Heating Houses using Surface Water: A Sustainable Alternative to Natural Gas

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Abstract

There is a crucial need for the Netherlands to reduce their natural gas consumption, as it has a large impact on our environment, due to CO2-emmisons. The housing stock is one area that consumes large amounts of natural gas, and thus must work towards reducing this, wherever possible. The easiest option is to insulate houses to reduce the energy demand for space heating. Unfortunately, this is not an option for the houses in the historic city centre of Groningen. Therefore, other solutions must be found to address this problem.

This research proposes a solution to this problem by using surface water sourced from the canals surrounding the historic centre of Groningen, in order to heat the surrounding houses by means of a heat pump system.

This solution was worked through by using different formulas, which allowed for the required parameters to be calculated in order to see whether the aforementioned solution is feasible. The questions that needs to be answered for this research are: a) Is their sufficient energy available to be extracted from the canals to meet the energy demand of the houses, and b) What is the most efficient manner of transferring this energy?

The use of surface water in combination with a heat storage system appears to be the best option, both for the capacity of the water as well as the transferring of the energy to the houses. This system will ensure that there is always sufficient heat available from the canal water to heat houses year-round, with limited adjustments needed to be made to the house, which would make agreements with inhabitants from the houses more likely.

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Abbreviations

SWTES: Surface Water Thermal Energy System

TES: Thermal Energy Storage

COP: Coefficient of Performance

KNMI: Koninklijke Nederlandse Meteorologisch Instituut

1. Introduction

The aim of this paper is to study whether real estate in the centre of Groningen can become less dependent on gas, using the alternative surface water (e.g. the canals in Groningen), to generate heat. This method has been proposed for home heating in the centre of Amsterdam, and it is important to investigate whether this could be an adequate and realistic solution for homes in the city centre of Groningen.

There is a crucial need that the Netherlands reduces their natural gas consumption, as it has a large impact on our environment. During the combustion of natural gas, $CO2$ is released, a greenhouse gas. These gasses keep solar heat trapped in our atmosphere which causes the earth's surface to warm up. However, despite its effect on our environment, natural gas has been a staple of our national energy supply since the sixties (Green & Bommer, 2019) and is used in a variety of ways by our industry and consumers. One of the uses is as a source of energy for cooking and heating our homes.

Reducing our CO_2 levels is also in line with our membership of the European Union (EU). The EU aims to be a 'climate neutral' economy by 2050, meaning that it does not contribute greenhouse gases, such as CO_2, to our atmosphere. This objective is at the heart of the European Green Deal and is consistent with the EU's commitment to global climate action under the Paris Agreement of 2015 (EU, 2020). Therefore, the overall movement towards renewable and sustainable energy is of great importance not only to our nation but also to the EU (Obalanlege et al., 2020).

One of the ways to reduce the CO_2 is to improve the current systems used to heat houses. As aforementioned, these currently rely largely on natural gas. Various initiatives have been proposed to reduce this dependency. One is to reduce the demand for energy, the other one is to change the type of energy supply. Many houses can be retrofitted to reduce their energy demand for space heating. Unfortunately, this is often not possible for historic houses in city centres. Some of these houses are built of single stone walls, which are impossible to insulate. Moreover, the majority of the houses in the centre are repository buildings. Due to strict regulations concerning repository buildings, it might not be possible to insulate the buildings to a high standard. As reduction in energy demand cannot easily be achieved, the possibility of reducing the CO_2 levels at the supplier of the energy must be considered.

The question therefore becomes: what alternatives to natural gas exist? One promising solution concerns the usage of low temperature heat emitted from the many canals the Netherlands contains, by means of a heat pump (Ligthart, 2019). The present paper applies this potential solution to the canals around the historic centre of Groningen, in a report addressed to the Centre for Energy and Environmental Science (IVEM). The report conducts research into the use of the low temperature heat of surface water of the canals in the historic centre of Groningen to heat the surrounding houses in a sustainable way.

2. Problem Context

2.1. Stakeholder analysis

According to Wieringa (2014), *“A stakeholder of a problem is a person, group of persons, or institution affected by treating the problem”*. The current problem is one that needs to be solved for the city centre of Groningen. Therefore, most stakeholders are found within the centre of Groningen.

The direct stakeholder for this study is Dr Benders of the Centre for Energy and Environmental Sciences for the University of Groningen (IVEM). The IVEM’s aim is to utilise state-of-the art research in order to contribute to the transitions towards a sustainable and environmentally friendly world.

The positive outcome of this study may reduce the consumption of natural gas in the Netherlands and thus reduces its overall levels of CO_2 emission. Dr Benders is the first supervisor of this project and has a vested interest in the outcome of this research. He specializes in Energy & Fuel Consumption and Environmental Sciences at the University of Groningen. He is therefore the problem owner of this project.

Another stakeholder within the city of Groningen is the Municipality of Groningen. The climate agreement of Paris states that by 2030, 70% of our electricity should be sourced sustainably (UNFCCC, 2015). The Municipality of Groningen are eventually responsible for upholding the agreement by supporting transitions to sustainable sources of energy and therefore are keen to support interventions that promote this, mainly through development of suitable plans, as well as providing subsidies. This institute has an interest in the outcome of this project and is therefore a stakeholder.

The population inhabiting the centre of Groningen are also stakeholders in this project. The outcome of this project has an influence on these inhabitants, seeing as they are the ones that have to pay for switching from natural gas to more sustainable heating systems. These costs can mount considerably (CE Delft, 2019).

As well as Dr Bender, the Municipality of Groningen and its inhabitants, the Commission of Groningen is also a stakeholder involved in this project. The city of Groningen suffers from over 80 earthquakes per year (NAM, 2020) due to the fact that natural gas is sourced in Groningen and thus pumped from the ground there. This causes a substantial amount of damage to the houses that residents of the Commission own. This therefore creates substantial interest in sourcing alternatives for natural gas, and makes the Commission of Groningen a stakeholder.

Lievense Engineering is the company which originated the idea behind this project, which was the first research for the city centre of Amsterdam. This idea being using surface water from canals rather than using natural gas as an alternative, a more sustainable energy source (Stam, 2019). Lievense began to examine the feasibility of this project for houses in the centre of Amsterdam, but the outcome of either project could have an impact on the other. Since Lievense Engineering is the company is interested to implement the idea of using surface water of the canals in the city centre in Amsterdam to heat the canal houses, they have an interest in the outcome of the project, and are thus the final stakeholders in this project.

2.2. System description

The following section will discuss the system behind this project and the requirements obtained by the stakeholder's analysis are processed in a scope.

2.2.1. Surface water for heating houses

The surface water of the canals in Groningen could be used to heat the houses in the centre of Groningen (Stam, 2019). Recent studies have indicated that in the Netherlands, there is a large potential for heat extraction from surface water. According to CE Delft, the potential is 150 PJ per year, which constitutes over 40% of the total national heat demand. Heat extraction from surface water could be realized using existing technologies and systems that are already available. For this process, an electrical heat exchanger is required, combined with a heat pump, compressor and a well-functioning piping network. Solar panels could be used to produce the needed electricity (Zhang, Ge & Ye, 2007)

The conditions to extract heat from the surface water of the canals are:

1. The surface water must be over 0 degrees Celsius.
2. The water source should either come from a large volume (e.g. a large lake) or the water should be constantly refreshed (e.g. a river).

Due to of these requirements, the capacity of the canals and the energy demand of the houses in Groningen will be discussed further on in this report.

The surface water that does fulfil these requirements can be harnessed in this project. A heat pump pumps up the temperature of the surface water and guides the water along a heat exchanger. This process results in heat being extracted from the water. A compressor is used to guide this heated water to a higher level. A second heat exchanger warms the water in the house to a certain supply temperature (T_{supply}). However, a percentage of this energy is required for the electricity of the heat pumps and heat exchanger; this percentage is depended on the coefficient of performance (COP) of the heat pump (Klimaatexpert, date unknown) which will be elaborated upon later in this report. However, this electricity can be generated through sustainable energy sources, including solar energy (Obalanlege et al., 2020).

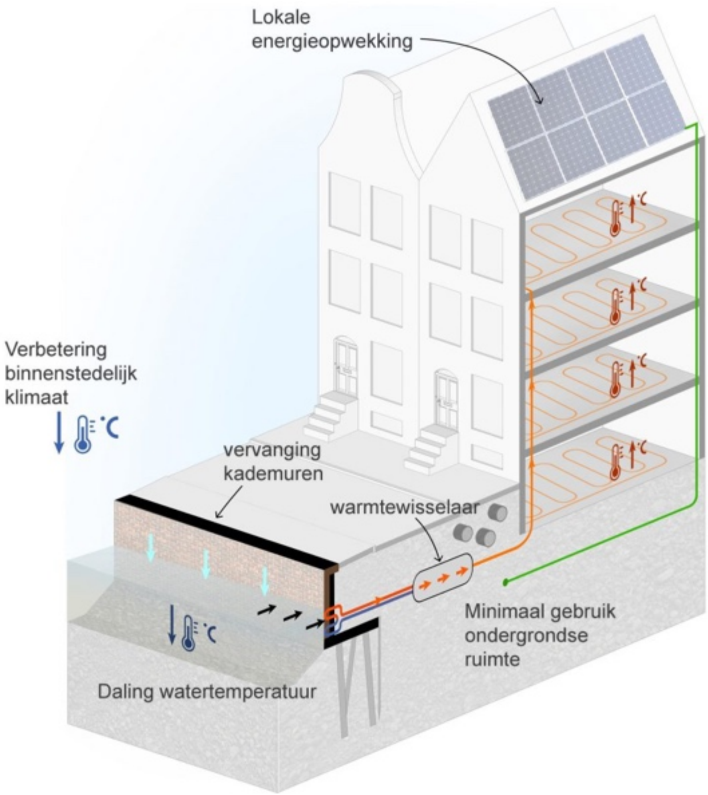

Figure 1: The visualization of the system, developed by the company Lievense.

2.2.2. Scope

The relevance of this concept could undoubtably be world-wide, but this is beyond the scope of this project. This project applies this solution solely to the centre of Groningen, and its nearby canals. However, *Lievense* already looked into the concept in Amsterdam; their advice of that project must be taken into consideration to find out if this solution might present a possibility for Groningen as well. This broadens the scope of the study, as the outcomes of the two projects are intertwined with one another.

2.3. Problem definition

The Netherlands needs to reduce their natural gas consumption, since the use of natural gas causes the emission CO_2 into our atmosphere. Thus, the housing stock must, wherever possible, reduce their present-day use of natural gas heating systems.

The most popular ways to reduce the CO_2 emission in the housing sector are:

- Very good insulation of the houses in combination with an air-source heat pump.
- Making use of a so-called district heating network. The source of such a network could be geothermal heat, waste heat of the industry.

Neither of these options' present viable solutions for historic city centres, as insulation is only possible to a certain extent, limited by no or small cavities between the walls and the historic character of the houses, for instance, an air-source heat pump cannot deliver sufficient capacity for these houses. Aquathermie also requires a solid base of insolation, as well as a so-called "heating network". All in all, this demonstrates aquathermy to be an equally improbable alternative. Alternative solutions are thus urgently needed to solve this problem.

The aim of this study is to suggest a solution to this problem by investigating to what extent it is possible to use the surface water sourced from the canals surrounding the historic centre of Groningen in order to heat the surrounding houses.

3. Design Orientation

3.1. Goal

The problem statement results in the following research aim:

To investigate the extent of the feasibility of utilising low heat temperature of surface water sourced from canals in the centre of Groningen in order to heat surrounding real estate, through the use of a heat pump system, as a viable alternative to natural gas.

3.2. Research questions

To reach the aforementioned aim several questions must be formulated and answered, consisting of a main research question and several sub-questions and design questions that cumulatively answer the main research question, and thus achieve the aim of this study.

3.2.1. Main research question

Based on this study's aim, and prior research by Lievense, the main research question is as follows:
To what extent is it possible to use the low heat temperature of the surface water of the canals, for the heating of the houses in the historic centre of Groningen, as an alternative for the use of natural gas?

To answer the main research question, it is necessary to first gather information regarding the present situation in Groningen and understand to which extent other heat pump possibilities could be applied in Groningen. As such, the following section outlines the subdivision of the main research question into different parameters, which are required to answer the main research question. The representative house, mentioned in the research questions, is a characteristic, poorly isolated, historic house in the city centre of Groningen.

3.2.2. Sub- research and design questions:

1. *What is the energy demand of a representative house in Groningen?*

2. *Is there enough heat available in one part of the canal, in front of one representative house, to meet the energy demand of that representative house?*

3. *What is the most efficient way of transferring the extracting energy from surface water: at a high or at a low supply temperature?*

4. *What is a suitable COP value for a heat pump?*

5. *What is the electrical demand of a heat pump?*

6. *How could the energy be best provided to the homes? Do the houses need modification in order to do so?*

4. Methodology

4.1. Cycle choice

To structure this study, Hevner's framework of three cycles of design science are applied to the problem. According to Hevner (2007), design science research is analysed as an embodiment of three closely related cycles of activities (Hevner, 2007). The design science research cycles are divided into: 1) the relevance cycle, 2) the rigor cycle and 3) the design cycle.

This occurred as follows in the present study: first, the *relevance cycle* was utilised to initiate the design science research within the context of an application. Afterwards, the *rigor cycle* was used. The major part of this cycle consists of the application of the rigor cycle to obtain information regarding the technical specifications of the heat pump, the technical specifications of the house and the capacity of the canals. Eventually, entering the *design cycle* was also deemed necessary, as many scenarios have to be designed in order to answer the research questions.

4.2. Methods and tools

In order to accomplish the aforementioned goal, different methods and tools must be utilised to acquire relevant data and information for this study. In this section, each method and its necessary tools are discussed based on their use and contribution to the present research.

4.2.1. Interviews

Interviews with employees from *Lievense* must first be conducted in order to gain more information about their heat pump system project in Amsterdam. Hence, their input information may be needed in order to determine the technical aspects of the system. This method can be relevant for every research question.

4.2.2. Literature review

To broaden the knowledge base, a thorough literature review must be conducted for this project, in order to answer the research questions. The tools used to gather state of the art studies were several bibliographic search tools such as *SmartCat, LibGuides, Web of Science* and *Google Scholar*. Books concerning sustainable manners to heat houses and concerning more technical aspects of the heat pump system were further utilised to broaden the scope of the literature review.

4.2.3. Scenarios

The application of scenarios is used to answer research question 2, 3, 4, 5 and 6. To answer research question 2, three scenarios have been researched to calculate the thermal power in order to see whether this meets the energy demand of the houses; 1) stagnant water, 2) slowly flowing water and 3) seasonal storage of heat in an aquifer. The outcome of the thermal capacity of the surface water in every scenario will be compared to the energy demand of the house. Research questions 4, 5 and 6 were needed to answer research question 3. Different situations have been researched, instead of scenarios. The situations alter the supply temperature that is provided to the homes, which is introduced in the system description. Three topics, 1) the COP-value of the heat pump, 2) the electrical demand of the heat pump, and 3) the adjustments to the homes, were divided into three different supply temperatures. After analysing the results of the situations, research question 3 could be answered: *How could the energy, extracted from the surface water, be transferred most efficient?*

4.2.4.Modelling

In order to be able to answer the first research question, the energy demand of a houses must be determined. For these calculations, a model house was selected in Groningen, located next to the canals in the historical city centre. The energy demand of this model house was used to calculate the right energy demand values on a monthly basis.

4.3. Deliverable and validation

At the end of the research a report will be delivered containing the potential solution to the main research question; *"To what extend is it possible to use the low heat temperature of the surface water of the canals, for the heating of the houses in the historical centre of Groningen, as an alternative to the use of natural gas?"*.

This report is structured along the aforementioned research questions. The six sub questions, which can be found on page 14 and 15, should be answered to be able to answer the abovementioned final main research question.
The deliverable can be validated by comparing one model to another to see if it works. Thus, by looking at other projects for instance. Since the existing knowledge base of other projects is an example for the project in Groningen, the model of Groningen could be compared to the model of the other project. Moreover, if comparing one model with another is not possible, then comparing one model with the result data in from literature research will be an option. A variety of studies have been done of a heat pump in combination with surface water. Thus, if this model and

those models mentioned in the literature have similar results, then your model is at least correct and you have validated your model.

At the end, the whole design of the surface water heat pump could be validated by testing the system in the real world. Ideally this would be possible, but due to the time constraints of the project, this will not be feasible.

5. Background & Theory

5.1. The effect of aquathermy

In aquathermy, thermal energy is obtained from water. This heat is primarily extracted when the water is warm, so naturally it follows that this occurs during the summer months, and partly pre- and post-season of the summer. There are two options available to use this heat obtained from surface water. The first option to extract heat from surface water is a direct connection from the warm surface water, via the heat pump system to homes, which is introduced in the system description section (2.2.1). The second option consists of a connection from the warm surface water, in the summer, to an aquifer in the subsurface. Since aquifers are also used as an open bottom energy system (Thermal Energy Storage (TES) system), a combination with such a system seems logical. The heat stored is subsequently utilized in the winter months that follow. The heat is pumped up from the TES system in the winter period and the heat is guided along the heat pump system to the homes. (Kruit, Schepers, Roosj & Boderie, 2018) This system will be elaborated in section 5.2.

5.2. Heat from surface water with the use of a TES system

Thermal energy can be extracteed from several different sources, such as watercourses, deep ponds and sea water. In this report, only watercourses will be taken into account, since the canals in Groningen are used for this project. In this section, the surface water in combination with a seasonal storage system (TES system) will be elaborated. Figure 3 represents a schematic view of the surface water thermal energy system (SWTES).

This system for extracting heat from surface water consists of the following aspects:

1. Surface water
2. Pump installation and heat exchanger
3. TES
4. Heat pump
5. Distribution network
6. Delivery system for users

These aspects can be obtained in Figure 3.

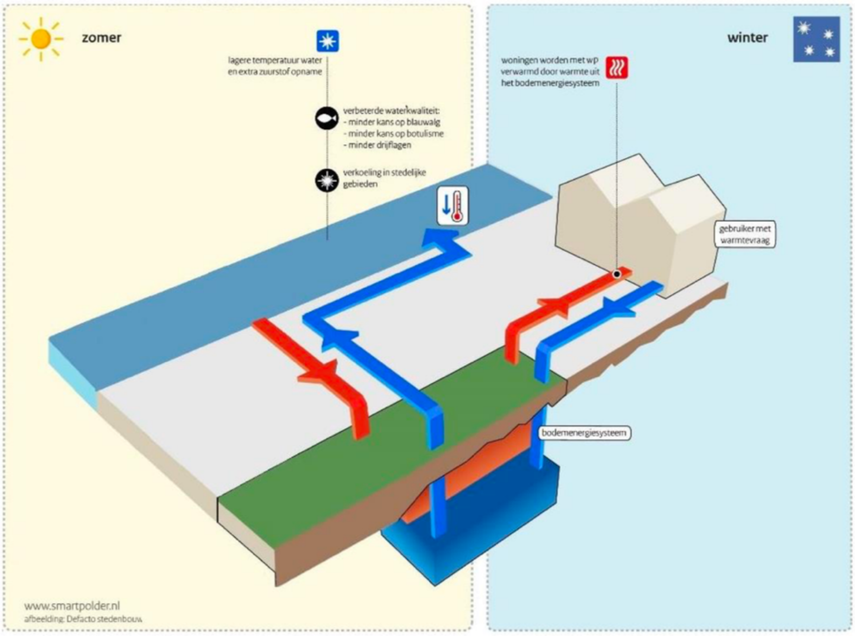

Figure 3: Schematic representation of SWTES (IF Technology, 2017)

In this system, the heat is extracted from the surface water in the summer by means of a pump and heat exchanger as detailed above. As a consequence, the surface water is cooled by a few degrees; 3 to 6 ºC. The heat is stored in an TES (aquifer). In winter, heat from the TES is upgraded to the required temperature. This heat is then distributed to customers through a heat network, which allows for the heating of homes. Three possibilities for heating networks are discussed in the next section (Kruit, Schepers, Roosj & Boderie, 2018).

SWTES is not merely limited to heating however-it is also suitable for the cooling of buildings. If necessary, surface water can thus also be used to supplement the cooling capacity of a thermal storage unit. However, the cooling demand of historic, poorly isolated houses is much lower than the heat demand, (Kruit, Schepers, Roosj & Boderie, 2018). For further clarification, see Figure 4, which offers a visual overview of the SWTES technical system.

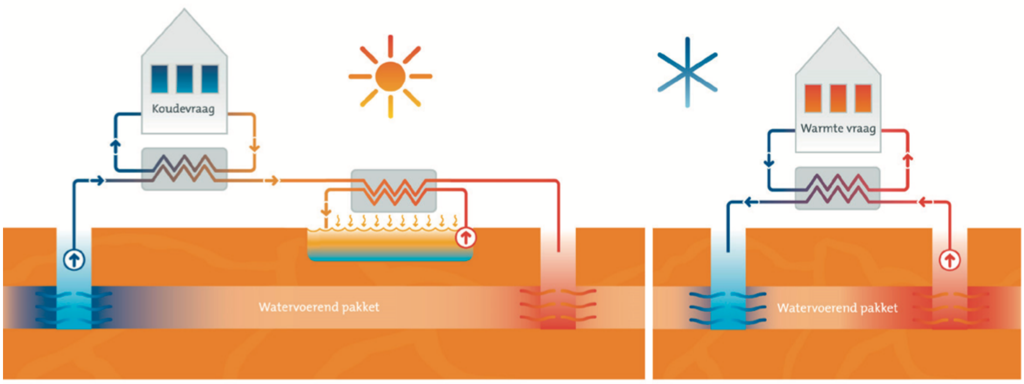

Figure 4: The technical system of the SWTES, in combination with a TES system. The summer and winter situation are shown. (Kleivegt & de Goo, 2018)

5.3. Different kinds of heat networks

The length and capacity of the network is certainly strongly dependent on the distance between source and customer(s) and the number of customers.

Heat and cold networks for thermal energy from surface water do not differ substantially from existing district heating networks, with the exception of temperatures: a heat pipe at SWTES has a temperature between 12-20 °C and a cold network of 5-12 °C (Kleivegt & de Goo, 2018).

However, the temperature of the surface water can be raised to 50 °C with a central heat pump. The temperature could be raised to a higher level, but this will be at the expense of the efficiency of the heat pump. District heating networks operate at temperatures of 70 °C and upwards. There are 3 possible variants for the network, described below:

1. **Low temperature decentralised network** (15 °C – 30 °C), with a heat pump per customer to upgrade the heat to the desired temperature. This is beneficial if customers have a low temperature requirement, for instance those living in more recently built constructions or those building fitted with underfloor heating mechanisms;
2. A central heat pump which increases the temperature to 40 or 50 °C. The heat network operates at this temperature. A heat pump may have been placed with customers who require further upgrading to 60 °C or higher (for hot water). This is also termed a '**hybrid network**', or a '**medium temperature network**';
3. A central heat pump increases the temperature to 70 °C, a **high temperature network**, rendering decentralized heat pumps no longer necessary. This variant results in a loss of efficiency of the heat pumps, but it requires fewer home modifications.

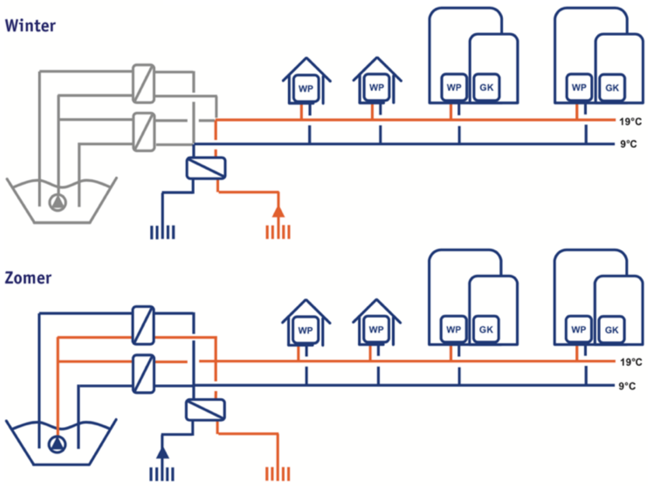

Figure 5: The above figures show the two extreme configurations for SWTES, the winter and the summer situation. Elaboration of SWTES with heat pump at customers, which is option 1: the low temperature network. WP stands for heat pump and GK stands for gas boiler. (Kleivegt & de Goo, 2018)

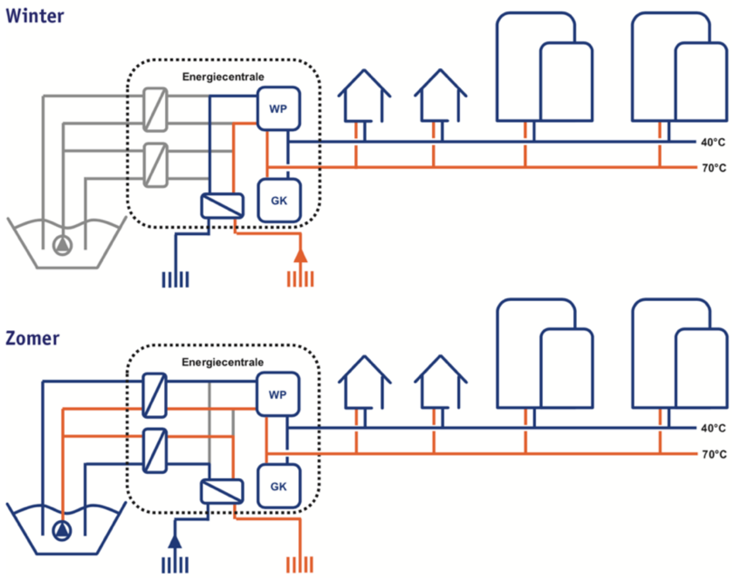

Figure 6: The above figures show the elaboration of SWTES with a central heat pump in the winter and summer, which is option 3: the high temperature network. WP stands for heat pump and GK stands for gas boiler. (Kleivegt & de Goo, 2018)

The consideration for the network variant depends, among other things, on several conditions:

a) Whether all customers require the *same temperature*, whether that be for heating or for cooling;
b) The *investment and operating costs* for central heat pumps as compared with decentralized heat pumps;

c) The *investment cost* required to connect buildings to the desired network for low temperatures. This is to say, the necessary modification required of the buildings.
d) The *scalability* of the concept: for instance, the possibility of connecting additional customers in a later phase;
e) The *losses* of a network at low temperatures vs. high temperatures.

6. Research Design & Result Analysation

6.1. Energy demand of the houses

The energy demand of the houses in Groningen is based on determining the natural gas consumption of the houses per year. To determine the natural gas consumption, a characteristic house of the area has been selected, located in the historic centre of Groningen. The other inclusion requirement for said model house was that it had to be located within one kilometre of the surface water (Kleivegt & de Goo, 2018). Since real estate in the city centre of Groningen does not exist of recently built modern houses, but predominantly old, poorly insulated houses which leads to heat losses, the average natural gas consumption is far higher for those houses in the city centre. The house which has been selected is the author's house, since this is located near the canals and is located in the city centre of Groningen. This historic house, which is inhabited by seven individuals, is old and poorly insulated, and thus a representative house for the area.

Firstly, the natural gas consumption data were requested from the energy supplier. The consumption in 2019 was 3,116 m^3 in total. One cubic meter of natural gas contains 31.6 Mega Joules of energy during combustion. This results in 98.6 GJ-energy per house for the entirety of the house.

Furthermore, for each high efficiency boiler there is a high heating value and a low heating value, when one looks only at the high heating value for the heat pump. A high efficiency boiler uses a condensation process, where gas is condensed resulting in a release of heat, which translates to extra efficiency for the high heating value comparable to the low heating value, which is, 105%. Hence, the amount of energy per house must be multiplied by 1.05. This results in an energy demand of 103.6 GJ for this household. The energy demand of the characteristic house calculated on a monthly basis; the results can be seen in Table 1.

The total amount of energy is used for space heating, cooking and hot tap water. This project focusses on space heating, and therefore only the space heating demand is considered in this report. On average, 71 % of the total energy demand is used for space heating (11Duurzaam, accessed: 07-06-20) This means 73.6 GJ of the 103.6 GJ is used for space heating per household in the city centre of Groningen. The energy demand of space heating per household was calculated on a monthly basis, and the results can be seen in Table 1.

Month in 2019	Average Outside Temperature (°C)	Total Energy Consumption (GJ)	Energy Consumption for Space Heating (GJ)
January	3.1	14.64	10.39
February	1.5	20.15	14.31
March	5.2	12.32	8.75
April	9.2	10.11	7.18
May	13.1	7.96	5.65
June	15.6	6.34	4.50
July	17.9	2.10	1.48
August	17.5	1.29	0.92
September	14.5	3.10	2.20
October	10.7	4.11	2.92
November	6.7	7.60	5.39
December	3.7	13.84	9.83

Table 1: Displays the relationship between the average outside temperature, the total energy consumption and the energy consumption just for space heating.

6.2. The capacity of Groningen's canal water

To calculate the capacity of the water in the canals of Groningen, the canal can be divided into separate parts. These parts, for instance, must be equal to the width of the houses next to the canals, in order to see if that part of the canal contains enough capacity to heat the house next to the canal. The total area of the model house is about 200 m^2 for the lower floor and upper floor. The dimensions of the building are 10 meters by 10 meters. The canal, which is located around the historic city centre of Groningen, is 24 meters width; half of the canal is used for the calculations, in order to use the other half for the houses at the other side of the canal. The calculations for the capacity are executed in section 6.2.3. First, the requirements for the potential of the water source are discussed.

6.2.1. The equilibrium principles of the water system

SWTES can be applied to all manner of water systems: rivers; canals; and ponds. There are several important considerations to keep in mind to consider each source's capacity, including: the flow; the distance between the intake and outlet points; the water volume; area, width and the permitted temperature change of the water system in relation to its ecology (Deltares, accessed 07-06-20). This study considers these factors as they relate to the canals of Groningen. In this section, the assumed principles of the equilibrium of the water are discussed.

The first principle is that the water at the intake point, where the water is pumped up by the heat pump, has a temperature corresponding to the reference situation. In other words: the water is in balance with the air temperature (Deltares, accessed 07-06-20).

The second principle is that, there is no recirculation or short circuit; this means that the temperature at the intake point has not increased or decreased as a result of a heat discharge or a cold discharge at the outlet (Deltares, accessed 07-06-20). The capacity of the water source is depended on the temperature difference between the inlet and outlet before and after discharge. A standard of a maximum of 3 ºC temperature rise of the water system before and after discharge is usually maintained, because such a variation also occurs naturally. Deviation is possible if, for instance, strong currents quickly mix the water to an acceptable temperature, or if the temperature difference is very local and fish can swim around the colder or warmer part, for example. This means the difference between the minimum and maximum temperature is 3°C (Kleivegt & de Goo, 2018).

This means that the temperature difference resulting from discharge between top and bottom layers at the intake point of water must equal zero. In case of a cold discharge, the water temperature at the bottom at the intake point must again be equal to the reference temperature (Deltares, 2018).

It follows that the amount of heat extraction from the surface water must not exceed the maximum cooling or heating that can occur as a result of exchange with the atmosphere. The exchange with the atmosphere is calculated according to equation 1 and the second term of equation 2, which quantifies the equalization of the temperature difference via the atmosphere (Deltares, 2018).

6.2.2. Heat extraction from surface water

By extracting heat, the source of water from which the extraction takes place becomes colder. Heat extraction is therefore equivalent to cooling water. Usable heat can be extracted in the summer when the surface water is warmer than, for example, 15 °C. The amount of heat that can be extracted under the circumstances is the heat extraction capacity (Deltares, accessed 07-07-20).
This heat extraction capacity depends on various factors, dependant on the season, as the flow of the water differs during these periods. In warmer seasons, the current of Groningen’s canals is markedly faster than in cooler seasons. This can be explained by looking at the lake which supplies Groningen: the IJsselmeer. During summer, water from the IJsselmeer is supplied to the ditches and canals to maintain the water levels for the surrounding farmers, needed for the agriculture. During the winter, the current grinds to a near halt, since no water is supplied from the IJsselmeer, as there is no water demand from agriculture. The velocity of the water flow in the summer would be about 0.15 m/s for the canals in the city centre of Groningen. In the winter, the flow velocity will be set to zero (Personal Communication Eric De Vries, 18-03-20).

The following section creates three hypothetical sketches, each suggesting a different water speed scenario. These scenarios will aid in determining the energy demand capabilities of canal water flowing at different speed. Furthermore, the scenarios serve to demonstrate the importance of water currents in extracting surface water for heating purposes.

6.2.3. Scenario Description

As aforementioned, the following three scenarios sketch possibilities of different water current strengths, in order to see at what point the energy demands of homes are met. In order to find this, three scenarios have been researched and calculations within these scenarios were done at three different supply temperatures. In the first scenario, the calculations were based on stagnant water. In the second scenario, the calculations were based on slowly flowing water, and the calculations in the third scenario were based on seasonal storage of heat in an aquifer. As discussed in section 6.2, the length of the area, which is needed to calculate the maximum heat extraction from the water, is equal to the length of the house, which is 10 meters. The width used for the calculations of the area, is equal to half of the width of the canal, which is 12 meters. The depth of the canal, used for the calculations, is 2.4 meters.

6.2.3.1. Scenario 1: Stagnant water

In the winter period, the current of the water in the canals is practically non-existent, so the flow rate, v_w [m/s], is set to zero. The thermal capacity is calculated, in order to determine the maximum amount of heat that can be extracted from the water. Formula 1 is that for which the thermal capacity of stagnant water can be calculated. This term quantifies equalization of the temperature difference via the atmosphere (Deltares, 2018). The thermal capacity depends on the surface of the water A [m^2], this is 10 by 12 m^2, which can be obtained in section 6.2.3. The formula also depends on the self-cooling number of water Z_{year}, for which the average number over the year is 10 W / m^2 °C. It also depends on the temperature amplitude between the minimum and maximum temperature of the surface water before and after the discharge, ΔT [°C] (Scholten & van der Meer, 2016). This temperature difference is 3 °C, as discussed in 6.2.1.

$$P_t = (A * Z_{year} * \Delta T) \qquad (1)$$

6.2.3.2. Scenario 2: Slowly flowing water

In the summer period, the current of the canals in Groningen flows substantially faster. The thermal capacity for slowly flowing water depends on factors other than the thermal capacity for stagnant water. The thermal capacity for slowly flowing water depends on the quantity of water (flow of the canal, q_{wl} [m^3/s]) = w [m] * d [m]

* v_w [m/s]). In this formula, the w corresponds to the width of the canal (w = 12 m), the d corresponds to the depth of the canal (d = 2.4 m) and v_w is the flow rate of the water, which is 0.15 m/s, as stated above. It also depends on the temperature amplitude between the minimum and maximum temperature of the surface water before and after the discharge, ΔT [°C] (ΔT = 3 °C), the density of water, ρ_{water} = 998 [kg/m³], and the heat capacity of water c_{water} = 4,185 [kJ / kg °C] (Scholten & van der Meer, 2016).

$$P_t = q_{wl} * \Delta T * \rho_{water} * c_{water} * \frac{A * Zyear * \Delta T}{1000}$$
$$= w * d * v_w * \Delta T * \rho_{water} * c_{water} + \frac{A * Zyear * \Delta T}{1000} \quad (3)$$

6.2.3.3. Scenario 3: Seasonal storage of heat in an aquifer

In the winter months, when the temperature of the surface water rises just above 0 degrees Celsius, the energy demand of houses rises. Therefore, the required supply temperature of water also rises as a consequence (T = 60/70 °C). As one can see, the difference between these two values is very high, which may create difficulties for the heat pump to extract sufficient heat from the already cold water in order to heat the homes to the desired temperature.

This problem could be solved by combining the heat pump system with a seasonal storage system (also called a thermal energy system (TES). In this system, the heat is extracted from the surface water in the summer by means of a pump and heat exchanger as mentioned in section 5.2. This heat is stored in an TES (aquifer). In winter, heat from the TES is upgraded to the required temperature. This heat is then distributed to customers through a heat network, which allows for the heating of homes. (Deltares, accessed 07-06-20).

The calculations for the capacity of the water source are almost the same as for the slowly flowing water, since the heat is extracted in the summer period, when the current of the water is 0.15 m/s. The difference here is that in order to combine this with a TES system, heat is only extracted during the summer months. The number of efficient hours, the number of hours when the heat can be extracted in this warmer period, is 2000 hours (Scholten & van der Meer, 2016). The amount of heat extraction is therefore calculated only for these hours, instead of per month. The calculated amount of energy that can be extracted from the water will be the amount for one year.

The power capacity is calculated by using Formula 3. After this, the total amount of energy that is present in the natural water system and can, in theory, be used, is calculated. The amount of energy Q_t [GJ/year], depends on the thermal power P_t [kW_t], and the number of efficient hours, h = 2000 [h].

$$Q_t = P_t * h * 0{,}0036 \quad (4)$$

6.2.4. Scenario Results

In Table 2, the results of the maximum extraction of the heat in that month are shown for scenario 1 and 2, calculated by the formulas mentioned in the system description. The thermal capacities were calculated for the entire year, in order to show a clear difference between the two situations; the effect of stagnant water and the effect when the water is slowly flowing. The calculated values of the power capacity must be compared to the energy demand of the homes, to examine whether the maximum heat extraction of the water can meet the energy demand of the homes to heat the houses.

6.2.4.1. Scenario 1

When the water of the canals remains in the stagnant situation, the power capacity values of the colder months January, February, and December are too low, to meet the energy demand of the homes. Therefore, it is impossible to implement this scenario, whereby the stagnant surface water is directly connected via heat pumps to the homes, in real life.

6.2.4.2. Scenario 2

When examining the second scenario, with slowly flowing water, the power capacity values are much higher compared to the values for stagnant water. As a result, there can be concluded that the current of the water has a major influence on the amount of heat that can be extracted from the water. If the water had a flow current during the whole year, the amount of energy, which is needed to meet the energy demand of the houses, will be enough. This problem should be addressed to the 'Water Channal Union', who are responsible for flood defence management, regional water management, and wastewater treatment. This institution could, for instance, realise to supply water from the IJsselmeer during the whole year, instead of just during the summer months. Hence, the realisation of the direct connection between the surface water and the heat pump system which is connected to the homes, might be possible.

Month	Energy demand (GJ)	Stagnant P_t (GJ)	Slowly flowing (v_w = 0.15) P_t (GJ)
January	10.39	9.64	144,989
February	14.31	8.71	130,968
March	8.75	9.64	144,989
April	7.18	9.33	140,312
May	5.65	9.64	144,989
June	4.50	9.33	140,312
July	1.48	9.64	144,989
August	0.92	9.64	144,989
September	2.20	9.33	140,312
October	2.92	9.64	144,989
November	5.39	9.33	140,312
December	9.83	9.64	144,989

Table 2: The calculated amount of energy that can be extracted from the water for Scenario's 1 and 2.

6.2.4.3. Scenario 3

The amount of energy that can be extracted from the surface water and stored in the TES system during the efficient hours in the summer, which equals 2000 hours, can be calculated by using equation 3 and 4. By using Formula 3, the surface water has a thermal power of 54,129,125 W. Utilising this quantity of thermal power in Formula 4, the amount of energy that is in the natural water system and can be theoretically used, is 389,730 GJ/year.

This calculated amount of energy is significantly high and meets the energy required for one year to heat one house; this total energy demand in one year is 73.6 GJ for space heating. Therefore, there can be concluded that using a TES system, in which the energy is stored which is extracted from the surface water in the summer months and utilize this energy from the TES system in the winter months, can be realised to meet the energy demand of the houses.

6.3. COP-value of the heat pump

Energy is consumed over the course of the heating network; for pumping the heat as well as the cold, and for building up the heat to the desired temperature. The efficiency of the total system is expressed in a "coefficient of performance" (COP), which measures the amount of energy used in a system to generate energy. For SWTES, this COP is determined by, in particular, the heat pump and, to a lesser extent, the pumps. Depending on the network, pump energy is mainly used for transport and distribution. A conceivable range for the COP of a heat pump is 3 to 7, thus for every GJ that is consumed in electrical energy, 3 to 7 GJ can be generated. The COP depends on the temperature of the surface water in addition to the desired temperature requested by the customer: the higher the temperature difference between the supply temperature and the temperature of the water source, the less favourable the COP (Kleivegt & de Goo, 2018). According to a study by Ecofys (Menkevelt, de Smidt, Oude Lohuis & van Melle, 2015), the COP depends on the delta temperature, which is the supply temperature minus the temperature of the water source. The formula below is designed for the COP for space heating, a linear fit with a COP of 6,25 at ΔT = 20°C and a COP of 3,75 at ΔT = 40°C (Menkevelt, de Smidt, Oude Lohuis & van Melle, 2015).

$$COP = 8.75 - 0.125\,(T_{supply} - T_{source}) \qquad (5)$$

From this linear fit, a COP is determined, by using the temperature data of the surface water from the Unie of Waterschaterschappen in Groningen. These temperatures were measured in the canal ‘Schuitendiep’, which is one of the canals around the city centre, situated in the North of Groningen. Aside from the temperature of the surface water, the average outside temperatures in the same year were requested by the KNMI. The temperature of the surface water depends on this external temperature.

In order to find the most suitable method for transferring heat extracted from water most efficiently, three different supply temperature situations were researched; at T = 35 °C, T = 50 °C and T = 65 °C. Table 3 in section 6.3.1, displays the relationship between the average outside temperature, the temperature of the surface water and the associated COP values of the heat pump calculated at the different supply temperatures.

T_{supply} = 35 °C

The situation assumes a supply temperature of 35 °C, which will represent a low temperature network, as described in section 5.3. In this situation, there is a direct connection between the surface water and the heat pump; the water pump drives the water from the canals to the heat exchanger of the pump and a compressor is used to guide the heated water to a higher level (Zhang, 2007). Then, a second heat exchanger warms the water in the house up to 35°C.

T_{supply} = 50 °C

The situation assumes a supply temperature of 50 °C, which will represent a hybrid temperature network, as described in section 5.3. In this situation, there is a direct connection between the surface water and the heat pump; the water pump drives the water from the canals to the heat exchanger of the pump and a compressor is used to guide the heated water to a higher level (Zhang, 2007). Then, a second heat exchanger warms the water in the house up to 50 °C.

T_{supply} = 65 °C
This situation assumes a supply temperature of 65 °C, which will represent a high temperature network, as described in section 5.3. This scenario does not allow for a a direct connection between the surface water and the heat pump, which will be elaborated upon in the results section. Then, a second heat exchanger warms the water in the house up to 65°C.

6.3.1. Results

The results of the COP values, which were calculated using the three different supply temperatures can be obtained in Table 3.

T_{supply} = 35 °C
When having a supply temperature of 35 °C, the COP values range between 4.63 and 7.06 and this is an enormously high efficiency of the heat pump. Therefore, this scenario can, in theory, be applied, when simply taking COP values into account.

T_{supply} = 50 °C
When having a supply temperature of 50 °C, the COP values range between 2.75 and 5.19, which is still a quite high efficiency of the heat pump. Therefore, this scenario can still be realised.

T_{supply} = 65 °C
The COP-values, when using a supply temperature of 65 °C without an TES system, which can be obtained from Table 3, are insufficiently low for using this system, as some of the values are below 1. In this case, there will not be a reason to change the heat source of the house. The heat source will not be more effective than using natural gas. When using 1 GJ of natural gas, 1 GJ of heat can never be generated, in fact there is always some heat loss. This means 1 GJ of natural gas will generate less than 1 GJ of heat, because of this the COP for using natural gas is always below 1. Using a heat pump can be much more effective than using natural gas, when the COP values are above 1. Another reason which clarifies the difficulty in heating up the entire body of cold water to 65 °C is that the water is sourced directly from the canal. As the heat pump system is an open system, to pump this water up to the house and subsequently heat this up sufficiently to warm up a house is quite the task. If for instance outside temperatures drop to 2 °C in the winter, as Table 3 demonstrates, the temperature of the water edges dangerously close to freezing, seeing as heat is constantly being extracted from the cold water. This water is sucked out of the canal, and carried along filters and heat exchangers, all the while at this near-freezing point. Water at this temperature massively decreases the efficiency of the heat pump.
This danger renders it impossible to use a high temperature network (T_{supply}= 65 °C), when the surface water is directly related to the heat pump.

In order to combat this problem, the combination of a TES-system could be utilised, as elaborated on in section 5.2. This means extracting the heat from surface water in the summer, which is subsequently stored in the TES system.
The temperature in such a TES-system remains constant at around 18 °C (Deltares, 2019), which is much higher than the temperature of the surface water in the winter. This in turn means the COP is no longer dependent on seasonal temperature changes and can remain constant across the year. With this new TES-system, the COP needs to be recalculated using Formula 5. If the T_{source} = 18 °C and the T_{supply} = 65 °C, then the COP value results in 2.9.

Month in 2015	Average Outside Temperature (°C)	Temperature Surface Water (°C)	COP T =35 °C	COP T =50 °C	COP T =65 °C (- TES)	COP at T =65 °C (+ TES)
January	3.0	4	4.88	3.00	0.50	2.9
February	1.5	2	4.63	2.75	0.25	2.9
March	4.4	5	5.00	3.13	0.63	2.9
April	7.8	9	5.50	3.63	1.13	2.9
May	11.2	13.5	6.06	4.19	1.69	2.9
June	14.2	15	6.25	4.38	1.88	2.9
July	18.5	21.5	7.06	5.19	2.69	2.9
August	17.9	19.5	6.81	4.94	2.44	2.9
September	14.6	18.5	6.69	4.81	2.31	2.9
October	10.7	13.9	6.11	4.24	1.74	2.9
November	9.1	10.3	5.66	3.79	1.29	2.9
December	6.9	7.6	5.33	3.45	0.95	2.9

Table 3: The relationship between the temperature of the average outside temperature, the temperature of the surface water and the associated COP values of the heat pump at T_{supply} = 35 °C, T_{supply} = 50 °C and T_{supply} = 65 °C with and without a TES system.

6.4. Electrical demand of the heat pump

The heat pump also consumes energy that must be generated. This electricity can be generated through sustainable energy sources, for instance solar energy. The electrical demand is calculated on a monthly basis by dividing the energy demand per month of the house by the COP value of the heat pump. From all the energy that a heat pump supplies, four parts come from the water source and one part comes from electricity. In other words, for every 5 GJ of heat it produces, the heat pump's heat supplied consists of 4 GJ of heat from the water source and 1 GJ of electricity. In this case, the COP will be 5. The electrical demand is calculated by equation 6. (Klimaatexpert, date unknown)

$$\textit{Electrical demand (GJ) = Energy demand (GJ) / COP} \qquad (6)$$

The electrical demand of the heat pump was calculated with the use of the COP calculated at the three different supply temperatures; at T = 35 °C, T = 50 °C and T = 65 °C. Table 4 in section 6.4,1, shows the outcomes of the calculations for electrical demand of the heat pump, at the required supply temperatures.

6.4.1. Results

The electrical demand, calculated at the three different supply temperatures, were collated in Table 4. The results of the calculation at the three different supply temperatures are discussed in this section.

T_{supply} = 35 °C

The high COP values when T_{supply} = 35 °C, result in significantly low electrical demand values of the heat pump. This is a beneficial result, since the electricity needed for the heat pump must also be generated via renewable energy sources for the system to be climate natural, such as solar energy. However, the disadvantage of this low temperature heating network, is that the homes has to be altered to a high extent, which will be discussed in the next section.

T_{supply} = 50 °C and T_{supply} = 65 °C

The electrical demand of the heat pump, for both supply temperatures, in February is significantly high, which can be a problem by finding a suitable heat pump.

Month	Energy demand (GJ)	Electrical demand (GJ) T = 35 °C	Electrical demand (GJ) T = 50 °C	Electrical demand (GJ) T = 65°C + TES
January	10.39	2.13	3.46	4.16
February	14.31	3.09	5.20	5.72
March	8.75	1.75	2.80	3.50
April	7.18	1.31	1.98	2.87
May	5.65	0.93	1.34	2.26
June	4.50	0.72	1.03	1.80
July	1.48	0.21	0.29	0.59
August	0.92	0.14	0.19	0.37
September	2.20	0.32	0.46	0.88
October	2.92	0.48	0.69	1.17
November	5.39	0.95	1.42	2.16
December	9.83	1.84	2.84	2.81

Table 4: The outcomes of the calculations for the electrical demand of the heat pump, at the required supply temperatures.

6.5. Adjustments to the houses

The historic houses in the city centre of Groningen are poorly isolated, therefore the houses might need some adjustments. These modifications are depended on the supply temperature of the homes. Therefore, the required adjustments are discuses for the three different supply temperatures; at T = 35 °C, T = 50 °C and T = 65 °C.

T_{supply} = 35 °C

When using a supply temperature of 35°C, the in-house heating surface must be substantially increased, in order to release the same amount of energy as when releasing a high temperature (T_{supply} = 60-70 °C). However, before a suitable heat network can be selected, consent for the plans must be obtained from the inhabitants of the houses around the canals of the city centre of Groningen agree with the plans. This will happen less likely if the costs escalate. This is a probable result if the houses have to be altered on a big scale; replacing the radiators for underfloor heating or having an extra insulation layer added on the inside of one's house. This will initially be unattractive for the inhabitants, since the costs for the heat pump are high and the costs for the modifications of their own homes are high. There exists a possibility to subsidise part of these costs, but this will amount to only a small part of the total amount.

T_{supply} = 50 °C

When using a supply temperature of 50°C, adjustments of the house to a certain extent cannot be avoided, as mentioned above. The level of modification might be less than in scenario 1, since the in-house heating surface must be increased, but not to the same level as compared to the supply temperature discussed in the above section, since this supply temperature is higher. In this case, the underfloor heating might be enough, and insulation could be postponed to a later stage. This way, the costs could partly be spread over several years. The cost might be still high, and therefore one cannot expect for all inhabitants to consent for the plans immediately.

T_{supply} = 65 °C

In this case, the homes require almost no adjustments, since the supplied water temperature is the same when using natural gas. This will be attractive for the inhabitants, since the costs for the modifications of their own homes are high. This way, the inhabitants will consent for the plans sooner, which will lead to the realisation of the project.

7. Discussion

The research posited a solution of finding an alternative to natural gas by using renewable energy to heat the houses in the historic centre of Groningen. The alternative proposed by this research consisted of using surface water sourced from the canals surrounding the historic centre of Groningen in order to heat the surrounding houses. The main research question consisted of working out the feasibility of this alternative, as well as proposing a number of alternatives in order for stakeholders in the project, including the inhabitants of the concerned houses and the city council. During this project, simplifications needed to be made, concerning the energy demand of the houses, the thermal capacities of the canal, as well as associated COP values and electrical demands of the heat pump.

The estimation of energy demand was required to compare those values to the thermal capacity of the canal. After all, the energy demand determines whether this surface water is capable of generating sufficient thermal capacity in order to heat the houses on a monthly basis. The only available measuring instrument for energy demand was that provided by the energy supplier, which is an inaccurate measurement of the true energy demand of a house. Initially, this study attempted to utilise a model which calculated, through the use of several measurements and calculations of energy loss, what an estimate energy demand of a house could be. Unfortunately, this model ran the risk of an incorrect estimation, since several parameters were not measured correctly. Thus, a far more pragmatic approach was using the monthly supply of gas from the energy supplier. However, the values of just one house were taken, taking a risk not being representative.

Another factor which could have had an impact on the accuracy of the calculations is the assumption this study made about the flow of canal water in the winter. It was assumed that the current of the water was zero during the winter period, as no water was supplied to the canals from the IJsselmeer, and the current of the water was 0.15 m/s in the summer period, as water from the IJsselmeer was supplied during this period. These assumptions were made by the ‘Water Channel Union’, since there is no interest in measuring these water currents on a monthly or yearly basis yet. However, these assumptions could have large impacts for the results of the calculated maximum heat extraction per month, since the values of the heat extraction change in a high extent if the water flows just with a small value for the current.

Moreover, the temperature of the canal water, which is required in order to calculate the COP value of the water pumps, were measured only once a month. If these temperatures were to be measured once a day, it would already give a much clearer indication of what these temperatures are in reality. This in turn would ensure more accurate COP values. As this was in the present study not a reality, the picture painted by the used COP-values may have been skewed.

8. Conclusion

The research aimed to *investigate the extent of the feasibility of utilising low heat temperature of surface water sourced from canals near the centre of Groningen in order to heat surrounding real estate*. To achieve this, a literature review was conducted in order to review the state-of-the-art information about this proposed alternative to natural gas and in order to find correct formulas from which to calculate the required parameters to give an answer to the main research question. The several parameters that were calculated for this research were a) the energy demand of the representative house, b) the thermal capacity of the canal part in front of the house, c) the COP values and d) the electrical demand of the heat pump.

First, the thermal capacity for the canal section in front of the representative house was calculated, in order to examine whether the heat capacity present in this section can meet the energy demand of a typical house in the historical centre of Groningen. Following these calculations, it can be concluded that the thermal capacity is strongly dependent on the current of the water in canals. Even when the value for the current is very low, the capacity of the surface water is sufficient in order to provide enough energy to heat the surrounding houses.
In the summer, there is current, due to water demand from agriculture, also leading to current in the canals of Groningen. In the winter, there is no such water demand, thus the surface water heat extraction capacity is low when it is the most needed. The hypothetical scenario concerning the winter period is therefore tricky, considering the total absence of a current. For the hypothetical summer scenario, when currents are stronger, much more heat can be extracted from the surface water in order to heat houses. If the local Water Channel Union can for instance arrange for water currents to flow year-round, a direct connection could be made from the surface water to the proposed heat pump system, in order to heat houses in the historical centre of Groningen.

Another alternative would be to use a combination of a heat pump system with a TES-system. This would allow for the extraction of heat from the canal during the summer months, this heat is stored in the TES-system, and would subsequently be used in the winter.

The next question was how this energy, extracted from the surface water, should be transferred: at a high or a low temperature. To answer this question the COP of the heat pump was calculated at three different supply temperatures: at T = 35 °C, T = 50 °C and T = 65 °C. These COP values must be above 1, in order to have greater efficiency than either gas or electrical heating systems. The highest COP-values can be found in combination with the lowest supply temperatures selected, as the supply temperature and the temperature of the surface water has the smallest difference.

This means that the low temperatures are the most suitable for the proposed water pump system. However, this suitability does not extend to the concerned houses: the lower the supply temperature, the greater adjustments need to be made to the concerned houses, which could heavily increase prices for the inhabitants. These increased costs could increase resistance to reducing the CO_2 for home heating. When a temperature of 50 is used, COP-values are still significantly high to heat the houses, although significant adjustments are still required to the houses, forming a great disadvantage. When a supply temperature of 65 °C is used, the COP-values fall under 1 in the colder winter months, meaning that the system is ineffective. This means that a combination of a high temperature with a TES-system would form a good alternative, considering the temperature of the source assumes a far more constant value, meaning the associated COP-values are also constant throughout the year. A temperature of 65 °C also means fewer adjustments need to be made to the houses.

The use of surface water in combination with the heat storage system appears to be the best option, both for the capacity of the water as well as the adjustments to the house. This system will ensure that there is always sufficient heat available from the canal water to heat houses year-round, with limited adjustments needed to be made to the house, which would make agreements with inhabitants more likely.

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