12th IEA Heat Pump Conference 2017

Heat pumps: the Dutch way

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Abstract

The Netherlands is a small but highly populated country next to the sea behind dunes and with some relatively big rivers. Therefor it has a special relationship with water. As in large cities almost three quarters of their energy consumption is in buildings this will be one of the main concerns. Careful building services design can minimize the need for heating and cooling throughout the year for example by applying nearby rivers and seasonal thermal energy source of heat pumps. One of the first project was the office building of the Governmental sea and river control agency RWS at Terneuzen. In Rotterdam there are some quite remarkable buildings which make use of heat pumps in combination with the surface water of river Maas: the Maas tower and De Rotterdam. Furthermore some interesting other examples are presented of apply the surface water of the North Sea in the Hague and Oostvoorne. It all shows the Dutch way of applying water as a source for heat pumps.

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Keyword: heat pumps; river water; sea water; aquifers

1. Introduction

The Netherlands is a small but highly populated country with some relatively big rivers. The concept of vertical living and working has been hailed as a solution to facilitate fast growth and urbanization of cities worldwide. The Netherlands's relationship with water is unlike that of any other country in the world. One third of the Dutch territory, roughly speaking, is actually below sea level, while another one third is very close to the official zero-measuring (NAP) level. However, water is not so much a threat, but an important asset. It can bridge economy and ecology when using the energy from the surface water from rivers and the sea. As in large cities almost three quarters of their energy consumption is in buildings this will be one of the main concerns. As city living takes centre stage, urban building of the future have to foster sustainable qualities, essentially functioning as a living organism and engaging with the users within. Cities throughout the world are growing rapidly, creating unprecedented pressure on material and energy resources. Cities with their financial and administrative centres are a key asset to the countries national economy and to the cities itself. The local authorities want to assure the city's continues dynamism given that its business require ideal conditions in which to operate [Beerda 2008]. The buildings need to help to optimize city-wide production, storage and consumption of everything from food and energy to water [Hargrave 2013]. As in large cities almost three quarters of their energy consumption is in buildings this will be one of the main concerns [Beerda 2008].
Careful building services design can minimize the need for heating and cooling throughout the year for example by applying nearby rivers and seasonal thermal energy storage. A good early example of this is the Governmental sea and river control agency) office building in Terneuzen. Also in Rotterdam there are some quite remarkable

buildings which make use of heat pumps in combination with the river Maas: the Maas tower and De Rotterdam. The energy generation system of the Maas tower in Rotterdam uses a monovalent heat pump system using surface water from the nearby river Maas in combination with aquifer thermal energy storage. In De Rotterdam, in partnership with Eneco, a sustainable energy supply concept was developed by generating heat and cold from existing sources through heat pumps making use for cooling of cold surface water from the river Maas. The special power generation of the Maas Tower as well as the collective power generation system of de Rotterdam ensures a substantial improvement in all areas compared to the energy requirements of the current Building Regulations. In the Hague there is a quite unique project which uses the sea as heat source to supply energy towards a whole new neighbourhood. In Oostvoorne there is a different use of the energy of the sea water. It all shows innovative Dutch ways to apply energy from surface water as a source for the heat pump.

2. Early application of water as a heat source: RWS Terneuzen

The RWS (= Rijkswaterstaat = Governmental sea and river control agency) office building in Terneuzen has been in use since 2000 and is still one of the most sustainable office buildings in The Netherlands. The office is situated on the complex of locks on the Ghent-Terneuzen Canal towards the sea. It was intended as a model office block for 'human- and environmentally-friendly' construction. The building's remarkable character and the design that incorporates the users' specific wishes and its surroundings combine to provide the users with an unusual building that sets them apart and the building is greatly enjoyed by its users. [Pötz et al., 2009]. A heat pump on canal water as heat source delivers heat supply for the low temperature wall and floor heating system.

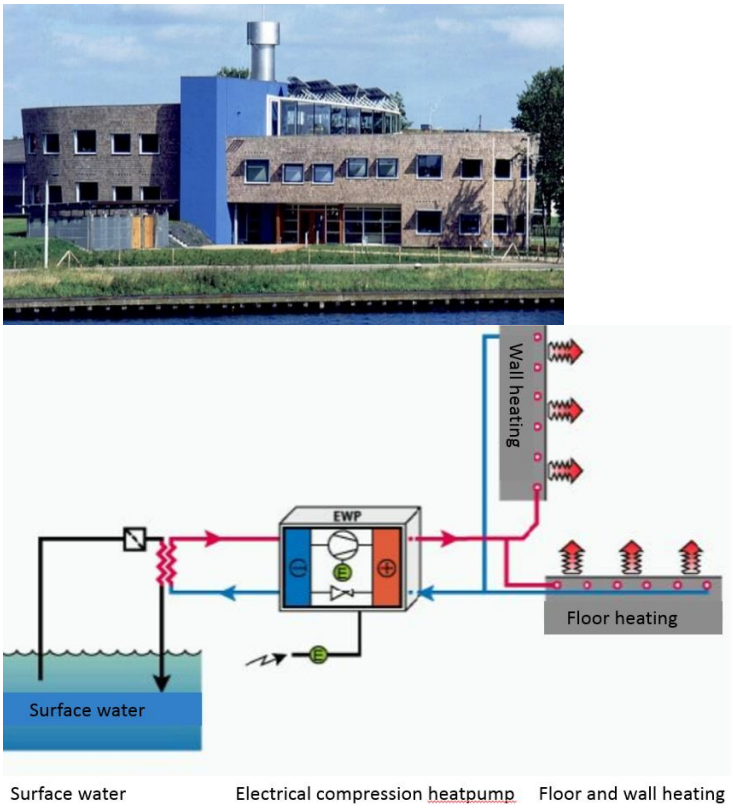


Figure 1. RWS Building Terneuzen and its energy principle

For the heat generation originally the heat pump release its heat through an open heat exchanger to the water of the canal. This open heat exchanger caused a lot of problems to corrosion problems due the brackish water in the canal. As a result the efficiency was low, now it has been replaced by a closed loop system which is filled with glycol and has a much better efficiency. The heat pump provides warm water for the heating system of 50 °C. Important for the efficiency is that the water of the canal is not too cold. If there is a hard winter the water in the canal can reach nearly the freezing point, which is not a good thing for the efficiency of the system. Caused by the economic crisis the industry connected to the canal had put less waste heat in the canal. Therefor it is necessary to heat up the water before supplied to het heat pump. Also the choice of heat exchanger and filter installation are important to reduce the effects of corrosion caused by the brackish water.

3. Tallest Dutch building: the Maas tower

The Maastower (165 meters) the highest building in the Netherlands and is a 44-storey office skyscraper complex designed by Odile Decq Benoit Cornette in cooperation with Dam & Partners. Construction started in October 2006 and on 9 December 2009 it was finished, see Fig. 1. Next to being the tallest building in the Netherlands, the Maas Tower also has some interesting notable sustainable features. The energy system of the Maas tower in Rotterdam uses a monovalent heat pump system which uses water from the nearby river Maas and aquifer thermal energy storage (ATES). The water of the river is led past a heat exchanger which is connected to the building's climate control system, In this way, the building can 'absorb' the warmth which is still present in the river in the autumn because due to industrial residual heat the average temperature of the river water is still above 20 °C. As the river water strongly cools down in winter a possibility was created to store the summer heat. The ATES exists of underground wells in the sand layers of the soil, for the thermal energy storage. The basic principle of an ATES system is the extraction and injection of ground water into two separate storage wells, located a sufficient distance apart from each other. During summertime water is extracted from the coldest well and used to cool the building. This heats the water from approx. 8 to 16 °C. The heated water is injected at the warm well and stored until the winter season. During winter the extraction/injection flow is inversed and the heated water (with a temperature of approx. 14 °C) is pumped back to the building. Using a heat pump the heat is extracted from the water and the cold water (6°C) will be injected in the cold well. This means that district heating is not required and CO2 emissions for the building are virtually halved when compared to a conventional design. At a depth of around 150 meters two wells were drilled for a doublet aquifer. One well contains the water which is warmed up during summer, while the other contains water which is cooled down to about 6 °C [OVG 2014a]. During winter time, when the river water is too cold to heat the office building, the system pumps up water from the warm well and after extracting the heat it is cooled down and stored in the cold well, see Fig. 2.

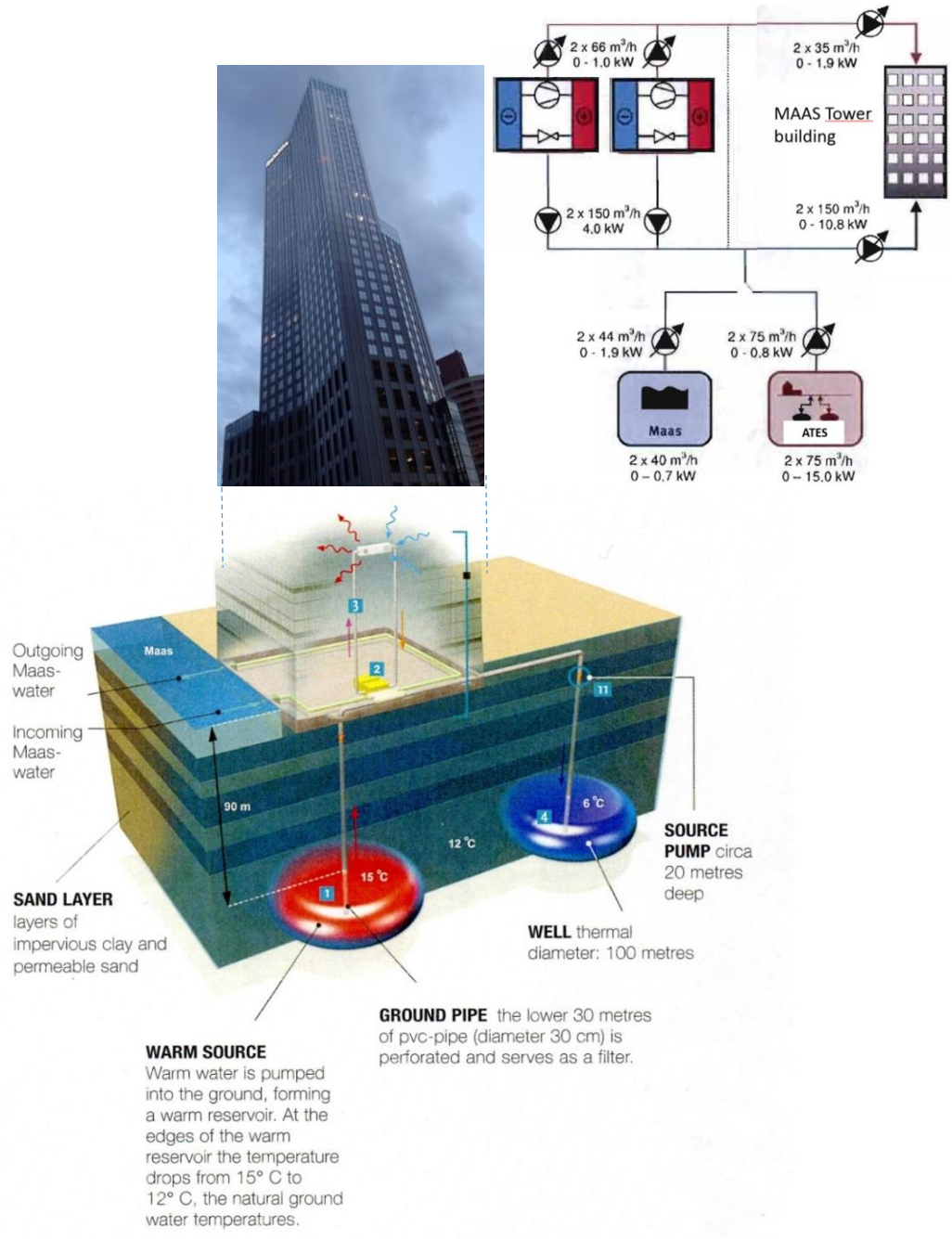


Figure 2. Maas Tower Rotterdam, tallest building in the Netherlands & Aquifer Thermal Energy Storage system in combination with energy exchange with the water from the river Maas [Molenaar 2011].

In the warm months, the exact opposite is done. During the first warm months of a year river water is being used, which is still cold enough at that time to cool the building. If the river temperature rises too much, water of the cold well is extracted. Energy storage in underground is not a new concept, but combining it with the use of river water made it a novelty. It is especially interesting to Rotterdam and some other cities in the Netherlands as there are many rivers and in the past often cities were initiated nearby rivers. In this way become energetic more economical, the system uses about 55% less primary energy and their CO2 emissions become half. The ATES-system of the Maas Tower was simulated and the results were validated by on site measurements [Molenaar 2011]. The results showed a seasonal performance factor (SPF) tor supplying heat by the heat pump of approximately 3.8. This is slightly higher than the expected value of the SPF of 3.6 based on literature. Measurements showed that the heat pumps uses approximately 78% of the total electricity use of the complete ATES-system, the (transport and source) pumps use the other 22% energy. The SPF of 47 for supplying cooling is high compared the values from literature with a SPF between 12 and 50 [11]. The Annual Performance Factor (APF) of the ATES-

system tor the year 2010 is 5.0. However considering the large amount of additional stored cooling the real APF is approximately 6.0. The usage of surface water (water of the river Maas) in combination with ground storage and heat pumps leads to advantages on for four aspects [Molenaar 2011]:
- Maas water can be used as regenerator. Maas water can approximately be used during 3.270 hours annually for the regeneration of heat and approximately 1.900 hours annually for the regeneration of cold.
- Maas water can be used to increase the temperature difference between the warm and cold well. By putting the Maas water system in sequence with the heat pump the well water can be extra cooled in the winter and in the summer the well water can be extra heated. In theory this alignment leads to a reduction of the water displacement leading to a reduction of the electrical use of 3.5%.
- Maas water can be used as a direct energy source in midseason. Maas water can approximately be used 5,440 hours annually as a heat source to the heat pump and it can approximately be used 3,000 hours annually for direct cooling supply. Using Maas water as a direct energy source hardly improves the energy efficiency; average of 1% energy reduction.
- Maas water can be used as back-up tor the wells of the aquifer. Maas water can also approximately be used 5,440 hours annually as back-up by failure of and/or maintenance on the ground wells (as heat or cold source tor the heat pump).

Adding surface water to the ATES system improves the efficiency (on average by 3.9%) because common problems of ATES (such as a low temperature difference between the warm and cold source, exceeding the design water displacement and an disturbed energy imbalance in the underground) can be reduced or even solved. The Maas Tower consequently has unprecedentedly low CO_2 emissions for a high-rise building. It is an iconic Dutch project for 'building with water' and an undoubtedly strong statement as it towers over the water [OVG 2014 a]. Techniplan Adviseurs, the consulting engineering company who did the HVAC design, won the Innovation award of the Dutch consulting engineers association for the system's design. The building also got the prestigious FGH Real Estate Award. It is a perfect example of optimum integration of heat pumps into an urban as well as water environment.

4. The biggest building of the Netherlands: De Rotterdam

Another interesting application of heat pumps using energy from the river Maas is the De Rotterdam. Design by architect Rem Koolhaas from OMA Architects, it became the largest building in the Netherlands, at 162,000 square meters of area and 149 meters' height [OVG 2014 b]. Its mass is broken down by three interconnected mixed-use towers, accommodating offices, apartments, a hotel, conference facilities, shops, restaurants, and cafes. In De Rotterdam sustainability is given its rightful attention while providing residents with comfort. In partnership with Eneco, a sustainable energy supply concept was developed to equip the 44 floors apartments with under-floor heating and cooling, by generating heat and cold from existing sources through heat pumps. The system allows high temperature cooling and low temperature heating because of the big active surface areas of exchanging energy within the rooms. The under-floor heating and cooling system makes use for cooling of cold water from the Maas. The interior temperature of every room is controlled by its own thermostat and high performance. Heat-reflective double-glazing and windows to let fresh air inside reduce the cooling demand. The energy concept of De Rotterdam, is a high complex mixture of different elements combined heat/power installation of the local City heating system, partly co-generation with bio-fuel, river Maas water cooling (Fig. 3), Aquifer thermal energy storage and heat pumps, see Fig. 4.

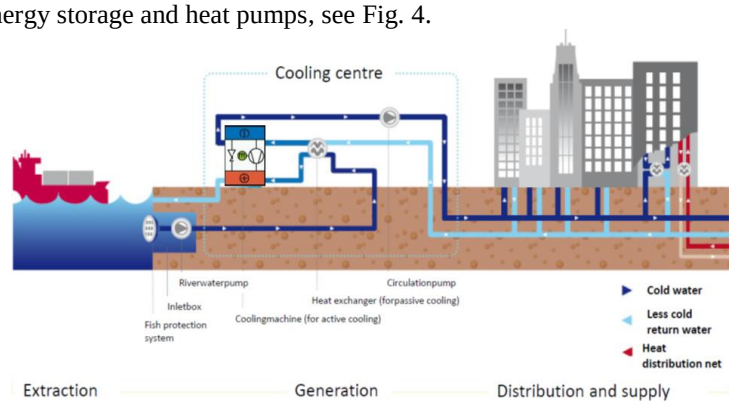


Figure 3. Energy concept of the heating and cooling supply of De Rotterdam

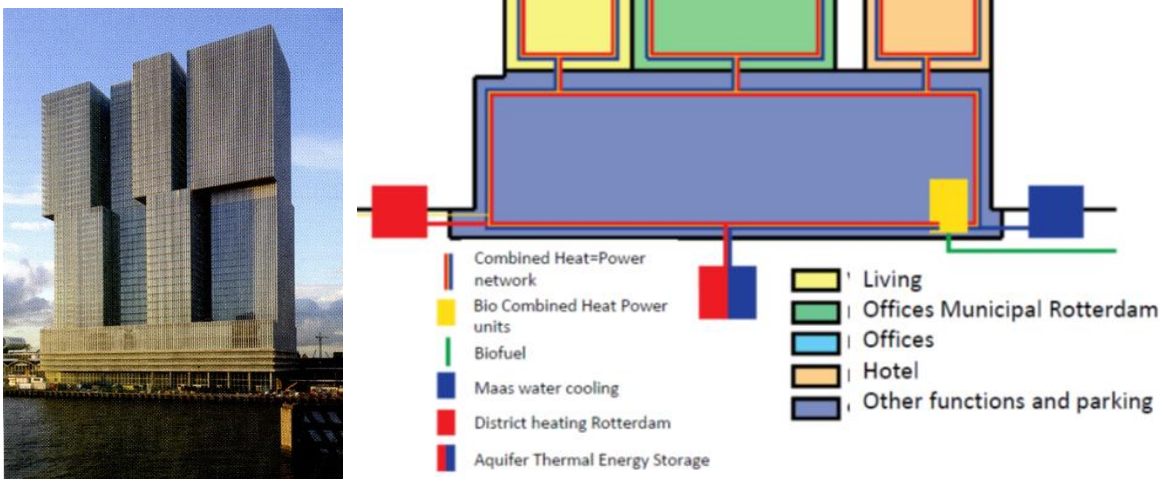


Figure 4. De Rotterdam and its total energy energy system

5. Sea water plant Duindorp – the Hague

In Duindorp, a small harbor town near the Hague in the Netherlands an innovative and sustainable district heating system was designed fed by the heat of the sea. The district heating system warms water at a central location and then distribute it through a system of underground pipes, see Fig, 4. None of the water in the pipes is used directly in homes, but the heat from the water is skimmed off and used by individual heat pumps in the houses to warm showers (maximum 60°C) and floors (maximum 45 °C).

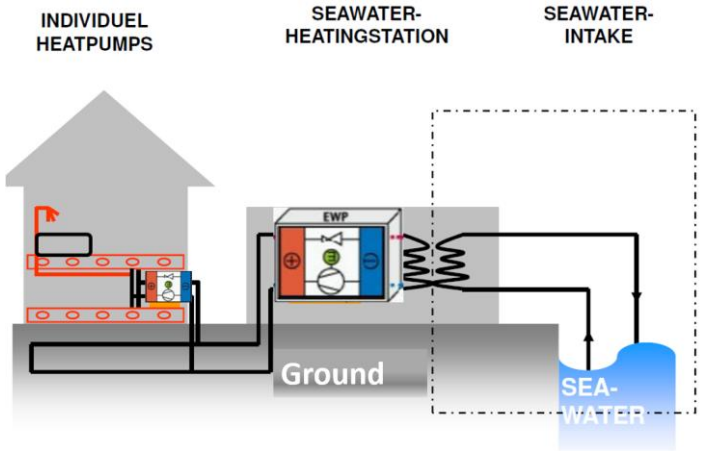


Figure 4. Energy concept district heating Duindorp with seawater as heat source

Sea water is being pumped up from the harbor. An extensive series of filters throughout the intake system ensures that no sea life is sucked into the district heating plant. The sea water is pumped thru the inox pipes towards the plant building where it is filtered further before it is going to be used as a heat source. The pumps have a capacity of 250 m3/hr each. The flow normally varies from 80 – 500 m3/hr. For most of the winter, the temperature in the harbor is right around 2 to 5°C and in summer it can climb to near 21°C. 0 °C has appeared only once: in the extreme winter of 1963.
At extreme low sea water temperature condition (0 °C or lower), the flow can be boosted to 750 m3/hr. There are 2 heat pumps of 1500 kW thermal power each. The seawater is used in a heat exchanger to heat freshwater for the pipes to around 12°C, resulting in 11 °C in the distribution net. The warmed freshwater is then sent out along a five mile network of insulated pipes that services the 789 homes in the new housing neighborhood. At every house connected to the system, a 5 kWh-capacity heat pump raises the temperature of the water to between 40–65 °C for heating and warm water. Annually this warm water accounts for almost 1/3 of the total heat demand. The houses are cooled as well: the floor heating system is used during summer to cool the houses. The heat that is retrieved from the houses is fed into the distribution network. On hot days in turn, the network is cooled by the sea.
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Summer condition – heat exchanger
When the temperature of the seawater is above 11 °C, the warmth of the sea water can directly be transferred by means of a heat exchanger to the water in the distribution network, see Fig. 5. In the heat exchanger sea water flows on one side and water from the distribution network on the other side. To prevent the system from fouling, the water in the distribution network is treated. Heat will flow thru the plate from the water with high temperature to the water with low temperature.
After passing the summer heat exchanger the sea water is led back returns to the sea. Because of the corrosivety of sea water, initially titanium was chosen as plate material. During the time from engineering to realization however, due to the price of this material, experimental newly developed sea water resistant aluminum alloy was used.

Winter condition
When the temperature of the seawater is lower than 11 °C, The warmth of the sea water can not longer being retrieved using the heat exchanger. Instead a heat pump is being used with its damper side connected to the sea water and the condenser to the distribution network water, see Fig. 5. It cools (retrieves heat) from the seawater, and brings the retrieved heat to the distribution network water.
Due to the small temperature difference between sea water (4 °C) and distribution network water (11 °C), only a small amount of compression is required. This results in a very high coefficient of performance: a COP of 11. This means that only 1 kWh of electricity is required to retrieve 11 kWh of heat from the sea water and boost it to a temperature of 11 °C. This reduces carbon emissions by 50 percent when compared to conventional heating using natural gas.
After being cooled down, the sea water leaves the heat pump is led back to the sea. At normal winter conditions, the intake temperature of the sea water is 4 °C, when leaving the system it is 0 °C. The minimum leaving temperature is –2 °C: the freezing temperature of the sea water. Some specification of the components can be found in table 1.

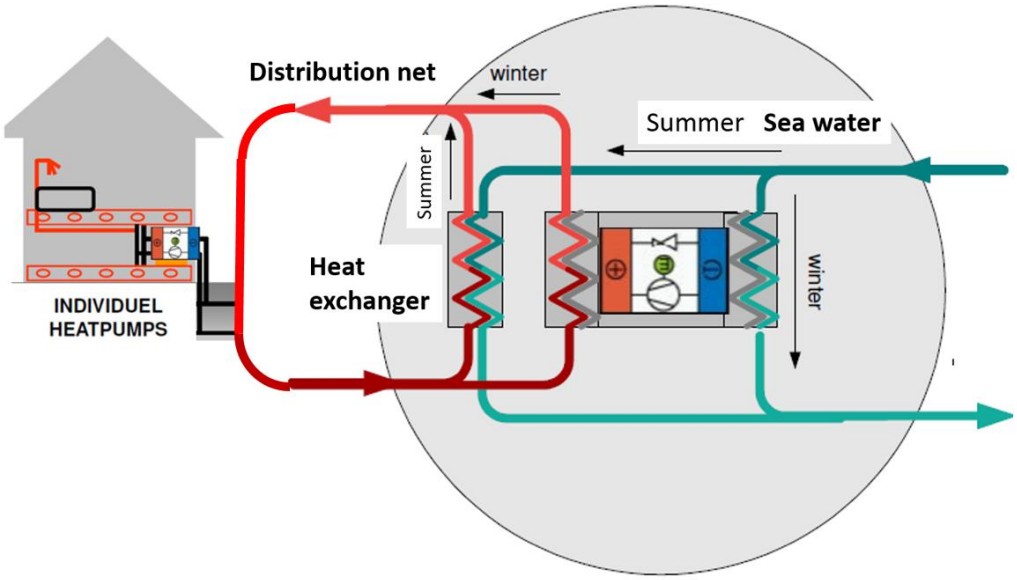


Figure 5. Different flow strategies heat exchanger and heat pump depending on summer or winter conditions

Table 1. Specifications of the heat pumps [Foster et al. 2016]

		Central heat pump		Individual heat pumps
		Winter	*Summer*	*Year-round*
Installed plant	Number of heat pumps	2 central heat pumps		1 per apartment
	Refrigerant	Ammonia		Not known
	Heat pumps used	York PAC 163HR		IVT (no longer in business)
Heating	Heat supply temperature	11°C	HP not used when sea above 11°C	Underfloor at 45°C DHW up to 60°C
	Source	Seawater	-	District heating network
	Source temperature,	3°C	Up to 20°C	11-20°C
	Max heat output	2.4 MW		6kW per apartment
Cooling	Cooling provided?	No		No
Performance	COP (heating)	11	Heat pump not used	3

While district heating systems and heat pumps with sea water as their heat source was not as such a new ideas, making the system run smoothly on the highly corrosive sea water with an affordable price tag was a massive undertaking. Dealing with huge volumes of very salty water in the mechanical systems every day and finding ways to battling the problem of corrosive seawater, bio fouling and cut down on cost replacing corroded components.

Seawater district heating will be most cost effective in areas where new development is taking place. Since district heating depends on an underground network of pipes, retrofitting a community to run on a district heating system would add considerably to the price tag. This design would work especially well and cost less if the community was near a large body of freshwater, when you don't have to worry less about water ruining equipment. Any town or city on the coasts, along the Great Lakes, or even near large rivers could benefit from a similar system.

6. Restaurant aan Zee Oostvoorn

The building "Aan Zee" was erected on a dyke about 9 meter above the water level and was completed in 2011. It is situated in a sand dune conservation area in Oostvoorne, the Netherlands, not far from the industry and harbor area "Maasvlakte". The special flair of the harbor facilities at a distance, combined with the protected flora and fauna in the direct vicinity, makes the building a unique symbol of sustainability. The design by Emma Architecten is strongly inspired by the surrounding landscape, from which the shapes and colors are taken and interpreted. The back portion of the building is anchored in the dunes with shipping containers, while the front half is a curving form with a wall of glass to take in the sights. A slatted wood rain screen tops the building to

help shield the sun and weather, further aging over time to blend with the landscape. It is a new type of restaurant as it is nearly autarkic. The restaurant has been designed to be as energy efficient and sustainable as possible through the use of efficient lighting and appliances, solar and wind energy, natural supply ventilation and even geothermal techniques for heating and cooling. Solar panels have been installed in the roof and visitors can climb to the top of its spiraling watchtower to enjoy the views. Electricity is generated by two windmills, each with 5 kWp, and photovoltaic elements on the roof, which produce about 13 kWp. To save energy, only LED lighting is used throughout the building, see Fig. 6.



Figure 6. Restaurant aan Zee Oostvoorne, roof with solar thermal and PV collectors and heat pump

The heat is generated by a geothermal heat pump with a maximum Coefficient of Performance (COP) of 4.4. Eleven probes at a depth of 95 meters provide a total of 2,090 meters of vertical storage, see Fig. 7. In combination with eight solar collectors (total 18,8 m², 13 kWp) and an 1,500 liters storage system the natural heating and cooling of the building is ensured, as is the hot water supply by means of solar and geothermal heat. The distribution of heat and cold in the building itself is achieved by an in-floor heating/cooling system. For this purpose, 3.100 meters of in-floor heating were installed throughout the building. Being close to the sea the ground water is heavily influenced by the current of the flood. Where normally you would prefer almost no water flow in the underground, here the effect is used to maximize the effect to improve the efficiency of the heat pump. Due to the stabile temperature of the ground in combination with the sea water flood influence there is always enough flow capacity around the borehole heat exchangers to maximize the heat exchange and optimize the efficiency of the heat pump.

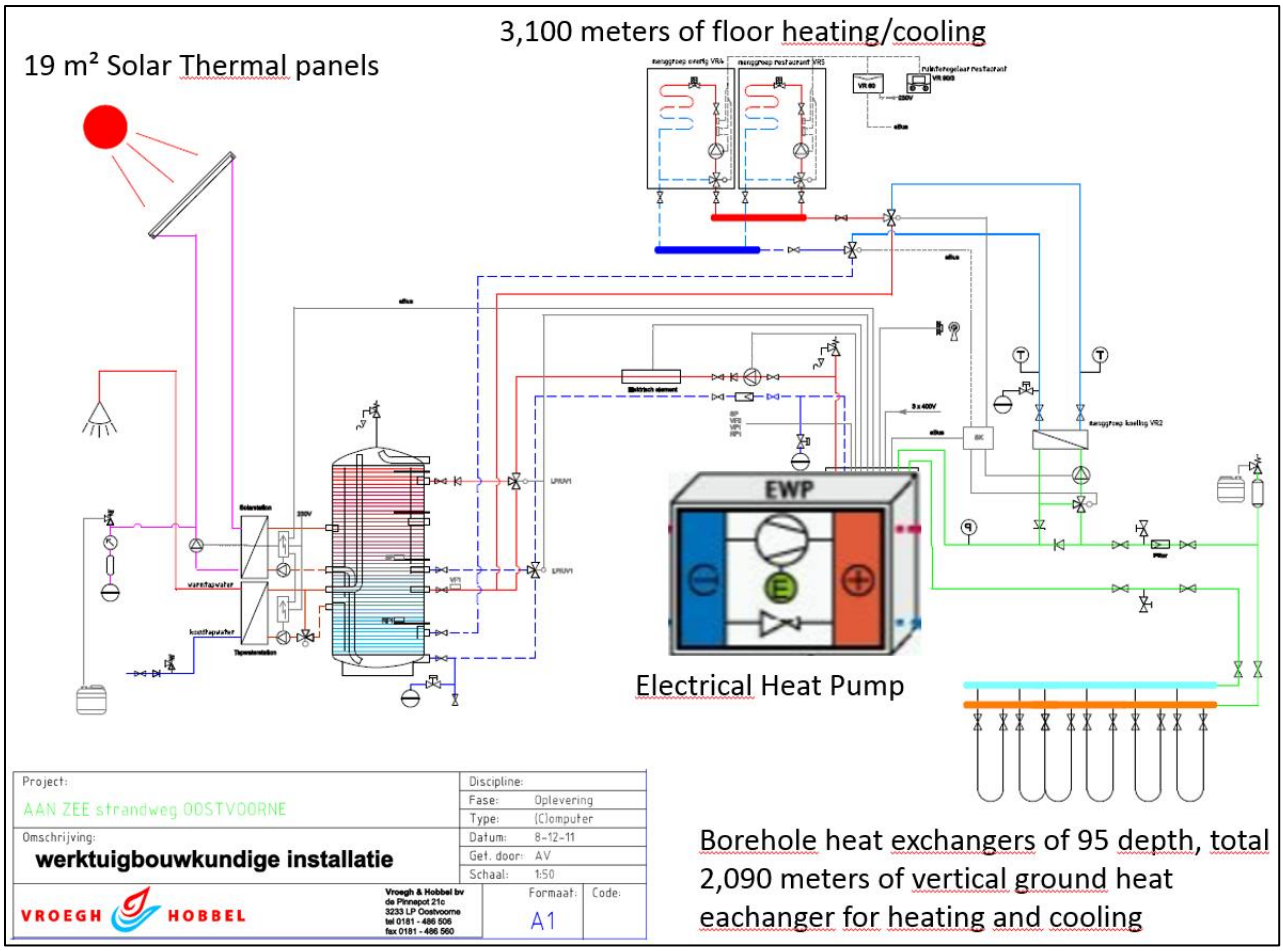


Figure 7. The energy concept of Restaurant at Sea

7. Discussion and Conclusion

People need buildings to protect them against the environmental conditions to be able to work and live. Building Services make it possible to provide comfort and an acceptable indoor Air Quality for building occupants. However, with 40% of the energy use within the developed world and 36% of the CO2 emissions the built environment is one of the most important areas for sustainable development [BPIE 2016]. Overall the energy use of offices is nearly 40% of the total energy use of the built environment, so quite substantial. In the Netherlands utility buildings have a relatively high energy consumption of around in total around 200 PJ/year, compared to around 350 PJ/year for households, see Fig. 1[CBS 2016]. More important, the energy consumption of utility buildings are increasing slightly, see Fig. 8, despite the 2020 targets set by the EU. This is due to higher comfort needs and the use of more conditioning systems with cooling.

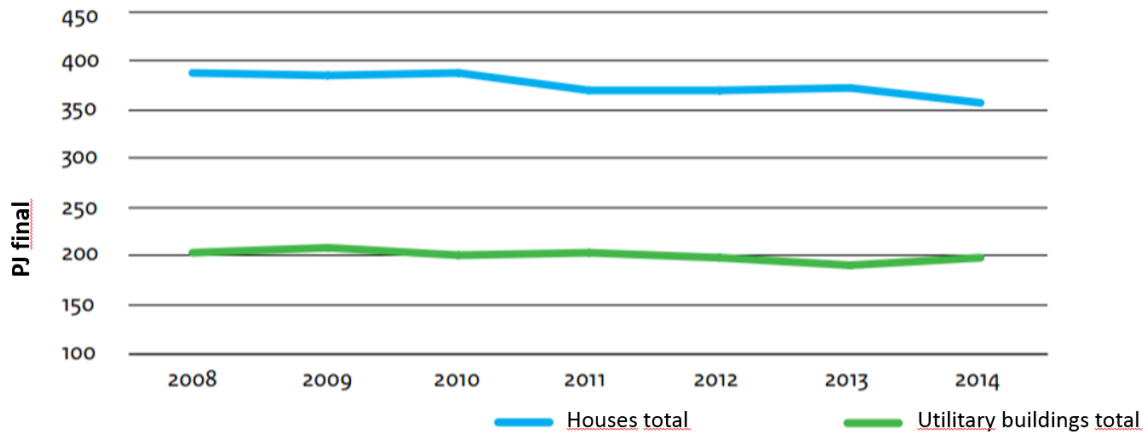


Fig. 8 The total energy use for utility buildings and for households [CBS 2016]

In the Netherlands sustainable performance is indicated by the Energy Performance Coefficient (EPC) which is described in the NEN 7120 norm. To reduce this high energy demand and pollution of greenhouse gasses the Energy Performance of Building Directive (EPBD) came in 2010 with plans for the European Union member states. One of these plans, as written in article 2 and 9 EPBD, is to reduce the energy demand and greenhouse gasses of new buildings. Building performance in the Netherlands is expressed in Energy Performance Coefficient (EPC): a policy tool according to Dutch standard NEN 7120 [DNI 2015] providing a calculation method for building energy performance. To determine the EPC the key characteristics of the building (dimensions, level of insulation of roof/walls/floor, type of materials and window including frame etc.) and installations (heating, cooling, hot water, ventilation, and lighting) are taken into account [Gvozdenovic 2014]. It gives an indication of the primary energy demand, one of the fixed input values in the EPC calculation is the building use. The future policy timeline for nZEB and their EPC-demand is shown in the table 2 [Gvozdenovic 2014].

Table 2: Future policy timeline

	EPC-demand				
	Future policy				
Year:	**2014**	**2015**	**2021**	**2030**	**2050**
Residential buildings	0.6	0.4	≈ 0 All new buildings nZEB Governmental buildings should be nZEB in 2019 5% of the existing buildings nZEB	30% of all buildings renovated (after 2015) have to be nZEB	80% decreased primary energy consumption compared to 1990
Offices	1.1	0.8			
Educational	1.3	0.7			

It is clearly shown that especially at schools there is a need for a hugh reduction of the energy use.
The RWS office Terneuzen has a EPC of 1,09, which was extremely good back in 2000, as is was design to be less than 45% of the legal requirements. However due to the discrepancy between the design assumptions and the real building as constructed and used, the actual annual primary energy consumption is 57% of the reference building, so around 30% more. However, despite the time elapsed since its design this building retains of of the most sustainable buildings in the Netherlands. The special power generation of the Maas Tower as well as the collective power generation system of de Rotterdam ensures a substantial improvement in all areas compared to the requirements of the current Building Regulations. As a result the EPC of the Maas Tower is 0.98.or 35% less than the current Building Regulations. The EPC of the mixed used sections of the Rotterdam are :
- Apartments 0.55 (31% less than Building Regulations)
- Hotel 0.93 (7% less than Building Regulations)
- Offices Mid Tower 0.82 (18% less than Building Regulations)
- Offices East Tower 0.77 (23% less than Building Regulations

Nearly all energy efficient buildings use heat pumps, so this is a requirement to reach for the energy reduction goals of the near future. By this cooling and heating can be achieved with a relatively low primary energy consumption, while improving the thermal comfort at the same time as most buildings now do not have cooling. Therefor heat pumps are a prerequisite for Dutch sustainability. So it is not strange that if we look at total the figures for all heat pumps, houses and commercial buildings in the Netherlands there is constant grow, see Fig.

9.

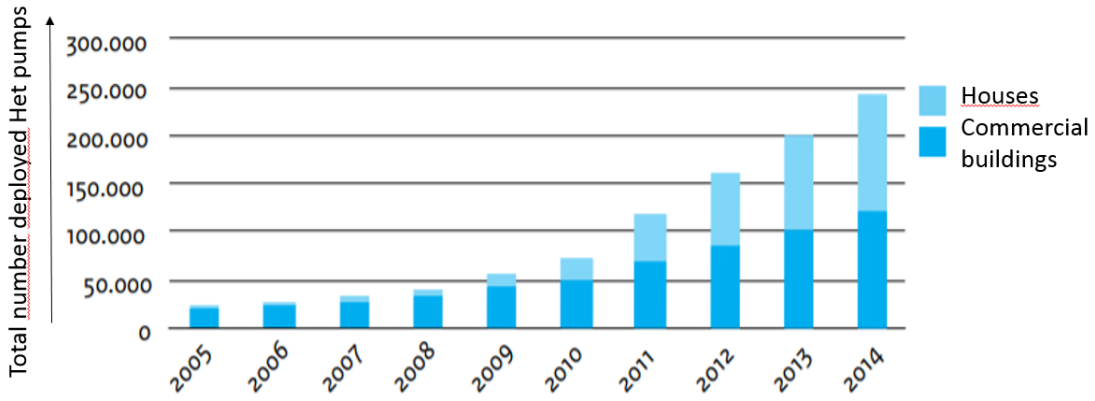


Figure 9. Sales of heat pumps houses and commercial buildings 2005-2014 [CBS 2015]

In this article we showed some interesting application of energy efficient buildings with heat pumps which used surface water either from rivers or the sea as energy source. These examples showed new possibilities for the Netherlands to use the available surface water and the sea as a useful energy source to further improve the energy efficiency of heat pumps in the Dutch built environment in a typically Dutch way.

Acknowledgements

Techniplan Consulting Engineers, Deerns consulting engineers, I. van Reek en Zn Bouw en Aannemingsbedrijf Oostvoorne and Vroegh & Hobbel BV, Oostvoorne all contributed to this article by providing information about their projects.

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