Case study on
Heat pumps in Arnhem, the Netherlands

Annex A.3 to Part 1 of the Study on the competitiveness of the renewable energy sector

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Abstract

The European Commission aims to analyse the **competitiveness of the European heating and cooling industry**. Four case studies of successful and competitive deployment of heating and cooling solutions at a city level from selected organizations support this analysis. The case studies aim to illustrate how competitive renewable energy technologies such as solar-thermal, biomass, biogas and heat pump are in the context of different local factors across Europe, and what are their impacts on local communities.

The current case study is based on the desk search, field visit and interviews. It presents a **renovation project involving 96 small houses in the Presikhaaf district of Arnhem** (the Netherlands). As part of the renovation, the houses were fully insulated to lower energy consumptions; in addition, solar photovoltaic (PV) panels were installed on the rooftops (35 panels per house, 300Wp per panel) to generate electricity and heat pumps (air-to-water, 8kW) were deployed for space heating and domestic hot water.

1 Introduction

This case study focuses on a renovation project involving **96 small houses** (12 blocks, 8 houses per block) originally built in the fifties, in the **Presikhaaf district of Arnhem**, one of the largest city in the Eastern part of the **Netherlands** (Figure 1). The houses currently host about **400 people** (on average 4.2 households per building). They are owned by a social housing company and have been recently (2015) refurbished and transformed in **zero-energy buildings**; in other words, the total amount of energy used by each house on a yearly basis is equivalent to the amount of renewable energy generated on-site.

Figure 1 Social housing in the Presikhaaf district of Arnhem, the Netherlands

Source: Nathan Group

As part of the renovation, the houses were **fully insulated** to lower energy consumptions. In addition, **solar photovoltaic** (PV) panels were installed on the rooftops (35 panels per house, 300Wp[1] per panel) to generate electricity and **heat pumps** (air-to-water, 8kW) [2] were deployed for space heating and domestic hot water. More specifically, each house was equipped with so-called '**energy modules**', i.e. small cabins (about 2m^2) placed near the front door[3] and including all the devices required to meet the energy needs of the building (space heating, ventilation, hot water and electricity)[4].

[1] Maximum capacity.

[2] This heat pump delivers on average 12.8 MWh of heat energy output per year. The heating capacity of the heat pump is variable, going from 1.5kW to 8kW of power, depending on the gap between the desired temperature for space heating and the external temperature.

[3] Energy modules are usually placed near the front or rear door of the house on a metal basis connected to the building foundations. They can also be installed in the roof, in case no room is available outside the house; however, this type of modules is less common. Energy modules are ready-to-use solutions that can be easily connected to the house by plugging in only a few pipes/wires.

[4] The energy module does not generate electricity; however, it includes the inverter to covert direct current from solar PV into utility frequency alternate current that can be self-consumed or fed into the electricity

Energy modules installed in Arnhem Presikhaaf are assembled by **Nathan Industries** a company belonging to the **Nathan Group**[5], a Dutch holding specialised in renewable heating and cooling solutions. Nathan Industries provided energy modules also for other, similar projects in the Netherlands (e.g., 191 houses in Stadskanaal and 111 houses in Heerhugoward). This confirms **that the solution adopted in Arnhem can be replicated** in other Dutch regions and, certainly, in EU countries with comparable weather conditions.

Table 1 Key technical characteristics

Location	Arnhem, the Netherlands
Number of houses	96
Number of households	400
Installation/Commissioning	2015
Expected lifetime	20 years
Investment costs	€10,000 to 12,000€ (energy module)
Investment support	Sustainable energy investment subsidy scheme (ISDE)
Operation support	Energy performance fee
Type of heat pump	Air-to-water, 8kW (max)
Coefficient of performance	>3
Yearly energy output (per heat pump)	12.8 MWh
Space heating	Wall radiators, hydronic distribution system, 40°C
Domestic hot water (per house)	185-litre storage system, 53°C to 58°C

Source: Authors' own elaboration.

2 Technology

Two renewable energy technologies have been adopted to transform the 96 small houses in zero-energy buildings:

i) **solar PV for electricity generation**; and

ii) **medium-sized air-to-water heat pumps for space heating** (with hydronic distribution) **and domestic hot water** (with a 185-litre storage system).

Air-to-water heat pumps convert energy from cold air to hot water. In a nutshell, a low-pressure vessel (the so-called 'evaporator') contains a refrigerant material in liquid form.[6] The boiling point of the refrigerant is very low (usually below 0°C) at low

grid. In addition, the energy modules installed in Arnhem do not generate air conditioning for three main reasons: i) the hydronic distribution system with traditional wall radiators cannot be used for cooling purposes; ii) air conditioning is not needed if one considers the average weather conditions of the city; and iii) the electricity required by air conditioning would not allow to meet the zero-energy target.

[5] The Nathan Group focuses on four main businesses: i) Nathan Systems, which represent providers of equipment in three mains segments (pipes and fittings, small components for underfloor heating and heat pumps) and offer integrated solutions to installers; ii) Nathan Projects, which install large heating and cooling systems (including ground-to-water and water-to-water heat pumps requiring deep hole drilling); iii) Nathan Industries, which assembles energy modules (i.e. the solution deployed in Arnhem); and iv) Nathan Service, which provide maintenance services.

[6] Heat pumps installed in Arnhem relies on the so-called R134a refrigerant.

pressure, therefore it evaporates even when in contact with low-temperature air. In Arnhem, installed heat pumps rely on the so-called R134a refrigerant, which evaporates at a temperature of -12°C or higher.[7] The resulting refrigerant gas is then compressed by an electric compressor. The growing pressure increases the boiling point of the refrigerant (e.g. up to 70-80°C), which therefore condensates in a high-pressure vessel (the so-called 'condenser') and releases energy. Such energy is used to warm the water for both space heating and domestic use. In Arnhem, water for space heating is kept at 40°C; water for domestic use is kept between 53°C and 58°C, thanks to a sensor installed in the storage system.[8] The refrigerant in liquid form is finally transferred back in the low-pressure vessel via a thermal expansion valve. The circle then restarts in a closed loop.

Figure 2 Energy modules

Source: Nathan Group

In Arnhem, the 'outside unit' of a typical heat pump (evaporator, compressor and expansion valve) and the 'inside unit' (condenser) are both included in the energy module (Figure 2); the two units are connected by pipes (the so-called 'split' system). The heat pump requires **electricity to fuel the compressor**. On average, the Coefficient of Performance (COP) of air-to-water, medium-sized heat pump is between 4 and 5, i.e. 1 kW of electrical energy input used to run a compressor, produces 4 to 5 kW of heat energy output; however, this depends on several factors, including the external temperature and the installed heating system. Theoretically, with high external temperature (e.g. 20°C) and underfloor heating requiring low-temperature water (35°C), the COP of an air-to-water heat pump may reach up to 9.5; by contrast, with low external temperature (-5°C) and wall radiators requiring high-temperature

[7] When the external temperature goes below -12°C, an emergency heat system (entirely electric) can be activated.

[8] On a weekly basis the domestic hot water is heated for a few hours above 60°C to avoid the proliferation of legionella bacteria.

water (65°C) the COP could go down to 2. This is because of the higher temperature gap, the higher the pressure to be reached by the compressor for condensing the refrigerant gas, which therefore requires more electricity. In Arnhem, the **COP is at slightly above 3** when the external temperature is about -5°C because the existing heating system still relies on wall radiators.

Air-to-water heat pumps are an efficient solution only when buildings are properly insulated. In this respect, during the refurbishing operation, large emphasis was placed on insulation: external walls are now featuring a triple-wall insulation (i.e. bricks, air, bricks, air, wood, plastic, polyester and bricks); roofs were refitted with 50cm insulation; the airtightness was finally checked via a blower door test[9]. Air-to-water heat pumps best perform with floor heating solutions, as they are able to keep the temperature flow constant, at any time of the day. Nonetheless, in the case of Arnhem, the existing **wall radiators** were not replaced. Interestingly, thanks to the excellent insulation, the temperature required to properly heat each house went from 70-80°C (before renovation) to 40°C (after renovation); the latter can be ensured by heat pumps.

3 Value chain

The **energy modules**, which include *inter alia* the heat pump, are assembled in the Netherlands. Most of the components are manufactured in the EU. However, **compressors** (which are the heart of a heat pump) are mainly produced in Far East countries by a limited number of companies, which have a quite strong market power. Therefore, the price of the compressor ends up affecting the price of the entire module.

Energy modules are then installed by expert, **independent installers**. The modules require only electricity to function. Nevertheless, **periodical checks** are required to maintain the components of the module and replace some consumables (e.g. air filters).

Installers also provide **after-sale services**. In fact, all energy systems of the house rely on **smart metres** connected to the web. These allow monitoring energy and water consumptions of each house and identify any loss in terms of energy efficiency. Such information is used by installers to intervene in case of detected problems as well as to plan maintenance activities. Similarly, if needed, they are used by the social housing company owning the houses to **suggest behavioural changes** in order to ensure the achievement of the **zero-energy target**, which is a requirement to benefit from public support schemes for social housing (see Chapter 4). In this respect, the web-based system is accessible by the tenant, the owner and the installer/responsible for maintenance.

[9] For further details, please see: https://en.wikipedia.org/wiki/Blower_door

Table 2 Value Chain

Inbound logistics	Operations	Outbound logistics	Sales	Service
Delivering energy modules' components to the assembler	Assembling the energy modules	Delivering energy modules to the renovation site	Installation of energy modules by expert, independent installers	Monitoring energy and water consumption via smart metres, maintenance of energy modules, advisory services to ensure the achievement of the zero-energy target

Source: Authors' own elaboration.

4 Local factors

After analysing alternative renewable options, **combining solar PV and air-to-water heat pumps** was considered the most efficient solution to achieve the zero-energy target. For instance, as things now stand, the electricity generated by covering the entire rooftop with solar PV panels is on average equivalent to all the electricity demanded by the house on an annual basis.[10] In this respect, installing **solar thermal panels** would have not only reduced the space available for generating electricity via solar PV but also increased the electricity demand, as (due to the **local weather conditions**) during winter time an electric boiler would have been necessary to complement solar heating.[11] In the same vein, **air-to-air heat pumps** would have not allowed achieving the zero-energy target, as they are efficient only in the so-called 'passive houses', which require a level of insulation (the so-called 'superinsulation') that cannot be achieved by renovating existing buildings. By contrast, air-to-water heat pumps included in the energy modules are quite compact, thus making the best use possible of the **very limited space available in social houses**, and allowed to **keep the existing heating distribution systems** (featuring wall radiators), thus **containing renovation costs**.

Each energy module costs between **10,000€ and 12,000€** and has an expected life of about **20 years**, which is similar to the lifetime of solar PV panels (between 15 to 20 years). **Maintenance costs** linked e.g. to air filtering systems tend to be quite low and are expected to further decline when a larger number of qualified installers will compete with each other on the market. The **payback period** for the entire zero-energy renovation (which costed about 75,000€ per house) is about **40 years**. With or without energy modules, the payback period of heat pumps (especially if one

[10] Due to the variability of the solar power generation, all the houses are connected to the grid and relies on net metering for balancing purposes. However, the overall electricity generated across one year matches the yearly electricity demand of the building.
[11] During the summer, part of the thermal energy generated would get lost, as the houses are note connected to any domestic hot water network to sell the hot water generated.

considers the need to improve the insulation of the building) is still high.[12] Therefore, in the absence of public support schemes, this technology may appeal only to wealthy, environmentally conscious buyers. In this context, the Dutch government supports investments in renewable heating and cooling by households and businesses via the so-called "**sustainable energy investment subsidy scheme**" (ISDE),[13] which offers grants that partially compensate initial investment costs for renewable solutions. In addition, the Dutch government fosters social housing companies (currently owning more than two million houses in the Netherlands)[14] to transform old houses in zero-energy buildings by allowing to increase the rent ceiling (which depends on the quality of the house) and charge tenants a small, additional monthly fee (the so-called '**energy performance fee'**) reflecting a share of the energy cost savings (lower or no energy bill) they benefit from.[15] Public support schemes in the field of heating generally aim to achieve the **full disconnection of all houses from the natural gas network in the Netherlands by 2050**.[16]

Interestingly, to transform social houses into zero-energy buildings it is required that no less than 70% of the tenants in a specific social housing district accept this transformation, which may increase their rent. In this respect, to get tenants' approval, the social housing companies in cooperation with renovation project developers are called to **communicate both the environmental benefits and direct benefits in terms of energy savings** (reduction in energy costs more than compensate a possible increase in the monthly rent) **and better living conditions**.

Each year about 300,000 natural gas heating systems are replaced in the Netherlands; however, most of the installers still prefer to rely on gas heating technologies, as they are more familiar with this type of equipment. Natural gas boilers can be installed in about half-a-day and are much cheaper than heat pumps when it comes to initial investment costs, without accounting for operational expenditures. By contrast, there is only a **limited number of installers capable of working with heat pumps** (reportedly, between 4,000 to 5,000 new installers would be required to meet market demand in the Netherlands) and the time required to install a heat pump is about 1.5 days (installation of the inside and outside units, adaptation of the heat distribution system), so installation costs are higher. Finally, natural gas is still too cheap in the Netherlands compared to electricity, thus impinging on the competitiveness of heat pumps.

5 Impacts

Social houses are rented to low-income families. This means that the Arnhem Presikhaaf project **ameliorated the living condition of about 400 low-income persons** by improving the ventilation system of each house, enabling insulation from cold and noises and ensuring that each house is properly heated during winter. In addition, the energy modules adopted in Arnhem allow for maintenance operations without any need for the households to be present, as they are placed outside the building and are always accessible by installers/technicians working for the social

[12] New air-to-water heat pumps have started competing with traditional gas-powered heating.
[13] For further details see: https://business.gov.nl/subsidy/sustainable-energy-investment-subsidy-isde/
[14] For further details see: https://www.government.nl/topics/housing/rented-housing
[15] For further details see: https://www.rijksoverheid.nl/onderwerpen/huurwoning/vraag-en-antwoord/regels-energieprestatievergoeding-epv-huurwoning
[16] For further details see: https://www.hollandtimes.nl/articles/national/the-netherlands-to-go-completely-gas-free-in-the-future/

housing company. Finally, the entire renovation lasted about 14 days per house, [17] thus minimising any discomfort for the tenants.

On average, a house similar to those renovated in Arnhem Presikhaaf consumed around 1,500m^3 of natural gas per year (1,800m^3 for corner houses) for heating purposes, which are equivalent to 2,800Kg of CO_2 (3,380Kg for corner houses). Considering that the 96 renovated houses are grouped in 12 blocks comprising 8 houses (of which 2 corner houses), the overall CO_2 emissions for heating purposes before renovation were equal to about 283,000Kg. As zero-energy houses generate no CO_2 emission, the combination of solar PV and air-to-water heat pumps allow **saving no less than 283,000 Kg of CO_2**. Savings are certainly larger than this figure if one considers that, besides stopping using natural gas, households also stopped using conventional grid electricity.

Impacts on employment are not substantial as both the installation of energy modules as well as maintenance operations require a number of workers that is not much different from those working on standard gas heated systems.

Table 3 Impacts

CO_2 savings (total)	283,000 Kg
Employment (net impact)	No impact
Social	Improved living conditions for 400 low-income households

Source: Authors' own elaboration.

6 Summary

In the Netherlands, the **long-term commitment to disconnect all houses from the natural gas network by 2050** is backed up by effective **public support schemes** to favour the transition toward renewable heating. Support schemes play a key role when it comes to the **deployment of heat pumps**, as at the current price of natural gas and electricity, the payback period for this renewable technology is still too long. Adding to that, the barriers in the deployment of this technology, such as shortage of skilled installers or the weak price competitiveness of heat pumps, would not be overcome in the absence of support schemes.

The Arnhem Presikhaaf case study demonstrates that support schemes in combination with well-planned renovation works, solar PV and heat pumps allow to transform old houses in **zero-energy buildings** at a reasonable cost. Besides leading to positive environmental impacts and substantial savings in CO_2 emission, renovation activities performed in Arnhem shows that the green energy transition can generate **direct benefits for households** in terms of both **energy cost savings** and **improved living conditions**.

[17] Including refurbishment of toilette and kitchen. The external part of the house was insulated in about one day.

CASE STUDY

Heat Pumps in Arnhem, the Netherlands (A3)

Source: Nathan Group (2019)

Heat pumps in Arnhem, the Netherlands

Overview and value chain analysis

Key information

- 96 zero-energy small houses being refurbished involving insulation, PV panels on rooftops (electricity) and medium-sized heat pumps to provide hot water and heat
- Air-to-water heat pumps (8kW – energy module) and solar PV
- Year of installation: 2015
- Price per energy module: EUR 10,000 - 12,000
- Total energy renovation price per house: EUR 75,000 (pay back period: 40 years)
- Yearly energy output (per heat pump): 12.8MWh

Value chain

Inbound logistics	Operations	Outbound logistics	Sales activities	Service provided
Delivering energy modules' components to the assembler	Assembling the energy modules	Delivering energy modules to the renovation site	Installation of energy modules by expert, independent installers	Monitoring energy and water consumption via smart metres, maintenance of energy modules, advisory services to ensure the achievement of the zero-energy target

Factors and impacts

Enablers

- Government target to disconnect all houses from national network by 2050
- National subsidy scheme providing grants to support households' and businesses' investments in RE
- National law allows social housing companies to increase the rent by an 'Energy Performance Fee' when houses are transformed into zero-energy buildings

Other factors

- Installers that replace natural gas boilers may prefer gas heating technologies that they know of already, and installers knowledgeable of heat pumps are in scarce supply
- The long pay-back period renders support schemes imperative for heat pumps to be competitive

Impacts

- CO_2 emissions saving of around 283,000 Kg per year
- Improved living conditions for 400 low-income households (ventilation and protection against outdoor noise)
- Contribution to the long-term commitment to disconnect all houses from the natural gas network by 2050 in the Netherlands