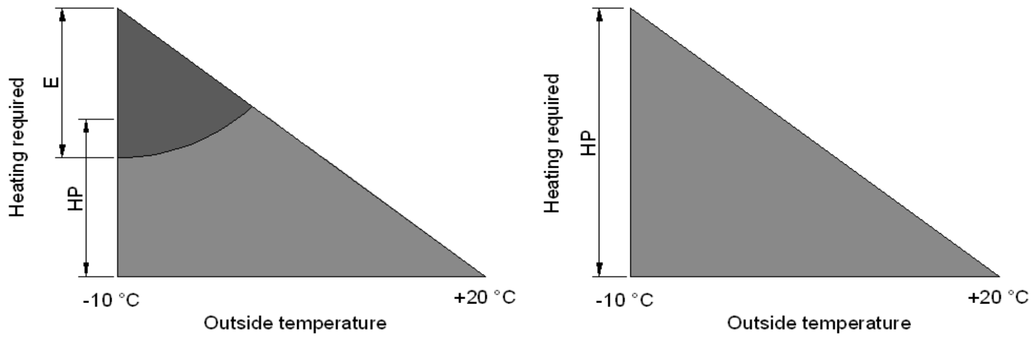

Figure 4 - Bivalent mono-energy (left) and monovalent (right) operation

1.4 Inverter heat pumps

The starts and stops of a heat pump is one of the major reasons for decreasing efficiency, it takes a moment before a heat pump is operating on its maximum efficiency. Some models solve this by applying an extra heating buffer, but lately most of the top brands in the residential heat pump market have introduced inverter heat pumps. A heat pump with inverter technology is able to throttle back the compressor, reducing its load and thermal output. Because of the lower load, the heat pump is able to lower the temperature difference between condenser and evaporator, thus increasing its efficiency.

The use of space for the extra buffer that's needed with non-inverter heat pumps is a major disadvantage. Space that can be sold or rented is expensive in the Dutch market with little room to build and high house prices. Because of the disadvantage of extra space use with non-inverter heat pumps and the better efficiency of inverter technology, non-inverter heat pumps will not be further discussed in this report.

1.5 Benefits of an air source heat pump

Heat pumps cannot be considered a totally renewable energy technology. The compressor and some other components use electric energy which is usually generated with the use of fossil fuels. When the electricity is generated using renewable sources such as photo voltaic cells or wind turbines, the combination of technology is considered renewable.

The most used fossil fuel heating system for newly built dwellings in the Netherlands is a high efficiency natural gas boiler (HR107). A typical corner dwelling that is well insulated has an annual energy use for heating and hot tap water of approximately 27 GJ. Using the CO_2 emission factors given by SenterNovem (table 1) the amount of CO_2 emitted is calculated.

Fuel	CO_2-emission factor kg/MJ
Natural gas	0,0560
Electricity	0,0694
External heat delivery with coals	0,094
External heat delivery with oil	0,0730
Waste incineration	0,0314

Table 1 - Emission factors used in EPC calculation using NEN 5128

For the natural gas boiler (annual efficiency of 85%) the amount of emitted carbon dioxide is:

$$Natural\ gas\ used = \frac{27\ GJ}{0,85} = 32\ GJ$$

$$CO_2\ emitted \approx\ 32 \cdot 0,0560 \approx\ \ 1,8\ tons\ CO_2$$

For the air source heat pump operating for heating and domestic water (SPF is approximately 3) the amount of emitted carbon dioxide is:

$$Electricity\ used = \frac{27\ GJ}{3} = 9\ GJ$$

$$CO_2\ emitted \approx\ 9 \cdot 0,0694 \approx\ \ 0,6\ tons\ CO_2$$

The carbon dioxide reduction in this example is about 67% compared to a natural gas boiler. When green electricity is used, the reduction potential is 100%. Another benefit is the cost saving on the annual energy bill.

Natural gas boiler annual energy cost.

$$Natural\ gas\ used = \frac{32\ \cdot 10^3 MJ}{31,65\ \ MJ/M^3} = 1.011\ M^3$$

$$Cost = 1.011\ \ \cdot € \ 0,58 = € \ 586,-$$

Air source heat pump energy cost.

$$Electricity\ used = \frac{9\ \cdot 10^3 MJ}{3,6\ MJ/kWh} = 2.500\ kWh$$

$$Cost = 2.500\ \ \cdot € \ 0,21 = € \ 525,-$$

Annual cost savings on energy in this example is about 10%. The price for natural gas is expected to rise faster (9% a year) than the price for electricity (6%) (figure 5), due to depletion of fossil fuels and the increasing use of renewable sources for electricity. This will make the potential for savings on energy cost increase. The required investment for a heat pump is, however, larger than a gas boiler. The comparison between a gas heater and a heat pump is not further discussed in this report.

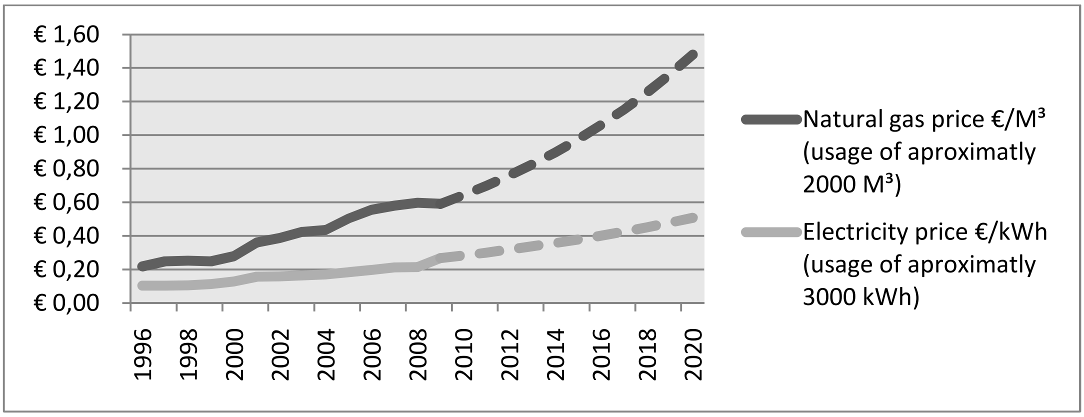

Figure 5 - Energy prices historical (solid lines) and forecast (marked)

2 Other components of the air source heat pump concept

2.1 Trias energetica as energy reduction guide

In 1996 SenterNovem introduced the Trias Energetica (figure 6) as a simple three-step plan to achieve the most sustainable energy management.

The three steps are:

1. Reduce unnecessary energy use, for example better insulation;
2. Use natural resources wherever possible at any level;
3. For the remaining energy need, use fossil fuels as efficient as possible;

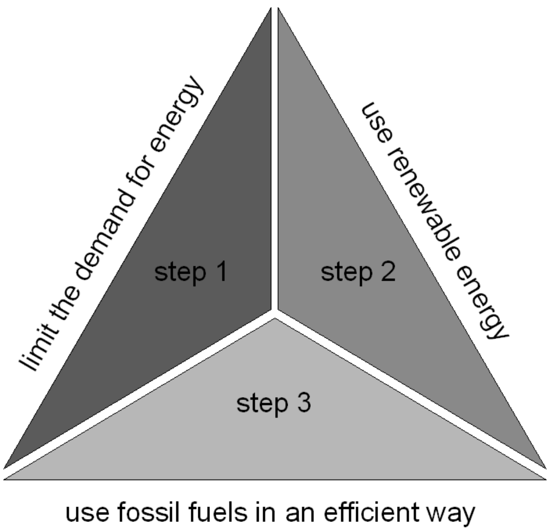

Figure 6 - Trias Energetica

The houses built in Almere Hout Noord will be designed and built using this concept. Determining the optimal cost/reduction factor for insulation is not addressed in this report because of the project boundaries. The standard

2.2 SenterNovem reference house

The final design and size of the dwellings build in Almere Hout Noord are unknown. This means the required energy for heating, which depends on size, isolation, windows, etc... can't be calculated. A commonly used method is making calculations based on the SenterNovem reference houses. Together with the standard Ymere values for improved insulation and glass (Annex 2) this is the basis for heat transmission calculations.

The calculations are made with BINK software using the ISSO 51 calculation method. The totals heat loss at an outside temperature of -10 °C for the corner house is little more than 9 kW and for the apartment almost 7 kW (Table 2).

Heat transmission at -10 °C		
Room	SenterNovem corner house	SenterNovem apartment
Living room / kitchen	4 kW	3,2 kW
Bathroom	0,9 kW	1,2 kW
Entry	0	-
Hall	0	-
Bedroom 1	1,1 kW	1,3 kW
Bedroom 2	0,6 kW	0,9 kW

Bedroom 3	0,7 kW	-
Toilet	0,3 kW	0,2 kW
Loft	1,4 kW	-
Total	9,0 kW	6,8 kW

Table 2 - Heat loss SenterNovem reference houses

The heating curve (figure 7) shows the amount of heat that's needed at given temperature. This curve is used in section 3 for making heat demand simulations.

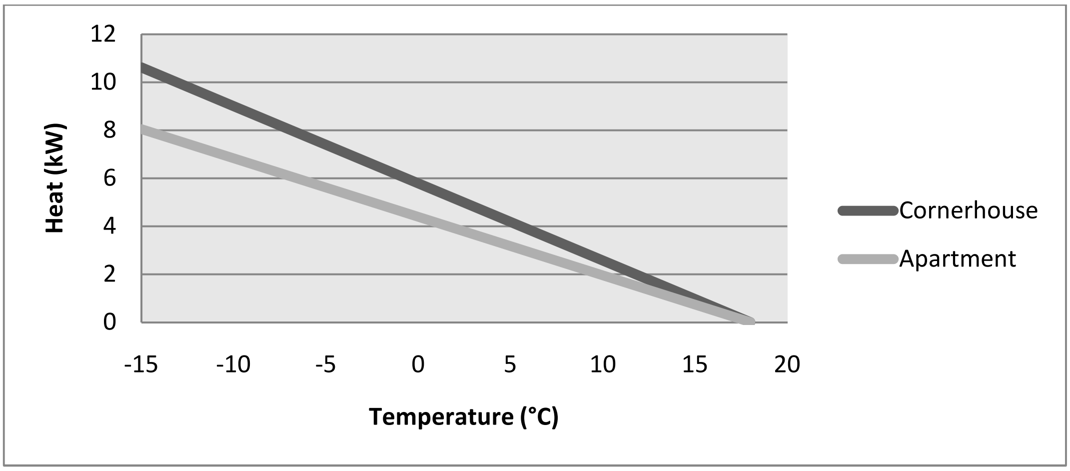

Figure 7 - Heating curve for the corner house and apartment

2.2 Solar collector

The benefit of a solar collector depends on the size of the collector in relationship to the hot water demand. When the size of the collector increases, the amount of energy needed for hot water decreases. This relationship is expressed as the reduction factor. The growth of the reduction factor is smaller for every extra m^2 added. A larger contribution to the hot water demand requires more energy delivered at a darker period of the year (winter, autumn) when the efficiency of the collector is smaller. This reduces the total efficiency of the system per m^2.

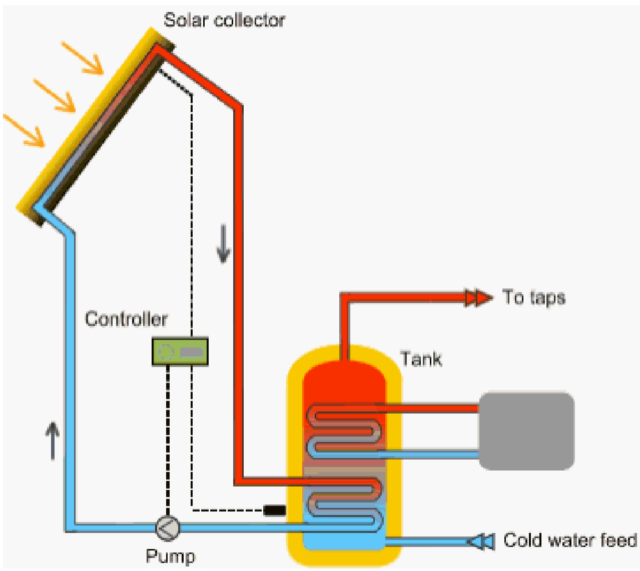

Figure 8 - Typical solar collector installation

For a corner house with four rooms the daily hot water demand is approximately 100 liter (table 10). This is an annual hot water demand of 36,5 m^3. With the formula from ISSO 59 (Annex 3) the optimal collector area for a reduction factor is calculated. Assumed is an equal amount of hot water during winter and summer.

$$20\% = 20 \times 36{,}5/1000 = 0{,}73\ m^2$$
$$30\% = 40 \times 36{,}5/1000 = 1{,}46\ m^2$$
$$40\% = 60 \times 36{,}5/1000 = 2{,}19\ m^2$$
$$50\% = 95 \times 36/1000 = 3{,}5\ m^2$$

The cost for the collector depends on the size of the collector, the installing and extra components differ little. Because the system already has a buffer for hot water, no extra buffer is needed, which decreases the cost for solar collector installation (table 3).

Collector size	Installing	Pump and piping	Collector	Total
0,73 m²	€ 300,-	€ 300,-	€ 300,-	€ 900,-
1,46 m²	€ 300,-	€ 300,-	€ 500,-	€ 1.100,-
2,19 m²	€ 400,-	€ 300,-	€ 700,-	€ 1.400,-
3,5 m²	€ 500,-	€ 300,-	€ 1000,-	€ 1.800,-

Table 3 - Cost for solar collector installation

When a solar collector has a reduction factor of 50%, it means an average annual reduction of 50%. In the summer period the reduction could be 80% and in the winter period 20%. A heat pump uses less energy for the same amount of hot water at high outside air temperatures (summer) compared to low outside air (winter) temperatures. This means that an annual reduction of hot water demand from a heat pump doesn't direct translate to the same percentage reduced energy used by the heat pump.

Because the exact reduction factors for every month are not available, the effect of energy used in the worst case is calculated (table 4). When a reduction of 50% is wanted, the worst case for a heat pump would be 0% reduction during 6 cold months (low COP) and 100% reduction during 6 warm months (high COP).

Annual hot water reduction factor	Cold months reduction factor	Warm months reduction factor	Annual energy demand reduction factor	Difference
50%	0%	100%	45%	10%
50%	20%	80%	47%	6%
50%	50%	50%	50%	0%
40%	0%	80%	36%	10%
30%	0%	60%	27%	10%
20%	0%	40%	18%	10%

Table 4 - Actual reduction factor for air source heat pumps

The table shows that the maximum difference in reduction is 10% in worst case scenario for an air source heat pump. Taking into consideration a lifespan of 20 years and a discount rate of 5% the cost per reduced kWh is calculated.

- Term of mortgage is 30 years;
- Emitted carbon dioxide is based on table 1;
- Electricity indexation is 4%;
- Electricity price in 2010 is € 0,21;

- Term of SDE (Subsidie Duurzame Energie) is 15 years;

Reduction	Collector size	Total mortgage	Reduced MWh	€/kWh	€/tons CO_2
18%	0,73 m²	€ 1.598,-	4,1 MWh	€ 0,39	€ 1,56
27%	1,46 m²	€ 1.953,-	6,1 MWh	€ 0,32	€ 1,28
36%	2,19 m²	€ 2.485,-	8,2 MWh	€ 0,30	€ 1,21
45%	3,5 m²	€ 3.195,-	10,2 MWh	€ 0,31	€ 1,25

Table 5 - Cost per reduced kWh and tons CO_2 with a solar collector

With an electricity indexation of 4% there is no payback period achieved for the 0,73 m² collector, the other sizes have an payback period of 10 to 12 years. When an index of 8% is used for electricity prices, the payback is achieved after 11 years for the 0,73 m² collector and 6 years for the 2,19 m² collector (Annex V).

2.3 Photo voltaic

The performances of photo voltaic (PV) systems depend greatly on the orientation and inclination of the system. The most effective for the Netherlands is an orientation to the south with an inclination of about 35º (figure 9). But even under less than ideal conditions, PV systems can still generate a sufficient amount of electricity. The roof orientation of the first building phase of Almere Hout Noord is mostly southeast (annex III), if the roof inclination is build between 10º and 50º the solar radiation is about 95% from optimal.

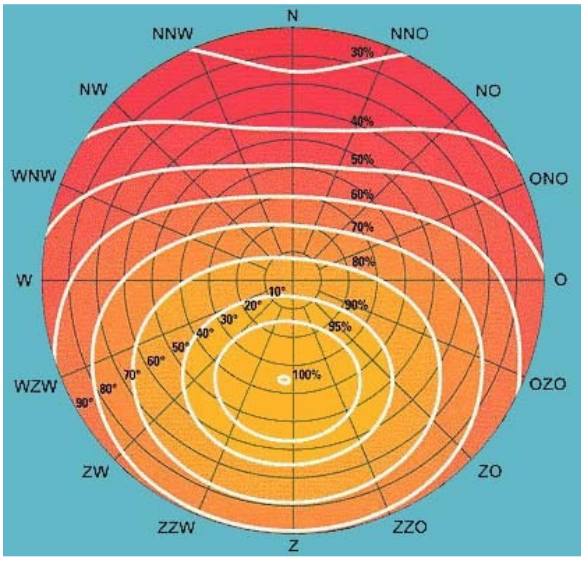

Figure 9 - Sun orientation and inclination

The capacity of photo voltaic cells is expressed as Watt peak. This is the nominal power under laboratory illumination conditions. The annual electricity generation for 100 Watt peak in the Netherlands is 90 kWh (Nefit solar) at optimal orientation and inclination. For Almere Hout Noord with mostly 95% solar radiation the annual generated electricity is 85,5 kWh for 100 Watt peak.

With the investment cost as given by Nefit the total costs and benefits are calculated. During the calculations the same assumptions are made as in paragraph 2.2, except for the lifetime which is 25 years for photo voltaic

PV capacity (Watt peak)	Investment (Excl. BTW)	Total mortgage	Reduced MWh	€/kWh	€/tons CO2
570	€ 2.200	€ 3.905	12,1 MWh	€ 0,32	€ 1,29
1.140	€ 4.400	€ 7.810	24,4 MWh	€ 0,32	€ 1,28
1.900	€ 6.520	€ 11.573	40,6 MWh	€ 0,28	€ 1,14
2.850	€ 9.775	€ 17.351	60,9 MWh	€ 0,28	€ 1,14
3.800	€ 12.463	€ 22.122	81,2 MWh	€ 0,27	€ 1,09

Table 6 - Cost per reduced kWh and tons CO2 with photo voltaic

With electricity indexation of 4% there is no payback period achieved. This is due to the SDE stop after 15 years. When an index of 8% is used, the payback is achieved after approximately 18 to 21 years (annex V).

2.4 Heat delivery system

The conventional heating system for Dutch dwellings consists of a high efficiency natural gas boiler, a water pipe system, and radiators as heat supply. The radiators operate at a temperature of 90-70 ℃. When using heat pumps in dwellings for heating, Low Temperature heating elements (40-30 ℃) are needed. There are two types of LT heating elements, radiant heating and LT convectors. It's also possible to combine the two heating elements in one heating system.

2.4.1 Radiant heating

Radiant heating systems involve supplying heat directly to surface elements as floors, walls or ceilings. Although a high amount of heat is transferred by radiation, radiant heating systems also depends on convection. Because hot air has the natural tendency to raise, floor heating is more effective than wall or ceiling heating.

There are three types of radiant floor heaters: radiant air floors; electric radiant floors; hydronic (hot water) radiant floors. Most of the radiant systems are hydronic radiant floors (hot flowing fluid in pipes). The pipes are often cast into a concrete slab (figure 10), sometimes they are directly attached to the floor or wooden surface.

Figure 10 - Hydronic radiant floor

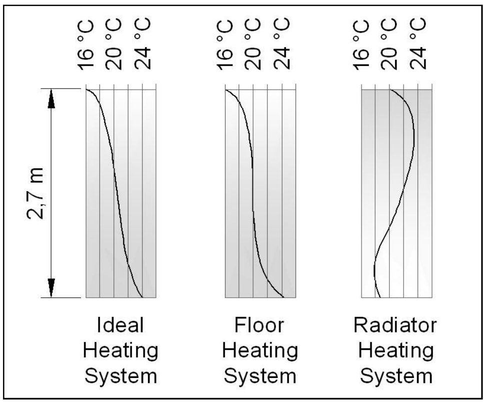

Figure 11 - Vertical temperature gradient

The two main advantages of underfloor heating are the increase in thermal comfort and the lack of space usage. Thermal comfort is affected by air temperature, mean radiant temperature, air velocity, relative humidity, conduction, clothing and metabolism. Underfloor heating affects mean radiant temperature (radiant asymmetry), air temperature (more steady) and conduction (feet on floor) positively.

One of the disadvantages of surface heating is the slow reaction to temperature changes. This is caused by the high amount of water in the piping and the thermal mass of the surrounding concrete. The slow reaction of radiant heating makes it unsuitable for bedrooms or the study, waiting a few hours before the room is at desired temperature is unacceptable.

The capacity of underfloor heating depends on the room temperature and the distance between the piping. The maximum amount of heat at 35 ℃ and a room temperature of 20 ℃ is 97 Watt per square meter.

Water temperature	Room temperature	Piping distance					
		300 mm	250 mm	200 mm	150 mm	100 mm	
35 ºC	15 ºC	73	84	97	112	129	W/m²
35 ºC	18 ºC	62	71	83	95	110	W/m²
35 ºC	20 ºC	55	63	73	84	97	W/m²
35 ºC	22 ºC	48	55	63	73	84	W/m²
35 ºC	24 ºC	41	46	54	62	71	W/m²

Table 7 - Underfloor heating power

Advantages
- Thermal comfort;
- Indoor air quality;
- No space usage;
- No service required;
- Well known;
- Costumers think of it as a luxury item ;

Disadvantages
- Slow reaction;
- Energy waste due to slow reaction;
- Limited amount of heat transferred
- Unsuitable for bedrooms and study's

2.3.2 Low temperature heating convectors

Most of the heating power of heating convectors is by convection and just a little by radiation. Conventional convectors are designed for use with a 90/70 ℃ or 80/60 C° water circuit. This high temperature makes the air rise quickly through the convector and creates a natural air flow along the surface of the convector, increasing the heating power substantially.

When low heating temperatures are used (35 ℃), the air rises slowly and thereby limiting the heating power greatly. Because of the low supply temperatures of air-water heat pumps new convectors are developed that are able to supply the needed heat at low temperatures. Some of these convectors use (low energy) ventilators to boost the air through the convector.

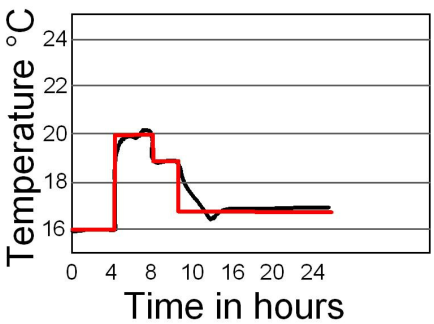

Figure 12 - Reaction of LT convectors

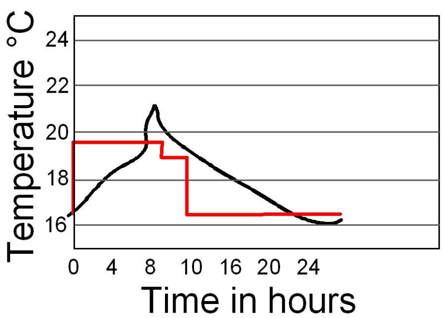

Figure 13 - Reaction of radiant heating

Another advantage of the convectors is the low water content. This means little time before the convector is at the desired temperature, and when the desired temperature is reached it stops heating almost immediately. Figure 12 and Figure 13 show the effect of difference in reaction time. The red line is the set point and the black line is the measured temperature. Every minute the temperature is above the set point is wasted energy.

Advantages
- Quick reaction;
- Low energy waste;

Disadvantages
- Space use;
- Service required;
- Noise;
- New to most costumers;

2.3.3 Combination of floor heating with heating elements

Because of the maximum capacity of floor heating at 35 ºC, the living room needs an additional heating element. A way to combine this two heating elements is giving the floor heating a set point of 18 ºC. The LT convector tunes the last 2 degrees to 20 ºC. In this case there is the luxury of floor heating and the quick reaction of LT convector.

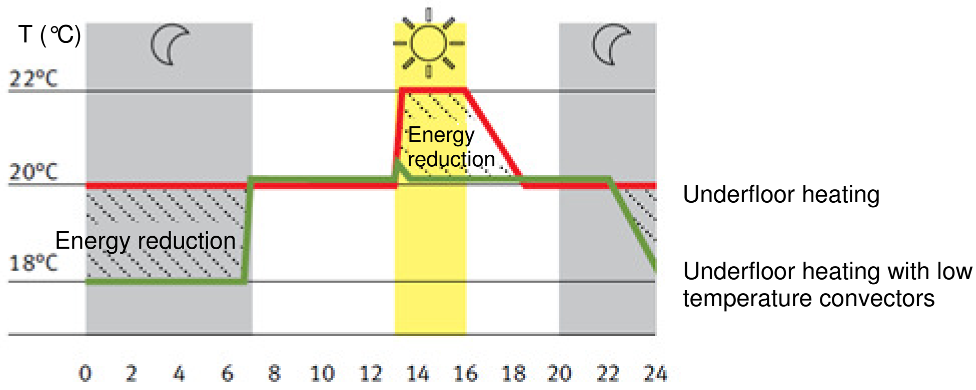

Figure 14 - Combination of floor heating with LT convectors

Because of the little time spend at bedrooms or study's, the LT convectors which react quickly to set points is advised. This increases the comfort and decreases the amount of energy needed for heating.

2.4 Heat storage

2.4.1 Hot tap water buffer dimension

The hot tap water comfort level is expressed as a CW class. The minimum CW class requirement which Ymere generally uses for new built dwellings is CW4. This means the hot water unit has to be able to deliver 8 liters a minute (table 8) with a temperature of 60 °C. A simple calculation learns that the power needed to produce this amount of hot water is:

$$P = \dot{m} \cdot c_p \cdot \Delta T = \left(\frac{8}{60}\right) \cdot 4{,}2 \cdot (60 - 10) = 28\ kW$$

CW class	Amount of hot water	Needed capacity
CW3	6 l/m 60°C	21 kW
CW4	8 l/m 60°C	28 kW
CW5	10 l/m 60°C	35 kW
CW5+	12 l/m 60°C	42 kW
CW 6	15 l/m 60°C	52,5 kW

Table 8 - Dutch hot tap water comfort classes

The capacity of an average residential heat pump is much lower than needed for hot water production (Annex 9). This requires a buffer which can be loaded slowly. The size of the buffer depends on the number of persons using a dwelling. When the composition of a family is not known, the size of the buffer is based on four persons.

Number of persons in dwelling	Volume standby boiler (55 °C) [liter]			
	Load time < 1,5 hour		1,5 hour < Load time < 16 hour	
	Shower	Bath	Shower	Bath
1 en 2	96	96	96	138
3	96	96	144	186
4	96	117	192	234
5	120	141	240	282

Table 9 - Volume of boiler needed for number of person living in the dwelling (ISSO-72)

The load time for a heat pump is calculated by the amount of hot water that is used during a day. The occupancy should be chosen 4 persons with a bath when the family composition is unknown. An average 10 kW heat pump working at 55 °C supply temperature and an outside temperature of 0 °C has a capacity of 6 kW. The load time is calculated as follows:

$$Load\ Time = \frac{heat\ needed\ (kWh)}{Power\ (kW)} = \frac{\left(\frac{135 \cdot 4{,}2 \cdot (55-10)}{3600}\right)}{6} = 1{,}7\ hours$$

In practice, the load time takes longer because of the power needed for heating operation during hot water operation.

Occupancy per dwelling [number of persons]	Hot tap water demand [liters of 55 ºC]	
	Shower	Bath
1	40	75
2	80	115
2,5	100	135
3	120	155
4	160	195
5	200	235

Table 10 - Hot tap water demand for dwelling occupancy (ISSO-72)

In this case, the size of the hot water buffer should be minimal 234 liter. The standby loss for a buffer of this size is between 50 Watt and 80 Watt. With an air source heat pump with an annual SPF = 2,8 for hot water this is between 150 and 250 kWh of electricity use a year.

2.4.2 Hot tap water load schedule

During a day, the efficiency of an air source heat pump is best between 13:00 and 16:00, when the outside temperature is highest. This is the best time to load the buffer when only considering the amount of energy used. The following table is the energy used for a 10 kW air source heat pump in the period 2003 – 2009 with a night schedule or a day schedule. The table is generated with a simulation (simulation is further explained in chapter 3).

	2003	2004	2005	2006	2007	2008	2009	
Night schedule (03:00-07:00)	1178	1154	1147	1137	1126	1145	1140	kWh
Day schedule (13:00-16:00)	1041	1050	1048	1042	1026	1042	1056	kWh
Difference	137	104	99	95	100	103	84	kWh

Table 11 - Energy used for hot water supply with a 10 kW air source heat pump

Some people have double tariff for electricity used, which means they pay less for used energy between 23:00 and 07:00. Assumed is a single tariff of €0,21/kWh and a double tariff of €0,19/kWh at night and €0,23/kWh at daytime. The data generated with the simulation (table 12) shows that the day operation with a single tariff is the best strategy for loading the buffer.

	2003	2004	2005	2006	2007	2008	2009	Aver
Single tariff (day operation)	€ 217	€ 218	€ 218	€ 217	€ 213	€ 217	€ 220	€ 217
Double tariff (night operation)	€ 224	€ 219	€ 218	€ 216	€ 214	€ 218	€ 217	€ 218
Double tariff (day operation)	€ 237	€ 239	€ 239	€ 237	€ 234	€ 237	€ 241	€ 238

Table 12 - Energy cost for day and night operation and single and double tariff

3 Variables for comparing heat pumps

3.1 System lay-out

Because of the advantage of the inverter heat pumps described in paragraph 1.3 and the need for a hot water buffer, the basic lay-out (figure 15) for the heat pump system is drawn. This is the foundation for further simulation and calculation.

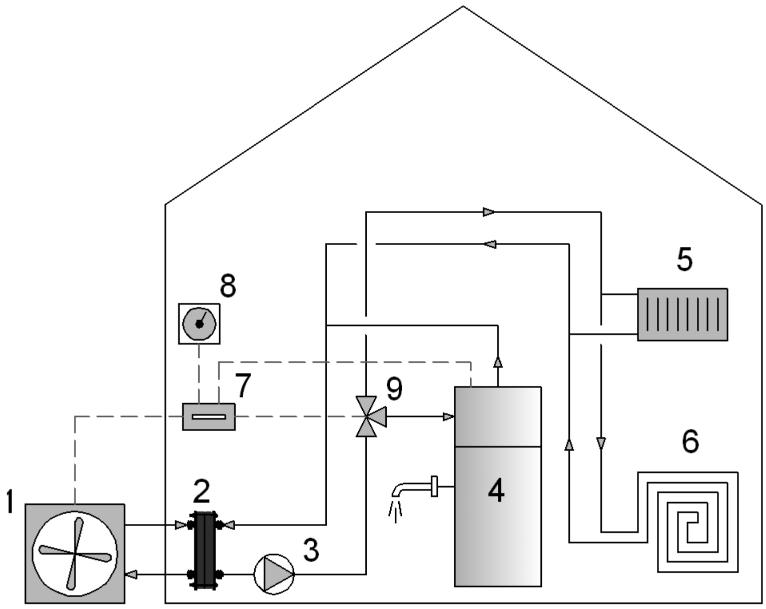

Figure 15 - System lay-out used for simulation

1	Inverter air source heat pump
2	Heat exchanger for separation between water and refrigerant
3	Circulation pump
4	Hot water boiler
5	Low temperature convectors
6	Floor heating
7	Controller
8	Thermostat

3.1 Outside air temperature

The standard for energy performance uses a reference year based on monthly averaged temperatures. Those averaged temperatures are not accurate enough for comparing air-water heat pumps (AWHP). This is because the achievement of AWHP strongly depends on the outside temperature, averaging the temperatures means inaccuracies to the efficiency of the heat pump and the amount of heat it has to deliver. The new Dutch NEN 5060 standard has hour based reference years which can be imported into for example Excel for energy simulations. Because this data is basically the same as free KNMI hourly weather files, the KNMI files are used.

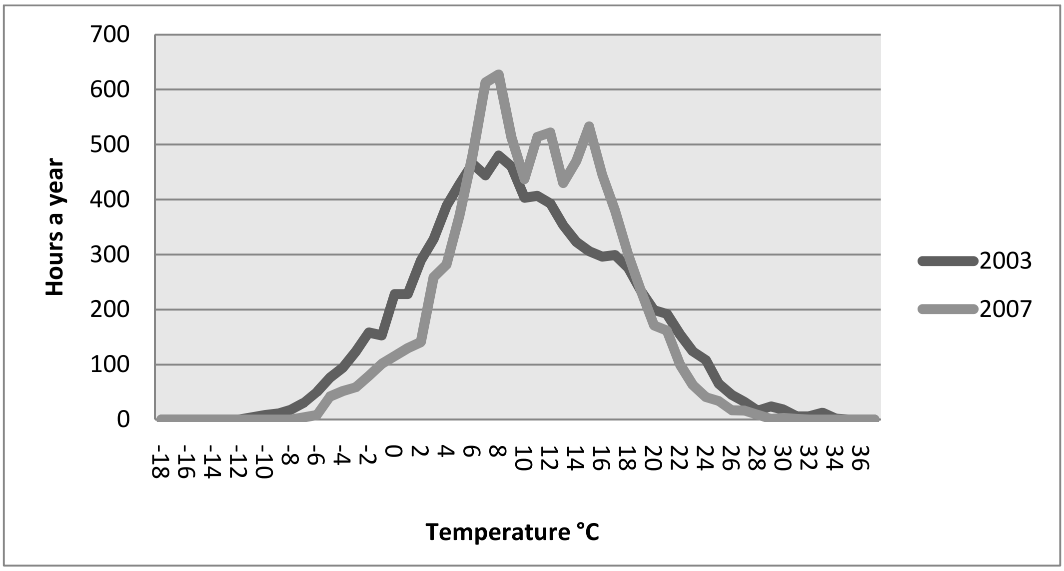

Figure 16 - Temperature frequency De Bilt (Netherlands) for 2003 and 2007

In order to limit the amount of data and keep the simulation manageable, only the weather files from 2003 till 2009 are used. The above figure shows the difference in temperature frequency between the year 2003 and 2007. The year 2003 had a cold autumn compared to 2007 which shows as more hours with a temperature between -8 ℃ and 6 ℃.

3.2 Load duration curve

The amount of heat a heat pump has to deliver depends on the heating curve combined with the outside temperature. By combining the heating curve with a weather file and simulating the thermal loads (occupancy, lighting and equipment), the amount of heat needed for every hour in a year is calculated. This is represented as a load duration curve (Figure 17).

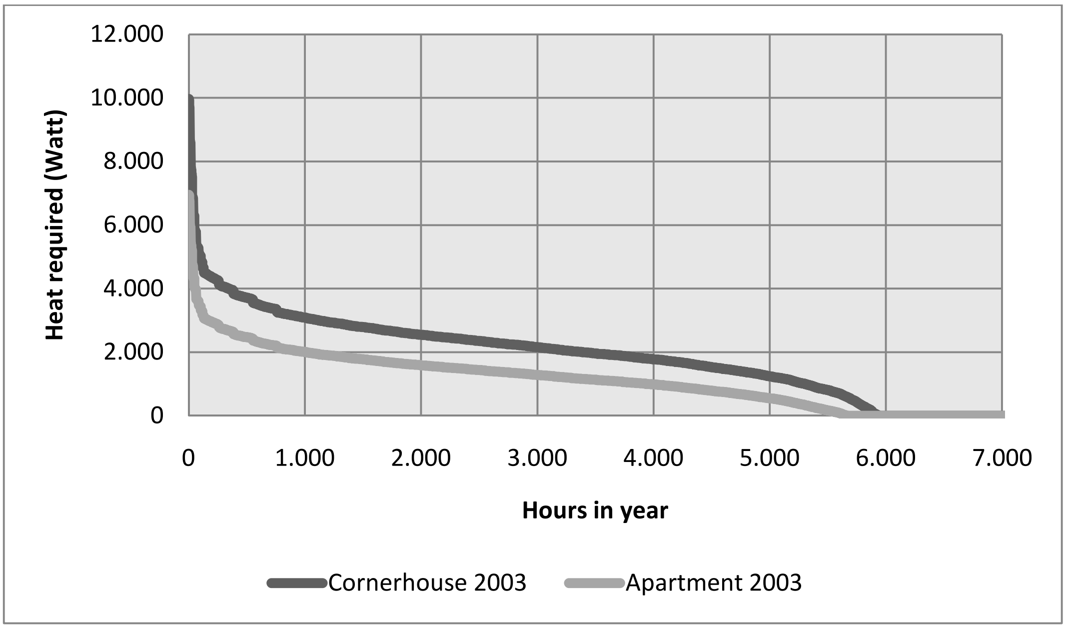

Figure 17 - Load duration curve corner house versus apartment

3.2 Cop curve

Manufacturers of heat pumps often only show the COP at an outside temperature of 7 °C and a condenser temperature of 35 °C. This is no indication for the actual performance of the heat pump at lower or higher temperatures. In order to make a fair comparison the COP curve is required at various condenser temperatures. Most of the active manufacturers and distributors of air source heat pumps were asked to send the COP curves of their heat pump. The following manufacturers send COP curves:

- Daikin;
- General;
- LG;
- Mitsubishi;
- Nathan;
- Stiebel Elton;

LG, Daikin General and Mitsubishi have inverter heat pumps, only these four will be used for a comparison on performance. In annex XI the COP curves of these heat pumps are anonymous given.

3.3 Energy use during defrost cycle

At temperatures around freezing point, the moisture in the outside air will freeze to the evaporator. This is caused by the high relative humidity which condenses when air is cooled by the evaporator. The condensate will freeze when the temperature of the evaporator is below 0 ºC.

When the amount of ice increases (figure 18) and starts working as an isolator, it decreases the efficiency and the capacity of the heat pump. As a result the air water heat pumps needs a defrost modus. Most heat pumps have a hot gas bypass, redirecting the hot gas from the compressor to the evaporator, which defrosts the evaporator. Some heat pumps have an electric heater to melt the ice. The effect of this defrosting shows as a steeper COP curve at around 6 ºC until 0 ºC (annex XI).

Figure 18 - Ice at a Carrier air source heat pump

3.4 Decreasing COP due to switching on and off

Heat pumps with inverter technology are capable of lowering their load to 25% of maximum. When the heat demand is below 25% the heat pump starts switching on and off. The effect is a decrease in efficiency depending on the times switched on and off; we assume for this simulation that the COP reduction is approximately 20%. This is confirmed by two manufacturers.

3.5 Dimensioning

The more power a residential air water heat pump is able to deliver, the overall efficiency decreases. However, when a heat pump has less capacity, it has to use the electric heater to deliver the amount of heat needed when the outside temperature drops. This influences the energy required for heating, and thus influencing the energy cost. But there are also investment costs and operation and maintenance cost. The investment cost increase with bigger heat pumps, the operation and maintenance cost are almost independent of the air water heat pump size.

- Bigger heat pumps have less COP curves;
- Bigger heat pumps are more expensive;
- Smaller heat pumps need more additional heating, thus decreasing SPF;
- Operation and maintenance cost are independent of heat pump size;
- Bigger heat pumps have more start/stops, decreasing it's performance at higher outside temperatures;

In order to determine what the optimum is between heat pump capacity and heating curve, a simplified model is used. The model is based on the average COP curve's and capacity's of several air water heat pumps at 35 ºC and 55 ºC (Annex VIII and Annex IX). Combining this data with the hourly temperatures during a year gives an approximation of the annual energy cost.

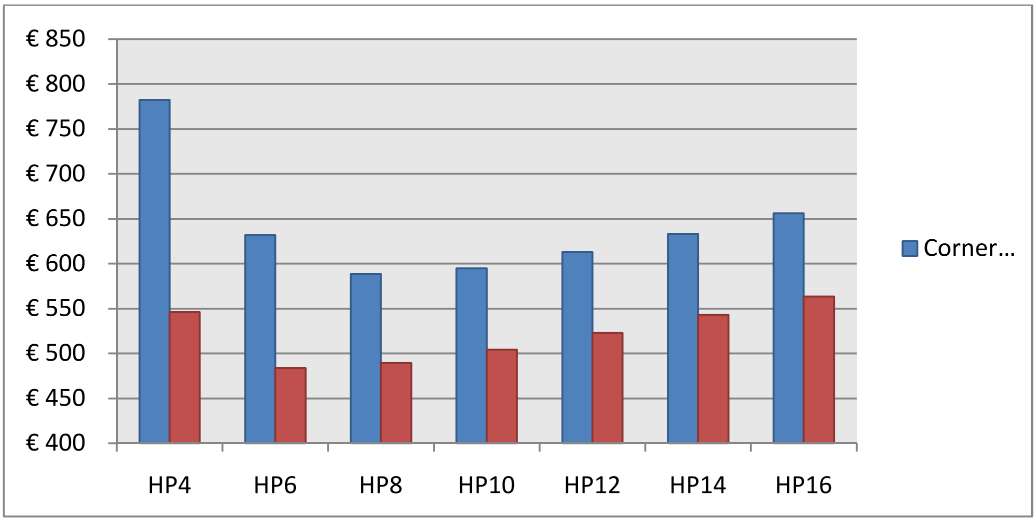

Figure 19 - Annual energy cost for various capacity heat pumps

The optimum for annual energy cost for the period 2003 – 2009 for the apartment is somewhere between a 6kW and 8kW model. For the Corner house, the optimum is somewhere between an 8kW and 10 kW model. However, the optimum also depends on the total cost of ownership.

The average prices between heat pumps with different capacity are small. The index ratings used are:

- Electricity indexation is 4%
- Electricity price in 2010 is € 0,21
- Inflation is 2%

- Discount rate is 5%
- Term of mortgage is 30 years
- Lifespan of heat pumps is 15 years

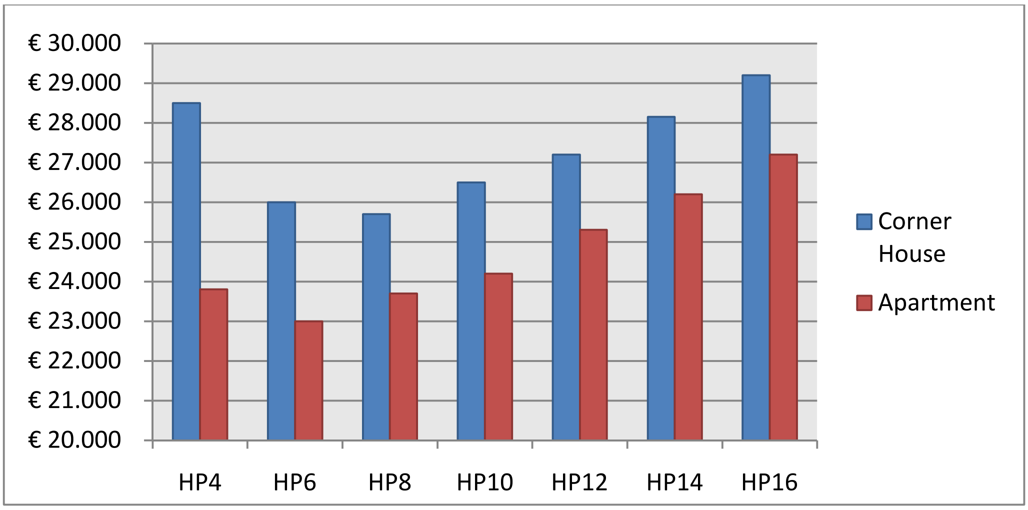

Figure 20 - Total cost of ownership for various capacity air source heat pums

The total cost is simulated for different heating curves (different houses). The optimal bivalent point (figure 21) is between -1,5 ºC and -5Cº. This is the point where around 95 - 97% of the annual needed heat is generated by the heat pump; the other 5 - 3% is generated by the electric heater.

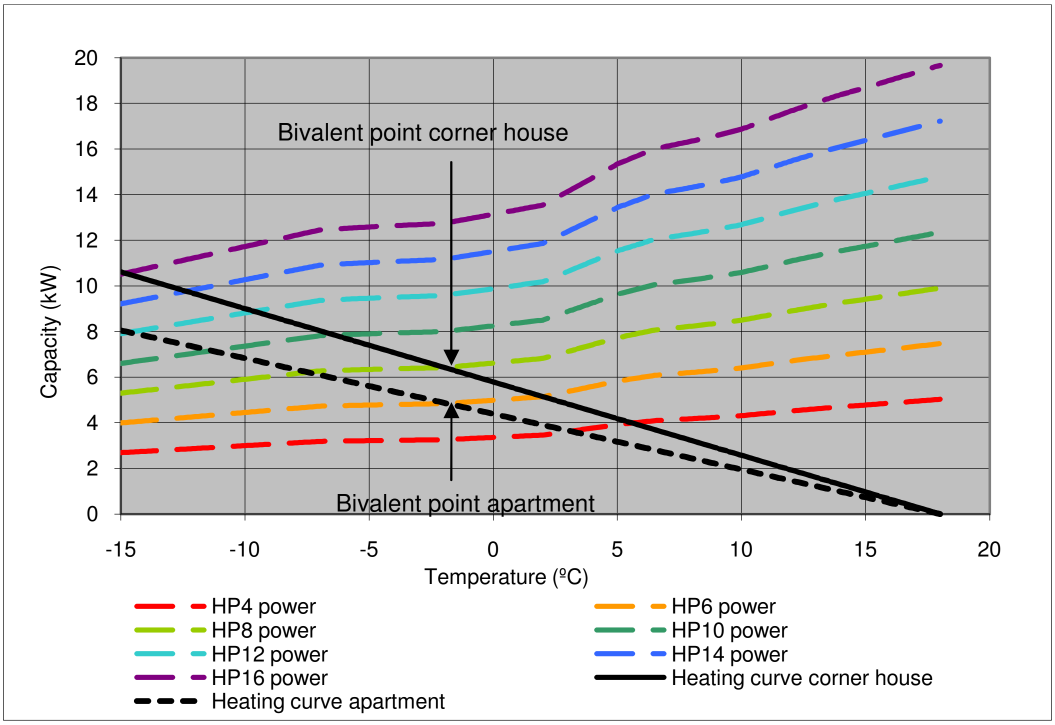

Figure 21 - Bivalent selection based on capacity in relation to heating curve

3.5 Comparison between heat pump brands

Based on the dimension analysis in paragraph 3.4 the heat pumps can be selected. Because of confidentially, the brands and models used for comparison are made anonymous. With the COP curves (annex XI) and the heating curve from the corner house, the energy used is simulated.

- Electricity indexation is 4%
- Electricity price in 2010 is € 0,21
- Inflation is 2%
- Discount rate is 5%
- Term of mortgage is 30 years
- Lifespan of heat pumps is 15 years

The average energy cost for the period 2003 – 2009 is shown in figure 22. There is a difference of € 100,- in annual energy cost between brand B and brand D. However, when looking at the total cost of ownership brand C is the best buy. The difference in total cost of ownership is almost € 4000,- between brand C and D. The high differences in cost indicate that's worth to compare different brands and models.

	Investment
A	€ 6.500
B	€ 7.000
C	€ 5.730
D	€ 7.800
Gas boiler	€ 2.000

Table 13 - Investment needed

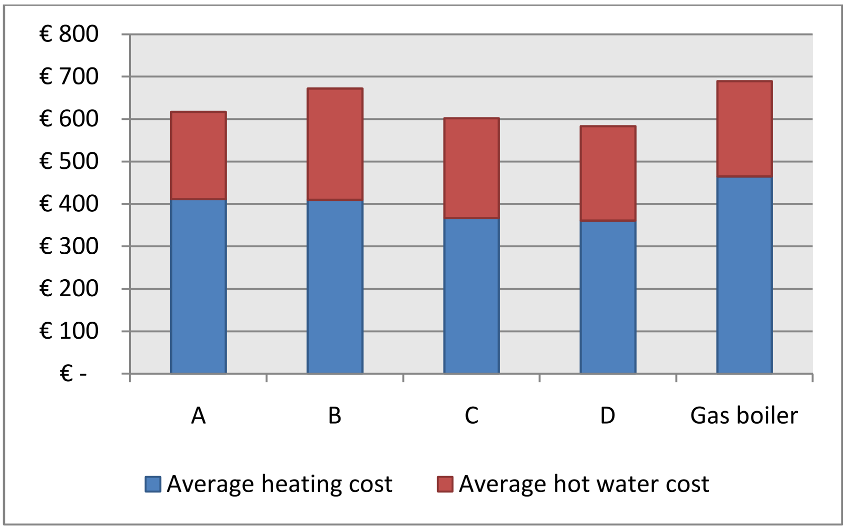

Figure 22 – Corner house annual energy cost

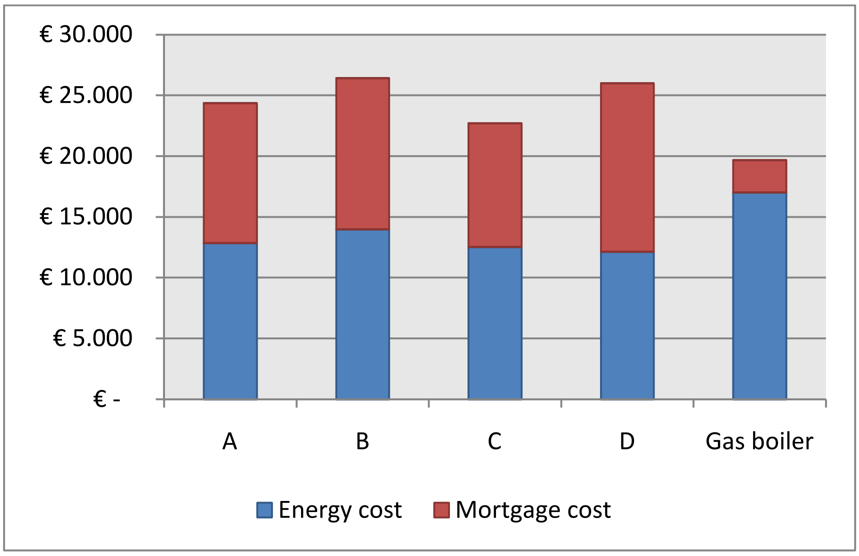

Figure 23 – Corner house total cost of ownership

4 Risks

4.1 Dimensioning the heat pump system

Designing a house, it's often not known what type of family will live there. A five person family with three children in the age of 12–18 years has a higher annual heat demand than a single person. The heat loss calculation for a corner house for instance is based on a average simultaneity of 2,5 person, when the required amount of heat is larger than the capacity of the heat pump, the electric auxiliary heater will switch on, causing high energy bills.

An air source heat pump with a capacity that's larger or smaller than optimal (figure 19) will annually use more energy than is needed. However, the negative effect on the energy use of a unit designed to small is larger than a unit designed to large. This makes it wise to select the slightly larger heat pump when the optimal heat pump size is not available. Especially when the family composition is unknown and the variation is wide, selecting a slightly larger heat pump is recommended.

The optimum size calculation (chapter 3, paragraph 5) is indicative; within a brand's model range it's possible that the smallest heat pump in a series has a better seasonal performance than the biggest capacity heat pump from another series. This is caused by the way heat pumps are manufactured; a series consists of the same evaporator and condenser with different capacity compressors. The smaller compressor models in the series have a slightly over-dimensioned evaporator and condenser, decreasing the temperature difference needed to exchange the energy. Because the COP depends on the temperature difference between evaporator side and condenser side, the performance of the heat pump increases, for larger models it is counterproductive. This way, the larger model in a series (for instance 8 kW) can have worse performance than the smaller model in a series (10 kW).

4.2 Fluctuating energy bills

Some years have a cold autumn or a hot spring, affecting the annual used energy by the air source heat pump. This is not only caused by the increase or decrease of heating demand, also the COP varies with the temperature, causing the heat pump to generate a high amount of heat with a low efficiency for colder outside temperatures. Consider figure 11 of chapter 3, 2003 had a cold autumn and winter which shows as many hours in the -8 °C to 4 °C range, 2007 had a mild winter showing as little hours in the -8 °C to 4 °C range and more hours in the 4 °C to 18 °C range. The effect is a high energy bill in 2003 and a low energy bill in 2007. This variation in energy bills can cause confusion among end users. Energy bills are common to slightly vary from year to year with traditional gas heated dwellings, however, for heat pumps this effect is accentuated by the varying COP (table 13).

	Average	Minimum	Maximum	Min %	Max %
Heat pump G	€ 361	€ 307	€ 399	-14,9%	10,6%
Heat pump H	€ 365	€ 315	€ 402	-13,7%	10,2%
Heat pump I	€ 415	€ 350	€ 460	-15,7%	10,9%
Heat pump J	€ 354	€ 307	€ 391	-13,3%	10,4%
Heat pump K	€ 376	€ 326	€ 415	-13,2%	10,6%
Heat pump L	€ 360	€ 306	€ 399	-15,0%	11,0%
Natural gas heater	€ 470	€ 423	€ 505	-9,9%	7,5%

Table 14 - Fluctuation of energy bills in the period 2003-2009

The annual energy bill in the period 2003 - 2009 for heat pumps is +/- 15%, for gas heater this is +/- 10%. However, when a good year is followed by bad year the increase in energy bill by a heat pump could be 35%, for a gas heater this is 22%.

4.3 Service and maintenance

The heat pump industry is still developing (figure 24). Although heat pumps are widely used in commercial buildings there are still few installations in dwelling in the Netherlands. The result is a lack of a fully developed and competitive industry that provides service, maintenance and repair of heat pumps. Most of the existing heating contractors are not capable of providing such services to heat pumps clients. This absence of a well regulated service and maintenance network increases the risks should errors to the heat pump system arise. There might be a opportunity for air-conditioning service providers to position themselves in the heat pump market.

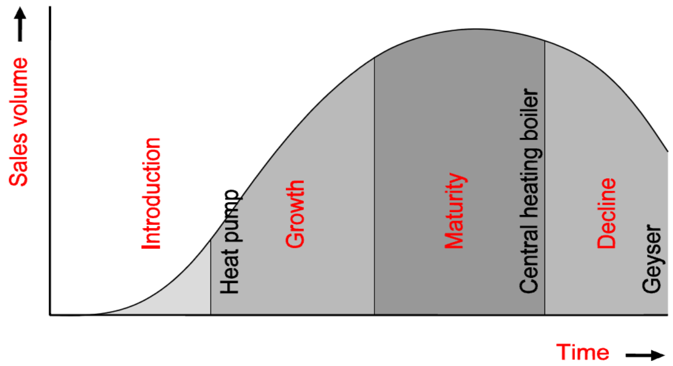

Figure 24 - Product life cycle curve

The amount of maintenance needed for air source heat pumps is little; SenterNovem indicates that the amount of maintenance cost is something like 2% of the investment. The biggest concern is keeping the outside unit clean and free of leaves, snow or ice. When the fan of the outside unit is hindered, it will start to use more energy than needed. You could compare the effect of a dirty outside unit with the effect of an air source heat pump that's designed to small, causing the auxiliary heater to switch on earlier.

4.4 Guaranteeing heat pump quality

When the new EPC demand of 0,8 was introduced in 2006, the balanced ventilation with heat recovery unit was regularly installed to easily increase the energy efficiency of a dwelling. Developers and installers where continuously searching for the cheapest possible system to meet the EPC demand, this created a price war among manufacturers of balanced ventilation systems that did not benefit the quality of these systems. In recent years there have been many complaints (for example Vathorst) about such ventilation systems, which gave the system a bad name. The effect is a decrease in heat recovery system sales. While theoretically the system has high potency when properly installed.

To prevent the same thing from happening to air source heat pumps the installation and quality needs to be coordinated. The first bad publicity is already done; recently project "de Teuge" in Zutphen was in the news because of much higher than average energy bills. The systems installed in "de Teuge" are water source heat pumps, but most people will associate heat pumps with high energy bills.

The installers and manufacturers of heat pumps have to be involved in the building process in an early stage in order to guarantee the operation and quality of the heat pump system. Ideal would be an independent organization that inspects quality and performance of installed air source heat pump systems. Also the residents have to be informed of the working of the heat pump installation and the pros and cons of the system. Avoid creating high expectations that can't be realized.

4.5 Noise

Air source heat pumps are usually located outside the house, often attached to a wall where connection to the heating system is easiest. All exterior residential heat pumps are noisy, this is a little bit due to the compressor but mainly to the powerful fan which blows the outside air at the evaporator. Figure 25 is an example of a Daikin Q11 heat pump in silent mode, the noise is still 42 dB(A).

Source of sound	Sound level in dB(A)	Perception
Watch ticking	10	Very quiet
Airco in theater	30	Very quiet
Airco in office	40	Quiet
River, quiet restaurant	50	Medium
Conversation	60	Loud
Loud music	80	Very loud

Figure 25 - Sound level perception

In order to prevent the amount of noise produced, the following should be considered:

- Installing a heat pump directly under or against windows should be avoided.
- Installation in niches, wall corners or between two walls causes an increase in noise production due to reflection.
- The distance to a dwelling must be chosen so that the noise at night doesn't exceed 30dB(A) (NEN 5077).
- When there are multiple units installed closely, the noise production will increase. The effect on noise production is about 3 dB(A) for every additional unit installed.

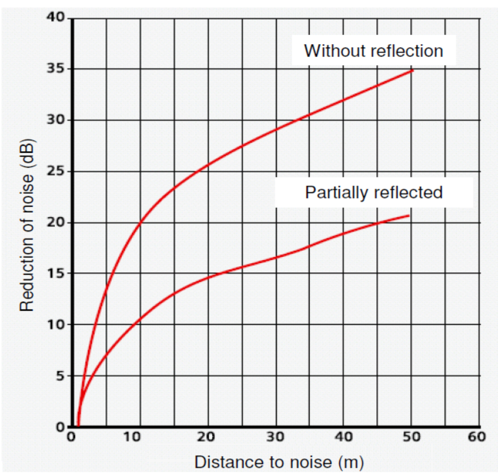

Figure 26 - Reduction of noise in relation to distance

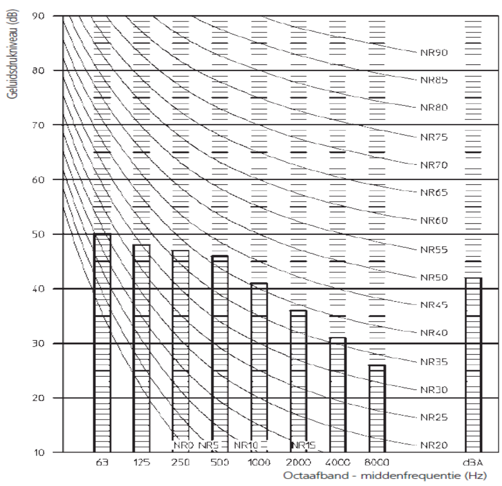

Figure 27 - Daikin Q11 in silent mode

4.6 Electric connection simultaneity

Heat pumps connected to the electric distribution net can cause problems because of the high currents at start-up and the peak power load from the auxiliary heaters. Especially for multiple heat pumps in a neighborhood, the simultaneous operation of heat pumps can cause errors to the distribution network. During cold winter days, the simultaneity of air source heat pumps can be 90% at temperatures below - 5 °C. The effect of this is a significantly higher simultaneity load per household (figure 28).

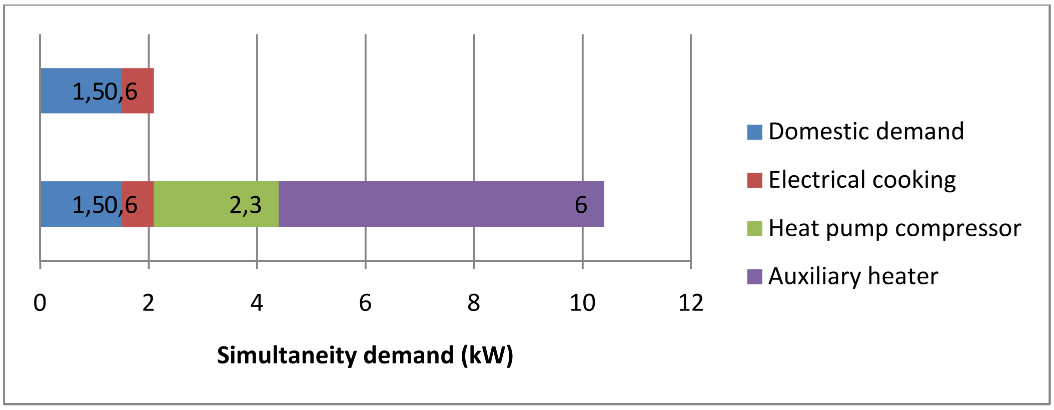

Figure 28 - Simultaneity demand for average household and 10kW heat pump

Because of this higher simultaneity the electrical network needs a heavier design. The cost is a extra € 2000,- per household (table 14, research by Stedin).

	Normal electricity network		Heat pump ready network	
	Per dwelling	1400 dwellings	Per dwelling	1400 dwellings
Low voltage net	€ 1.000	€ 1.400.000	€ 2.000	€ 2.800.000
Middle voltage net	-	-	€ 1.000	€ 1.400.000

Table 15 - Price of normal and heat pump ready network. (Source: Stedin)

Most of the air source heat pumps in the residential market have an electrical heater for anti-legionella operation. Protection against legionella is a hot item in the Netherland since the incident at a flower exhibition in Bovencarspel. When installing heat pumps in a residential area it must be taking into account that the anti-legionella operation is programmed on different times for every heat pump. Also the hot water operation, which is usually once or twice a day, should be coordinated to avoid high simultaneity. There are already some manufactures that have special software to coordinate this. The network operators are busy with development of power matching systems to match the supply and demand of power in their network.

In order to avoid voltage variance and high simultaneity the following should be considered:

- Soft start mechanisms fitted to spread the load on start up;
- Low torque compressors;
- Three phase connection;
- Special software for simultaneity coordination;
- Get the network distributor Involved at the start of the project

6 Design directives

Designing a house or building starts with purchasing the ground which it will be standing on. The initial allocation of the land influences the energy used of a dwelling. Almost every small change in design affects energy used by the building. This chapter gives some main directives which have to be considered while designing a house or a building with air source heat pumps.

6.1 Developer

It's recommended to decide early in a project which energy performances have to be achieved. Ask a consultant and an architect to work together as early as possible in order to design a reliable energy system which includes the heat pump for the dwelling. This generally improves the performance and the quality of the modern techniques that are used in energy efficient dwellings.

Determine how the energy performances are measured. Consider assembling a specialised inspection team to determine if dwellings are built according to the specification. Review the design and determine the impact of changes whenever possible. An air source heat pump in a dwelling that's less insulated as specified will have to use its auxiliary heater more than needed, thus decreasing the annual efficiency of the heat pump. Decreasing efficiency means higher energy bills for residents.

The orientation of a dwelling affects its energy use and potential for solar energy. There are consultants who have the proper software to determine the optimal orientation, considering heating load, cooling load and solar energy.

Collaborate with experienced building partners who already learned from previous projects. Assemble you building team as early as possible to accomplish integrated designing, decreasing building time and building cost.

6.2 Architecture

The use of concrete tunnel methods or wood skeleton constructions as building techniques influence the energy use of a building (figure 29). A heavy building uses more energy during the winter and summer, but less energy during autumn and spring. A more evenly divided heating and cooling load during a year for light buildings will increase the efficiency of an air source heat pump compared to heavy building. This is caused by the higher outside temperatures during spring and autumn (high COP) then winter. When implementing air source heat pumps it is advised to build light structures like wood skeleton constructions.

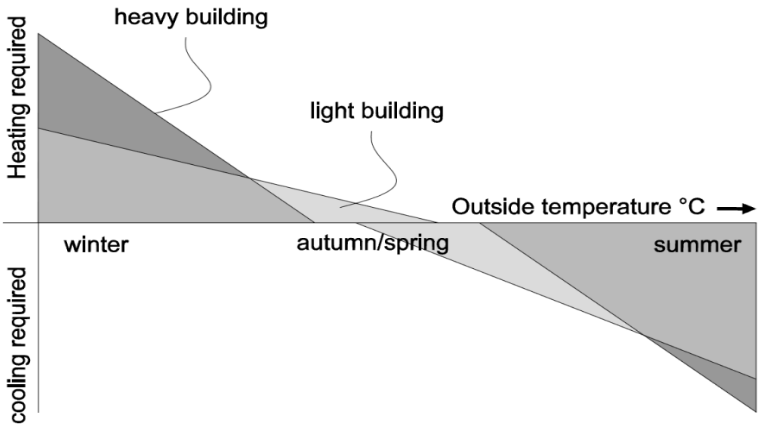

Figure 29 - The effect of thermal mass on annual heating demand

Take advantage of solar energy during winter (low sun) and keep solar energy out during the summer (high sun) by using overhanging blinds whenever possible.

Recommendations for the placement and surroundings of the outside unit

- The heat pump must be accessible on all sides for maintenance
- The air intake and outlet should be free from obstacles. As the air leaves the heat pump approximately 5 ºC under the outside temperature, avoid directing the air at walls.
- Do not install a heat pump in a pit. Cold air has the tendency to fall making the heat pump cool and reuse its own leaving air. A slightly uplifted placement for the unit is recommended.
- A condensation water piping has to be fit to the unit and the condensation water must have a safe way to be drained. In winter, the condensation water can makes dangerously slippery patches on the floor.

Recommendations for installing an inside unit

- Indoor heat pump units need air ducts for airflow. Placement in the corner of a technical room with two outside walls is preferable so that short circuiting the air flow is prevented. When this is not possible certain measures have to be taken. For example creating height difference between inlet and outlet.
- When the air in and outlet designed at the roof, the maximum boost pressure of the ventilator has to be considered. The ventilators of heat pumps are usually not designed to boost a lot of power to overcome the resistance of long air ducts. The manufacturers of the heat pumps will probably have to make a custom-built adjustment to the machine to overcome this problem.
- A condensation water piping has to be fit to the unit and the condensation water must have a safe way to be drained.

6.3 Energy consultant

Dimension the heat pump on a proper heat loss calculation, a unit too small or too large increases the annual energy bill.

Get involved in designing and dimensioning the dwelling and the heating system in an early stage, advice the architect and the developer on the issues named in the above paragraphs.

Involve the different manufacturers of heat pumps in the process in order to get the specific details of the different types of heat pumps. Sometimes small specifications differences of heat pumps in combination with the specific design off the dwelling make large quality variations.

Design a dimensioning tool for the selection of the best-suited heat pump for the dwellings.

6.4 Installers

Monitor the quality of the system during build. When any changes are made in the building design or heating system design, consult the designing team and the manufacturer off the heat pump. Involve the manufacturer in designing the final heating system.

6.5 Manufacturers

Monitoring heat pump systems is critical in determining heating performance and heating efficiency. If problems arise with electricity consumption, the cause of the high electricity used is easily determined.

Note the energy use during standby or summer periods, especially the crankcase heater and the bottom plate heater. There's still a lot to win in improving technology of air source heat pumps.

Get involved in the designing process of heating systems for dwellings, advice installers and energy consultants. Set design guidelines and communicate this with the branch associations and research institutes such as ISSO, NEN and TNO.

Help to provide the designers with a tool to make a well-calculated choice for the best product to fit in the dwelling. Even when this means competitive product will better suit for the specific design. The trust of costumers is fragile; damaging the image of heat pumps will slow down sales and the development of heat pumps.

6 Conclusion and recommendations

The aim of this study was to establish if air source heat pump concepts are worth to consider as a residential heating option and how to maximize its potential. Key elements of the study were investigating the air source heat pump technology, considerations for optimizing its performance and surrounding components and what risks and design directives have to be taken into consideration.

Air source heat pumps have the potential of contributing to the reduction of emitted carbon dioxide with about 67% compared to natural gas heaters. There is also the possibility of saving on annual energy cost compared to gas heaters, but the margin is thin.

Best heat pump system is an inverter controlled heat pump, which provides for heating demand and hot water.

Solar energy can contribute to lowering the energy demand of a dwelling. Considering payback period, an 2,19 m^2 for an average 4 person household is the best option. If wanted, more energy can be reduced by applying photo voltaic cells.

Best option for the distribution system is floor heating in the living room with an additional low temperature convector. This system benefits of the thermal comfort from floor heating and the quick reaction of low temperature convectors.

When dimensioning an heat pump system, use a bivalent point between - 1,5 °C and – 5 °C to optimize the annual needed heat. At this point only 5 – 3% of the annual needed heat is generated by the auxiliary electric heater.

There are still some developments needed in heat pumps to reduce the risks involved with air source heat pump systems. Especially the noise generation is an issue of concern.

Recommendations

Implement the recommendations for designing air source heat pumps on a small scale. For example, 5 or 10 dwellings with different brands and monitor the systems. Feedback the information generated with the project to manufacturers, developers, installers and consultants in order to improve systems and have some insight in the actual performance of air source heat pumps systems.

Areas for further research

Software package for easy comparison between different heat pump systems, brands and models is needed.

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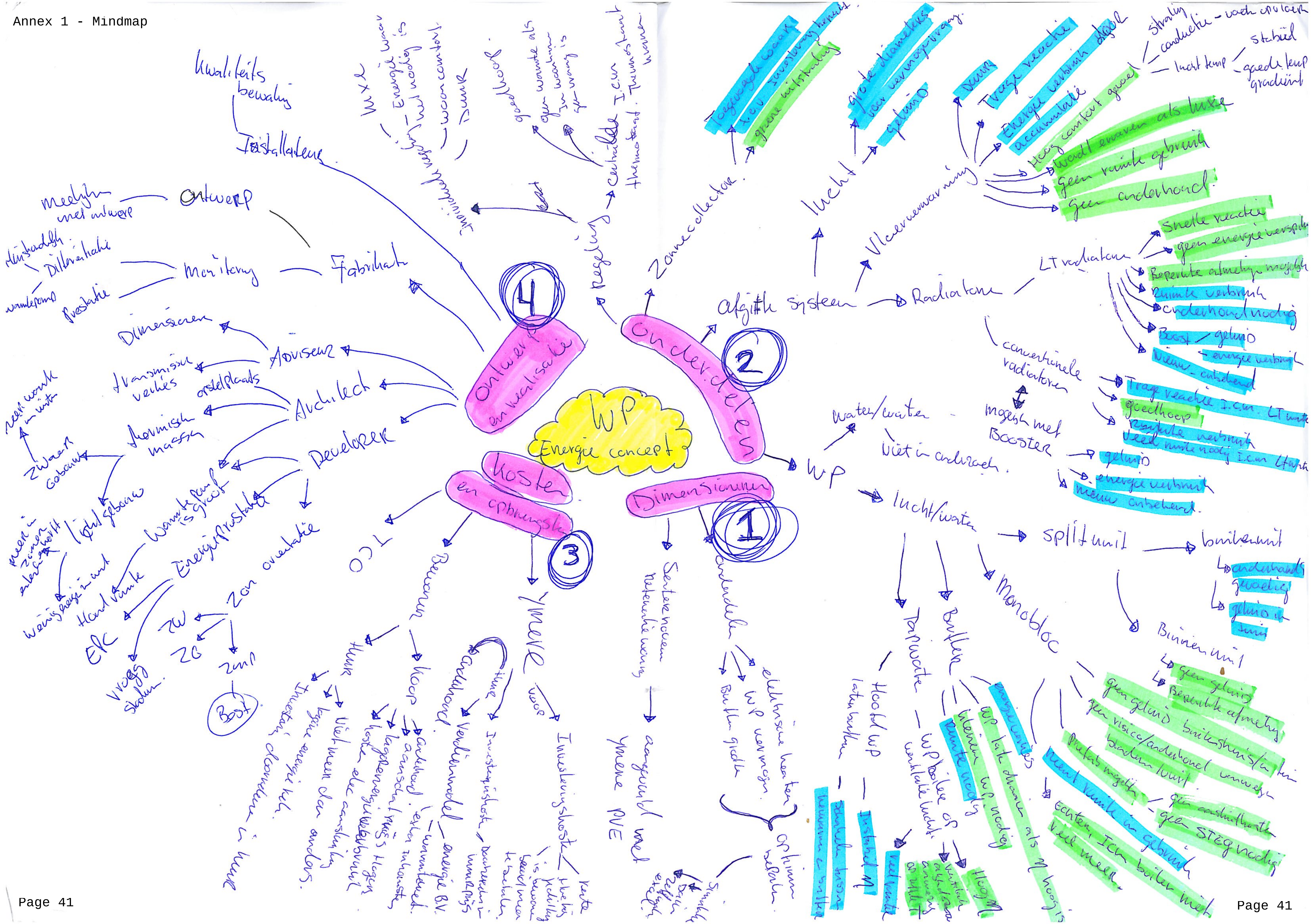
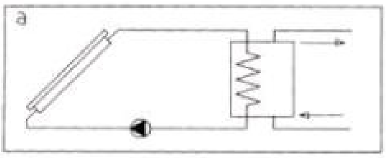
Annex


WP
Energie concept
Ontwerp en realisatie
Onderdelen
Kosten en opbrengsten
Dimensioneren
Afgifte systeem
Radiatoren
LT radiatoren
Vloerverwarming
Lucht
Zonnecollectoren
Regeling
WP
Water/water
Lucht/water
Splitunit
Buitenunit
Binnenunit
Monobloc
Boiler
Tapwater
Adviseur
Architect
Developer
Fabrikant
Monitoring
Ontwerp
Installateur
Zon
EPC
TCO

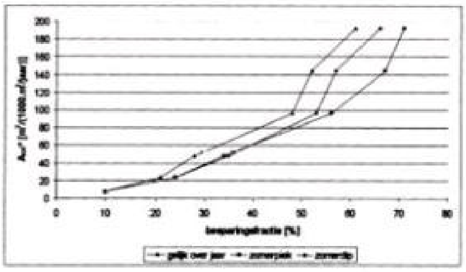
Annex II Insulation values Ymere

Omschrijving				
Nutsvoorziening	Elektriciteit	Individueel		
Woningtype	Hoekwoning			
Bouwkundig concept	C2a			
Orientatie voorgevel	Noord			
Beukbreedte h.o.h. [m]	5,4			
Diepte uitwendig [m]	9,2			
Verdiepingshoogte [m]	2,6			
Bouwlagen	3			
Woonoppervlak [m²] GBO	124,3			
Verliesoppervlak [m²]	243,7			
Percentage glas [%]	14			
Dakhoek [graden]	43			
Bouwkundige maatregelen				
			[€/eenh.]	[€/m2GBO]
Rc bg vloer [m²K/W]	5,0		€ 500	€ 4,02
Rc zijgevel [m²K/W]	5,0		€ 1.200	€ 9,65
Rc voor/achtergevel [m²K/W]	5,0		€ 600	€ 4,83
Rc dak [m²K/W]	6,0		€ 900	€ 7,24
Infiltratie [l/s.m²]	0,625		€ 0	
U raam [W/m²K]	1,6			
U glas [W/m²K]	1,0		€ 0	€ 0,00
U kozijn [W/m²K]	2,4		€ 0	€ 0,00
U entree deur [W/m²K]	2,0		€ 0	
ZTA glas [%]	60		€ 0	€ 0,00
Zonwering [Orientatie]	Ja, Z		€ 1.750	€ 14,08
Koudebrug berekening	Ja			
Meerkosten bouwkundig tov PVE 2007			**€ 4.950**	**€ 39,82**

Annex III ISSO 59 – Paragraph 3.4.2.3



a. *Optimale collectoroppervlakte A_{col}^{*} per warmtevraag van 1000 m^3/jaar:*



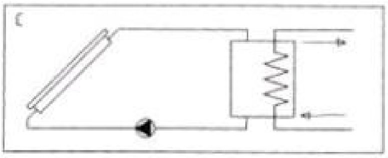
f_{besp} [%]	A_{col}^{*} [m^2 per 1000 m^3/jaar]		
	jaar gelijk	zomerpiek	zomerdip
20	20	20	20
30	40	40	50
40	60	60	75
50	95	85	
60		115	

Optimale collectoroppervlakte =
A_{col}^{*} · volume warmwater [m^3/jaar] / 1000

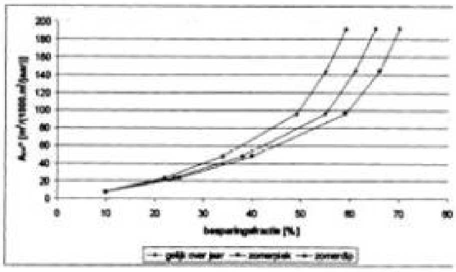
b. *Optimale vatinhoud V_{vat}^{*} per m^2 collectoroppervlakte voor een gelijkmatige tapwaterafname over de dag:*

f_{besp} [%]	V_{vat}^{*} [l/m^2]
20	20
30	20
40	20
50	20
60	20

Optimale vatinhoud =
V_{vat}^{*} · optimale collectoroppervlakte



a. *Optimale collectoroppervlakte A_{col}^{*} per warmtevraag van 1000 m^3/jaar:*



f_{besp} [%]	A_{col}^{*} [m^2 per 1000 m^3/jaar]		
	jaar gelijk	zomerpiek	zomerdip
20	20	20	20
30	35	35	40
40	55	50	70
50	85	75	
60		100	

Optimale collectoroppervlakte =
A_{col}^{*} · volume warmwater [m^3/jaar] / 1000

b. *Optimale vatinhoud V_{vat}^{*} per m^2 collectoroppervlakte voor een gelijkmatige tapwaterafname over de dag:*

f_{besp} [%]	V_{vat}^{*} [l/m^2]
20	50
30	45
40	40
50	35
60	30

Optimale vatinhoud =
V_{vat}^{*} · optimale collectoroppervlakte

Annex IV Solar collector profit versus cost

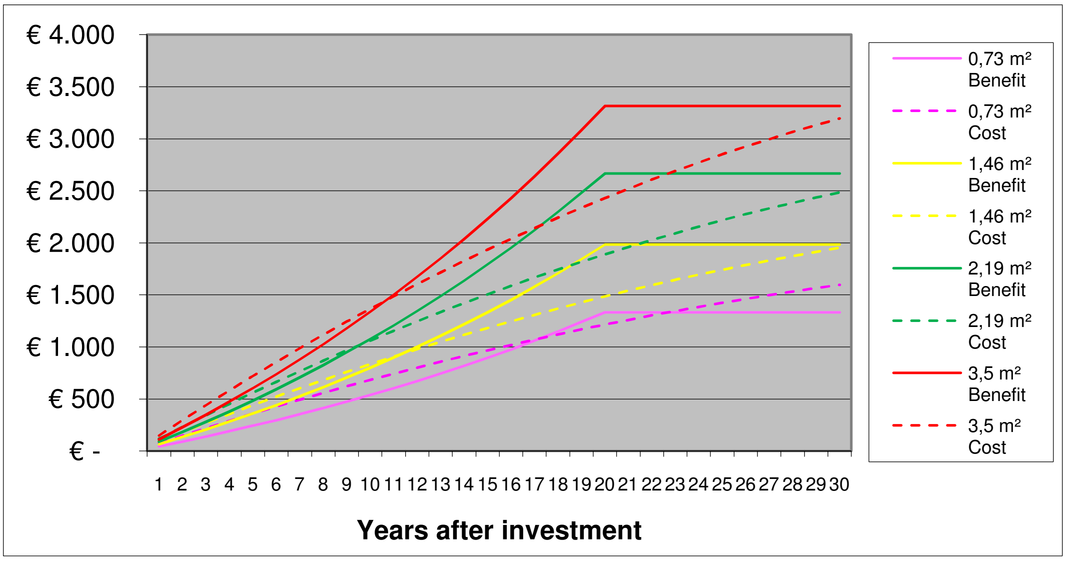


Figure 30 - Cost versus profit for solar collector (4% electricity indexation)

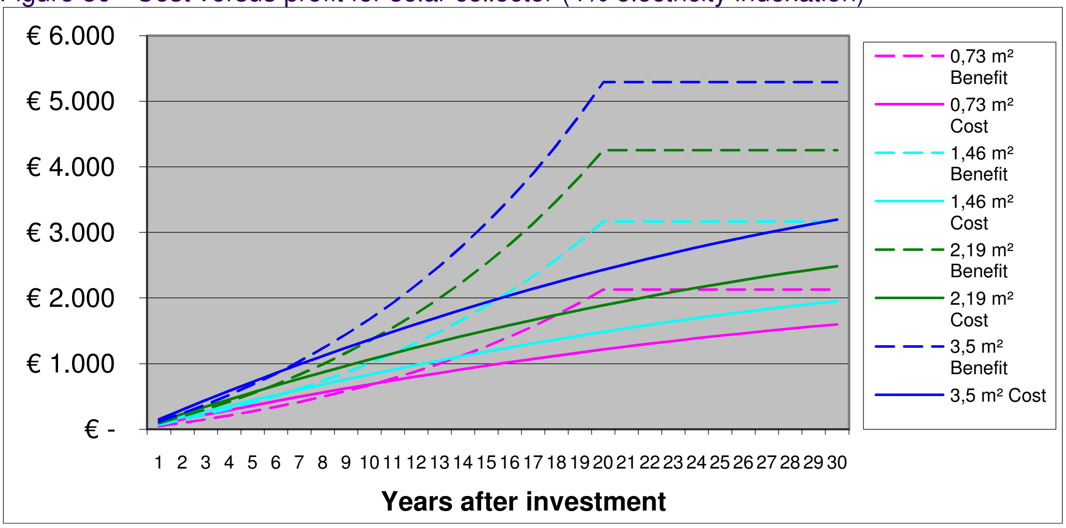


Figure 31 - Cost versus profit for solar collector (8% electricity indexation)

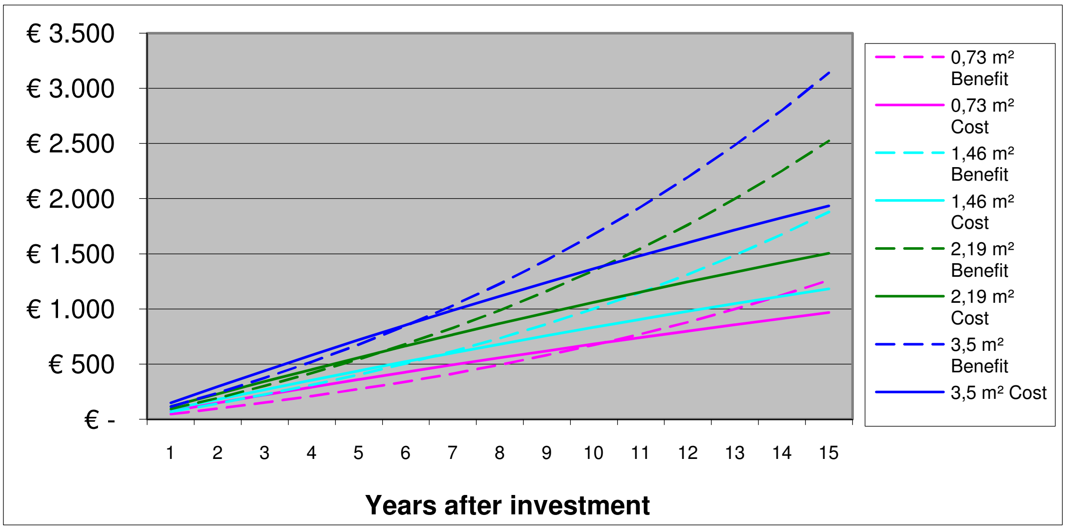


Figure 32 - Cost versus profit for solar collector (8% electricity indexation)

Annex V Photo Voltaic profit versus cost

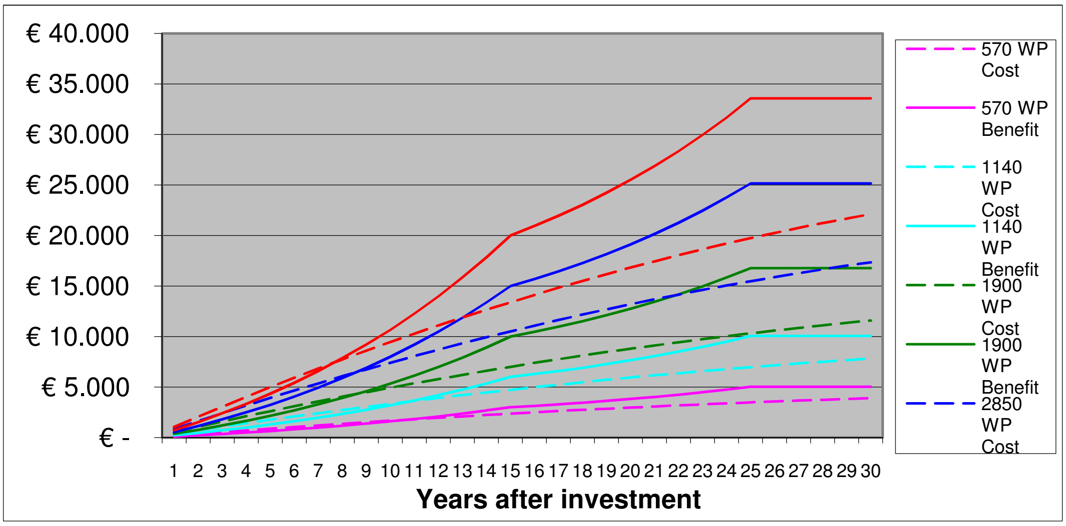


Figure 33 - Cost versus profit for photo voltaic (4% electricity indexation)

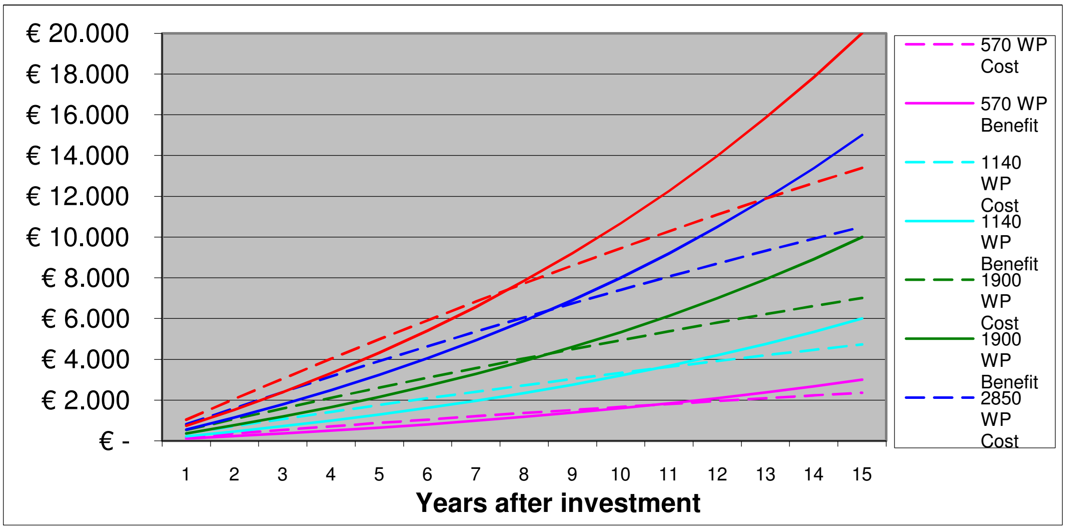
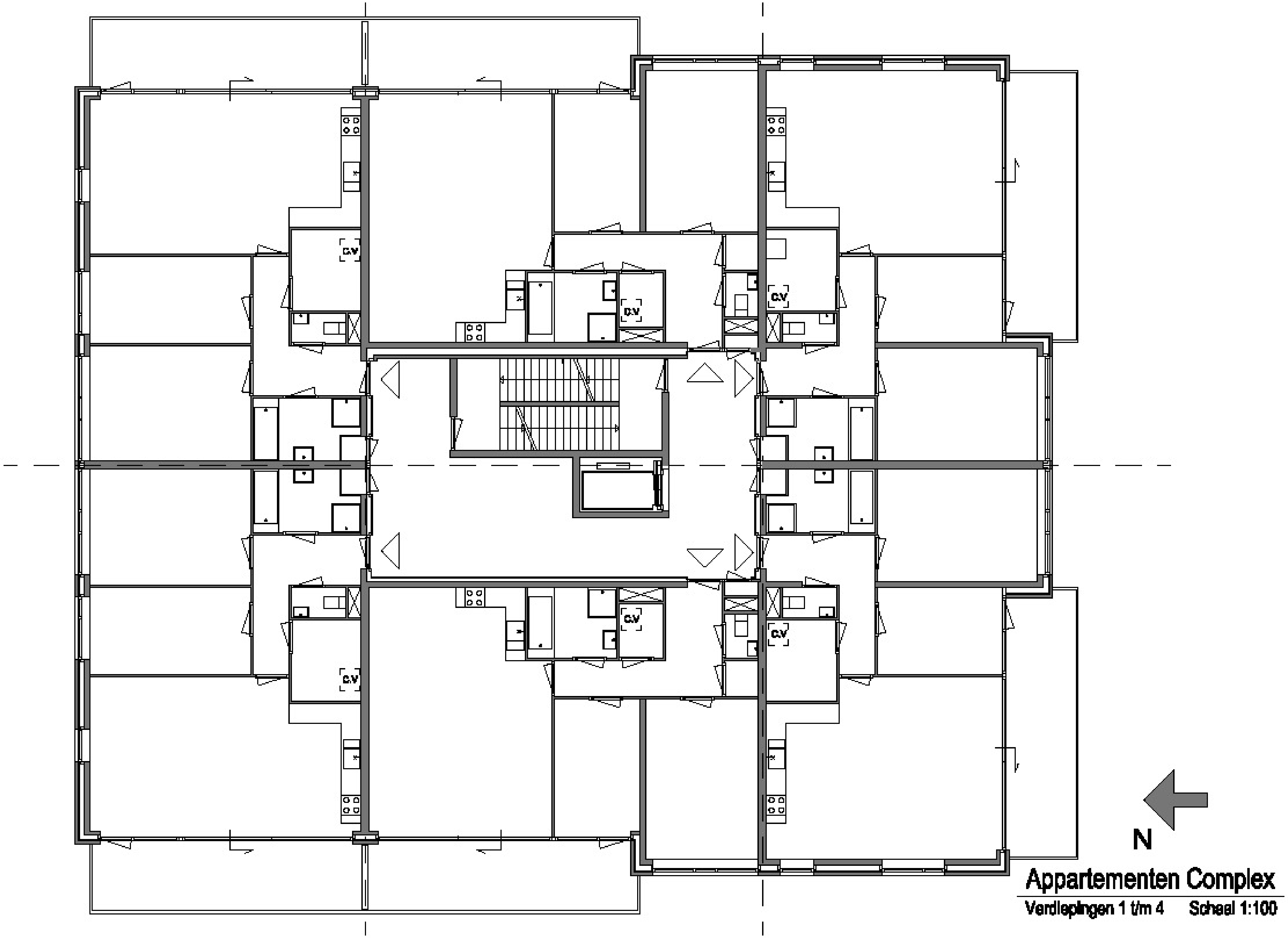


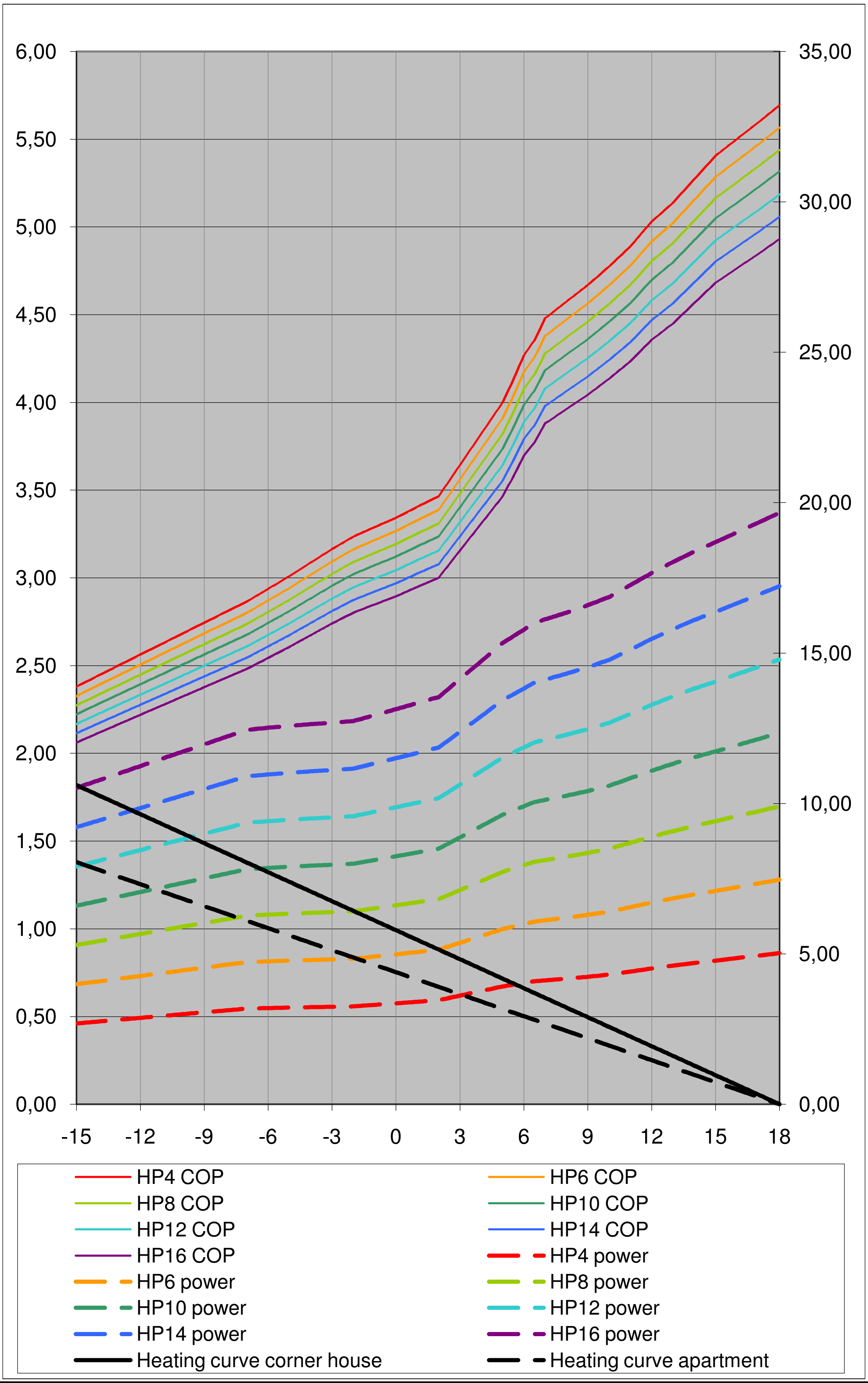
Figure 34 - Cost versus profit for photo voltaic (4% electricity indexation)

Annex VI Senter Novem Reference House Layout

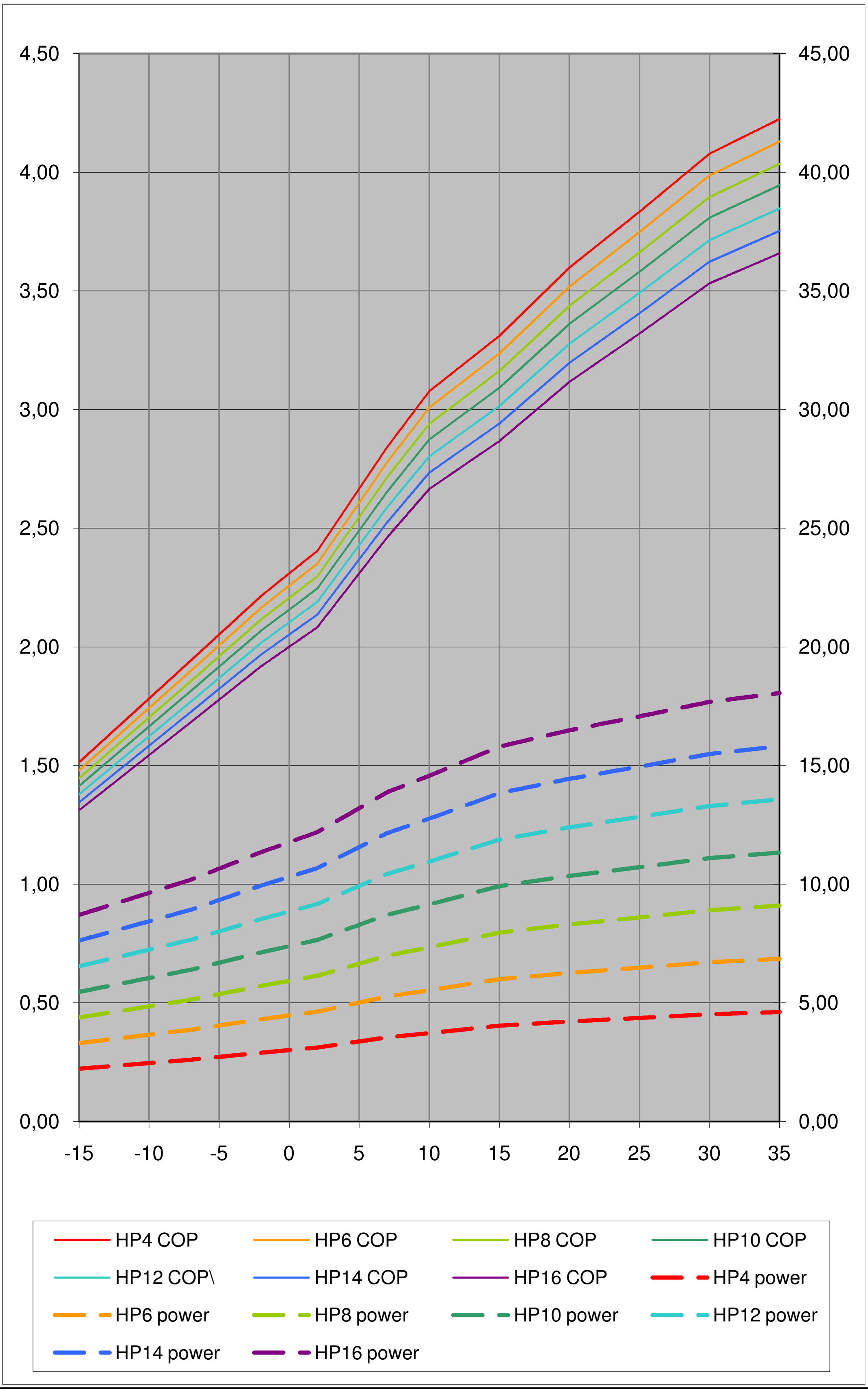
Annex VII Senter Novem reference appartement layout



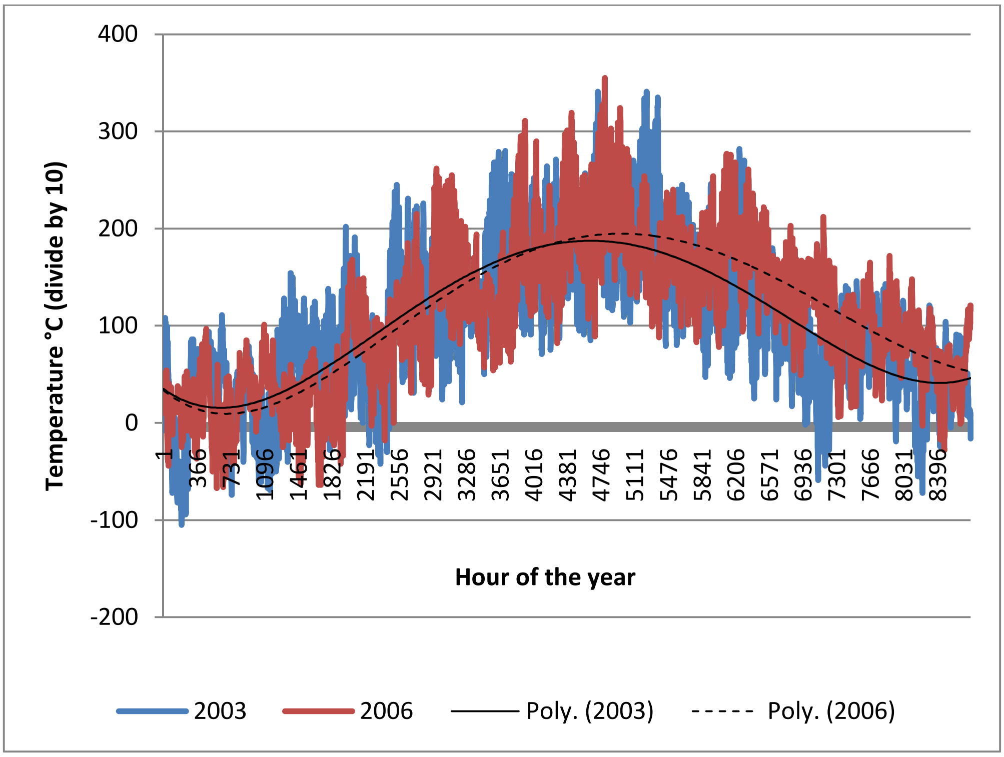
Annex VIII COP curves for average heat pumps 35 °C



Annex IX COP curves for average heat pumps 55 °C



Annex X KNMI temperature files



Annex XI COP curves heat pumps during heating 35 °C