EMERGING HEAT PUMP CONCEPTS FOR LOW ENERGY HOUSES IN THE NETHERLANDS

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Abstract: From a survey of emerging concepts for low energy houses in the Netherlands, it can be concluded that heat pumps are a cost effective and practicable solution for achieving the low energy and energy neutral ambitions suitable for large volume housing projects. These solutions are analyzed from a concept point of view, but also from the point of view of the design process and goal management. The use of monitoring to reduce the maintenance costs, improve user satisfaction, and further improvement of the low energy housing concepts is discussed.

Key Words: heat pumps, compressor, efficiency

1 INTRODUCTION

In the EU, all new building projects after 2020 will have to meet the requirement of nearly zero energy consumption. To determine what this goal means for the direction of building practice and for the development of heat pumps, we performed a study on the emerging concepts for low energy buildings using heat pumps in the Netherlands. Ambitious and progressive developers and housing corporations already have realized several relevant projects that can be characterised as low energy. The thermal energy consumption of these houses range from 40 kWh/m2.a to 15 kWh/m2.a. The study was aimed at proving information on feasible heat pump concepts for low energy, low cost housing projects, suitable for social housing and entry level buyers.

All the concepts described in the paper are considered suitable to achieve an energy performance of up to the nearly zero energy level. To achieve this goal, some form of energy production will be necessary at the house or in the vicinity of the house. As this is not cost effective at the moment, and the building code does not require it, energy production from sustainable sources is not implemented in any of the projects, but could be added using solar cells. This technology is used as a measuring stick for determining the costs of energy production as compared to the cost of further energetic improvement of the house. From this, it is clear that the energetic quality of houses will be further improved compared to the present practice. While the insulation values will further increase, the optimum will not result in extreme insulation, as the energy requirement for room heating quickly becomes minor to the energy requirement of other energy functions such as water heating, pumping, ventilators, lighting and other equipment. Building quality will be crucial, avoiding air leaks and thermal bridges. The thermal energy requirement will become more strongly dependent on user behaviour, the cooling demand and the dynamics of the building. While the last two factors are determined by the design and can be calculated, consumer behaviour can vary widely between families, even families of comparable composition and occupation. Project evaluations show that the differences in thermal energy consumption between families can range over 1 to 3 over a longer period. These large differences in energy behaviour are as yet not fully understood, and were not taken into account in the design of domestic buildings in the Netherlands. When the heat pump system is not laid out for this, the backup heating element will become active and the energy costs can reach unacceptable levels. Remote read out the energy consumption on a frequent basis can help to correct this.

Considering the target groups of social housing tenants an entry level buyers, the total user costs for the low energy concepts is an important issue. An analysis of concepts performed by the author (2011) shows that in larger projects, the costs of individual heat pumps compete favourably with gas heated homes with the same energy performance at the present market prices for energy. Compared to gas heating, the application of a heat pump will reduce the relative importance of thermal insulation of the shell, but increase the importance of a consistent and high building quality. The internal heat production from inhabitants and equipment, the low infiltration value and the heat recovery from ventilation air or demand controlled ventilation avoids the need for a high thermal building mass, and high quality prefab components can be used. The energy requirement for hot water production can be reduced by using a solar collector or using shower heat recovery. The former will give a higher energy consumption reduction, but the latter gives a more robust system.

Table 1 shows the present Dutch energy requirement and the requirement for 2015 for a middle house in a row with 124 m2 of useful floor area. Such is a house is allowed to have a calculated annual primary energy consumption of 34 GJ. This will be reduced to 24.6 GJ in 2015. Houses meeting the present requirement will have about 8 GJ for room heating, 8 GJ for hot water production en 18 GJ for other building related functions such as auxiliary energy, ventilators, pumps, lighting and summer comfort. This is about 18 kWh/m2 for room heating including ventilation heat recovery with insulation levels of about Rc 4 for outer walls and Rc 5 for the roof.

This insulation level is about optimal for this type of house. Increasing the insulation level will not reduce the energy consumption for room heating per rato, as ventilation and infiltration losses will remain at the same level. Increasing the insulation will also increase the energy requirement for summer comfort (space cooling), reduce the available inner space and increase costs as special constructions will be necessary. Doubling the wall and roof insulation will only result in 1 GJ energy conservation on a total of 34 GJ. Using individual ground source heat pumps will reduce the energy consumption for room heating, hot water production and summer comfort, adding up to 6 GJ. This is primary energy using the conversion factor of the national grid. Combining a heat pump sustainable electricity production, further increases the performance .

A ground source can replace thermal mass in the building as a buffering mechanism for temperature swings and will perform better, as the heat transfer from the stoney mass and concrete is limited by the diffusion equation. Water from a properly dimensioned ground source gives a better heat transfer. Short term regeneration of the source can be done during the heating season, using a solar collector (see concept 1). This will also improve efficiency.

In apartment buildings, a collective source will save space and costs. The capacity of the distribution system can be used as a short term buffer (day night rhythm), avoiding the pumping energy for the well. Walls between apartments should be insulated, as temperature settings will differ between apartments. Practice shows differences of 1:4 in energy consumption, due to transmission through uninsulated participation walls.

Table 1: Energy balance and design heating capacity of a typical house in the middle of a row, satisfying the present requirements (EPC = 0.6) and with increased insulation

	Annual [GJ]	**Annual [GJ]**	**February [GJ]**	**February [GJ]**
	Normal insulation Rc 4 to 5	Double insulation Rc 7 to 8	Normal insulation Rc 4 to 5	Double insulation Rc 7 to 8
Conduction and radiation losses	16	13	1.97	1.38
infitration thermal loss	2	2	0.27	0.27
ventilation thermal loss	7	7	0.41	0.41
useful internal thermal gains	17	15	1.49	1.04
heating energy	8	7	1.16	1.02
cooling energy	3	3	0.01	0.02

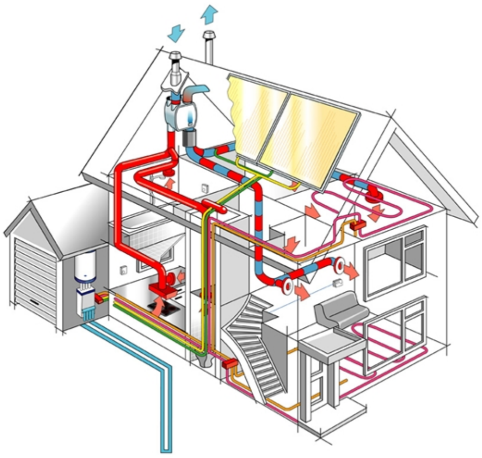
2 Low energy housing concepts with heat pumps

As the main goal was to find examples and results of low energy housing concepts have good potential for the main housing market, including social housing and beginning house owners, we focused on terraced houses and apartments that use heat pumps and are being monitored and offered at competitive market prices. This resulted in four building concepts, three using a ground source systems and one using an air to water system. The data on the air source system is still limited, however, as the projects are relatively new, and problems still exist, interfering with the monitoring of the results. For this reason it could not be included in this paper.

2.1 Low energy concept #1: Seasonal storage and solar collector integrated heat pump with individual ground sources

Project: Carré, Delfgauw, terraced houses. This concept realizes an energy performance coefficient of 0.6 with insulation levels (Rc) of 3.5 to 4 [m2.K/W], an Uc-value for windows of

1.2 [W/m2.K], balanced ventilation and ventilation heat recovery of 90%. The solar collectors add to the production of hot water and regenerate the ground source.



Operating principle

The good energy performance is achieved by a combination of measures:

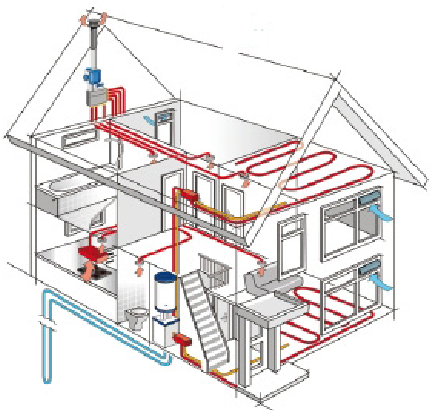
- Heat recovery from the ventilation air
- The heat pump with (closed) ground source
- Low temperature heating
- The solar collector
- The improved insulation level

The good integration of system and the building, and between system components and the possibility to add other options to cope with differences between houses due to location, orientation and size.

2.2 Low energy concept #2: Seasonal storage integrated heat pump concept with individual ground sources and demand controlled ventilation

Project: De Caaien, Ypenburg, terraced houses
This concept is calculated to have an excellent energy performance of 0.38, with insulation values of 3,5 to 5 [m2.K/W] and an Uc for windows of 1,5 [W/m2.K]. The measured infiltration is 0.2 [dm3/m2.s]. This is much better than the standard value used in the EPC calculation method. As a result, the thermal energy consumption is lower than the calculated value.

Operating principle



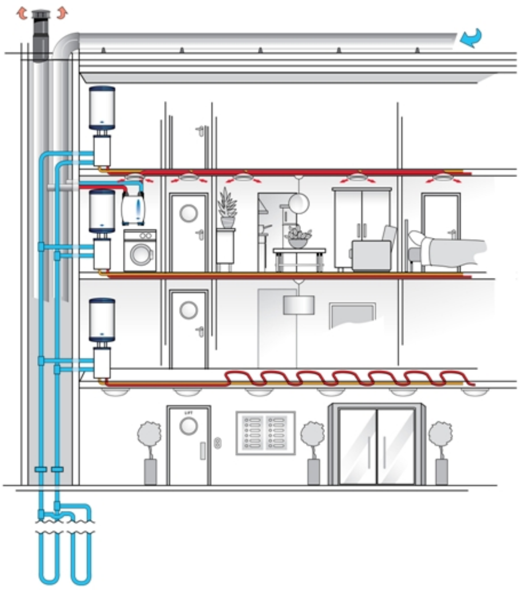
The good energy performance is achieved by a combination of measures:

- Demand controlled ventilation
- Excellent infiltration value
- The heat pump with (closed) ground source
- Low temperature heating
- The improved insulation level

- The good integration of system and the building, and between system components and the possibility to add other options to cope with differences between houses due to location, orientation and size.

2.3 Low energy concept #3: Seasonal storage with collective ground source system for low energy apartments

Project: De Tas, Biddinghuizen, apartments. An energy performance coefficient of 0.5 is realized with insulation levels of 3 [m2.K/W] for walls, floor and roof and Uc 1.2 [W/m2.K] for the windows. In the calculation of the energy performance coefficient, a 'normal 'value for the infiltration is used of 0,625 [dm3/m2.s]. The concept can be extended to include active use of thermal solar energy and photovoltaics.

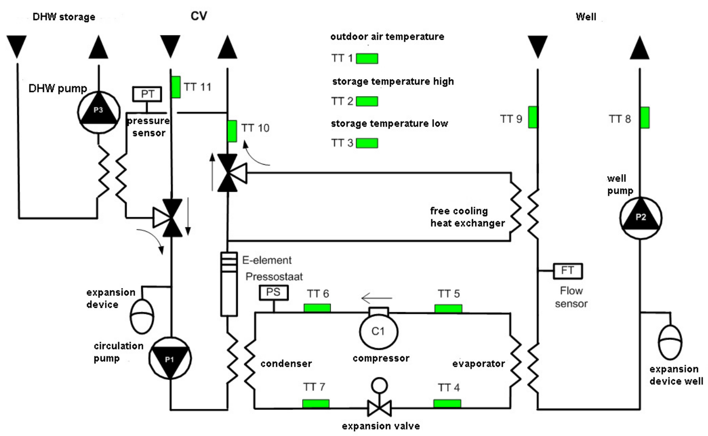


Operating principle

The good energy performance is achieved by a combination of measures:

- Heat recovery from ventilation air
- The heat pumps with collective ground source
- Active use of the thermal capacity of the distribution system as a buffer between apartments with different orientations and the day-night rhythm
- Low thermal losses in the distribution system because of the low temperature (7 to 17 degrees)
- Low temperature heating
- High efficiency glazing
- The good integration of system and the building, and between system components and the possibility to add other options to cope with differences between houses due to location, orientation and size.

3 Monitoring set up



Many self contained heat pumps will already have temperature and pressure measuring points, an energy consumption meter and some form of data logging. This data will typically be used for maintenance and servicing of the heat pump itself. But the performance of the system is also strongly dependent on changes in the source temperature, the properties of the building or apartment and user behaviour. These influences are monitored by temperature measurements of the subtraction and injection temperature of the ground source, the supply and return temperatures of the heating system and the operation of hot water heat exchanger, the temperatures of the hot water tank, the operation of the heating element, the room temperature and the outdoor temperature. This arrangement has proved to be valuable to explain deviances from the normal, calculated energy consumption, and can also be used as a remote early warning system to avoid high energy bills and service needs. The energy output of the system can be calculated from the temperatures, the pressures and the known flow resistance of the room heating circuit, the water heating element and the closed ground source. This can be unreliable when parts of the circuit can be switched off. The alternative would include expensive flow meters, but these can also be unreliable at the low flow rates. It will also include errors due to the measurement of temperature differences, adding up inaccuracies. A solar collector will add to the performance of the system and should also be monitored. As a solar collector will reduce the use of the ground source, and can add to the regeneration of the source, a part of the contribution of the collector will be in a better performance of the heat pump.

Monitoring results

The monitoring of the performance of the systems in their respective buildings show a large variation in the energy consumption, due to differences in user behaviour, orientation of the house of apartment, location within the building and user behaviour. These differences are larger than was expected. This can lead to higher than necessary energy costs for those with a large deviation from the 'normal' consumption. The mean level of hot water consumption also appears to be higher than expected, possible due to some behavioural effect.

When correcting for the extremes, the systems perform well, showing a seasonal performance on primary energy of between 180% and 250%, using a conversion factor of 0.42 for the efficiency of the national electricity producing system. This excludes the circulation pump of the heating system, that will be used anyway (i.e. also for a gas heating system). The well pump is included.

At this energetic performance, it is safe to say that the total costs of the heat pump solutions will be competitive with other low energy solutions, considering the energy costs, the financing costs and the maintenance and replacement costs.

4 Integrative design aspects

The monitoring of the systems also leads to insights that can be used for improved design and dimensioning of the systems and improved integration of the building and the systems used. This is much more of an issue for heat pump systems than it was (or is) for the much used gas heating systems. Gas boilers are less dependent on the building and the user behaviour, as these can have a large over capacity at little extra costs.

In the concepts, the integration of the building and the heating systems includes:

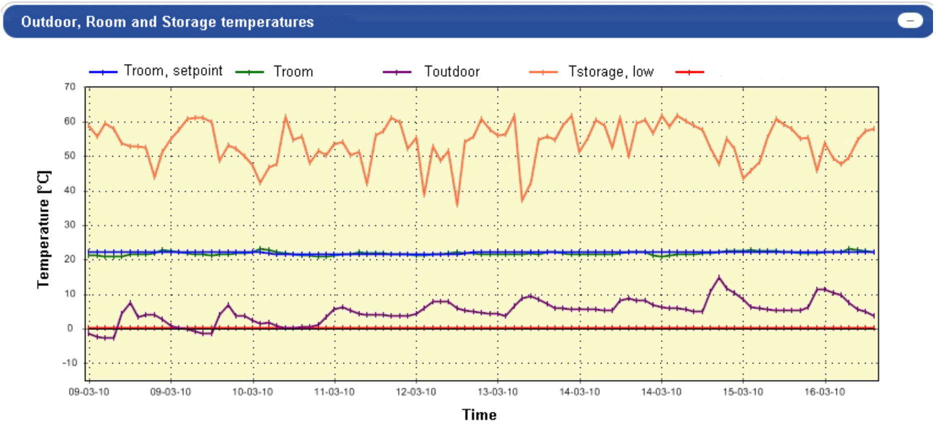
- Using the thermal building mass as a buffer
- Regenerating the source and free cooling
- Integrating the heat pump in the building
- Lay out the building for low temperature heating, high comfort
- Negotiating the costs of the heat pump against costs of other measures needed to achieve the energy performance

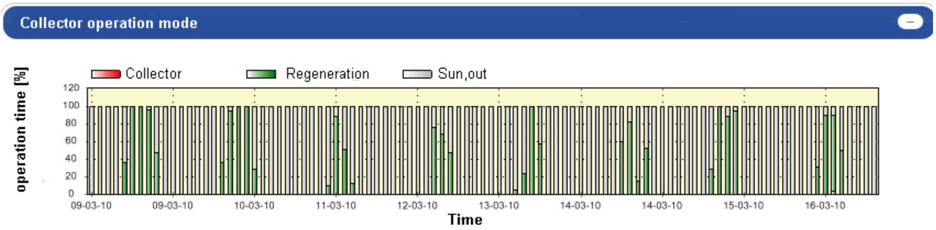
Using the thermal building mass as a buffer

In balanced ventilation systems with heat recovery, the building mass will buffer the temperature of the ventilation air. This reduces the variations in the heating load. In demand controlled mechanical ventilation systems with pressure entry vents, this effect can be obtained by sucking the air in using also the vents from other rooms.

Regenerating the source and free cooling

For best results, vertical ground sources need to be regenerated. In summer, this can be done by cooling the house through heat exchange with the source. This makes it possible to design the house more freely, as a cooling load is acceptable. This can result in more attractive and comfortable homes. A solar collector can add to the regeneration of the source, resulting in a hybrid system. This system will also make the heat capacity of the underground available for short term thermal buffering.





Integrating the heat pump in the building

The optimal place for the heat pump can be different from a gas boiler, as no smoke channel is necessary. Instead, the access to the source and the vicinity of the hot water tank are important, as is the accessibility for servicing and replacement and avoiding sound problems. Traditional house layout and design will not take this into account, and changes to accommodate the heat pump can be costly. Houses should be designed with the heat pump in mind. This involves a change in the traditionally sequential design process. Architects will work side by side with experts from installation firms. In the emerging concepts, this is done under the supervision and responsibility of the project developer and also includes the assurance of the build quality. It will involve a lot of training and instruction to transmit this approach to the market as a whole.

Lay out of the building for low temperature heating

Low temperature heating is sensitive to unbalance and sudden changes in the heating load. These can occur when the users are not satisfied with the indoor climate and temperature distribution. It should be taken into account that a part of the users prefer to sleep with an open window. This can cause thermal flows in the building, as the thermal insulation and the air tight shell is broken by the opened window. The effect can be reduced by insulating the inner wall and floor, avoiding communal walls with living rooms and switching off the mechanical ventilation when the windows are opened. This behaviour can be influenced by differentiating the temperatures of rooms. In apartment buildings, the participating walls between apartments should be insulated.

Negotiating the costs of the heat pump against costs of other measures

The costs of the heat pump must be compared to the costs of alternative concepts. In the case of the heat pump, it is possible to attain an energy performance that makes the concept suitable for energy neutral buildings, at current market conditions.

5 Conclusion

This study has shown that there is a strong interrelation between the design of the building and that of the heat pump system. An integrated design approach will result in cost reductions and better performance, making heat pumps an attractive choice at the present market prices for energy. The reduced capacity of the heating system places an emphasis on an excellent building quality, avoiding air leaks and thermal bridges. Differences in behaviour between users can also strongly influence the energy consumption and energy costs. The differences should be taken into account in the dimensioning of the system, and measures should be taken to increase the robustness, such as insulation of participating walls and heat recovery from ventilation air and shower water.

Integrating the design of the heat pump system with other system components can also result in better performance and cost optimisation. A solar collector can be used to increase the ground source temperature in sunny periods during the winter, even when the temperature is too low to feed into the hot water boiler. This will improve the over all efficiency. In the summer, a heat pump in combination with solar cells can produce hot water very efficiently and environmentally friendly.

Full monitoring of the systems has several advantages for improving the design, avoiding problems, maintenance and user contacts. The results show a need for an update of the existing design methods and assumptions, as the variation in consumption patterns is much bigger than was expected.

In the EU, installation firms will be certified for doing heat pump projects. This is only one step of many steps needed to implement the integrated design method as a standard for building low energy houses, as also the architects, the project developers, and the building owners will have to adapt. Building owners and local communities interested in low energy houses should require an integrated approach and ask guarantees on the energy performance and the quality of the indoor climate.

6 References

DGMR Bouw, 2009, *Aanscherpingsstudie EPC woningbouw 2011*, www.senternovem.nl

ECN, 2010, *Waardering van passiefhuizen volgens EPN en PHPP*, ECN-M 10-075

IF Technology, 2007, *Koude/warmteopslag in de praktijk: Meetgegevens van 67 projecten*, Opdrachtgever SenterNovem, www.senternovem.nl2/56280/MaK

Kolokotroni, M, 2007, *The London Heat Island and building design*, Brunel University(West London), presentation

Koster, S.J., 2011, *De rol van ESCO's bij het realiseren van warmtepompsystemen in woningbouwprojecten,* study commissioned bij AgenstschapNL

Kleefkens, O. and S.J. Koster, 2010, *Emerging Heat pump concepts for low energy houses in the Netherlands*, country report for annex 32 of the IEA Heat Pump Program

Lente-akkoord, 2010, *Lente-akkoord KopStaart aanpak juni 2010*, www.lente-akkoord.nl

Millward Brown, 2010, *Benchmarking individuele monovalente warmtepompen, study on the energy consumption of dwellings with individual heat pumps in project de Teuge, Zutphen*, project 56104243, Alliander(Arnhem)

Papatheodorou N. G., G.I. Fragogiannis and Prof. S. K. Stamataki, 2008, *Transient simulation of a hybrid ground source system*. 3rd IC-SCCE, Athens, 9-12 July

Yavuzturk, C and Jeffrey D. Spitler, 1999, A Short Time Step Response Factor Model for Vertical Ground Loop Heat Exchangers, ASHRAE Transactions. 105(2): 475-485