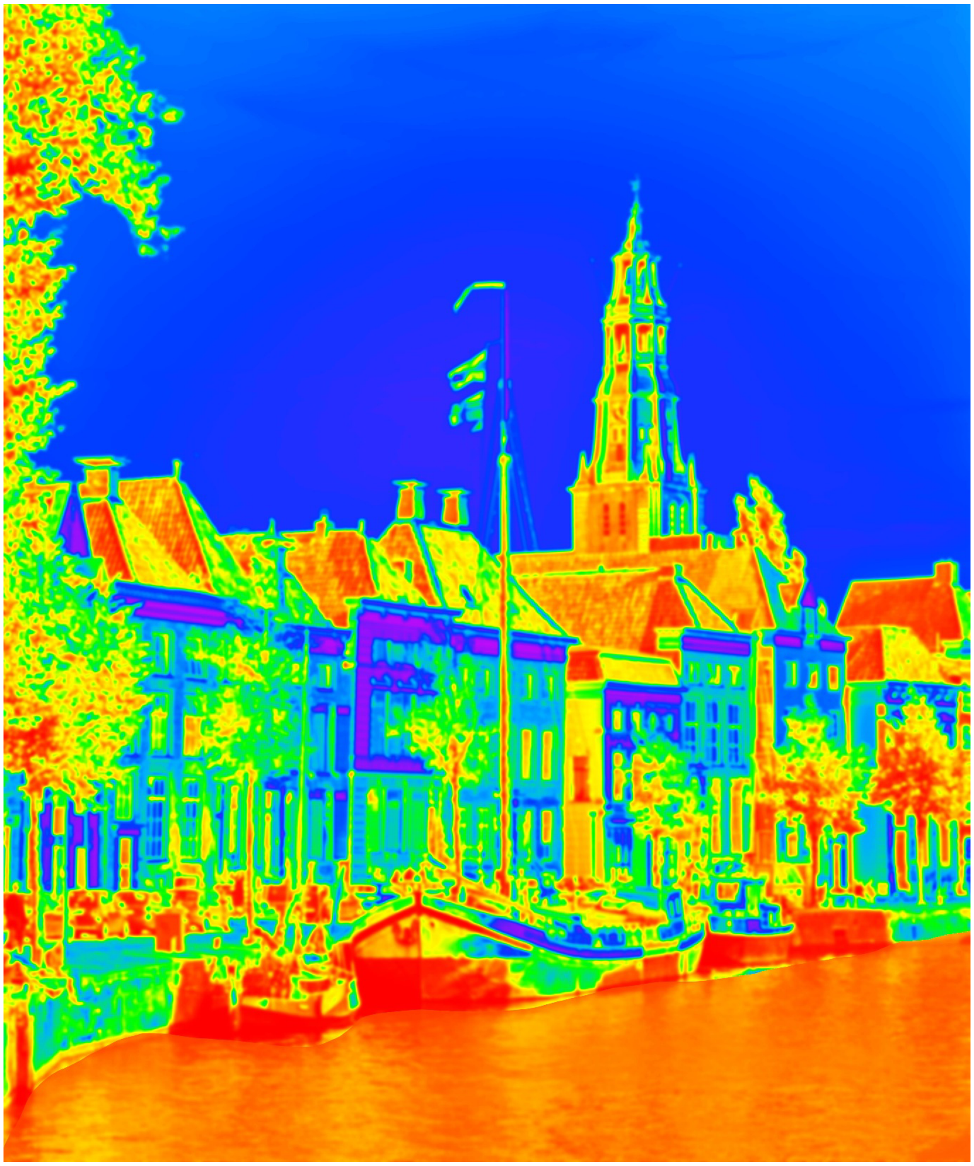
Extracting thermal energy from city canals

Applying a transition and innovation theory perspective to identify opportunities and barriers for using surface water thermal energy systems to heat historical buildings in the case of the city center of Groningen



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2023

Colophon

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Date: 2023-07-03
Version: Final
Cover photo: Author, 2023

Acknowledgements

Dear reader,

After almost 6 years of studying at the Faculty of Spatial Sciences at the University of Groningen, handing in this master's thesis feels like reaching the last chapter of a valuable book. It has been a journey of learning, not only about the academic world but also about myself.

I am passionate about the energy transition and the urgent need to become more sustainable, therefore this thesis holds great significance to me. Throughout the process of writing this thesis, one prevailing theme remained a constant source of motivation: the realization that substantial efforts are still required to achieve a more sustainable future.

Writing this thesis would not have been possible without the help of several people who I would like to thank. First of all, I would like to thank Dr. Ferry van Kann for his supervision throughout the research. As a supervisor, he made the research process enjoyable. The consulting or ‘bijpraat’ sessions, and feedback have helped and inspired me throughout the research. Next, I want to thank all the interviewees who generously shared their insights and took the time to contribute to my research. Furthermore, thanks to Nelson for his consultancy and Bram en Siem for renting me a lovely office. Finally, I would like to thank Dad, Mum, and Jet for their constant support throughout the process of writing this thesis.

Enjoy reading,

Stef van Oosterhout

Groningen, June 2023

Abstract

The energy transition has become a vital response to tackle the pressing challenge of global warming. Recognizing its crucial significance, diverse national and local efforts have been initiated to reduce CO2 emissions and shift towards sustainable energy sources. In line with these efforts, the municipality of Groningen has developed a heat transition plan for its inner city, which consists of a hybrid approach to address the heating needs. However, this approach highlights the need for tailored solutions to overcome the unique challenges posed by the protected status of historical buildings, particularly concerning insulation, and subsequent heating difficulties. Surface water thermal energy systems offers the potential to meet the heating demand by using the presence of surface water in the form of city canals to heat historical buildings. The purpose of this research is to understand the opportunities and barriers related to using surface water thermal energy systems for heating historical buildings in Groningen's city center from a transition and innovation theory perspective. The data collection analysis was accomplished through a literature review, open interviews, semi-structured interviews, and participant observation. Results show that successful implementation of SWTE systems requires careful consideration of technical and spatial requirements, including compatibility with historical buildings, availability of subsurface space, and involvement of key stakeholders. The complexity involved means that only large organizations or collective groups are equipped for the implementation of SWTE. While SWTE has successfully met the heat demand in a provincial government building, relying solely on this technology is not feasible due to the limited maturity of the innovation. Overall, SWTE implementation in Groningen is constrained by spatial and technical factors but can be feasible if these are carefully considered, water is heated collectively, and the system will be part of a larger heating system.

Key concepts: Energy Transition, Surface Water Thermal Energy, Historical Buildings, City Canal, District Heating

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List of abbreviations

IPCC	Intergovernmental Panel on Climate Change
CO2	Carbon Dioxide
TEO	Thermische Energie Oppervlaktewater
TED	Thermische Energie Drinkwater
TEA	Thermische Energie Afvalwater
SWTE	Surface water thermal energy
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
ATES	Aquifer thermal energy storage
Q	Amount of energy in Joules
m	Mass in gram
Cw	Volumetric heat capacity (J/g*°C)
ΔT	Temperature change in °C
J	Joules
MT	Middle temperature
HT	High temperature
GJ	Gigajoules
ha	Hectare
NAT	Netwerk Aquathermie (Network Aquathermia)

1. Introduction

1.1. Energy transition in the Netherlands

The demand for renewable energy sources gained increasing attention due to the growing awareness of climate change implications (Van der Hoek, 2012). The Paris Climate Agreement of 2015 and recent reports from the Intergovernmental Panel on Climate Change (IPCC) emphasize the urgent need to reduce carbon dioxide (CO2) emissions as well as transition our energy use in order to achieve the desired stabilization of global warming at 1.5°C (UNFCCC, 2015; IPCC, 2018). In response to this global state of rising awareness, European initiatives such as the Green Deal and various policy measures targeting CO2 emissions reduction have been introduced (European Commission, 2019). Concurrently, the Netherlands has been progressively minimizing its reliance on natural gas. To do so, new buildings are constructed without a connection to gas infrastructure, and existing buildings are transitioned towards the use of collective heat networks (Rijksoverheid, 2016). Notably, within the built environment of the Netherlands, approximately 24.1 billion kg of CO2 (equivalent to 15% of the nation's total CO2 emissions) is generated primarily through natural gas usage for heating (CBS, 2018). Addressing this significant carbon footprint is imperative, as the government aims to achieve carbon neutrality by 2050 (Rijksoverheid, 2023). The national climate agreement sets a target to transition 1.5 million Dutch households away from natural gas dependency by 2030 and reduce CO2 emissions from the built environment by 3.4 million tons, compared to the initial scenario. To achieve this, 1.5 million Dutch households will be connected to collective heat systems, with over half of these homes being connected to a heat network. Municipalities are currently developing plans to determine the priority neighborhoods for heat network connections, although these plans are not fully finalized yet (Klimaatakkoord, 2019).

This Green Deal and national climate agreement have paved the way for various local initiatives, with Groningen being one of the pioneering cities in the Netherlands. Groningen has devised a comprehensive heat transition plan, which aims to achieve carbon neutrality by 2035 through the implementation of a new heating grid. This plan includes initiatives to reduce gas emissions by exclusively using the heating grid, electricity, or hybrid heating systems, which combine electric heat pumps with (green) gas to meet heating demands. In areas with historical buildings, such as the inner city, hybrid heating systems are preferred due to limited insulation options imposed by building restrictions. However, it is worth noting that these hybrid systems still rely on limited quantities of green gas or serve as an interim solution (Gemeente Groningen, 2021).

1.2. Historical buildings

Groningen consists of many historical buildings as visible in Figure 2. These buildings often contribute to and enhance the image of a city (Cabeza et al., 2018). Historical buildings, despite positively enhancing the image of the city, are often less energy efficient compared to modern ones (Cabeza et al., 2018; van Krugten et al., 2016). A prominent example can be observed in the city center of Groningen, where the University of Groningen encounters challenges related to the insulation and heating of its historical buildings (Ukrant, 2022). This emphasizes the necessity of exploring alternative technologies, such as heat pumps, to enable sustainable heating solutions while preserving the built heritage of Groningen.

1.3. A new heating technology using surface water

A relatively new concept shows that the water cycle has the potential to play a significant role in the development of these technologies. It is possible to directly extract thermal energy from water in the water cycle or to use it as an energy carrier (Van der Hoek , 2012; Kruit et al., 2018). Moreover, research by Kruit et al., (2018) highlights the fact that this technology, called aquathermia, has a high potential to address a part of the heat demand in the Netherlands. It has been estimated that approximately 40% of the total heat demand of the Netherlands could be covered using aquathermia (Kruit et al., 2018). Aquathermia is a concept that is systematically categorized into three types, based on the different sources of water that are used for heating: surface water (TEO), freshwater (TEA), and wastewater (TED) (Kruit et al., 2018). Thermal energy from surface water (TEO, as illustrated in Figure 1, will be denoted as ''surface water thermal energy'' (SWTE) from this point onward, aligning with the findings of Dehens et al. (2020), Kruit et al. (2018), and de Fockert et al. (2021).

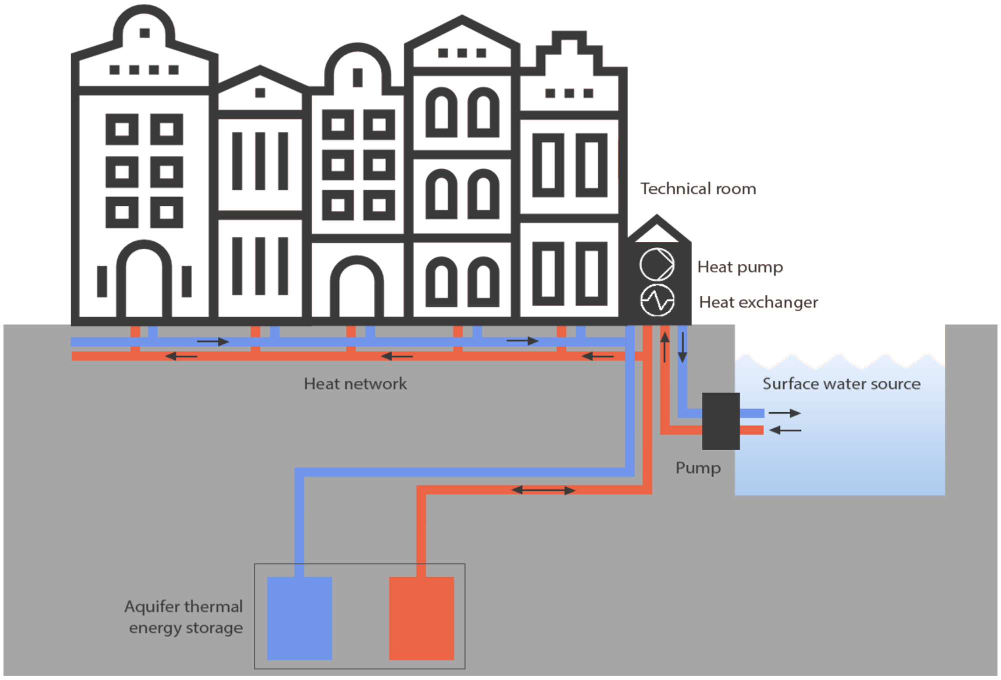


Figure 1: Visualization An SWTE system (Kruit et al., 2018; Dehens et al., 2020; Author, 2023)

This SWTE system is already implemented at the provincial government building of Groningen and a building complex close to the city center of Groningen (Bodemenergie 2021; Provincie Groningen, 2021; ECW, 2021). Although, the presence of urban surface water in and around the city center has greater potential to supply the heat demand as hybrid forms of heating are needed. This is supported by van der Meulen (2023), arguing that even small surface water bodies can potentially contribute to SWTE systems. Furthermore, an explorative study by Roosjen et al., (2021) recommends including aquathermal energy as a promising source in visions and plans and concludes that it could be applicable for larger-scale applications than previously imagined. Although, it is believed that there is still a lot of uncertainty and various risks regarding these new technologies (Cabeza et al., 2018; de Fockert et al., 2021). Hence, considering the imperative energy transition we face, it is vital to examine the opportunities and barriers associated with implementing SWTE systems for heating historical buildings in the city center of Groningen. Such an investigation can provide policymakers with valuable insights to make well-informed decisions regarding the integration of these systems into the city's infrastructure.

1.4. Societal relevance

The municipality of Groningen lists buildings as national monuments, municipal monuments, and iconic buildings which should be preserved or protected over time which are visualized in Figure 2 (Gemeente Groningen, 2023; Monumenten.nl, 2023). These monuments and iconic buildings are of interest to the municipality because of their cultural and historical importance, aesthetics, and scientific importance (Gemeente Groningen, 2020).

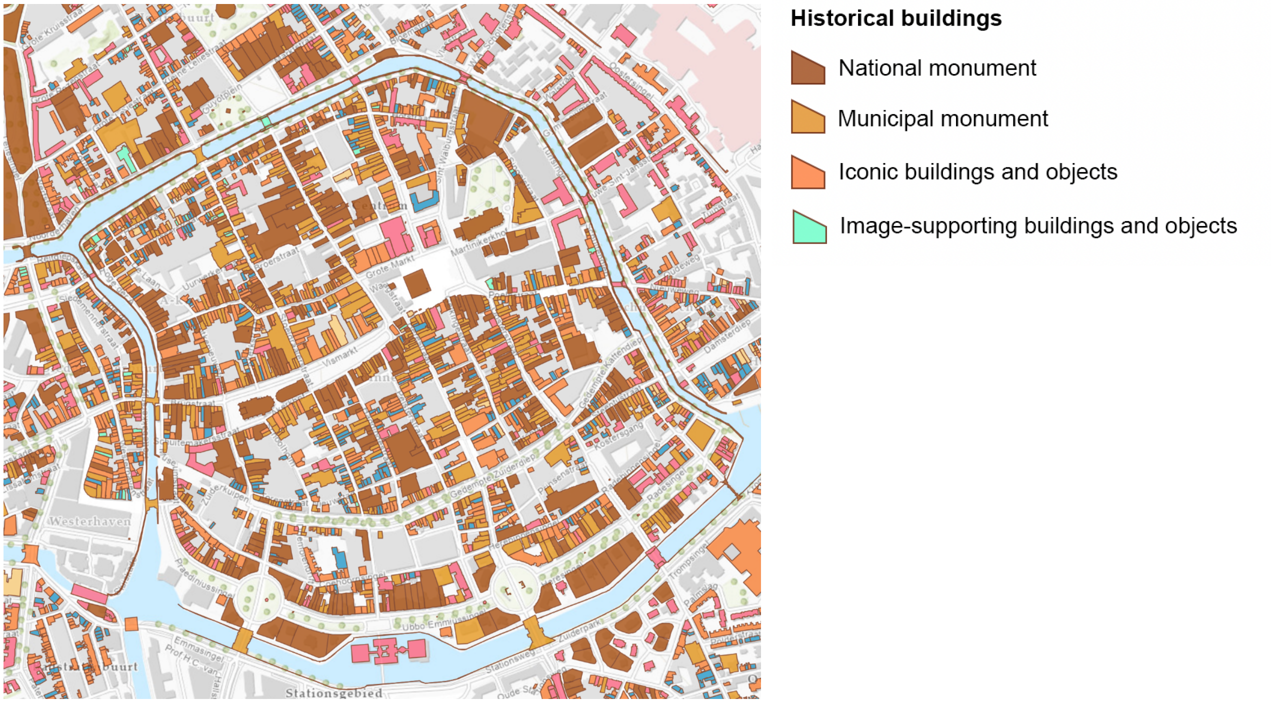


Figure 2: Map of Groningen showing historical buildings: national monuments, municipal monuments, image supporting, and iconic buildings (Gemeente Groningen, n.d.)

Moreover, the character of a townscape is often shaped by its historical buildings, which not only contribute to the visual appeal of urban areas that residents enjoy but also serve as a magnet for tourists (Cabeza et al., 2018). In addition, these buildings can actively enhance the meaning and quality of people's living spaces, while also providing a distinct sense of identity (Historic England, 2018; RVO, 2023). In response to this, laws have been and are still being developed, such as the monument law, which asks for special building application procedures before renovations, or any other changes to these buildings. The major goal is to stop changes that might damage the cultural value of these buildings (Van Krugten et al., 2016). Some of the buildings are listed as iconic buildings that still require special permission to change the outside. Subsequently, this leads to numerous administrative procedures (Erfgoedloket Groningen, 2023).

The city center of Groningen is home to numerous listed buildings, which poses a challenge in terms of implementing heat networks and insulation measures, as outlined in the heat transition plan. Hybrid forms of heating are deemed necessary to achieve sustainability goals due to the unsuitability of these buildings for conventional heat networks and limited insulation possibilities (Gemeente Groningen, 2021; Gemeente Groningen, 2023) However, a significant issue arises when considering the implementation of energy-efficient measures, as they may potentially alter or harm the historical integrity of these buildings, necessitating numerous special permissions. This is supported by studies by van Hal et al., (2010) and van Krugten et al., (2016), who highlight a continuous tension between raising energy efficiency and preserving built heritage. By focusing on preserving historical buildings and built heritage, SWTE systems could offer a solution for the city center of Groningen and other historical cities that are surrounded by canals.

1.5. Scientific relevance

The core of the existing literature on aquathermia focuses on three types of different sources of water: surface water (TEO), freshwater (TED), and wastewater (TEA) (Kruit et al., 2018; Dehens et al., 2020; de Fockert et al., 2021). In a study from Dehens et al., (2020) a framework is developed which facilitates comparison between diverse technical configurations for aquathermia and provides the reader with a decision tree based on the technical-economical potential of SWTE systems. Kruit et al., (2018) especially focus on the national potential of using aquathermia regarding several conditions regarding technical and economic parameters. De Fockert et al., (2021) add to the research of Kruit et al., (2018) and present feasibility studies that describe how to transform technical knowledge about aquathermia systems into practice. These authors all describe aquathermia systems, however, they do not specifically emphasize the use of surface water as a primary source, which is available in and around the city center of Groningen due to its surrounding city canals.

Literature found on sustainable heating via SWTE systems, consists of two feasibility studies where rivers, lakes, or other water bodies are being examined to serve a specific heating demand. These feasibility studies consist of research by van der Brugge et al., (2022), which focuses on extracting thermal energy out of water bodies such as lakes in Holland Rijnmond, and Roosjen et al., (2021) who conducted a study on the applicability of an SWTE system on the river Waal near Nijmegen. Additionally, van der Meulen (2023) shows that using canals as a source of thermal energy is feasible, and even relatively small urban water bodies have the potential for sustainable heating. Yet, the research of van der Meulen (2023) does not provide the academic world with information on the type of buildings that will be heated with this promising technology. The feasibility study of van der Brugge et al., (2022) describes SWTE systems from a regional perspective and Roosjen (2021) focuses on the city of Nijmegen as a whole. Both feasibility studies do not provide information on the heating for specific types of buildings and thus historical buildings.

The importance of improving sustainable heating in historical dwellings, the challenge of matching sustainability objectives, and preserving cultural and historical values are discussed by the research of van Hal et al., (2010) and van Krugten et al., (2016). Despite the importance of improving sustainable heating in historical buildings, a research gap has been identified. Therefore, this research provides new perspectives to the planning debate on how SWTE systems can contribute to the sustainable heating of historical buildings to preserve them.

1.6. Research objectives

Utilizing a case study approach, this research concentrates on the city center of Groningen in the Netherlands to identify and explore technical spatial opportunities and barriers associated with SWTE systems from a transition and innovation theory perspective. Additionally, the study aims to evaluate how, and if the concept can operate effectively under these circumstances.

The concept of technical spatial refers to an integration of technical components and spatial considerations within this technology. Technical components entail for example required temperature levels of the surface water and filter requirements. Spatial aspects such as subsurface infrastructure and location, scale, and proximity considerations are relevant to the implementation and operation of an SWTE system. It excludes specific technical requirements of individual components. The forthcoming national environmental law and heat law are excluded from the scope of this research. Furthermore, a time scale that is aligned with both national and local sustainability objectives is implemented.

1.7. Research questions

Based on the research objectives the following research questions are formulated:

How can surface water thermal energy systems enable sustainable heating of historical buildings using canal water in the city center of Groningen using an innovation and transition perspective?

To support this central question, several sub-questions have been formulated:

1. How can surface water thermal energy systems be conceptualized from a combination of an innovation and transition theory perspective?
2. What is the current state of the technology used to extract thermal energy from surface water systems based on a literature study?
3. How do surface water thermal energy systems empirically operate?
4. What are necessary technical and spatial conditions that need to be met to effectively use surface water thermal energy systems to heat historical buildings?
5. Who are the key actors and stakeholders involved in the implementation of surface water thermal energy systems?
6. What can be learned from the perspectives of relevant stakeholders regarding the use of surface water thermal energy systems to heat historical buildings focusing on opportunities and barriers?
7. What lessons can be learned from the potential implementation of surface water thermal energy systems in Groningen?

1.8. Reading guide

This thesis starts with a categorization of aquathermia systems where SWTE was defined, technical information, and the formulation of the research problem concerning the research questions. The theoretical framework in Chapter 2 will first explore concepts and theories related to SWTE systems, subsequently link a combination of innovation and transition theory to SWTE systems, and lastly present the multi-criteria analysis, that serves as a conceptual model. Chapter 3 provides an examination of the diverse research methods employed to address the primary research question and its associated sub-questions. Subsequently, in Chapter 4, the study findings are presented. Finally, the concluding Chapters 5 and 6, present the key findings, engages in a comprehensive discussion of the multi-criteria analysis outcomes, and highlight practical implications and avenues for future research. The reference list and appendices are located at the end of the report in Chapters 7 and 8.

2. Theoretical framework

This chapter presents and links concepts and theories that are relevant to answer the first two research questions. Chapter 2.1 examines whether SWTE systems can be categorized as innovations and how they can be utilized within the current transition using transition and innovation theory. To do so, this chapter will develop one perspective combining transition and innovation theory. Chapter 2.2 focuses on the technical aspects of SWTE systems and the known barriers. Chapter 2.3 zooms in on the trias energetica and how that concept is connected to rational energy use for specifically historical buildings. Finally, these findings are translated to the multi-criteria analysis in Chapter 2.4, which is used as the conceptual model of this research.

2.1. A combination of transition and innovation theory as guidance

2.1.1. Transition theory

To meet the sustainability goals of the climate agreement of Paris to prevent further environmental degradation an energy transition is needed. The Dutch National Institute for Public Health and the Environment (RIVM) defined the current energy transition as the switch from fossil fuels to sustainable sources (RIVM, 2023). This transition is often seen as a fundamental change in our energy system. To delve deeper into the potential of SWTE as a new technology within this transition, it is important to first comprehend the concept of a transition. However, transition management will be excluded from this.

A seminal article in the field of transition theory, authored by Geels and Kemp (2000), highlights the notion of transitions as profound transformations in the shaping and fulfillment of specific societal functions, viewed as socio-technical systems. A more elaborated definition can be found in a paper from Loorbach (2007) that states ''Transitions are transformation processes in which existing structures, institutions, culture, and practices are broken down and new ones are established.'' (Loorbach, 2007, p.17). This definition implies transitions having a start- and end-phase. Additionally, according to van der Brugge et al., (2005), a transition is a long-term process with a duration of 25 to 50 years that results from the co-evolution of technical, economic, ecological, institutional, and cultural developments and processes on different scales levels. These three definitions highlight the long-term duration of a transition happening at different categories of processes and different scale levels within a socio-technic system. Three key concepts are seen as the base of transition theory: multi-stage, multi-level, and transition management (van der Brugge et al., 2005) The multiple stages that can be identified within a possible transition and at what levels these happen are relevant to understand the position of an SWTE system, and thus, will be described below.

The multi-stage concept looks at transitions from a perspective of change tempo. Therefore, a transition can be described in 4 phases or stages that are visible in Figure 3 (van der Brugge et al., 2005). These stages are divided into a *preliminary development phase (1)* of a dynamic equilibrium in which the current situation does not change visually, but changes happen beneath the surface. *A take-off phase (2),* where thresholds are crossed and the system's state begins to change, is a phase where SWTE systems could be situated based on current information. Third, an *acceleration phase (3)* involves observable structural changes happening rapidly because of an accumulation of sociocultural, economic, ecological, and institutional changes that support one another. And finally, *a phase of stabilization (4)* in which the rate of social change slows, and a new dynamic equilibrium is attained. It should be noted that the speed of change in transition processes is a relative concept that needs the establishment of system boundaries.

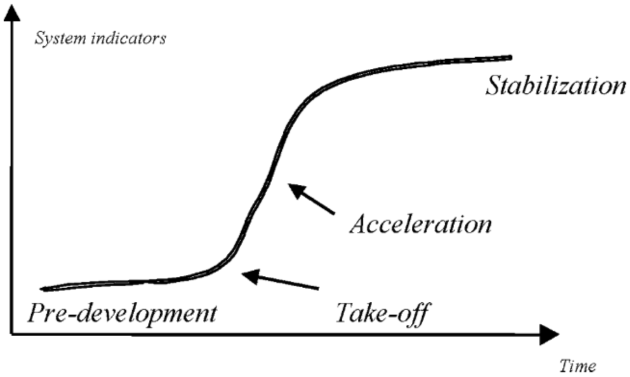


Figure 3: A transition with its four phases between two dynamic equilibria influenced by systems indicators (van der Brugge et al., 2005)

The second concept within the transition theory is the multi-level concept, which shows a division between scale levels where transitions take place within the socio-technical landscape. The levels are derived from Geels & Kemp (2000) and are landscape, regimes, and niches and are visualized in Figure 4 below.

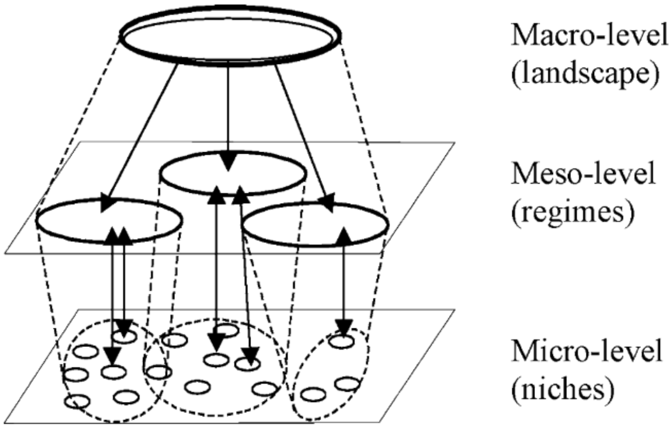


Figure 4: Multi-level model (Geels & Kemp, 2000; van der Brugge et al., 2005)

At the landscape level, many autonomous trends influence both the regime and niche levels as visualized with arrows in Figure 4. These developments include changes in social values, political cultures, and economic progress. It is critical to emphasize that these trends cannot be reversed by one actor but must be accepted by many actors. The landscape level can be seen as the overall societal setting where change, like our energy transition happens.

The regime-level represents a synthesis of the dominant structure, culture, and practices. Structure entails the institutional framework, culture refers to the prevailing perspective, and practices encompass norms, procedures, and habits. The regime-level is characterized by its inflexibility, which provides stability to the societal structure. For instance, roads and power grids are prime examples of physical stability, while intangible aspects include the networks formed by various actors and the established rules they follow. This inflexible character can benefit the system during periods of stability; however, it can become an obstacle during transitions as most institutions still need to be adapted (Loorbach, 2007).

The last level is the most important level due to the match with new technologies such as SWTE systems. This level is the niche level also referred to as the micro level. On this level novelties are created, tested, and diffused within these niches. Novelties are often seen as new technologies, new rules, legislation, concepts, or ideas just like SWTE systems (Geels & Kemp, 2000; Loorbach, 2007)

When broadening the perspective beyond specific niches and examining the interconnections among them, another significant role of niches becomes apparent. Niche markets can facilitate the wider adoption of new technologies like SWTE systems. Nevertheless, these innovations should be protected to do so (Geels & Kemp, 2000; Loorbach, 2007). Without protection of a niche, it becomes difficult for an innovation to reach or gain momentum in the take-off phase. These new technologies, or better, innovations developed on a niche level can create tension upwards to the regime level. This tension results from potential changes at this level starting a transition. However, the regime level, which could be seen as the different energy systems used in cities, is inflexible. This inflexibility makes it difficult for unprotected innovations to make a difference on this level as it is locked within the current energy landscape. In conclusion, the niche SWTE systems are in, is locked within the current regime due to its inflexibility and should be protected to reach the regime level (Geels & Kemp, 2000).

2.1.2. Innovation theory

Starting from this niche level, the concept of innovation comes around. Because SWTE systems have the potential to be categorized as a technological innovation, it is critical to obtain a greater understanding of how such an innovation is defined, how it spreads, and at what rate it can spread, as illustrated in Figure 3. Furthermore, it is important to understand the position of our innovation named SWTE systems within these niches. This understanding can help to shed light on why SWTE remains situated in the pre-development phase at a niche level and does not influence the regime level to start a transition on a landscape level.

An innovation is defined by Rogers (2003, p.12) as: "An idea, practice, or object that is perceived as new by an individual or other unit of adoption". Perceptions of this definition differ as one can see a new technology as something that is very innovative and similarly one can see the same new technology as something that is less innovative. Some innovations can diffuse rapidly from the first introduction and result in usage worldwide (Rogers, 2003). In order to assess the potential adoption of SWTE systems, it is important to examine the factors that contribute to their adoption and consider how they address five key characteristics related to the rate of adoption of innovations. The rate of adoption is determined by 5 different variables (Rogers, 2003):

1. Perceived attributes of innovation
2. Type of innovation decision
3. Communication channels
4. Nature of the social system
5. The extent of change agents' promotion efforts

With regards to SWTE systems primarily the first variable, perceived attributes of innovation, is relevant as this first determines how and if innovations are being adopted. Excluding the other variables enables a more targeted and focused examination of factors relating to stakeholders' views and evaluations of the innovation itself, rather than larger contextual elements that may influence the adoption process.

Perceived attributes of innovation

Innovations like SWTE systems can be adopted by stakeholders, and the pace at which this occurs is described by Rogers (2003) as the rate of adoption. Understanding the rate of adoption of SWTE systems by stakeholders is crucial to assess their potential for widespread implementation within the energy transition. According to Rogers (2003) the innovation is adopted by members of a social system, instead of stakeholders. Five different characteristics determine the rate of adoption of an innovation (Rogers, 2003). The first characteristic, *relative advantage (1)*, relates to how much an innovation is thought to be better compared to its forerunner. Innovations that surpass previous or other techniques are easier to adopt and deploy. *Compatibility* (2) is the second characteristic and describes the extent to which an invention aligns with the values, past experiences, and needs of potential adopters. The third characteristic, *complexity (3)*, corresponds to how difficult the innovation is to use or understand. Straightforward innovations tend to be more comprehensible, thereby facilitating adoption. The fourth characteristic is trialability (4) which demonstrates the degree of feasibility in testing or experimenting with the innovation. Innovations require an investment of time and resources, resulting in those that can be tested have a greater probability to be adopted. Finally, the fifth characteristic is *observability* (5), and refers to the visibility of an innovation regarding the potential adopters. Innovations that have observable positive results after deployment are more likely to diffuse (Rogers, 2003). However, the observability of these types of innovations could potentially be a problem as research by Kapoot et al., (2014) and Tapaninen, (2009) show a non-significant effect of observability of sustainable energy systems. This makes it more relevant, in the scope of this research, to change observability to *imperceptibility* of an innovation.

2.1.3. The interconnectedness of transition and innovation theory

In conclusion, the theories of transition and innovation are intricately intertwined. When considering SWTE systems as a niche within a broader transition, particularly within the context of the Netherlands, it becomes evident that the niche must possess superior, mature, or stand-alone technological innovation. This innovation must be robust enough to ensure the smooth functioning of the entire system, as depicted in Figure 5. Only by being a superior or stand-alone technological innovation can the influence of other factors such as ecology and institutions be minimized. Otherwise, these factors will significantly impact the innovation and hinder its transition potential (van der Brugge et al., 2005).

Therefore, it is crucial to acknowledge this technological innovation, in a niche, is influenced by both the current regime and landscape levels. Situated within an inflexible context due to their interconnectivity, these levels shape the framework within which the innovation operates (Geels & Kemp, 2000; van der Brugge et al., 2005; Loorbach et al., 2007).

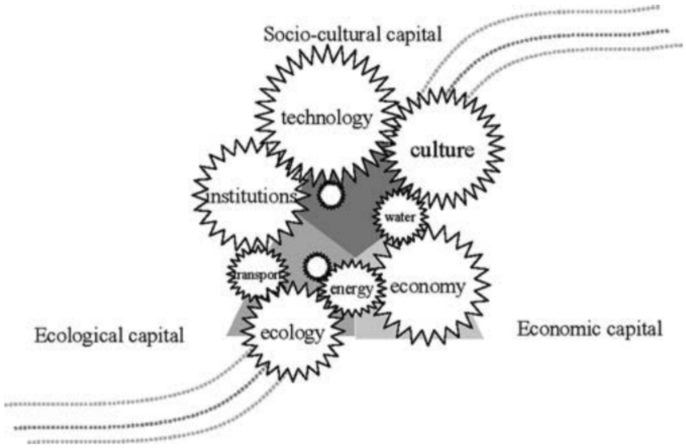


Figure 5: An illustration of how transition is a complex set of cogwheels in a metaphorical way (van der Brugge et al., 2005)

2.2. Sustainable heating of historical buildings

This subsection offers an overview of the necessity for SWTE systems by explaining the trias energetica concept. It emphasizes the significance of heating characteristics in historical buildings and delves into the definition of historical buildings within the context of this research.

2.2.1. Trias energetica

The building stock has a considerable impact on carbon emissions. Finding sustainable heating options for these buildings is critical given the goal of becoming carbon neutral by 2030. Achieving this requires a thorough investigation of the most environmentally friendly alternatives. Before delving into a potential technical solution, it is critical to take into consideration the "trias energetica" as a useful framework for evaluating energy strategies that could contribute to understanding the topic being studied.

Next to finding technologies that use renewable energy sources, it is argued to increase energy efficiency by, for example, reducing energy consumption and temperature levels of the heating demand (van Leeuwen et al., 2017). The trias energetica, a three-step implementation strategy to guide and optimize energy use in a sustainable manner, is a useful framework and is depicted in Figure 6.

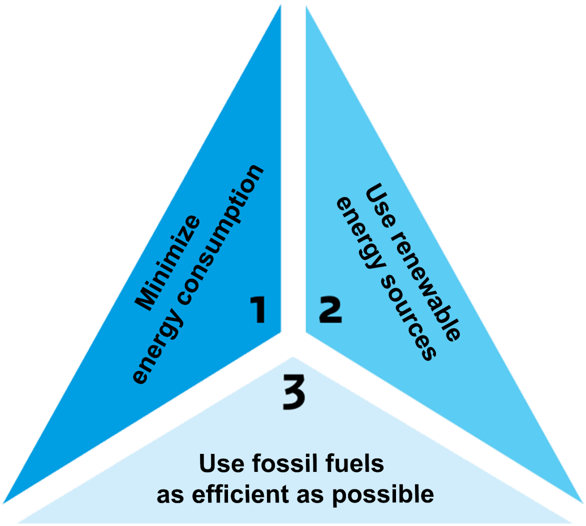


Figure 6: Trias energetica principle (Duijvenstein, 1993; Lysen, 1996; RVO, 2013; Author, 2023)

This implementation method is based on research by Duijvenstein (1993) and Lysen (1996) where Duijvenstein focuses on the 3 different steps and Lysen (1996) focused on the concepts. These 3 steps are:

1. Reduce and/or minimize energy consumption, rational use of energy
2. Use renewable energy sources
3. If necessary, use fossil fuels as efficient as possible

The transition from gas usage to potentially implementing SWTE systems for heating historical buildings can be regarded as the second step within the framework of utilizing renewable energy sources. However, prior to embarking on this second step, it is imperative to consider the initial step.

2.2.2. Rational use of energy

Other steps, related to and in parallel with step 1 of the trias energetica, are described by Cabeza et al. (2018), who argued that there are numerous ways to significantly reduce energy consumption when it comes to space heating of buildings. According to Cabeza et al.'s (2018) research, the following technical methods are primarily used to reduce the heating load of historical buildings and hence minimize energy consumption:

1. Reducing temperature differences between indoors and outdoors by adopting Adaptive Thermal Comfort principles
2. Improving the building envelope.
3. Increasing the efficiency of heating and cooling equipment.
4. Replacing the building with new construction.

According to Van Krugten et al. (2016), improving the energy performance of historical buildings can be difficult for actors while maintaining their cultural significance. Additionally, specific decision-making procedures must be followed in order to approve changes to buildings that have received heritage designation (Van Krugten et al., 2016; Erfgoedloket Groningen, 2023). Furthermore, buildings can be protected not only for their visual appearance, but also for their construction techniques and materials (Cabeza et al., 2018).

2.2.3. Historical buildings

In the context of Groningen, the municipality lists buildings as national monuments, municipal monuments, and both iconic and image-supporting buildings which should be preserved or protected over time (Gemeente Groningen, 2023; Monumenten.nl, 2023). Scientific, aesthetic, and historical importance contribute to their interest in preserving them (Gemeente Groningen, 2020). This study uses, the definition of a 'historical building' by Cabeza et al. (2018), which specifies that a building must have been constructed before 1945 to be considered as such. This is connected to the classification of the Gemeente Groningen where national monuments, municipal monuments, iconic buildings, and image supporting buildings are listed. These buildings are grouped based on their current uses which result in the following classification: residential, commercial, and public. A brief overview is shown in Figure 7 below.

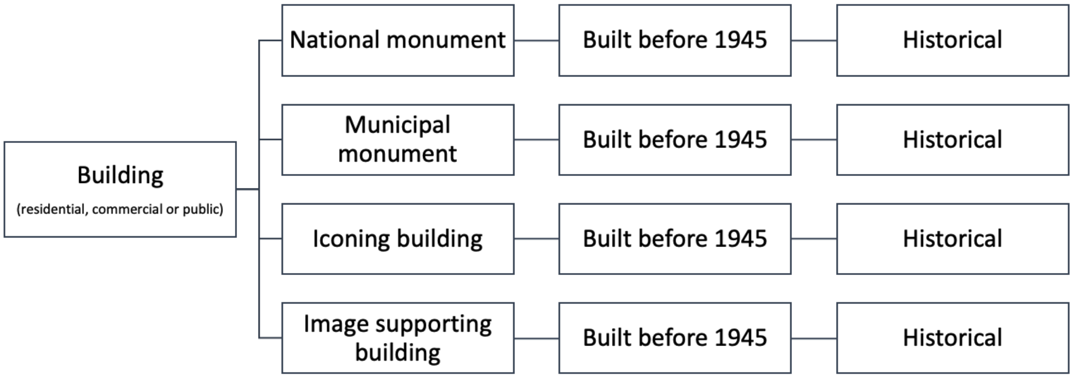


Figure 7: Overview of criteria for historical buildings (Cabeza et al., 2010; Gemeente Groningen, 2020; Author, 2023)

2.2.4. Heating historical buildings

In general, buildings, including historical buildings in the context of this research, employ heating systems to achieve and sustain comfortable indoor temperatures. These systems generate and/or transfer heat, as well as produce hot tap water (Cabeza et al., 2018). Typically, historical buildings exhibit higher energy demands for heating compared to buildings constructed after 1945, as indicated by studies conducted by Cabeza et al. (2018) and van Krugten et al. (2016). This disparity arises from the unique building typology and poor energy performance of historical buildings. Consequently, it becomes imperative for consumers to adopt sustainable heating methods for these buildings to attain significant environmental impact. In this study, "sustainable heating" refers to a technique for generating and/or transmitting heat to maintain comfortable indoor temperatures in private, public, and commercial buildings without the use of gas. To fulfill the heating requirements of historical buildings, it is essential to rely on green technologies to meet the remaining electricity demand, as suggested by Lysen (1996). However, when it comes to energy efficiency in historical buildings, challenges can arise due to the absence of mandatory energy labels, as highlighted by van Krugten et al. (2016) and Rijksoverheid (2023). An energy label ranges between A++ to G and ranks a building according to its energy performance, with G indicating very energy inefficient buildings and A++ the most energy efficient ones. This label issue becomes important when discussing the technical configurations in Chapter 2.3.2, as assumptions in literature often are made based on these efficiency labels and thus numbers.

2.3. Surface water thermal energy systems

Given the quest for covering the remaining demands of energy in a sustainable way, based on the rational use of energy in Chapter 2.2.2 (Lysen 1996; Cabezat et al., 2018)., surface water thermal energy systems could offer a potential solution. Moreover, this technology seems a promising innovation that an actor can adopt (Rogers, 2003). However, before this innovation is tested and compared to the five attributes of innovation, it is necessary to investigate whether using STWE is technically feasible for providing the heating demand of historical buildings.

To start, SWTE utilizes a water source that has a temperature within a range of 7 to 25°C. The extraction of water occurs, using pumps, primarily when the water is warm. This happens especially during summer, as well as pre- and post-season. This thermal energy is usually stored for use during winter months, which implies the use of seasonal storage. Storing this heat in a water bearing layer in the ground, known as an aquifer, is a logical choice given that aquifers are frequently used as an open-loop energy system for heat and cold storage, and the soils in many Dutch locations are suitable for this purpose because of the high porosity and permeability of sandy soils at around 100 meters deep. The concept of heat and cold storage in the subsurface is called aquifer thermal energy storage (ATES) and goes hand in hand with an SWTE system (Kruit et al., 2018; Dehens et al., 2020).

The process of harvesting energy from surface water involves, as visualized in Figure 1, the utilization of a surface water source, a pumping installation, a technical room housing a heat exchanger and heat pump, an ATES system, a heat network, and a user delivery system. Aside from extracting and facilitating heat, SWTE can also provide for the cooling demand.

Various key stakeholders play a crucial role in the operation of SWTE systems. The stakeholders that can be identified, based on Kleiwegt & de Coo (2018) are visible in Table 1 below.

Stakeholder	Role
Source provider	The water source is made available to the producer under specific conditions for extracting heat
Producer	Heat is extracted from the source by the producer. With a heat pump, the producer can directly upgrade this heat to a higher temperature and supply it to an object or a district heating network before or after it meets the ATES. The company that invests in the heat exchanger or heat pump is known as the producer. Market players such as energy producers or installation management companies, as well as water authorities or municipalities, may serve this function.
Network company	Heat and/or cold transport to the end user can be performed by a variety of stakeholders, including those in the thermal energy sector and those who are the producers and consumers themselves.
Supplier	Monitoring the functioning of the ATES, heat exchanger, and/or heat pump to ensure that the supply and demand for heat are in sync.
Consumer	Consumers are historical buildings with a shopping, public or housing function. The number of consumers, which might range from a single entity to a cluster of entities, has a large influence on the project's complexity.

Table 1: Stakeholders of SWTE systems and their roles based on Kleiwegt & de Coo (2018)

Three different categories based on Kleiwigt & de Coo (2018) and Buijze et al., (2019) are associated with the previously mentioned roles: (1) separation of producer, network company, and supplier, (2) Integrated producer-supplier relationship and a separated network company and, (3) Integrated heat supplier. This classification of stakeholders and connected categorization reveals a great number of actors on different levels and phases for the effective use of SWTE systems.

2.3.1. Thermal energy extraction

Surface water is utilized as a source of thermal energy by taking advantage of temperature differences between this water body and another medium. The process of extracting energy from a surface water body relies on basic thermodynamic principles that explain the relationship between temperature differences, or, thermal potentials, and heat transfer. To understand this energy extraction process it is essential to consider one thermodynamic principle. This principle is based on cause and effect, where any temperature difference creates an imbalance (Schmidt, 2022).

The Zeroth law of thermodynamics states that: if two systems are both in thermal equilibrium with a third system, then they are in thermal equilibrium with each other (Schmidt, 2022). Temperature is a measure that can be assigned to the thermal state of a system as visualized in Figure 8 below.

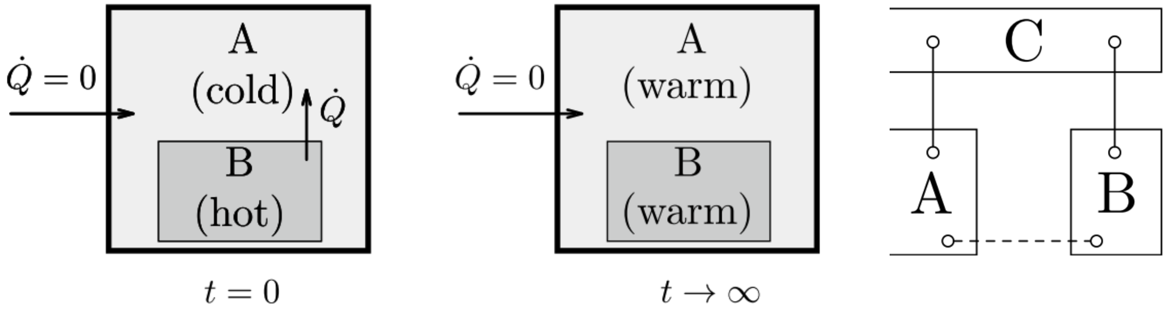


Figure 8: Visualization of two systems and heat transfer and the Zeroth law of thermodynamics (Schmidt, 2022)

This equation leads to the notion that, in the case of disparate system temperatures, systems are not in thermal equilibrium with one another resulting in the transfer of heat. In the case of an SWTE system, this transfer occurs within the heat exchanger between surface water and water in the heat exchanger.

Additionally, the amount of energy required to heat a certain volume of water by 1 °C is known as the volumetric heat capacity. This amount of energy, on the other hand, can be obtained when cooling water and then heating another system. The equation below shows how to calculate the amount of energy that is generated when transferring heat from 1 system to another just like the process within the heat exchanger (Laloui & Rotta Loria, 2020).

$$Q = m * Cw * \Delta T$$

Q = Amount of energy in Joules

m = Mass in gram

Cw = Volumetric heat capacity (J/kg*°C)

ΔT = Temperature change °C

4184 J/kg*°C is the volumetric heat capacity of water. This indicates that 4184 Joules (J) of energy has been released during the cooling of 1 m^3 of water by 1°C.

2.3.2. Technical configurations

This section delves into the technical configurations of an SWTE system and provides different options for using this technology based on available literature. It is important to mention that this technology can be used within a wide variety of different components. The most suitable option for using SWTE systems for historical buildings, based on the available literature, will be discussed, and is visualized in bold in Figure 9.

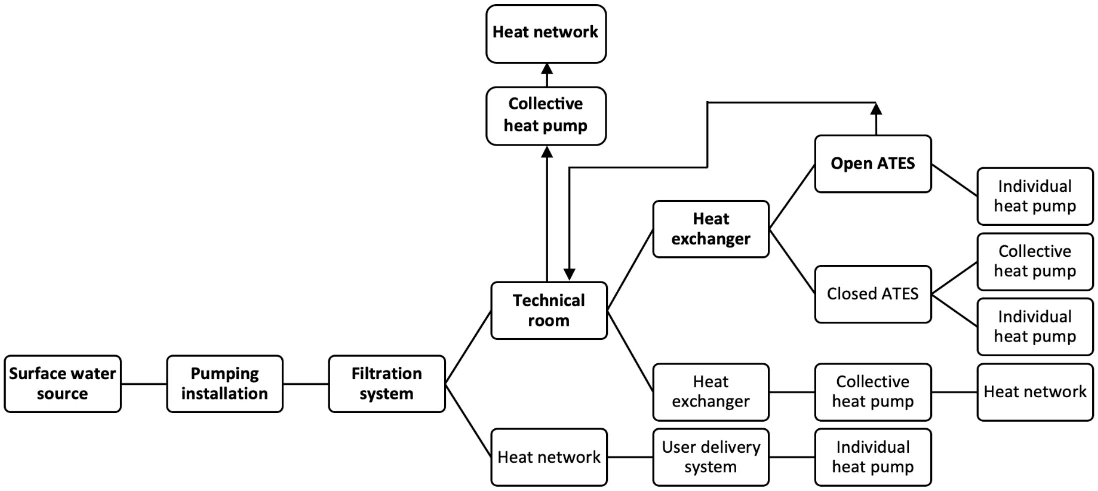


Figure 9: SWTE system and its several configurations (Dehens et al., 2020; Kruit et al., 2018; de Fockert et al., 2021)

In general, the system exists out of:

1. Surface water source
2. Pumping installation
3. Technical room
4. ATES
5. Heat network
6. Delivery system

To extract thermal energy from surface water, water is taken from the *source* (1) and discharged at a lower temperature. This water has a temperature within a range of 7 to 25°C and can be cooled down to a maximum of 6°C (Kruit et al., 2018). The water that pumped from the surface water using *pumping installation* (2) and is guided through a filter system before the next step (Kruit et al., 2018; de Jong & Dionisio, 2022). The next step can be divided into two parts. One approach involves using water directly at its current temperature, which refers to the temperature at which it was sourced and heating it with an individual heat pump. However, this option is not suitable for historical buildings due to the need to raise this temperature to a higher level. This temperature upgrade is essential for heating systems in buildings with inadequate insulation (Dehens et al., 2020; van Propering-Verkerk et al., 2021). The alternative, more suitable, second part involves the water initially encountering a heat exchanger located in the *technical room* (3) (Kruit et al., 2018; Dehens et al., 2020). In this technical room both the heat exchanger and heat pump are situated (Dehens et al., 2020). As the water cannot be directly used in summer, and heating demands are high in winter, it is a logical step to make use of a buffer system. This buffer system is the *ATES* (4). In an ATES system, thermal energy is stored by utilizing a water-bearing stratum (aquifer) in the subsurface. This aquifer is configured as a "doublet" consisting of at least one warm and one cold source. The warm source is tapped by pumping groundwater to extract heat, which is transferred to the heat pump through a heat exchanger when heat is required. Similarly, cold water is pumped from the cold source when there is a need for cooling, and the extracted cold is transferred to the heat pump through a heat exchanger. After being extracted, the pumped groundwater is warmed up and then recharged into the warm source. This ATES system is an open system, as opposed to a closed system (also known as ground loops). A closed system uses the ground's conductivity, whereas an open system pumps and uses groundwater (Dehens et al., 2020).

The captured and deposited energy must be upgraded by the use of an electric heat pump. This could be done in two ways where within the first option the heat pump is linked to a collective heating network. Alternatively, each building could use an individual heat pump where heating distribution infrastructure is necessary as well for providing it to end-users (Kruit et al., 2018). In the case of a group heat pump, a central technical room is needed where the temperature will be upgraded sufficiently before it will be distributed to users via a network controlled by for example a provider (Table 1) (Dehens et al., 2020).

The poor energy performance levels of historical buildings result in the need for a 'sufficient' supply temperature of at least 70°C in order to match the heating demand. This temperature level is called middle temperature (MT) and fluctuates between 55°C and 75°C. According to Dehens et al., (2020), this temperature level is suitable for buildings assigned with ‘approximately’ energy label D. Buildings that have other labels, meaning there is no insulation level requirement, could potentially need high temperature (HT) levels ranging between 75°C and 120°C (Dehens et al., 2020). However, this is very interconnected with the amount of energy saving measures that are possible for the historical building and is further based on step 2 of Chapter 2.2.2 (van Krugten et al., 2016; Cabeza et al., 2018). Other irrelevant temperature levels, in terms of the demand of historical buildings, are called ‘’ZLT’’ and ‘’LT’’ and can be translated to very low temperature directly from the source (between 10-30°C) and low temperature (between 30-55°C) (Dehens et al., 2020). The heat that is extracted from the surface water and stored in the ATES will be, after heating it with the collective heat pump, transferred via a *heat network* (5) to the end user(s) via a user *delivery system* (6) that transfers the heat to the existing heating network of the historical building. One important last note is, compared to the former gas use era, that this system should consist of a system that can cover peak loads or a backup system in case of anomalies, where the peak load system can cover the backup (Dehens et al., 2020).

2.3.3. Technical heat potential of surface water

According to the study of Dehens et al., (2020), the technical potential of surface water thermal energy can be seen as the potential supply that can be harnessed from a water body using existing technological capabilities.

The first step in determining the heat potential of surface water is to calculate the total volume of the local water system (1). The volume of a body of water is calculated by multiplying its depth by its surface area. This information, which is normally available from water authorities, is a critical factor for further calculations. After calculating the volume, the second step is to determine the heat potential of the surface water (2). It has been estimated that 1 m^3 of water may produce around 0.25 GJ (Gigajoules) of heat throughout a 5-month season, given a maximum temperature increase of 3°C. Calculating the overall heat potential of the surface water source, the last step (3) is to multiply the calculated volume by the heat potential per m^3 (Dehens et al., 2020).

The study conducted by Kruit et al. (2018), as mentioned in the introduction, highlights the substantial potential of energy generated by surface water. Based on their calculations, thermal energy from surface water has a theoretical capacity to exceed the whole heat demand in the Netherlands. In particular, the country's recoverable energy per square meter of sand is projected to be 0.0021 GJ/year (Kruit et al., 2018). It is crucial to note, however, that the amount of recoverable energy varies by area, varying from 5000 GJ per hectare (ha) in North and South Holland to 1000 GJ/ha in the country's eastern and northeastern regions due to the subsurface conditions related to ATES use.

Based on preliminary estimations, aquathermia can provide 12% of the national heat demand and 54% of the cooling requirements, according to a report by Kleiwegt en de Coo (2018). These statistics indicate the economic potential obtained from expected future heat demand, taking three critical elements into account: the viability of the heat demand location for a heat network, the proximity of the heat source, and the capacity of the substrate as a heat buffer.

2.3.4. Surface water thermal energy systems as an innovation

In the pursuit of a sustainable heating method, SWTE systems have emerged as a technology that could technically be used to heat historical buildings. This sub-chapter aims to evaluate the SWTE system based on Chapter 2.1.3. where the interconnectedness of transition and innovation theory has been addressed.

To start, it seems that the operation of SWTE systems involves multiple stakeholders on different levels for the effective use of the system. This implies that collaboration between lots of these stakeholders is necessary for a successful implementation of an SWTE project. This could then be regarded as something that is difficult to implement for adopters, resulting in a high degree of complexity. Moreover, unlike specific products that can be easily tested or experimented with, SWTE systems often require substantial different configurations as described in Chapter 2.3.2. This hampers individuals or small-scale consumers from directly testing this specific technology themselves, resulting in a relatively poor trialability.

Contrarily, SWTE systems exhibit a subtle visual presence and are commonly situated in technical rooms. Additionally, the process of pumping water from the surface source remains largely imperceptible.

Given the acknowledged complexity associated with stakeholders, limited trialability, and certain positive perceptions regarding imperceptibility, it is believed that SWTE systems, when evaluated as standalone innovations, may not possess complete superiority over alternative solutions. Consequently, it is crucial to gain a deeper comprehension of additional potential barriers before proceeding with empirical implementation.

2.3.5. Barriers to surface water thermal energy systems implementation

As previously discussed SWTE systems face technically speaking not that many obstacles, however, other barriers should be understood. Therefore, this section discusses the barriers that are known and relevant to the research and vital to keep in mind regarding the SWTE systems implementation. Most relevant barriers that were found are divided into (1) technical spatial, (2) social, (3), environmental, (4) economical, and (5) political barriers.

Regarding the *technical-spatial (1)* challenges, several barriers could be identified. Firstly, securing a higher temperature heat supply for historical buildings, which is necessary to maintain acceptable heating levels, is one of the most significant and challenging implementation challenges. Because the energy from the surface water source is only available at low temperatures, it is challenging to upgrade the existing heating systems and implement the necessary insulation measures to raise them to the necessary MT or HT level which subsequently costs energy (van Krugten et al., 2016; Kleiwegt & de Coo, 2018; van Popering-Verkerk et al., 2021). Secondly, in order to prevent heat loss, the distance between the source and the consumer should be limited (van Popering-Verkerk et al., 2021). Third, to maintain a continuous heat supply and to handle peak loads, most heat systems require a backup provision. Currently, natural gas or wood pellet systems are commonly used to supply this backup, resulting in potential CO2 emissions (van Popering-Verkerk et al., 2021). Fourthly, the flow rate of the surface water source should be considered during the design of the pumping installation. Standing water, which is characterized by limited or no movement, requires a larger pump, and therefore more energy is needed to guide the water past the heat exchanger. Flowing water like a river or canal that has continuous movement, can positively influence the energy that is needed for the pumping installation (Dehens et al., 2020). Fifth, the subsurface brings several challenges regarding the suitability of using an ATES system. In general, specific policies or Natura 2000 areas determine where these underground buffers can be placed. The system needs to be installed in a layer that contains enough sand, also known as an aquifer (van Popering-Verkerk et al., 2021). Sixtly, it is space below the surface could potentially be limited according to Dehens et al., (2020). Lastly in this most relevant list, prevention of thermal interference among the inlet and outlet sites is critical for the source, since it can result in an unwanted short circuit and a severe drop in efficiency. In the case of quickly flowing water, this requires placing the inlet and outlet locations upstream and downstream (Kleiwegt & de Coo, 2018).

An SWTE system cannot exist in isolation; it must be integrated into its surroundings while taking the *social* (2) side in respect. Such integration may have short-term negative consequences for people living near the project site, such as disruptions (van Popering-Verkerk et al., 2021) Subsequently, residents' active participation is critical in aquathermia projects, particularly in existing built-up regions, with diverse stakeholders, intertwined interests, and a variety of obstacles (Kleiwegt & de Coo, 2018; Popering-Verkerk et al., 2021) Obviously, the energy transition is not the only issue that neighborhoods and communities face. Because of this, the governance of SWTE systems is a social and procedural challenge (Popering-Verkerk et al., 2021).

Environmental (3) influences are present, specifically in terms of the interaction of the SWTE system with the ecosystem of the surface water or with subsurface water flows. First, the process of pumping surface water poses a potential risk to small animals such as zooplankton and fish larvae. They may be sucked into the system and suffer injury as a result of the exerted forces and temperature changes. This interaction seems most harmful for smaller or closed waterbodies compared to bigger dynamic waterbodies (de Jong & Dionisio, 2022). Secondly, if cold water is discharged, it causes a temperature difference between the intake and expelled water. When the cooled water returns into the water system, it mixes with the existing water. The degree of mixing is determined by elements such as water system size, flow dynamics, and temperature differentials. This mixing degree is critical in determining the ecological consequences of extraction from surface water (Wortelboer & Harezlak, 2020). Third, groundwater quality, temperature levels, and specific flows could potentially be influenced by ATES systems (Klewigt & de Coo, 2018). Overall, there are limitations to research on the influence of SWTE systems on the environment and further in-depth research should take place to investigate its influence (de Jong & Dionisio, 2022).

In terms of economical (4) barriers, it is widely recognized that aquathermia projects typically require substantial investments and are characterized by limited flexibility, resulting in higher costs for adaptation (van Popering-Verkerk, 2021). Specifically focusing on SWTE systems, one crucial factor for cost reduction is minimizing the distance between the heat source and the end consumer, thereby reducing expenses associated with transportation infrastructure (van Popering-Verkerk et al., 2021). Second, increasing the insulation performance of historical buildings in preparation for the use of SWTE systems brings great investment costs. This necessitates sufficient economical capacity from various types of customers. Moreover, variables such as soil composition and customer energy demand influence the economic feasibility of the ATES system (van Popering-Verkerk et al., 2021). Additionally, the depth of the sand layer in the subsoil has an impact on the economical viability of an ATES system, with deeper locations in the aquifer zone being less economically feasible (Dehens et al., 2020).

In relation to the *political* (5) barriers, there are specific challenges highlighted by Buijze et al. (2019). When a collective heat supply system is implemented and construction activities are involved, adherence to relevant regulations, such as environmental laws, becomes crucial. With regard to the extraction and discharge of surface water, there are specific regulations to consider. It is essential to obtain permits when the quantity of extraction exceeds 100 m^3/h and the discharge exceeds 5000 m^3/h. It is important to note that the discharged surface water should not be contaminated and must not contain any waste materials, pollutants, or harmful substances. The last relevant requirement is that the discharge should not result in a deterioration of water quality (van Popering-Verkerk, 2021).

2.4. Multi-criteria decision analysis

The multi-criteria decision analysis in Figure 10 below presents the conflicting criteria that are expected to be related to the technical spatial potential of SWTE systems, based on previously discussed theory. A division between supply and demand is made enabling an extensive evaluation of the technical spatial potential of SWTE systems by taking into account both the criteria related to the supply and demand

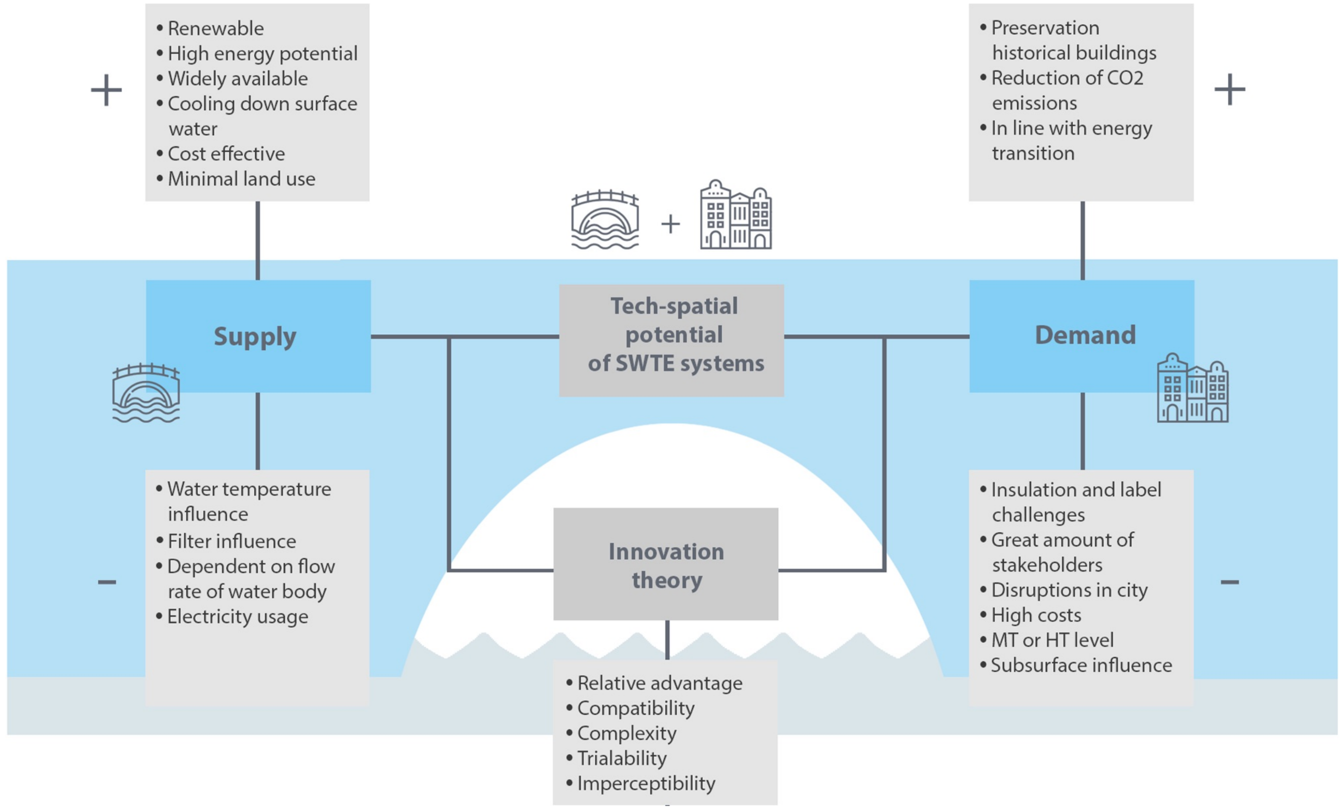


Figure 10: The multi-criteria decision analysis, that also serves a conceptual model (Author, 2023)

2.5. Expectations

This research focuses on how SWTE systems enable sustainable heating of historical buildings using canal water in the city center of Groningen. The expectations are that SWTE energy systems are technically viable to heat historical buildings. However, difficulties will be faced regarding the additional insulation measures that are needed in historical buildings. Additionally, the number of stakeholders involved and the willingness to adapt to such systems will bring problems regarding widespread implementation. Finally, alternative sustainable technologies such as green gas could negatively influence the development of SWTE systems.

3. Methodology

This chapter will present the methodology of this research. First, the research design is explained and visualized. Second, the case study of this thesis is introduced. Third, data collection methods will be examined. Fourth, the analysis methods utilized will be discussed. Finally, the ethical considerations pertaining to this methodology will be presented.

3.1. Research design

Data is obtained via six different sources: desk research, open interviews, a literature review, semi-structured interviews, participant observation, and a test case analysis. Using this variety of methods, the author can strengthen the validity of research findings (Clifford et al., 2010). The findings of the desk research help to gain insights and preliminary answer sub-questions 3, 4, and 6. Additionally, it provides input for the semi-structured interviews and the creation of the code tree later in the research phase. Information gathered from the participant observation serves as input for answering sub-questions 3, 4, and 5. Interview answers that are gathered via the semi-structured interviews provide the rest of the information needed to answer sub-questions 3, 4, 5, 6, and 7. This all is done in a cyclical pattern, visible in Figure 11, where continuous adaptation takes place.

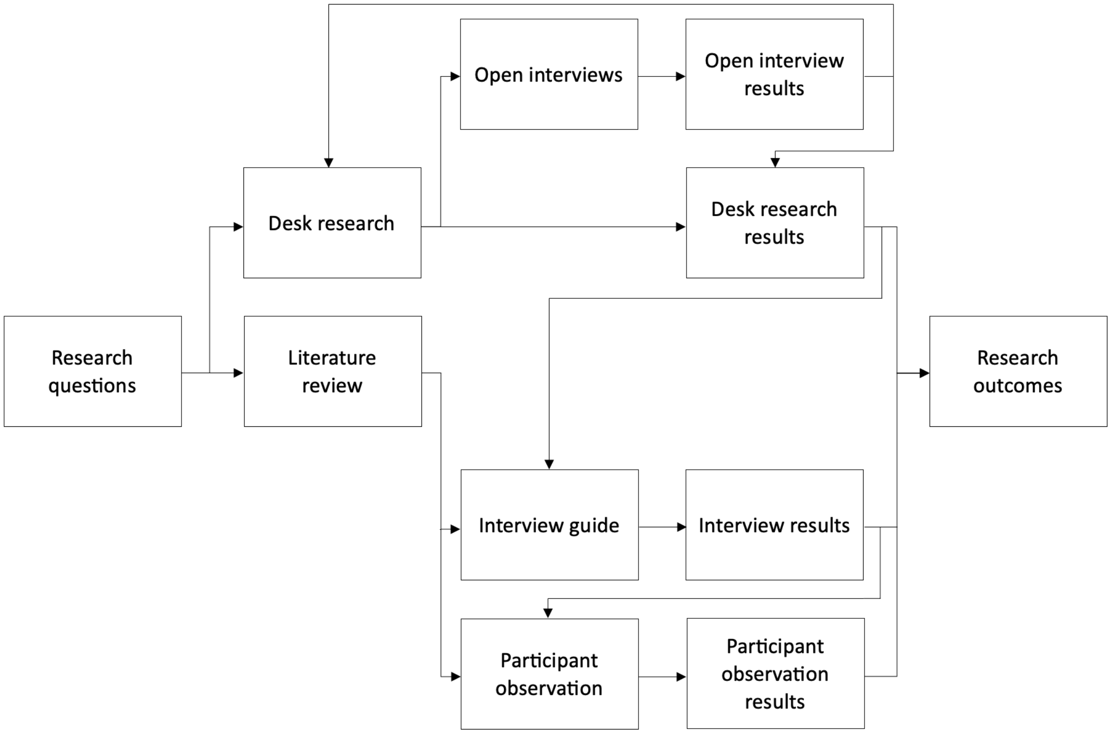


Figure 11: Schematic overview of the research design (Author, 2023)

3.2. Case study approach

This research adopts a case study approach, that according to Simons (2009), can be seen as an in-depth examination from different points of view of the complexities and uniqueness of a specific project, policy, institution, program, or system in a real-life context. The in-depth examination of a specific project makes a case study approach a suitable method for this research. By zooming in on the city center of Groningen the potential implementation of a SWTE system can be examined from different points highlighting complexities and uniqueness Additionally, next to the general case, this research uses an embedded case to examine the potential of a project in a real-life context. These findings can serve as a valuable resource for connecting additional historical buildings to SWTE systems. Moreover, these results can offer important insights and lessons to other Dutch municipalities that find themselves in earlier stages of the heat transition process. By sharing this information, municipalities can benefit from the knowledge gained and apply it effectively to their own contexts, accelerating their progress in adopting SWTE systems and achieving sustainable heating solutions for historical buildings (Lincoln and Guba, 1985).

3.2.1. Case selection

The municipality of Groningen is unlike other municipalities in the Netherlands, determined to become gas free by 2035 (Gemeente Groningen, 2021). These set targets for 2035 differ compared to the national goal of becoming carbon neutral in 2050. Moreover, Groningen was the first municipality in the Netherlands that presented its heat transition plan combined with explaining how the set targets will be reached.

The Province of Groningen had an early ambition, compared to the publication of the heat transition plan, to make the provincial government building more sustainable (Spie, 2023). The project, completed in 2021, focused on disconnecting the provincial government building from gas infrastructure. This partly historical building faced difficulties regarding insulation. However, nowadays the building is solely heated using heat pumps in combination with an ATES system and water from its city canals (Provincie Groningen, 2021).

The preferred hybrid heating systems of the municipality, the frontrunner role of the province, and a specific SWTE project used to heat a historical building makes the city of Groningen a relevant case to explore.

Additionally, an embedded case is chosen, serving as an indicator to show the heat potential of city canals. For this case, the Academy Building is chosen as it is the largest historical building of the University of Groningen located in the city center. Therefore, it could be a potential user of an SWTE system. Moreover, this specific building has the greatest heating demand of all historical university buildings in the city center making it valuable to highlight the potential match between the supply and demand.

3.2.2. Case descriptions

The city of Groningen is located in the Northern part of the Netherlands and surrounded by canals visible in Figure 12. The exact study area that is being examined chosen is visualized with a black line in Figure 14 below.

Figure 13: Groningen and its city canals at De Lage der Aa (Author, 2020)

Figure 12: The Academy Building (Discover Groningen, 2020)

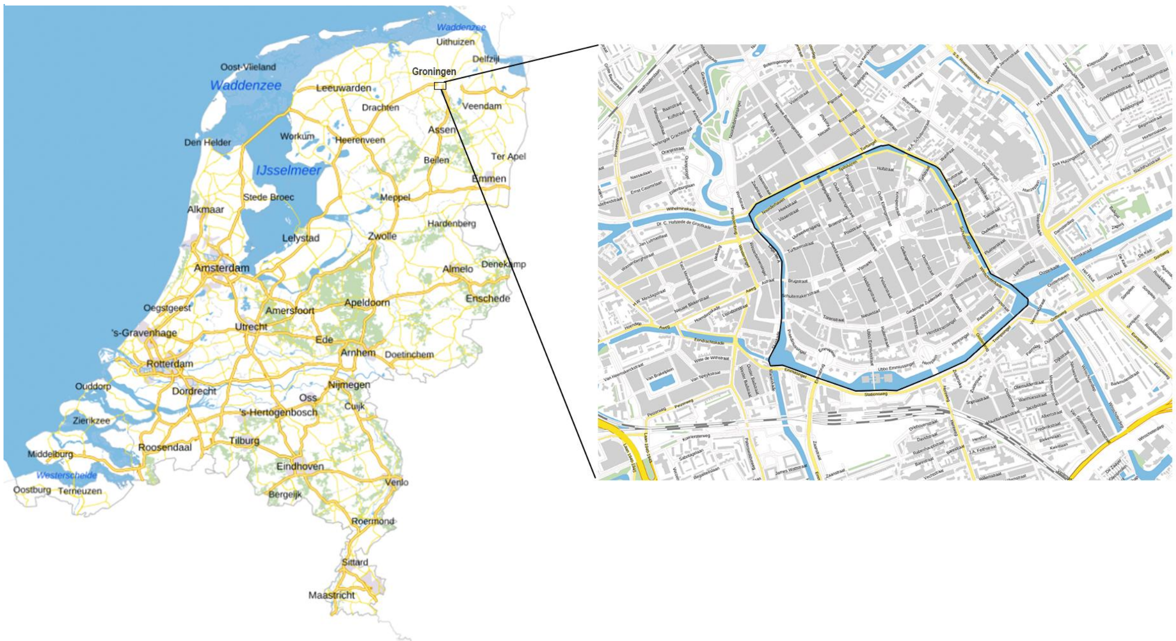


Figure 14: Map of the Netherlands with a close-up of Groningen (r) and the selected area with historical buildings (PDOK, 2023; Author, 2023)

Based on the equation of the heat capacity in Chapter 2.3.1 and the identified barriers in Chapter 2.3.5, it is relevant to highlight the information, visible in Table 2 and Figure 15, about the flow rate, volume (depth and width of the canals) temperature levels of the surface water. This information is gathered via secondary data gathering and is not publicly available (BRIES Energietechniek, 2020; *M*4. (March 3, 2023). Personal interview). Regarding the temperature levels, it is estimated that, given the legal constraints by Kruit et al., (2018) of cooling the water, extraction can occur above 15°C. The cumulative temperature visualized in Figure 15 shows that this is the case for 36% of the time in a year, resulting in 130 days of potential water extraction.

Flow rate	**Depth**	**Width**	**Surface**	**Volume**	**Temperature**
1000 m^3/h*	1.5 m (average)	20 m (average)	Variable	Variable	130 days above 15°C

Table 2: Information about the flow rate, depth, width, and temperature of the surface water (BRIES Energietechniek, 2020; M4. (March 3, 2023). Personal interview)

* If the Dorkwerd pumping station operates during the summer season at a rate of 3 m^3/s, the Turfsingel experiences a significant flow rate reaching approximately 1000 m^3/h (BRIES Energietechniek, 2020).

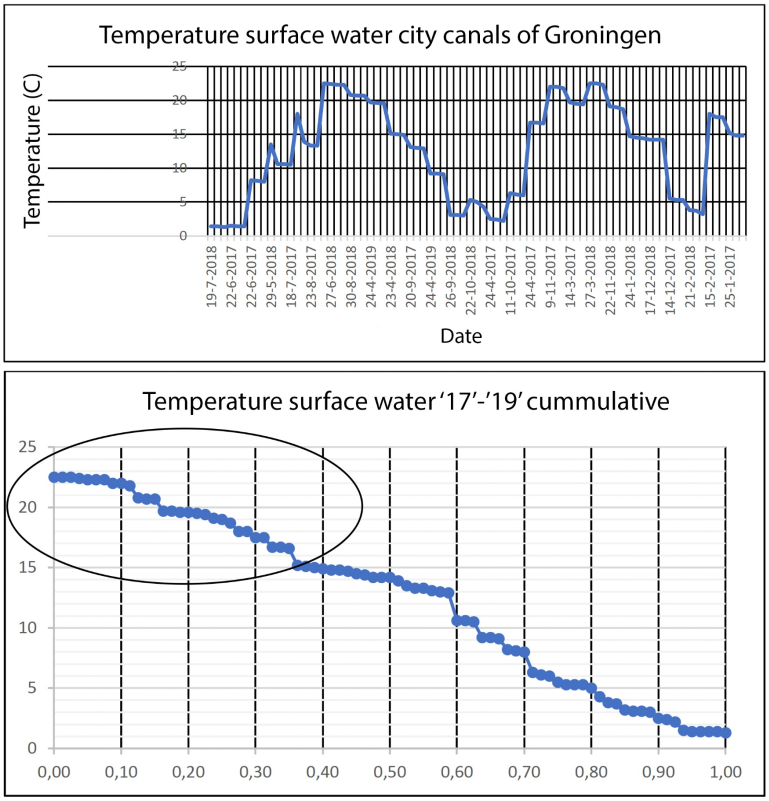


Figure 15: Temperature levels of all measurement points including a cumulative visualization (BRIES Energietechniek, 2020; Author, 2023)

The main building of the University of Groningen is the Academy Building and serves as the central hub for thousands of students. The present-day Academy Building was built in 1909 and is visualized in Figure 14 (Discover Groningen, 2020).

3.3. Data collection methods

Table 3 presents an overview of the sub research questions and methods utilized to answer these questions, followed by a detailed explanation of the methods that are employed. Sub-questions 1 and 2 focus on theory while the remaining questions focus on the empirical aspects.

Research question	**Method**
SQ1: How can surface water thermal energy systems be conceptualized from a combination of an innovation and transition theory perspective?	Literature review
SQ2: What is the current state of the technology used to extract thermal energy from surface water systems based on a literature study?	Literature review
SQ3: How do surface water thermal energy systems empirically operate?	Desk research, semi-structured interviews, participant observation
SQ4: What are necessary technical and spatial conditions that need to be met to effectively use surface water thermal energy systems to heat historical buildings?	Desk research, semi-structured interviews, participant observation
SQ5: Who are the key actors and stakeholders involved in the implementation and operation of surface water thermal energy systems?	Literature review, semi-structured interviews
SQ6: What can be learned from the perspectives of relevant stakeholders regarding the use of surface water thermal energy systems to heat historical buildings focusing on opportunities and barriers?	Desk research, semi-structured interviews, participant observation, test case analysis
SQ7: What lessons can be learned from the potential implementation of surface water thermal energy systems in Groningen?	Semi-structured interviews, participant observation, test case analysis

Table 3: An overview of the used research methods per sub-question

3.3.1. Desk research

Desk research consists of gathering preexisting data, which was originally collected for a different purpose, but is accessible for others to utilize (White, 2010). By gathering this data, the researcher is able to further formulate the specific focus of the research and justificate specific choices. Data that is collected within this desk research provides a basis and context for the later, more intensive, research (White, 2010). Sub-questions 2, 3, 4 and 5 will all be partly answered with findings from the desk research. Sub-question 3 explores how SWTE systems empirically operate, making it a useful approach with regard to this question. Several maps, figures, publications, and tools will be used. After drawing insights from these the author understands the importance of seeking additional knowledge to delve deeper into the subject matter. As a result, the author uses an open interview question list (Appendix A) that is emailed to respondents selected based on their contribution to relevant research papers. These papers were mainly found while doing desk research. The question list contains questions focusing on the vision of the respondents about utilizing SWTE systems to heat historical buildings. These specialists are authors from several publications (Kruit et al., 2018; Dehens et al., 2020; van der Meulen, 2023). Other specialists are found via LinkedIn and are advisors from a private firm and the water authority of Hunze and Aa's. An overview of the e-mail respondents is given in Table 4 below.

Respondent	**Function**	**Company**	**Medium**	**Date**
M1	Advisor Geothermal Energy and Aquathermia in the Energy Transition	VHGM	Mail and phone	16-01-2023 and 20-01-2023
M2	Advisor	Deltares	Mail	16-01-2023
M3	Advisor	CE Delft	Mail	16-01-2023
M4	Policy advisor	Water authority Hunze en Aa’s	Mail	03-03-2023
M5	Advisor	NAT	Mail	14-04-2023
M6	Advisor energy transition	Gemeente Groningen	Mail	17-04-2023

Table 4: Overview of the e-mail respondents

These answers result in the use of tools that help to further understand the potential of an SWTE system. An application is employed as the initial tool to facilitate the identification of available local surface water resources for authorities and aquathermia project developers. This aquathermia potential map, developed by the heating collective "WarmingUp," provides users with access to a data viewer (WarmingUp, 2023). The second tool that is used is created by The Netherlands Organization for Applied Scientific Research and is called ‘Dinoloket’. This tool enables users to make a cross-section with all of the subsurface layers based on several measurements. This can provide a preliminary assessment of the feasibility of utilizing ATES systems at specific locations (TNO-GSN, 2023a).

As part of the desk research strategy, an embedded test case analysis is conducted that involves an indicative calculation. This calculation aims to assess the feasibility of using aquathermia systems to meet part of the energy needs of the university. To accomplish this, the formula from Chapter 2.3 is utilized, and the tools from WarmingUp (2023), TNO-GSN (2023a) and information provided by the water authority. Additionally, information provided by BRIES Energietechniek (2020) and Nijeboer-Hage (2019) is used.

3.3.2. Literature review

Data from several academic journals and research organizations are critically reviewed. A literature review allows to identify gaps, trends, and key discoveries in the field by examining earlier studies, theories, and scholarly works. This process helps in placing this research within the larger academic landscape (Knopf, 2006). The results of this review can be found in Chapter 2 of this research and will provide results to sub-questions 1, 2 and partly sub-question 5. Answering sub research question 2 with this step is vital because first theoretical barriers need to be identified prior to answering the next sub research questions focusing on the empirical operation and a concrete case. Databases like SmartCat and Google Scholar are used to search for academic papers. Furthermore, research reports from other research organizations such as CE Delft, Deltares, and Netwerk Aquathermie (NAT) are included.

3.3.3. Semi-structured interviews

To answer sub-questions 3, 4, 5, 6, and 7, semi-structured interviews are being conducted. A semi-structured interview is a verbal interaction where the interviewer seeks information from another individual by asking an array of questions. While the interviewer prepares a list of predetermined questions, these interviews take on a more conversational tone, allowing participants to delve into subjects that they think are essential (Longhurst, 2010). To get a great overview of information, the PESTEL framework is used serving as inspiration for developing the questions.

Participants for the semi-structured interview, as shown in Table 5, are chosen based on the relevant functions and roles identified in Table 1. These include the engineer responsible for designing the heat system at the provincial government building, a geohydrologist that collaborated with the engineer on this project, an advisor of the municipality focusing on energy transition projects, the university real estate manager, and representatives from NAT and advisory groups. The engineer's input provides information on the SWTE system's technical feasibility and operation. The practical knowledge of the geohydrologist assists in evaluating the potential and limitations of the surface water source. The municipal advisor provides information on technical, regulatory, and policy matters. The real estate manager offers insight into the practical concerns and potential obstacles associated with adopting the system as a potential customer. Representatives from NAT and one advisory organization contribute by sharing their knowledge of recent developments and best practices. The insights gained from these diverse participants collectively strengthen the research with an extensive understanding of the many variables and challenges connected when considering the employment of SWTE systems. The interview guide can be found in Appendix B.

Respondent	**Function**	**Company**	**Link with Table 1 (Kleiwegt & De Coo, 2018)**	**Medium**	**Date**	**Duration**
R1	Ingenieur	Nijeboer Hage	-	In-person	30-03-2023	60 mins
R2	Geohydroligist	BRIES	-	In-person	18-04-2023	60 mins
R3	Advisor	Dunea, NAT	Source provider	Google Meet	20-04-2023	50 mins
R4	Advisor	WarmteStad	Network company, supplier	In-person	23-04-2023	50 mins
R5	Manager	Vastgoedorganisatie RUG	Consumer	In-person	02-05-2023	40 mins
R6	Advisor Energy transition	Gemeente Groningen	Source provider, consumer	In-person	16-05-2023	40 mins
R7	Advisor	NAT	-	Google Meet	16-05-2023	60 mins

Table 5: An overview of interviewees of the semi-structured interview, based on (Kleiwegt & De Coo, 2018)

3.3.4. Participant observation

This study is additionally acquiring insights into the operation of the SWTE system through a guided site visit conducted at the provincial government building. The collaboration of R1 and the building manager facilitated the implementation of this participant observation. This entails the participation and observation of a project or phenomenon where field notes, photographs, sketches, or video recordings are used for data collection. This method is being employed because it can help improve understanding of the setting and increase validity (Kawulich, 2005). Notes and photos are being taken, and when specific components are relevant, questions are being asked.

3.4. Data analysis

3.4.1. Analysis of desk research

To analyze the different components of the desk research several steps were taken. First, the author used an organized method for assessing the emails' content. The author will carefully read each mail answer, looking for repeating themes, patterns, and ideas. The author summarizes the emails' main conclusions using the results of this analysis. To ensure that these results are properly incorporated into the broader analysis and interpretation, findings are recorded in multiple overview tables and a notebook that can be found in Appendix D. Second, an embedded case study calculation is conducted to estimate the potential of the heat the canals can provide for the university buildings. The calculation uses a formula, based on Chapter 2.3, taking into account parameters such as the temperature and the heat demand of the university buildings. This allowed for an indicative assessment of the compatibility between the available canal water supply and the buildings' heating demand.

3.4.2. SWOT analysis of semi-structured interviews

The ''Dictafoon'' software from Apple is used to record each of the semi-structured interviews. The recordings are converted into Word transcripts, and ATLAS.ti software is used to conduct the analysis. The interviews are analyzed using both inductive and deductive coding (Fereday & Muir-Cochrane, 2006). First, the deductive codes are developed through the key concepts that are aligned with the multi-criteria decision framework and are based on a SWOT analysis as shown in Table 5. This SWOT analysis allows for an evaluation of internal and external factors regarding the strengths, weaknesses, opportunities, and threats identified through the interviews (Namugenyi et al., 2019). In order to capture the variety and complexity of this data, inductive coding is then applied. According to Linneberg & Korsgaard (2019), this arrangement kept structure from the start of the study while yet allowing for a more inductive method later on. Table 5 provides a summary of the deductive codes in use, derived from the conceptual model in Figure 10. Appendix CI and CII list the added inductive codes in a code tree representation.

Side	Theme	Code	Link with theory
Supply	Strengths	Renewable	(Kruit et al., 2018; Dehens et al., 2020)
		High energy potential	(Kruit et al., 2018; Dehens et al., 2020)
		Availability	(Kruit et al., 2018; Dehens et al., 2020)
	Weaknesses	Flow rate dependency	(Dehens et al., 2020).
		Electricity usage	(van Krugten et al., 2016; Kleiwegt & de Coo, 2018; van Popering-Verkerk et al., 2021)
	Opportunities	Cost effective	(Nijeboer-Hage, 2019)
		Minimal land use	(BRIES Energietechniek, 2020)
		Cooling down surface water	(BRIES Energietechniek, 2020)
	Threats	Water temperature influence	(Buijze et al., 2019; Wortelboer & Harezlak, 2020; de Jong & Dionisio, 2022)
		Filter influence	(Wortelboer & Harezlak, 2020; de Jong & Dionisio, 2022)
Demand	Strengths	Preservation	(Cabeza et al., 2018)
		CO2 reduction	(Kruit et al., 2018; Dehens et al., 2020)
	Weaknesses	Insulation and label challenges	(van Krugten et al., 2016; Cabeza et al., 2018)
		Stakeholders	(Kleiwegt & de Coo, 2018; Buijze et al,. 2019)
		MT or HT level	(van Krugten et al., 2016; Kleiwegt & de Coo, 2018; van Popering-Verkerk et al., 2021)
	Opportunities	In line with energy transition	(Kruit et al., 2018; Dehens et al., 2020)
	Threats	Subsurface influence	(Kleiwegt & de Coo, 2018; Dehens et al., 2020; van Popering-Verkerk et al., 2021)
		Disruptions	(Popering-Verkerk et al., 2021)
		High costs	(Dehens et al., 2020; van Popering-Verkerk, 2021)

Table 6: Deductive code scheme with connected literature

3.4.3. Analysis of participant observation

The participant observation is analyzed twofold. On the one hand, notes that are written down will be analyzed, if necessary, based on the code tree visible in Table 5. On the other hand, photos that will be taken are going to be used to strengthen interviews and refer to the technical side and feasibility of an SWTE system.

3.5. Research ethics

This study places a high value on ethical issues, with a special emphasis on privacy. Participants involved in the semi-structured interviews are provided with comprehensive information regarding their rights before engaging in the interview process (see Appendix B). They were informed that participation was entirely optional and that they had the right to revoke their consent at any time without giving a reason. Participants were also given the assurance that only the supervisor would have access to their identities, which will remain anonymous. All interviewees acknowledged and agreed upon these rights. The interview data was safely stored in a Dropbox folder. Similar rights and safeguards were explained to and approved by the concerned parties before beginning participant observation. Additionally, participants' explicit approval was requested before taking and using their photos in the research report.

4. Results

This chapter presents the empirical findings of the research, which were obtained through desk research, open interviews, and semi-structured interviews with key stakeholders and advisors. These findings will be presented alongside relevant data, analysis, and information that address sub-questions 3, 4, 5, 6, and 7. The first section discusses the preliminary input data considering the empirical operation of SWTE systems. The second section focuses on the technical spatial conditions for using an SWTE system to heat historical buildings. This will consist of both design and construction conditions, as well as a description of an existing operating SWTE system. The third section identifies the key actors and stakeholders involved. In the fourth section, an analysis will be conducted regarding the strengths, weaknesses, opportunities, and threats related to the demand and supply of SWTE systems. Finally, the case of Groningen will be examined, highlighting the opportunities and barriers to the potential implementation of SWTE systems. This analysis will include the outcomes of the test case analysis.

4.1. Input data of empirical operation SWTE systems

This section briefly presents the preliminary findings that were gathered through desk research, to preliminary answer research question 3: ''How do surface water thermal energy systems empirically operate?''. These results from the desk research gave input for later research steps as the interview guide and general research outcomes, as visualized in Table 12.

In general, desk research respondents were enthusiastic and interested in the research. Some were very critical regarding the technical feasibility of an SWTE system to heat historical buildings, others thought it would be feasible with some adjustments or effort. To start, M2 explained that it is vital to connect an SWTE system to an ATES installation to store the heat. Moreover, this system is seen as an expensive one and it is only possible to heat historical buildings when there is a sufficient amount of demand. Overall, M1 made it clear that it is practically feasible, but the demand aspect could hamper implementation.

> *''Aquathermia with surface water as a source is feasible, only when there is sufficient demand''. (M1)*

This notion was supported by the response of M3 who stated that the scale of a project influences the feasibility of such a project. According to M3, the focus in this case should be on economies of scale. Contradictory, M5 was not positive about the use of an SWTE for historical buildings:

> *''This will be hard to implement''.* (M5)

Moreover, M2 stated that the potential of the surface water source can cover the energy demand of historical buildings, however, it could be challenging to match the system with historical buildings. Additionally, M3 talked about the measures that could be taken to match an SWTE system with historical buildings. M3 stresses that the supply temperature needs to be high enough to cover the demand of a historical building. In order to decrease this HT demand, every small step regarding insulation of a historical building, despite restrictions, is a valuable contribution that was mentioned by both M3 and M5. Among other noticeable responses was the statement M1 made:

> *''Because the water needs to be upgraded in terms of temperature, there should be sufficient space for the placement of a heat pump'' (M1).*

This heat pump can indeed be placed within the historical building resulting in the individual use of a heat pump. The other option would be something on a district level, however, distribution should then be regulated centrally. This was supported by M6 who believes in a future use of a collective heat network for the existing building stock. Additionally, M3 made a relevant notion regarding the technical-spatial scope of this study regarding the available space in the subsurface of a historical city. This should definitely be taken into account considering a potential implementation of a heat network or other infrastructure below city streets

Both M1 and M6 tipped the author regarding the need to conduct a test case analysis and how that possibly would look like. Several tools and tips, as mentioned in Chapter 3.3.1, were provided regarding the collection of relevant data on the city's canals

Finally, the final comment of M3 seemed positive about the found research gap.

> *''Seems like a charming circular idea for municipalities to utilize canal water for their own city center! If you can position it well in comparison to alternatives and assess the technical feasibility, I'm very curious about the opportunities'' (M3).*

4.2. Necessary technical spatial conditions for an SWTE system to heat historical buildings

This section will delve deeper into how SWTE systems empirically operate and added to the preliminary findings gathered via the desk research presented in Chapter 4.1. These empirical findings have been observed twofold, on the one hand, the engineer and geohydrologist that designed the SWTE system of the provincial government building were interviewed. On the other hand, the author made a guided visit to the basement of the provincial government building where the heating system is situated, gaining results via participant observation.

Later a PowerPoint presentation (Nijeboer-Hage, 2019), a performance rapport (Spie, 2023), and the permit application (BRIES energietechniek, 2020) were sent. These provided additional information about the project and will be addressed as well. Therefore, this section will provide answers to sub-question 3: ''How do surface water thermal energy systems empirically operate?''

4.2.1. Design and construction conditions

To start, the provincial government building consists of two parts: one well-isolated and relatively new building, and one historical part that is, due to restrictions, poorly insulated. This section will focus on the historical part of the building.

According to R1, the building already had two wells that were connected to the groundwater system 100 meters below the surface. Because there has always been an imbalance, these wells were never used. However, these could be transformed for the use of an ATES. This showed that drilling new wells for an ATES was not necessary in this case. The scan that was made before construction showed that the heating demand (around 800 Mwh as visible in Figure 15) for the historical part of the building required HT. According to R1 and the presentation, the first point of the trias energetica explained in Chapter 2.2.1, reducing the energy demand was not relevant, and *''out of scope'' (R1)* because of the strict building permits. This can be explained by the historical status of the building as it is classified as a municipal monument.

Following the statement of R1 regarding the motivation of the chosen system it becomes clear that next to covering the heat demand, also a political motivation was at hand.

> *''The provincial government building wanted to cut back gas and make a statement about this''. (R1)*

The results of the scan further showed that there was an 800mW gap to fill, as visible in Figure 16 below. Options to cover this gap in the supply of the heat demand of the building were: the use of hydrogen, air heat pumps, and an SWTE system. However, the first two mentioned options proved to be less suitable, compared to the implementation of an SWTE system to fill this gap. Therefore, the advice of (R2) was asked when the decision was made to install this SWTE system.

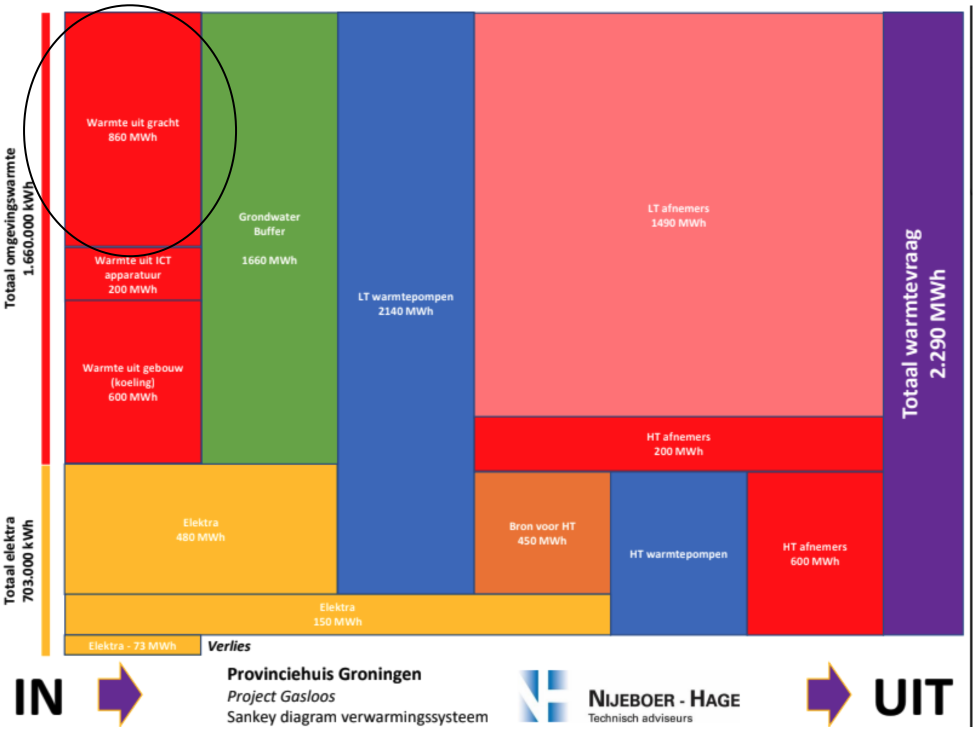


Figure 16: Yearly energy demand of the Provincial Government

The newly constructed situation zoomed in on the heating of the historical part, consisting of a heating system, partly fed with water from a surface water source at the Turfsingel, with an ATES and 4 heat pumps providing low-temperature heat. Before the hot water flows from these heat pumps to the booster heat pumps, it is stored in a buffer for LT. Afterward, the water meets the HT booster heat pumps, and after another buffer tank, the water will be distributed to the heat network of the historical building. This is all visible in Figure 17 where existing components are connected to the division made in Chapter 2.3.2. Components 1, 2, 3, and 4 are similar to the identified components in Chapter 2.3.2. A difference in this case is that the technical room (3) is divided into multiple rooms often situated in the basement of the building, consisting of two separate rooms for the low- and high-temperature heat pumps, and one room with a heat exchanger. This shows that some serious space is needed for the operation of this system. Only component 6 differs as a consumer delivery system is irrelevant because of the individual use of the heat of this system and is therefore not visible within this system.

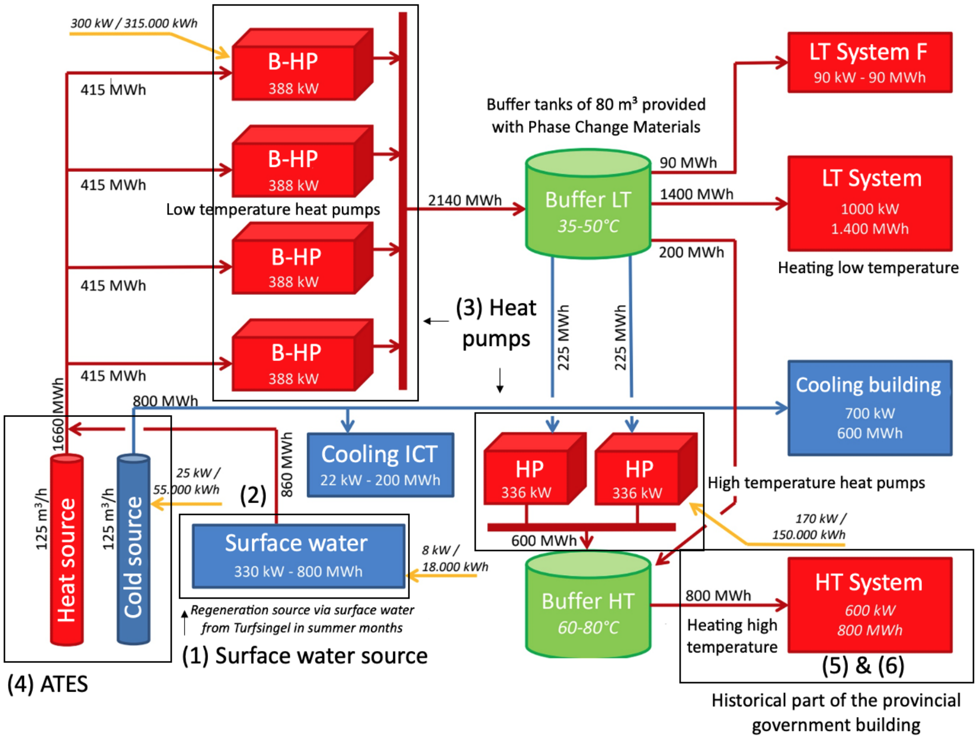


Figure 17: The heating and cooling system of the Provincial Government building

4.2.2. Operation of the system at the provincial government building

This section will briefly describe the identified components of the SWTE system at the provincial government building, their technical functions, and the spatial implications in, around, and below the building.

Starting with the surface water source (1), located at the city canal between the quay wall and a houseboat. The inlet, which consists of an intake basket where water meets the first filter, is placed on the left side, and the outlet beneath the Sint Jansbrug. This is visible in Figure 18 where the pipes placed below the water level can be found.

Additionally, the surface water is pumped through the pumping installation, approximately located in Figure 17 at location (2) and placed in a separate basement next to the Turfsingel (Figure 19). Between the pipes of this pumping installation, several rubber components are mounted preventing any additional vibration influence on the system.

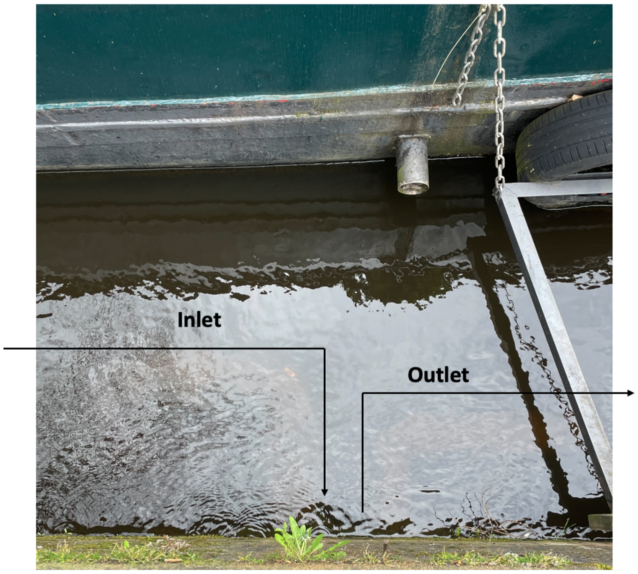


Figure 18: The inlet and outlet of the surface water source (Author, 2023)

Figure 19: The pumping installation (Author, 2023)

As said, different than the configuration discussed in Chapter 2.3.2, the technical room (3) is divided into multiple rooms consisting of an additional filtration system, heat exchangers, and a low-temperature heat pump, providing the heat for the both non-monumental and monument side of the provincial government building and a high-temperature heat pump. After the water is pumped, it meets the second round of filtration before meeting the heat exchanger as visible in Figure 20 below. This filtration device needs maintenance once or twice a year to clean and empty filters. After that, the water will be pumped into the ATES system (4) of the building. Important to note is that it became apparent that a spare component, that is submerged into the production (hot) well of the ATES installation, was stored to prevent disruptions of the system in case of malfunction.

Figure 21: The filtration system

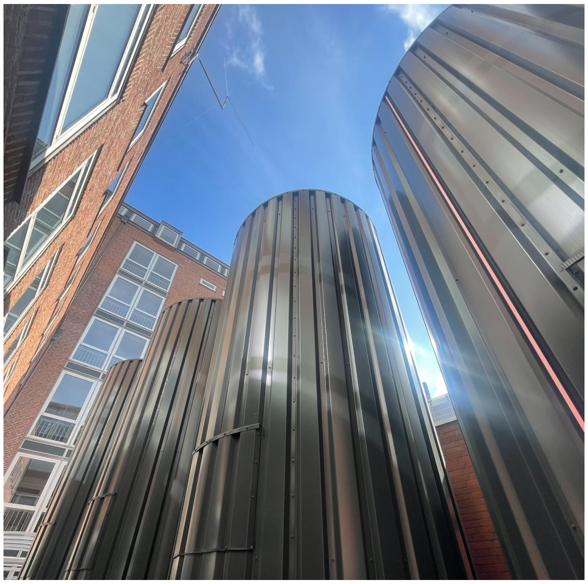


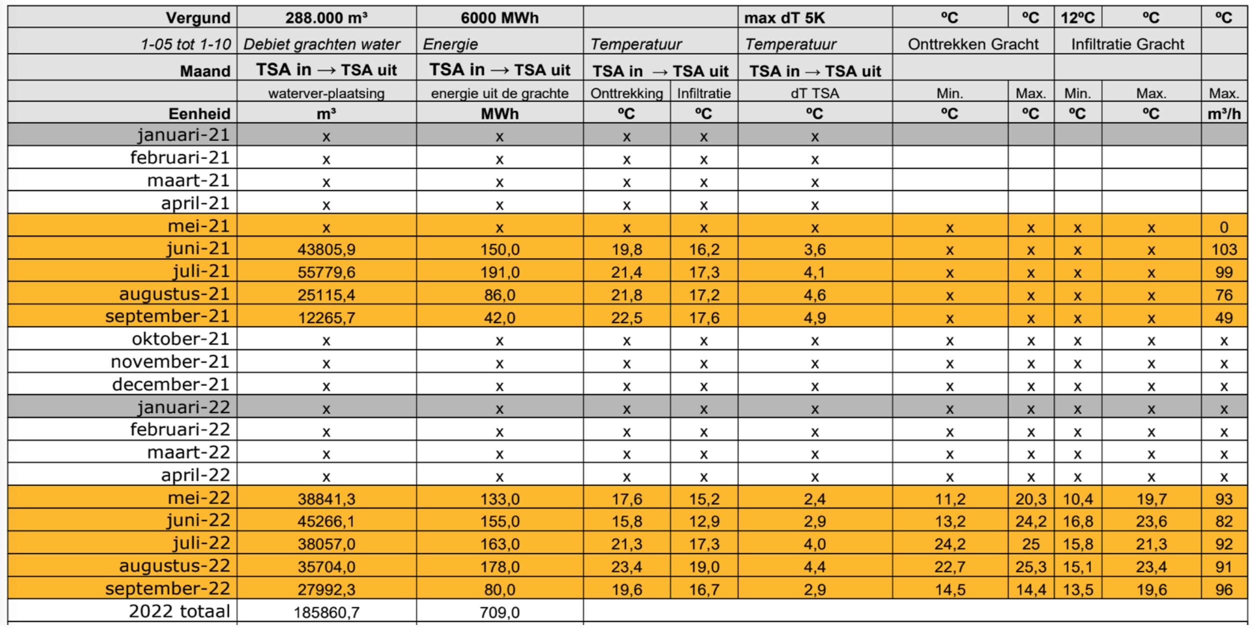
Figure 20: The buffer tanks

After pumping the water from the ATES well and upgrading the temperature to 50°C, the water is pumped towards the high-temperature heat pump where it will be upgraded to a temperature of approximately 90°C. After that, it is stored in buffer tanks that are placed outside of the building and visible in Figure 21. After this the water is ready to be pumped into the heat network (5) of the building to serve the heat demand of the municipal part.

To add, one specific question was asked on-site regarding interesting findings. The author noticed an enormous network of pipes with a lot of insulation around them (Figure 22). The question focused on possible losses of heat within this network. It became clear that only 2% of heat is lost within the whole system, which was told to be very low.

Figure 22: Pipe network with insulation

Finally, the author received a performance report of the surface water installation at the provincial government building that is visualized in Table 7 below. Pumps run from May until September and pump around 28000 to 45000 m^3 water. This is pumped with a maximum of 103 m^3 an hour and cooled down with a maximum of 4.9°C. This matched with the given permits as the maximum temperature difference is 6°C and the maximum amount of yearly pumped water is 288.000 m^3. All this pumper water served for 709MWh in 2022 which comes close to the preferred 800MWh.



Vergund	**288.000 m^3**	**6000 MWh**			**max dT 5K**	**°C**	**°C**	**12°C**	**°C**	**°C**
1-05 tot 1-10	*Debiet grachten water*	*Energie*	*Temperatuur*		*Temperatuur*	Onttrekken Gracht		Infiltratie Gracht		
Maand	**TSA in → TSA uit**	**TSA in → TSA uit**	**TSA in → TSA uit**		**TSA in → TSA uit**					
	waterver-plaatsing	energie uit de grachte	Onttrekking	Infiltratie	dT TSA	Min.	Max.	Min.	Max.	Max.
Eenheid	**m^3**	**MWh**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**m^3/h**
januari-21	x	x	x	x	x					
februari-21	x	x	x	x	x					
maart-21	x	x	x	x	x					
april-21	x	x	x	x	x					
mei-21	x	x	x	x	x	x	x	x	x	0
juni-21	43805,9	150,0	19,8	16,2	3,6	x	x	x	x	103
juli-21	55779,6	191,0	21,4	17,3	4,1	x	x	x	x	99
augustus-21	25115,4	86,0	21,8	17,2	4,6	x	x	x	x	76
september-21	12265,7	42,0	22,5	17,6	4,9	x	x	x	x	49
oktober-21	x	x	x	x	x	x	x	x	x	x
november-21	x	x	x	x	x	x	x	x	x	x
december-21	x	x	x	x	x	x	x	x	x	x
januari-22	x	x	x	x	x	x	x	x	x	x
februari-22	x	x	x	x	x	x	x	x	x	x
maart-22	x	x	x	x	x	x	x	x	x	x
april-22	x	x	x	x	x	x	x	x	x	x
mei-22	38841,3	133,0	17,6	15,2	2,4	11,2	20,3	10,4	19,7	93
juni-22	45266,1	155,0	15,8	12,9	2,9	13,2	24,2	16,8	23,6	82
juli-22	38057,0	163,0	21,3	17,3	4,0	24,2	25	15,8	21,3	92
augustus-22	35704,0	178,0	23,4	19,0	4,4	22,7	25,3	15,1	23,4	91
september-22	27992,3	80,0	19,6	16,7	2,9	14,5	14,4	13,5	19,6	96
2022 totaal	185860,7	709,0								

Table 7: Performance operation report of 2023 (Spie, 2023)

4.3. Identified actors and stakeholders

Stakeholders were initially identified through the literature research and were further explored through the interviews. Within this section, an overview of all identified stakeholders, their roles, and responsibilities will be presented, and therefore this section answers research question 4: ''Who are key actors and stakeholders involved in the implementation and usage of surface water thermal energy systems?''.

The stakeholders identified thus far are primarily associated with the operation side of an SWTE system. Nonetheless, the broader scope of the research encompasses both the implementation and usage of an SWTE system. Specific questions related to the implementation were posed to the geohydrologist and engineer, focusing on their collaboration and experiences in working with various actors and stakeholders. They provided answers with additional information about organizations they engaged with throughout the implementation and operation of the SWTE at the provincial government building. Moreover, some other interviewees added some extra insights into stakeholders or actors concerning the implementation or operation of an SWTE system. First, an overview of the found stakeholders is elaborated on and later the stakeholders are mapped in a matrix.

4.3.1. Implementation actors and stakeholders

In general, R1 is an engineer who got assigned to the project to redesign, without the use of natural gas, the heating system of the provincial government building. As part of an independent consultancy firm, R1 did not have comprehensive knowledge about the hydrology part and hired R2 for the design consultancy of the SWTE. Moreover, this excluded the construction of the system which was executed by another firm. R1 noticed that ''we have seen all parties'', meaning that R1 has seen an enormous amount of, in this case, external stakeholders and actors before the operationalization of the system. The water authority of Hunze and Aa's, the municipality of Groningen, the province of Groningen, a contact person for the ATES permits, the monument committee, and even road workers were mentioned by R1 as stakeholders that were directly contacted. With regards to the experience of, even more, stakeholders were added (R2). First, it was highlighted that indeed the municipality and the province were key stakeholders regarding the project. Even boat owners were contacted with regard to the possible nuisance of the sound of the water outlet of the system (R2). In line with such a specific actor group, R1 told a story about an initial plan where a part of the pumping installation would be installed in an empty part of the bridge crossing the city canal. Surprisingly, resistance came from an unexpected side namely the group of bridge operators. As R1 stated:

‘’A comprehensive plan was developed for an installation at the bridgehead, but ultimately the group of bridge operators disagreed with it." (R1).

Responses were less focused on the roles of, the great amount of, stakeholders, still, R1 felt resistance in the design phase of the project:

"The number was not necessarily a problem, but everyone defended their own territory, even up to the bridge operators, and that made it challenging." (R1)

R7 received signals about the fact that permit applications are becoming more difficult for projects, this is partly because of legal constraints by for example the water authorities.

4.3.2. Operation actors and stakeholders

Previously mentioned actors and stakeholders are mainly connected to the SWTE system at the provincial government building. In general, these stakeholders seem all relevant, though, when an SWTE system would be connected to a heat network instead of solely one great consumer as the provincial government building, some other actors and stakeholders can come around. This was mentioned by R1 who tipped the author about a possible implementation of a heat network. In the case of Groningen, this heat network provider is the company WarmteStad, which was then interviewed. Questions regarding the role of this, likely internal stakeholder, WarmeStad were answered by R4 and gave insight into their three main components of what they provide infrastructure for source, distribution, and consumer. This is focused on the needed infrastructure for a heat network and matches with the third category found in Chapter 2.3 and matches with an integrated heat supplier.

Both R3 and R6 noticed that there is a great number of owners of historical buildings. These are in the context of this research classified as consumers. Moreover, historical buildings are not necessarily only owned by private owners, but lots of corporations and landlords. According to R6, this specific group of consumers does not pay the energy bill resulting in a low need to corporate or switch to a different system.

‘’When looking at the city center, one can observe numerous organizations that solely engage in property rental, they just don’t care about rental rates paid by tenants.’’ (R6)

4.3.3. Combination of all actors and stakeholders

All actors and stakeholders involved in the implementation of SWTE systems are listed in this subsection. The analysis seeks to provide an in-depth understanding from an implementor viewpoint while taking into account the importance of involving both internal and external stakeholders. The power and interests of both internal and external stakeholders are taken into account in a stakeholder matrix in Figure 23 which sheds light on this complex web of stakeholders. Moreover, actors can be identified regarding their relatively low interest in the project implementation. In this case, road workers, landlords, boat owners, and bridge operators can be viewed as actors. The remaining parties are seen as stakeholders. Combining these viewpoints allows us to get an insightful understanding of the dynamics, dependencies, and potential conflicts that may influence the SWTE system implementation's success.

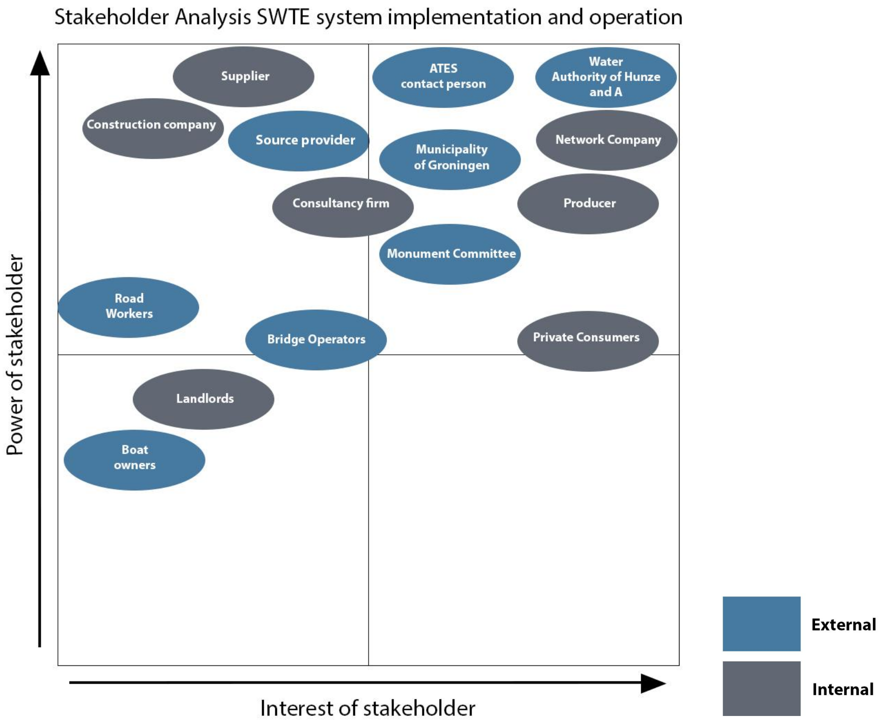


Figure 23: Stakeholder analysis with on the Y-axis the power of the stakeholder, and on the X-axis the level of interest

4.4. SWOT analysis SWTE systems

Using a SWOT analysis this chapter provides results to sub-question 6: *''What can be learned from the perspectives of relevant stakeholders regarding the use of surface water thermal energy systems to heat historical buildings focusing on opportunities and barriers?"* and 7:*''What lessons can be learned from the potential implementation of surface water thermal energy systems in Groningen?"* By bringing together the results from the semi-structured interviews, strengths, weaknesses, opportunities, and threats have been identified. Results are presented based on Figure 10, where first the supply side will be discussed. Second, the demand side, and finally, both are brought together. A summary of the SWOT analysis is visible in Figure 24.

4.4.1. Supply

This section elaborates on the left side of the multi-criteria decision analysis, visible in Figure 110, where the supply side is presented. This is done via a SWOT analysis, identified strengths (1), weaknesses (2), opportunities (3), and threats (4) will be discussed.

1. Strengths

Regarding strengths on the supply side of SWTE systems, several notions were made. (R1) started with the statement that this surface water source is an inexhaustible source of heat, hinting at a highly abundant source of heat. This is supported by (R6), who states that indeed this source, surface water, is widely present and that the energy of the sun on the water can significantly cover the heat demand. Additionally, R7 expects that, compared to the theoretical potential of 40%, between 15 and 20% of the built environment will make use of a source of aqua thermal energy, which partly covers SWTE systems. Moreover, the technical potential expressed in 350 peta joules (PJ), as presented by Kruit et al. (2020), is approximately only 25% more than the expected real-life estimation that will undoubtedly be utilized in the future, demonstrating a relatively substantial energy potential covering more than 12% of the heat demand of the built environment. The last identified strength is connected to the ownership of the source, as R2 philosophically responded to the author's question with another question:

"To whom does the oxygen in the air belong?" (R2).

With this comment, R2 highlighted the limited legislative implications when utilizing surface water as a source. While the subsurface is regulated, surface water lacks these rules. Therefore, it became clear that this is still based on a first-come, first-serve principle and is not regulated. This was emphasized by R1, R2, R3, and R7. Subsequently, it will remain a common good, just like oxygen (R7). Because of the current function at NAT, R7 already encountered discussion with water authorities and governmental bodies that sought to earn money with water. Moreover, it has been highlighted that some signals were received regarding more legal applications regarding ownership (R3). Nonetheless, it was made sure that this would never happen directly, showing us that alongside the widely available source, ownership is also a strength (R7). This is supported by R2, who mentioned that the collective use of a surface water source could mutually reinforce.

2. Weaknesses

The supply side also showed some weaknesses which will be covered in this section. Starting with the fact that pumping water requires energy. This is highlighted by R1 who explains that a lot of compressor energy is needed to pump the water with a constant flow of 100 m^3 an hour in the case of the provincial government building. Second, the flow rate of the surface water source is important to consider in terms of a potential short circuit when water is brought back to the surface water, this is mentioned by R1, R2, and R7. Especially the importance of flow rate, because of the needed renewal of the water to prevent short circuit, was explained (R7).

> *''When dealing with stagnant water, you draw from one side and discharge from the other side, thus involving a gradual process. When it is completely stagnant, it moves towards the inlet. If there is flow, there is renewal'' (R7).*

Interference prevention measures, visualized in Figure 17, are taken (R2). First, the inlet is placed upstream. Second, by placing the outlet close to the bridge, the water meets a narrow part of the city canal resulting in a relatively higher flow rate (R2).

The last identified weakness, as mentioned by several interviewees (R1, R2, R6) concerns problems that occur when filtering the surface water. As the surface water will meet a heat exchanger in a later stadium, it needs to be filtered from algae and other particles because of both corrosion that can occur and a possible blockage. This results in blockage of the filter basket by algae and mussels. This is a problem that is widely acknowledged in the field of water consultancy according to (R2).

> *''In the presence of a water current, a substantial amount of nutrients flows through these points, enabling efficient feeding for mussels.'' (R2)*

This is something that prevented the SWTE system from working properly in the beginning (R1). This was solved with the help of a self-cleaning mechanism which now works properly. Yet, this component still needs maintenance, so every year the filter basket is manually changed with the help of a diver, to be cleaned.

3. Opportunities

Opportunities on the supply side of an SWTE system are considered. First of all, it is worth mentioning that the overall system of an SWTE system is known to be costly (R3). However, despite the initial investment, the operational costs are relatively low. This is evident in the case of the municipal government building, where the initial investment was significant, but the system has proven to save larger amounts of money than expected, as reported by Nijeboer-Hage (2019).

Secondly, obtaining the permit for the surface water system was relatively simple, thanks to the enthusiastic response from the water authorities. They recognized the cooling function of the system for the city canal water, which could effectively prevent the growth of algae.

Third, heat networks and connected components continuously develop as explained by R3 and R4. The new, 5th generation of heat networks has increased in efficiency, which could imply a better integration with SWTE systems.

4. Threats

Finally, SWTE system supply-side threats are discussed. The possible ecological damage that could result from scaling up and broadening the system's applicability concerned the responders. The primary danger to the ecological balance was determined to be the extraction of heat, thus cooling the surface water (R7). Since earlier techniques predominantly involved heat discharge into surface water, there is minimal knowledge of the ecological impact of cold water discharge, causing an increase in this doubt (R2).

The filtration process within the SWTE system was highlighted as an area of uncertainty. The ecological implications of such fine filtration and the effects of returning residues to the water system remain poorly understood. It is unclear how this process affects the ecological functioning of the water system (R7). The impact of thorough filtration on the presence of smaller organisms in the water has raised concerns regarding its potential consequences for the ecological balance (R7). Ongoing research is being conducted to investigate the effects of the filtration process, with a particular focus on understanding its consequences on smaller organisms within the water system (R7).

4.4.2. Demand

This section elaborates on the right side of the multi-criteria decision analysis, visible in Figure 10, where the demand side is presented. This is done via SWOT analysis, identified strengths (1), weaknesses (2), opportunities (3), and threats (4) are discussed.

1. Strengths

The interviews revealed several strengths associated with the demand side of the SWTE system, particularly in the context of innovations and CO2 reduction goals.

Modern technological developments concerning insulation measures, such as vacuum glass, have been suggested as potential solutions to improving the insulation in historical buildings (R6). Although costly, these technologies present options to improve historic buildings' energy efficiency while balancing preservation and sustainable performance.

Political influence and CO2 reduction were considered a driver for adopting the SWTE system. The transition to being gas-free was mentioned as a window of opportunity for the deployment of such systems (R5). Additionally, the fact that this system is carbon-free was a positive aspect mentioned by (R3). Subsequently, (R3) expressed the belief that opportunities for alternative energy sources, such as aquathermia, will increase in the future, driven by the collective will to move away from fossil fuels (R3).

Furthermore, a political-based decision-making process was identified as a factor (R1). This implies that political support could exist for implementing an SWTE system, providing a favorable environment for its adoption and operation.

2. Weaknesses

Several weaknesses are mentioned regarding the demand side of an SWTE system, primarily related to insulation and label challenges, the number of stakeholders involved, ATES usage, and specific other uncertainties.

Insulation and label challenges were recognized as significant limitations. There is a clear emphasis on the need to reduce energy consumption in historical buildings (R7). Poorly insulated buildings require additional steps for effective utilization, including trying to get an as low as possible temperature delivery through heat pumps (R7). According to R6 the existing building stock, particularly historical buildings, presents challenges for insulation, making it difficult to implement an SWTE system and achieve sufficient energy efficiency with the state of technology of heat pumps nowadays (R6). However, it is still believed by R3 and R7 who both work for NAT, that it will be possible to implement. Yet, the energy demand of the historical buildings needs to be lowered.

The large number of stakeholders involved was identified as another weakness (R1, R2, R3). The presence of a great number of stakeholders resulted in collaboration challenges which were explained by (R1).

''We have encountered a narrow-minded perspective." (R1)

Meaning that implementation and design were done without the consideration of relevant parties. The diversity of stakeholders can create complexity in the implementation process (R3). Yet, there are projects known by R3 where relatively large numbers of stakeholders signed for participation.

The usage of ATES was mentioned as a weakness as the implementation and operation of WKO systems entail energy consumption and CO2 emissions during installation (R7).

Configuration uncertainties and maintenance challenges were also identified. Losses in the piping system of potential heat networks were mentioned as a concern (R4). Moreover, the management and maintenance of the SWTE system at the provincial government building were described as complex and reliant on empirical learning (R1).

3. Opportunities

Several opportunities exist on the demand side of the SWTE system, offering potential benefits and advantages. These opportunities include the suitability of the system in places with high building density, available subsidies, and cost-effectiveness of the system.

The high building density in certain areas was identified as an opportunity for SWTE systems. The presence of multiple buildings in proximity, such as in the Lage der Aa, creates a favorable environment for efficient heat distribution as explained by (R4).

Subsidies are seen as a significant opportunity to support the implementation of the SWTE system. Various subsidies were mentioned, including the Energy Investment Deduction (EIA) and the SDE++ (Stimulation of Sustainable Energy Production) scheme, which covers aquathermia under specific conditions for companies (R4). Additionally, subsidies for end-users, such as the recent WIS (Warmtenetten Investeringssubsidie), were mentioned (R4). These financial incentives could imply a contribution to making the SWTE system more economically viable and attractive to stakeholders.

One strong opportunity was highlighted as cost-effectiveness of the system. In the specific case of the SWTE system at the provincial government building, the potential for substantial savings became clear. This system is estimated to annually save €200.000 on an investment of €2.7 million, resulting in a return on investment of 12 to 13 years which is relatively fast (R1). The cost-effectiveness was further emphasized in the context of collective systems, where multiple end-users can benefit from shared infrastructure, leading to cost reductions (R7). This is, in general, supported by M1 who stated that it is economically feasible with a sufficient number of participants.

4. Threats

Several threats exist on the demand side of the SWTE system, posing challenges and potential obstacles. These threats include subsurface influence, disruptions during construction and system implementation, high investment costs, the development of alternative technologies, and variations in building types and space availability.

Subsurface influence was identified as a threat to the implementation of the SWTE system. The presence of existing underground infrastructure and considerations such as archeology, soil contamination, and limited space poses challenges according to R1, R2, R3, and R4. This was highlighted by R2:

> *"A distribution system in the city, connecting all houses with a central intake, is truly a hell of a job." (R2)*

This does not mean that R2 does not believe in the potential operation of such a system, though it was made clear that it requires a serious tailor-made approach. Furthermore, as stated by R4, the level of commitment from specific stakeholders plays a crucial role. The case of Amsterdam is cited as an example, where heat networks have been successfully implemented despite challenging subsurface conditions in terms of space (R4).

Disruptions during construction and system implementation were acknowledged as potential threats. Stakeholders mentioned the challenges encountered while installing the SWTE system, such as drilling through thick concrete walls, causing temporary inconveniences and other disturbances in the city center (R1, R2).

High costs were identified as a threat to the adoption of the SWTE system (R1, R2, R3, R4, R6). Interesting was the opinion about the traditional business model for heat companies of (R7). This model focuses on maximizing energy sales but may not align with the collective approach of minimizing energy consumption. This misalignment may impact the economic feasibility of the SWTE systems.

Alternative technologies, such as green gas or hydrogen, were mentioned as potential threats. Yet, concerns were raised about the technical feasibility and justification of using certain technologies, such as burning hydrogen for heat supply (R1). Moreover, the availability of green gas is still very uncertain and needs upscaling (R4, R6). Although, the availability and lobbying for alternative technologies could impact the implementation of the SWTE system (R7).

Last, variations in building types and space availability can be seen as potential threats. Differences in energy demand and heating requirements among different building types in city centers complicate the design and implementation of a standardized solution (R5, R7). Constraints related to building structures, such as wooden floors that lead to vibrations due to running heat pumps and limited space for technical rooms, may further hinder the installation of the SWTE system (R3, R7). Yet, these technical rooms do not necessarily need to be placed individually and could be placed for collective purposes in basements (R4).

4.4.3. Overall system

Table 8 below, summarizes the identified strengths, weaknesses, opportunities and threats.

S • Abundant and inexhaustible source of heat from surface water • Technical potential covering more than 12% of the heat demand of the built environment • Surface water source ownership based on first-come, first-serve principle • Relatively simple permit process for surface water system • Low operational costs of SWTE systems • Cost-effectiveness of the system in the long run	**W** • Energy consumption required for pumping water • Potential short circuiting and flow rate issues with surface water source • Challenges in filtering surface water and preventing blockages • Insulation and label challenges in historical buildings • Collaboration challenges due to the involvement of multiple stakeholders • Energy consumption and CO2 emissions using ATES • Configuration uncertainties and maintenance challenges
O • Integration with improved insulation technologies in historical buildings • Political support and CO2 reduction goals driving adoption of SWTE systems • Availability of subsidies for implementation and operation • Suitability of SWTE system in areas with high building density • Continuous development of heat networks and connected components • Cost-effectiveness of the system, especially in collective systems	**T** • Uncertainty and potential ecological impact of the filtration process • Challenges posed by subsurface influence and existing underground infrastructure • Disruptions and nuisance during construction and system implementation • High initial investment costs • Development and competition from alternative technologies • Variations in building types and space availability complicating standardization

Table 8: A summary of the SWOT analysis

4.5. The case of Groningen

Through a combination of desk research, interview answers, participant observation, and a test case analysis results are gathered that answer the final sub-question 6: ''*What can be learned from the perspectives of relevant stakeholders regarding the use of surface water thermal energy systems to heat historical buildings focusing on opportunities and barriers?*" In this section, the test case will be discussed and answers to the calculation will be provided.

4.5.1. Test case

In this section, an indicative calculation will be presented to examine the potential match between the energy demand of a specific university building and the available energy from the city canal. This test case analysis aims to provide a preliminary result of whether the energy needs of a historical building can be met by utilizing solely an SWTE system. This test case analysis takes into account factors such as ATES suitability, the thermal capacity of the canal, legal cooling limits, and the average energy usage of the Academy Building. As discussed in

Chapter 2.3, an SWTE system goes hand in hand with an ATES system. This ATES system works best with subsurface layers that consist of sandy soils at around 100 meters deep (Kruit et al., 2018; Dehens et al., 2020). The analysis conducted on the website of 'Dinoloket' shows that this is the case for the subsurface below the city center of Groningen (TNO-GSN, 2023a). This is because the Formation of Peize and Waalre (PZWA), encircled in Figure 24, is a layer of fluvial deposits consisting of fine to coarse sand (TNO-GSN, 2023b; TNO-GSN, 2023c).

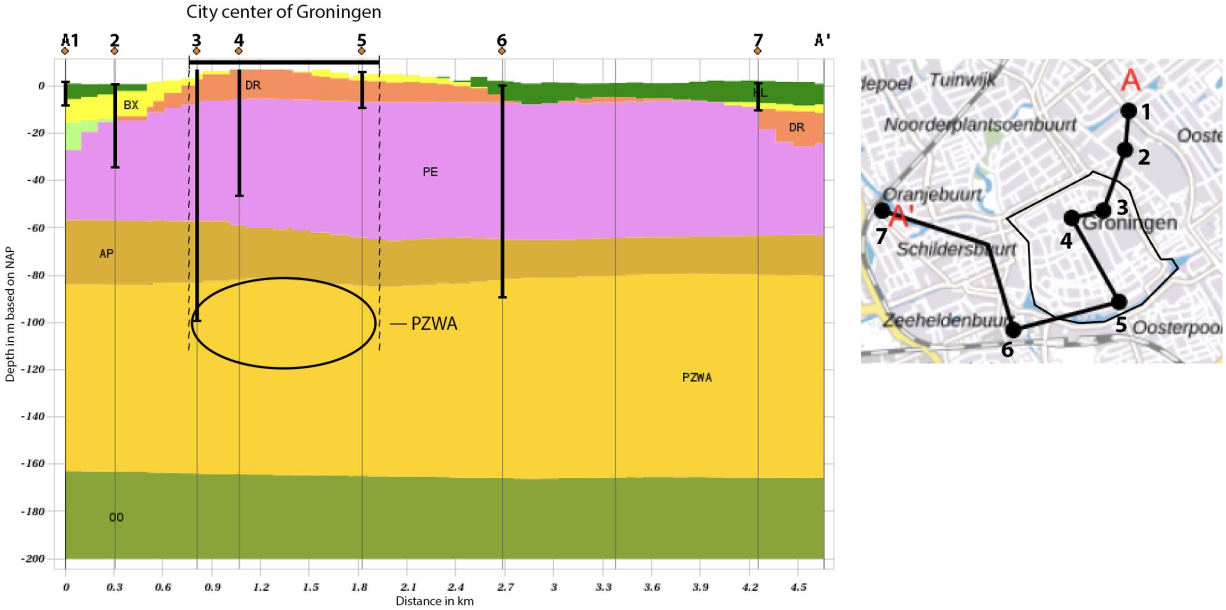


Figure 24: Cross-section of the subsurface conditions around 100m deep including a map of the measurement points (TNO-GSN, 2023a; Author; 2023)

Based on the information provided by (R5) it became apparent that the university building uses 194,962.6 m³ of natural gas on average over 5 years (2017-2022) (Appendix F). This amount of gas is transformed into the amount of kWh by multiplying it by the caloric value of Dutch natural gas, derived from 3nergie (2023) which is 9,7694444. This results in an energetic demand of 1.904.162,6 kWh, which needs to be loaded within a period of 3 to 4 months (BRIES Energietechniek, 2020)

Based on the formula Q = m * Cw * T, a pumping flow of 100 m³ (BRIES Energietechniek, 2020) and a given maximum cooling of 6° C (Kruit et al., 2018). The thermal supply that can be loaded is 100/3600 * 4184 * 6 = 697,3 kW.

To cover the demand of the university building of 1.904.162,6 kWh, the system needs to run for 114 days. This is calculated by: 1.904.162,6 / 697,3 = 2.730,7 (hours). 2730,7 / 24 = 113,78 days.

As shown by BRIES Energietechniek (2020) in Chapter 3.2.2, the water temperature is 130 days a year suitable for surface water extraction. This results in a buffer of (130-114=16) 16 days for the system of the university building. Based on this information it becomes clear that the average yearly gas consumption indicates a significant energy demand that is translated into kilowatt-hours. Taking the suitable water temperature levels in the city canals into account, the extraction is limited to a specific number of days that match the thermal supply capacity. Hence, the energy demand of the Academy Building can be fulfilled by operating the system for a certain number of days, which is within the system's maximum operational capacity.

Some general visions were identified regarding the overall implementation or switch to an SWTE system in the case of Groningen. Both R5 and R6 were asked regarding their thoughts about switching to an SWTE system and whether this would be a realistic option.

In the case of the University of Groningen, it was disclosed that the current emphasis is on the coming renovation of another significant building of the university, namely the Harmoniegebouw. This upcoming renovation project suggests a chance for incorporating energy-efficient systems or technologies that align with sustainable practices. Yet, the development of this renovation is outsourced to a company in the market seeking the most cost-effective solution (R5). As explained by R5, the university needs to pay its bills:

> *“"But ultimately, we are just a company. So that also means it must be paid for."“’(R5)*

To add, it is extremely important for an organization like the University of Groningen to have energy supply reliability, it should work properly at all times (R5).

Lastly, R6 emphasizes that the primary interest of the municipality is in exploring ATES systems and does not want to obligate citizens to switch to expensive sustainable heating solutions. Nonetheless, the municipality does not hinder the implementation of SWTE systems (R6). Overall, the municipality is there to inform its citizens about all the different choices that can be made and provide them with information regarding the costs (R6).

5. Discussion

This chapter offers a discussion of the study's findings in relation to theory. It explores how these findings address the research questions and presents answers to observed differences and similarities.

5.1. Empirical operation of surface water thermal energy systems

Comparing the theoretical findings with empirical results, several dissimilarities are highlighted. Empirical observations show that the implementation of SWTE systems in real-life situations may not always align with the theoretical configurations and options.

To start, the theory emphasizes the need for a sufficient supply temperature (Kleiwegt & Coo, 2018; Dehens et al., 2020), whether it is uncertain if MT is possible or should be covered by HT for the needs of historical buildings. In contrast, the empirical section provides insights into the actual temperature levels needed in SWTE systems or how well they match the heating demand of historical buildings (Nijeboer-Hage, 2019). It would be beneficial to conduct a comparison between the theoretical temperature range and empirical data, while also examining real-life information regarding the measures taken to appropriately align supply and demand. For instance, the inclusion of two booster heat pumps at the Provincial Government building and the implementation of permitted insulation measures could be considered in this analysis (R1, R2, R7).

Additionally, various barriers related to technical-spatial, social, environmental, economic, and political aspects of SWTE system implementation were identified (Kruit et al., 2018; Kleiwegt & de Coo, 2018; Dehens et al., 2020). These barriers provide important insights into the challenges that may arise during the deployment of SWTE systems. Nonetheless, the empirical section delves deeper into these findings regarding the potential short circuits, subsurface suitability, and legal implications. With regards to short circuits, little is written in theory and the potential of SWTE seems more important than taking this into account (R1, R2). The empirical operation made it clear that flow rates of for example a city canal are extremely important to consider whether a system can operate somewhere (R1, R2) contrasting with Kruit et al., (2018) who solely focus on flow rates in terms of required pumping energy. Lastly, regulations were described as important to consider (Buijze et al., 2019). Yet, real-life examples show these were relatively easy to overcome, and despite the ecological uncertainties, water authorities remained positive about the extraction (R1, R2).

5.2. Valuation of surface water thermal energy systems as innovation

This section discusses the translation of SWTE into an innovation and assesses its potential for widespread usage, considering the opportunities and barriers identified. Building upon the information presented in Chapter 2.3.4, this section expands on the empirical findings related to the attributes of innovation described by Rogers (2003), providing a deeper analysis.

5.2.1. Relative advantage

SWTE systems offer several characteristics that demonstrate their relative advantage compared to other sustainable heating systems. These include the abundance of surface water as an inexhaustible heat source (R2), the surface potential to cover a significant portion of the heat demand in the built environment (Kruit et al., 2018), and relatively low operational costs (R1). To add, the technologies that could potentially compete with SWTE, for example, green gas and hydrogen, have limited availability (yet) (R6, R7). However, it seems that the respondents are rather hesitant to state that SWTE systems are a great innovation to heat historical buildings. It could be that this hesitancy primarily results from the high investment costs and construction efforts associated with SWTE implementation (R1, R3, R7). Additionally, the influence of lobbying efforts promoting alternative technologies can impact the choice of the chosen heating technology (R7). Consequently, the perceived relative advantage of SWTE systems seems somewhat limited. Determining the optimal alternative sustainable option for historical buildings remains unclear and will ultimately be determined by market dynamics.

5.2.2. Compatibility

The abundant and widely available source of heat matches the heat demand making it highly compatible (Kruit et al., 2018; Dehens et al., 2020). Yet, historical buildings and poor insulation present challenges for the effective implementation of an SWTE system. The operational effectiveness of the system is demonstrated to be highest when energy demand is minimized (M1, M2, R3, R7). However, insulation measures seem to develop (R6), indicating a certain level of increasing compatibility with existing building structures. Moreover, subsurface conditions do hamper the possible implementation of heat networks according to all interviewees. Despite some little notions, Kruit et al., (2018), Kleiwegt & de Coo, (2018), and Dehens et al., (2020) barely touch upon this when considering the potential. These challenges suggest that SWTE systems may not be fully compatible with existing insulation in the buildings and, more critically, conditions below the streets. Therefore, these may require adaptations or can be viewed as less compatible with places in city centers where subsurface conditions are poor (R1, R2, R4, R5).

5.2.3. Complexity

The analysis of the strengths, weaknesses, opportunities, and threats reveals a rather complex implementation and operation of SWTE systems. These complexities include problems related to the subsurface conditions, uncertainties in configuration and maintenance, concerns about the ecological impact and filtration processes, and the involvement of multiple stakeholders (Kleiwegt & de Coo, 2018; Popering-Verkerk et al., 2021). The problems related to filtration processes, maintenance, and concerns about ecological impacts are little described by de Jong & Dionisio (2022). In contrast, the many stakeholders involved do not appear to hinder the implementation of an SWTE system, particularly when considering the case of the provincial government building. This seems surprising as numerous stakeholders were identified in addition to research by Kleiwegt & de Coo (2020). It seems that the rather technical side of SWTE system implementation results in a high degree of complexity (R1, R5, R6). Nevertheless when considering individual implementations instead of collective ones or provincial-initiated ones, the presence of numerous powerful stakeholders can result in a complex obstacle that needs to be overcome.

5.2.4. Trialability

The available subsidies (R4), high building density (R4, R7), and cost-effectiveness (R1) indicate a favorable environment for trialability. The availability of financial incentives and the potential for substantial savings can encourage stakeholders to experiment with pilot SWTE systems and test their feasibility. Additionally, the mentioned projects with multiple stakeholders signing up for participation suggest a willingness to explore and trial these systems (R3). Moreover, the municipality does not hamper these projects and people are free to choose those (R6). However, it seems that this situation is favorable for larger organizations who have the financial resources and meet the eligibility criteria for the available subsidies, which are primarily designed for entities other than individuals or smaller consumers. Consequently, this arrangement leads to limited trialability for individuals or smaller consumers and seems more suitable for the collective use. Lastly, the decision to implement an SWTE system at the provincial government building was driven not only by the necessity to fulfill the heat demand but also by political factors, making it a prestigious project. The emphasis on prestige significantly diminishes the trialability for the average consumer, as the project becomes less accessible. Regarding the potential of SWTE, the adopter, or unit of adoption as stated by Rogers (2003) is only briefly touched upon in Dehens et al., (2020). It seems that the focus is more on the description of the potential rather than explaining who can make use of this potential. Individuals are less likely to be classified as unit of adoption within this scope (R6, R7).

5.2.5. Imperceptibility

Despite SWTE systems being installed in basements and using surface water as a source making them highly imperceptible, it seems that heat pumps and additional booster heat pumps take serious amounts of space. Moreover, they can be noticed in forms of nuisance in operation and construction. In historical buildings, the use of heat pumps can generate vibrations, resulting in disturbances. Additionally, construction in the streets is highly visible due to the related disruptions and nuisance. In addition, the lengthy construction periods will likely result in high resistance by residents or shop owners (R2, R5, R6, R7) This is very limited touched upon by articles focusing on SWTE (Kleiwegt & de Coo, 2018; Dehens et al., 2020; Popering-Verkerk et al., 2021). In summary, despite high operational imperceptibility, there is a notable level of construction of these systems, leading to a low degree of imperceptibility.

5.3. Maturity of surface water thermal energy systems in a niche

SWTE as an innovation appears to lack the ability to thrive independently, indicating its current immaturity or lack of superiority (van der Brugge et al., 2005). This assessment is based on the recognition that SWTE systems perform poorly on certain essential attributes of innovation (Rogers, 2003). While some attributes are valued relatively highly, the innovation requires protection to establish itself as a standalone innovation. Considering the relative advantage of alternative sustainable options like green gas or hydrogen, providing protection and subsidies from the municipality could prove beneficial. These measures would facilitate the trialability of SWTE systems, although the implementation process would still be complex due to spatial and subsurface conditions. Protecting the innovation may not alleviate this inherent complexity but can potentially help expand its niche within historical cities. The transition from a niche solution to broader regime-level adoption of SWTE systems appears to be contingent on the suitability of subsurface conditions and additional permitted insulation measures (Geels & Kemp, 2000; van der Brugge et al., 2005).

5.4. Implications for the case of Groningen

To start, the SWTE system at the provincial government building shows that the surface water source can serve 800 Mwh, which exactly matches the HT demand (R1). However, this is just part of a system where the total demand is approximately three times higher than this specific system. This shows us that it is indeed possible to heat a historical building with the use of a city canal in Groningen, however, in combination with the previously acknowledged limited maturity of this innovation, it seems not feasible to solely use SWTE for the heating demand of historical buildings.

Nonetheless, the calculations demonstrate that relying solely on surface water has the theoretical potential to cover the heat demand of buildings with city canals in proximity, offering a sustainable and efficient alternative to traditional energy sources. Moreover, these findings can offer valuable insights for other similar adopters seeking to assess the feasibility of using surface water thermal energy extraction to meet their energy demands, filling the gap of Dehens et al., (2020).

Adopters can learn from this case, which has a substantial heat demand, and explore the feasibility of implementing similar systems in their buildings. By assessing their energy requirements, and evaluating available surface water sources, adopters can determine if utilizing surface water as a heat source is viable for their specific contexts. However, the buffer that is identified seems rather short in terms of days that are needed for maintenance or anomalies in temperature or other operational disruptions. Therefore, this buffer limitation should be taken into consideration.

Moreover, there might be a matching opportunity with another university building. When looking at the multi-stage model from van der Brugge et al., (2005), visualized in Figure 3, and the information provided by (R5), it can be noticed that this renovation process still has to be started. If this renovation is located in the take-off phase, which is the case according to the provided information (R5), it suggests a potential match and compatibility with the integration of SWTE technology. However, as R5 made clear, it should be reliable as a source. Therefore, considering the acknowledged complexity of adoption, it seems that an SWTE system only has the potential to be connected as an additional source for a greater heating system. In terms of the economic feasibility, it seems positive that the university is a great organization, despite the need to pay their bills, the operation costs are low, and it has been demonstrated to be a cost-effective system in the long run (R5, R6, R7).

Lastly, the municipality of Groningen primarily focuses on exploring ATES systems and does not impose obligations on citizens to switch to expensive sustainable heating solutions. This could be the reason that the municipality's approach appears cautious It seems that its lack of endorsement for a specific niche hinders implementation. As a result, consumers, or adopters, are left in uncertainty about whether and which technology to implement. This ambiguity, particularly concerning the protected status of historical buildings, may lead to suboptimal choices and letting SWTE be situated in a niche (Geels & Kemp, 2000). The municipality should play a more proactive role in safeguarding suitable innovations that can sustainably heat the historical city center.

6. Conclusion

In this chapter, the research questions will be answered and the conclusion to this research will be presented. This conclusion is based on the results presented in Chapter 4 and the previously acknowledged discussion in Chapter 5. Finally, contributions to the academic debate and the transferability of the findings will be presented.

6.1. Answers to the sub-questions

Sub-question 1: ‘‘*How can surface water thermal energy systems be conceptualized from a combination of an innovation and transition theory perspective?”*

From an innovation and transition theory perspective, an SWTE system offers a relative advantage such as water being an abundant heat source and the limited availability of green gas or hydrogen. However, hesitancy exists in heating historical buildings due to high investment costs and substantial implementation efforts. Compatibility challenges arise from historical buildings, poor insulation, and subsurface conditions. Implementation complexity arises from technical issues, and ecological concerns, and can arise due to the involvement of multiple stakeholders. Trialability is limited for individuals but favorable for larger consumers with subsidies. SWTE systems are operationally imperceptible but highly noticeable during construction. In general, SWTE can be seen as an innovation that is promising in terms of its relative advantage and potential compatibility with heat demand. Nevertheless, successful implementation and widespread adoption require addressing complexity, trialability limitations, and construction challenges regarding disruptions. Therefore, SWTE can be classified as an adaptable innovation, however solely context-dependent in terms of historical buildings and available room in the subsurface of a city center.

Sub-question 2: *‘’What is the current state of the technology used to extract thermal energy from surface water systems based on a literature study?”*

Literature shows that an SWTE system typically consists of a surface water source, pumping installation, technical room with a heat pump and heat exchanger, ATES, heat network, and delivery system. Surface water is extracted and pumped through a filtration system before being either heated through an individual heat pump or directed to a heat exchanger located in the technical room. The use of a buffer system, such as ATES, is highly recommended for seasonal heat storage. The ATES system utilizes a water-bearing stratum in the subsurface, with warm and cold sources, to store and extract thermal energy. The captured energy is upgraded using an electric heat pump, either in a collective heating network or through individual heat pumps. The temperature requirements for historical buildings vary (HT or MT), based on their energy label and insulation levels. The heated water is transferred through a heat network to the end user(s) via a user delivery system. It is important to have a system that can cover peak loads or a backup system for anomalies.

Sub-question 3: *''How do surface water thermal energy systems empirically operate?''*

The findings from desk research and interviews with key stakeholders indicate a range of perspectives on the feasibility and empirical operation of SWTE systems for heating historical buildings. There are concerns present about the technical feasibility and costs. The scale of the project is seen as a crucial factor, with economies of scale playing a great role in implementation. Additionally, stakeholders highlighted the importance of matching SWTE systems with historical buildings and the need for high enough supply temperatures to meet the demand. The availability of space in the subsurface of historical cities was also recognized as a relevant spatial consideration for implementing a heat network or other infrastructure. In general, the system is able to empirically operate with the use of an ATES system and sufficient insulation measures on the supply side.

Sub-question 4: *''What are necessary technical and spatial conditions to effectively use surface water thermal energy systems to heat historical buildings?''*

The investigation of the SWTE system in the provincial government building provides insights into the technical and spatial conditions required for its operation. The historical part of the building, which is a municipal monument, posed challenges in terms of insulation and reducing energy demand. The existing wells in the building were repurposed for the ATES system, eliminating the need for new drilling. The system involves heat pumps, buffers for low-temperature and high-temperature heat, and a heat network for distributing the heat within the historical building. The surface water source, pumping installation, filtration system, and ATES system are key components of the SWTE system. The technical rooms housing these components require adequate space in the basement of the building. In the context of a collective system, it is possible to locate the heat network externally.

Sub-question 5: *''Who are the key actors and stakeholders involved in the implementation and operation of surface water thermal energy systems?''*

The implementation phase involved multiple stakeholders, including the designer of the project, a geohydrologist, the water authority, the municipality, the province, the ATES permit contact person, the monument committee, road workers, construction companies, and even unexpected actors such as bridge operators and boat owners. These stakeholders played crucial roles in the planning and execution of the SWTE system.

In the operation phase, key stakeholders in SWTE system operation include source providers, producers, network companies, suppliers, and consumers like landlords or private ones.

Although it may seem complex, collaborating with a diverse range of stakeholders, including the powerful water authorities, is achievable. The key requirement lies in meeting the criteria set by the influential stakeholder, which in this case is the water authorities. This collaboration does not add a layer of complexity to the implementation process

Sub-question 6: *''What can be learned from the perspectives of relevant stakeholders regarding the use of surface water thermal energy systems to heat historical buildings focusing on opportunities and barriers?''*

The perspectives of relevant stakeholders provide valuable insights into the opportunities and barriers associated with using SWTE systems to heat historical buildings. Opportunities on both the supply and demand sides are evident. To start, systems offer an abundant and inexhaustible heat source from surface water, along with relatively low operational costs and the absence of strict regulations regarding ownership. The efficiency of heat networks integrating with SWTE systems is also improving. Moreover, implementation can be supported by subsidies and the cost-effectiveness of collective setups.

However, numerous barriers exist that need to be addressed. Starting with the insulation and labeling challenges in historical buildings, collaboration complexities due to multiple stakeholders, and challenges with filtering surface water. Moreover, uncertainties regarding the ecological impact of filtration processes and the potential damage caused by cooling surface water are barriers to be considered. Most relevant identified barriers focus on subsurface influences on system implementation, disruptions during construction, high investment costs, the development of alternative technologies, and available space.

In conclusion, the insights from stakeholders emphasize the opportunities and barriers associated with implementing SWTE systems for heating historical buildings. While opportunities exist, it is crucial to recognize that barriers tend to be more prevalent in this context resulting in a cautious stance among stakeholders regarding the use of SWTE systems for heating historical buildings.

Sub-question 7: *''What lessons can be learned from the potential implementation of surface water thermal energy systems in Groningen?''*

The potential implementation of SWTE systems in Groningen offers valuable lessons to be learned. The calculation demonstrates that relying solely on surface water has the theoretical potential to meet the heat demand of buildings situated near city canals, providing a sustainable and efficient alternative to traditional energy sources. This can serve as an inspiration for similar consumers who are exploring the feasibility of SWTE systems to fulfill their energy demands.

However, it is important to consider the identified short buffer period for maintenance or potential operational disruptions. This limited buffer should be taken into account when planning the implementation of SWTE systems to ensure reliable and uninterrupted operation.

Furthermore, the research indicates a potential match and compatibility between SWTE technology and the renovation of historical buildings within the university. By integrating SWTE systems as an additional heat source within a larger heating system, the economic feasibility can be positively influenced. The operational costs are low, making it a cost-effective long-term solution.

6.2. Answering the main research question

"How can surface water thermal energy systems enable sustainable heating of historical buildings using canal water in the city center of Groningen using an innovation and transition perspective?"

The successful implementation of SWTE systems requires careful consideration of technical and spatial requirements. First, considerations regarding the compatibility of the system with historical buildings in terms of temperature level. This can be increased with additional insulation measures. Third, the availability of space in the subsurface is critical. Additionally, the involvement of numerous key actors and stakeholders, including government bodies, experts, and organizations, is essential for addressing the technical and spatial challenges and realizing the opportunities. Finally, the complexity involved in implementing an SWTE system means that only large organizations or collective groups have the capacity to undertake such a project These factors contribute to the relatively low scoring of SWTE as an innovation, especially for individual adopter. This shows the need for protection within its niche.

Contradictory, the SWTE system at the provincial government building demonstrates that surface water can effectively meet the heat demand of a historical building. Yet, when considering the limited maturity of this innovation, solely relying on SWTE for the heating demand of other units of adoption may not be feasible. Besides meeting the heat demand, the indicative calculation shows that surface water has the theoretical potential to cover the heat demand of buildings near city canals, providing a sustainable and efficient alternative to traditional energy sources. These findings provide valuable insights for other consumers interested in assessing the feasibility of using SWTE to meet their energy demands. By evaluating their energy requirements and available surface water sources, adopters can determine the viability of implementing similar systems in their buildings. It is important to consider the buffer for maintenance and operational disruptions, as the identified buffer appears relatively short.

In addition, the integration of SWTE technology during the renovation of historical buildings presents a potential opportunity for compatibility and a greater heating system. Despite the cautious approach of the municipality, which primarily focuses on exploring other systems, there is an opportunity for them to play a more proactive role in supporting suitable innovations and ensuring sustainable heating in the historical city center. The municipality's lack of endorsement for a specific niche hinders implementation and may leave consumers uncertain about which technology to adopt. To avoid suboptimal choices, the municipality should provide clearer guidance and actively safeguard suitable innovations for sustainable heating.

In summary, while there are enabling factors that support the implementation of SWTE systems in Groningen, the presence of hampering factors hinders the innovation's progress toward maturity. As a result, the implementation of SWTE systems for sustainable heating for historical buildings in Groningen, is limited to spatial and some technical constraints. To encompass these, subsurface conditions should be evaluated, and additional insulation measure should be investigated and implemented to increase the level of compatibility. Moreover, when ecological influences of filtration and temperature decrease should become less uncertain and complex. Only when previously mentioned factors are carefully considered, water is heated collectively, and the system is part of a larger heating system, an SWTE system can be implemented for heating historical buildings in the city center of Groningen.

6.3. Contributions and transferability of the findings

Until now, limited research has been conducted on the sustainable heating of historical buildings using SWTE systems. Previous research on the technical feasibility of SWTE systems did not make a distinction between specific building typologies or focused on spatial conditions in city centers. This study added to this research with insights into specific views from relevant stakeholders and examples of empirical observations.

Despite solely focusing on the niche where SWTE systems do operate, it could be argued that aquathermia systems like the ones using sewage water (TEA) and drinking water (TED) could learn from this case by focusing on heating historical buildings.

Moreover, the research focuses on historical buildings close to city canals in a city center and found that, except for some technical barriers, the most hampering ones were related to spatial conditions. These do not always exist for historical buildings, especially for those outside of city centers close to canals or other types of surface water.

7. Reflection

Within this chapter strengths and limitations of the research are provided, accompanied by an examination of the expected results compared to the findings and conclusion. Furthermore, recommendations for future research are given. The chapter concludes by providing a personal reflection.

7.1. Strengths and limitations of the research

The conceptualization of SWTE systems as a niche within the multi-level perspective, along with considering the perceived attributes of innovations, provided a solid framework for investigating the possible implementation. Viewing SWTE systems as an innovative niche shed light on the obstacles hindering its widespread adoption. Additionally, employing a diverse range of research methods proved highly valuable in obtaining meaningful results. Notably, the emphasis on qualitative methods and the informal approach of the respondents greatly facilitated asking relevant questions.

However, it is important to acknowledge some limitations in this research. The available literature on SWTE systems is relatively limited and often written by a specific group of researchers from knowledge institutes. This could bring some bias, therefore future research could benefit from considering a broader range of sources, if available, to enhance the overall understanding. Furthermore, the calculations performed were merely indicative and did not account for various contextual factors. Nevertheless, the outcomes of this study feel natural and robust due to the site visit, inclusion of multiple stakeholders, and the extensive literature review.

7.2. Expected results

This research expected that SWTE energy systems are technically viable to heat historical buildings. However, difficulties were expected to be faced regarding insulation measures, the number of stakeholders, willingness to adapt, and alternative sustainable technologies. The findings partly align with these expectations, as insulation measures were identified as crucial for integrating SWTE systems with historical buildings. However, the emphasis on willingness to adapt was not prominent, as economic viability seemed to be a more significant factor. The limited availability of alternative sustainable technologies did not pose a significant threat to the adoption of SWTE systems because of their limited availability.

Surprisingly, the research revealed unexpected complexities associated with the spatial conditions of the subsurface in historical cities. Furthermore, the potential ecological impact of filtration was not foreseen during the research planning phase, highlighting the importance of further exploration in this area.

7.3. Recommendations for future research

Despite several acknowledged technical barriers, this research showed that SWTE has the technical potential to provide for the heating demand of historical buildings. However, spatial conditions can hamper the implementation making it a relatively poor-performing innovation within a city center. Therefore, further research should be conducted to specifically investigate the subsurface conditions that pose challenges to implementation. By studying these conditions, suitable locations for the installation of SWTE systems can be identified, potentially overcoming spatial constraints.

Moreover, ecological concerns related to the filtration of surface water should be further investigated. Understanding the potential negative consequences for ecosystems and developing mitigation strategies are crucial for ensuring the environmental sustainability of present and future SWTE systems.

Lastly, conducting comparative studies between SWTE systems and other sustainable heating technologies would provide valuable insights that were not explored extensively in this research. This comparative analysis would assess how SWTE systems perform in relation to alternative technologies and explore the potential for integrating different technologies to maximize heating efficiency and sustainability

7.4. Personal reflection

As this chapter marks the end of this thesis, I would like to reflect on the research process. The journey began with submitting a preliminary research proposal that I wrote with a lot of effort during my busy time as a photographer at the Amsterdam Dance Event. This showcases the unique combination that shaped the research process, as I balanced my time between working on the thesis and capturing photos at festivals.

In terms of the actual research, it started well with positive input and enthusiastic respondents willing to assist me. I found myself engaged in the (preliminary) results and eagerly collected vast amounts of data through various methods. However, this presented a challenge when it came to structuring and presenting the results effectively. Additionally, the timing of data collection sometimes made it difficult to maintain a clear overview. Another struggle was connecting literature gathered from various research organizations with the existing academic literature and subsequently discussing findings with the literature.

On a positive note, this research journey has further deepened my interest in the energy transition and its associated challenges. The complex nature of technical spatial conditions, high implementation costs, decision-making, and human behavior add another layer of intricacy. I am excited to put this knowledge into practice while continuing to refine my photography skills.

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9. Appendices

Appendix A: Open interview mail

Dear [Name],

I am writing this email to you regarding my interest in aquathermia. I noticed that you [Relevant connection to topic, author of document, function e.g.] so I hope I have reached out to the right person.

Let me briefly explain the topic of my research, which is still in its initial phase. Firstly, I am in the final stages of completing my master's degree in environmental and Infrastructure Planning at the University of Groningen. In my research, I aim to conduct a technical and spatial planning feasibility study focused on preserving old buildings, heritage, and monuments in historical city centers. This is because heating these buildings is often costly, inefficient, and with the urgency of transitioning away from gas, alternative solutions are needed. This is where I see the potential for aquathermia, specifically extracting heat from surface water such as city canals, which often have a close proximity to a heat source. I want to explore the requirements for implementing this on a larger scale and how it can be utilized to preserve the architectural beauty of city centers. In essence, how can a building truly benefit from this approach?

Now, I have a few questions for you:

1. Do you have any documents that would be interesting for me to read and gain a deeper understanding of the subject?
2. Based on your experience, do you have any tips on how to approach this research topic?
3. What are your thoughts on the idea of using canal water to heat old buildings?

Thank you in advance!
Best regards,

Stef van Oosterhout
Student Environmental and Infrastructure Planning

Appendix B: Interview guides

I. Interview guide English

Introduction

Discuss the perspective of the thesis on old buildings and scaling up for the entire city center, exploring technical-spatial possibilities and barriers. Initially, approaching the technical aspects to assess what is possible and feasible. Then focusing on the collective aspect and how to implement it in a historic city center.

- In the research, your name will be anonymized.
- The data will be shared with my supervisor.
- The anonymized data will be used in this research.
- The data (audio recordings) will be retained for a maximum of 3 months.
- You are free to stop this interview at any time without providing a reason.

Do you agree with these terms?

Intro

1. Could you tell me a bit about yourself and your role?
2. What contributions have you made to aquathermia research within [different per respondent], and how are you further involved in aquathermia?
3. How do you envision the use of aquathermia in an ideal situation in the future?

General Aquathermia

4. From your perspective, what is the driving force or motivation behind choosing aquathermia for a project?
5. Is there potential for aquathermia, and if so, what kind of potential are we talking about?
    a. How much energy can be generated in an ideal scenario?
    b. Can aquathermia fully replace existing concepts in the energy transition?
    c. What are the climate and sustainability benefits of this concept?
6. Could you explain how TEO aquathermia works?
    a. What components make up such a system?

    b. How does water temperature play a role in aquathermia?
        i. Are there any available figures or research on this?
    c. How does the flow rate of a lake/river affect the operation of aquathermia?
        i. Are there any available figures or research on this?
    d. Are there any circumstances where surface water cannot be used or is less suitable as a source?
    e. How does the financing work?
        i. Are there specific elements that make the system expensive or cost-effective?
        ii. Are there subsidies available? Specifically for certain components of this system?

7. What are the negative aspects encountered in existing aquathermia projects in the Netherlands?
    a. What technical hiccups and obstacles have you come across?
        i. I've heard about mussels and algae growth, could you provide more information on this?
        ii. Monumental quay walls
    b. What legal hiccups and obstacles have you encountered?
    c. What ecological components have you faced?
    d. What is needed to overcome these barriers?

8. Who actually owns this heat?
9. What are the positive aspects?
    a. What often turns out to be less challenging in hindsight, compared to the initial estimation during project implementation?

Aquathermia Using Canal Water

10. I have created a system layout (see system diagram), does it align with your understanding, or should anything be added to this system?
    1. Surface water source
    2. Pumping installation
    3. Technical room
    4. Heat exchanger
    5. Heat pump
    6. Aquifer thermal energy storage (WKO system)

    7. Heat network
    8. User delivery system

11. What are your thoughts on the idea of using canal water to heat old buildings?
12. Does it have further potential?
13. Why is it not yet implemented on a large scale?
    a. Do you see any potential obstacles specific to canal water and heating old buildings?
    b. What would be necessary to overcome these barriers?

14. What would be required to scale up this approach?
    a. Based on your experience, do you have any tips for addressing and scaling up my "gap"?
15. Are there any other known developments that could hinder aquathermia and limit the progress of this concept?
    a. Heat exchangers in sheet piling
    b. Biogas/green gas
    c. Geothermal energy
    d. Hydrogen
    e. Etc.

Conclusion

16. Do you have any documents that would be interesting for me to read and delve deeper into the topic?
17. Any further additions or questions that I might have missed?
18. Do you have any other questions?

Thanks for your time!

II. Interview guide Dutch

Introductie

Bespreek invalshoek scriptie oude gebouwen en opschalen voor gehele binnenstad en kijken naar technisch-ruimtelijke mogelijkheden en barrières. Eerst technisch aanvliegen en kijken wat mogelijk en haalbaar is. Daarna meer op het collectief en hoe vorm te geven in een historische binnenstad.

- In het onderzoek zal uw naam geanonimiseerd worden
- De gegevens worden gedeeld met mijn supervisor
- De geanonimiseerde data zal in dit onderzoek gebruikt worden
- De data (geluidsopname) zal maximaal 3 maanden worden bewaard
- U mag elk moment stoppen met dit interview zonder daar een reden voor te geven

Gaat u hiermee akkoord?

Intro

1. Kunt u mij iets vertellen over uzelf en uw functie?
2. Wat heeft u bijgedragen aan onderzoeken binnen [verschillend per respondent], en hoe bent u verder betrokken bij aquathermie?
3. Hoe ziet u het gebruik van aquathermie voor zich in een ideale situatie in de toekomst?

Aquathermie algemeen

4. Wat is, in jouw perspectief, de drijfveer/beweegreden achter een project waarbij voor aquathermie wordt gekozen?
5. Is er potentie voor aquathermie en zo ja, wat voor potentie hebben we het dan over?
    a. Hoeveel kan er mee opgewekt worden in een ideale situatie?
    b. Kan aquathermie bestaande concepten volledig vervangen in de energietransitie?
    c. Wat zijn de klimaat en duurzaamheids voordelen van dit concept?

6. Kunt u mij iets vertellen over de werking van TEO aquathermie?

    a. Uit wat voor onderdelen bestaat zo’n systeem?
    b. Hoe speelt de watertemperatuur een rol bij aquathermie?
        i. Zijn hier cijfers/ onderzoeken van beschikbaar?
    c. Hoe speelt het debiet van een plas/loop/rivier een rol in de werking van aquatermie?
        i. Zijn hier cijfers/ onderzoeken van beschikbaar?
    d. Zijn er omstandigheden wanneer oppervlaktewater niet of minder goed als bron gebruikt kan worden?
    e. Hoe zit het financieel in elkaar?
        i. Zijn er specifieke elementen die het systeem duur maken, of juist niet?
        ii. Bestaan er subsidies? En voor specifieke onderdelen van dit systeem?

7. Wat zijn negatieve elementen waar tegenaan wordt gelopen, kijkend naar de verschillende projecten die bestaan in Nederland?
    a. Welke technische hick-ups en obstakels komen jullie tegen?
        i. Mij is verteld over de mosselen en de algengroei, kunt u mij hier misschien iets meer over vertellen?
        ii. Monumentale kademuren
    b. Welke legal hick-ups en obstakels komen jullie tegen?
    c. Welke ecologische componenten lopen jullie tegenaan?
    d. Wat is nodig om deze barrières uit de weg te gaan?

8. Van wie is deze warmte eigenlijk?

9. Wat zijn positieve elementen?
    a. Wat valt vaak mee achteraf, wat veel erger is ingeschat kijkend naar de implementatie van een project?

Aquathermie grachtenwater

10. Zelf heb ik nu een indeling gemaakt (zie afbeelding systeem), klopt dit volgens jou of zou er nog iets toegevoegd moeten worden aan dit systeem?
    1. Surface water source
    2. Pumping installation
    3. Technical room
        a. Heat exchanger

        b. Heat pump
    4. Aquifer thermal energy storage (WKO systeem)
    5. Heat network
    6. User delivery system

11. Wat denkt u zelf van het idee om grachtenwater te gebruiken om oude gebouwen te verwarmen?
12. Heeft dit verdere potentie?
13. Waarom wordt dit nog niet grootschalig ingezet?
    a. Zie jij potentiële obstakels om dit specifiek voor stadsgrachten toe te passen en daarmee oude gebouwen te verwarmen?
    b. Wat zou nodig zijn om deze barrières uit de weg te gaan?
14. Wat zou er nodig zijn om dit op te schalen?
    a. Heeft u misschien, kijkend naar uw ervaring, nog tips om mijn "gap" aan te vliegen en op te schalen?
15. Zijn er andere ontwikkelingen bekend die aquathermie in de weg kunnen zitten en de ontwikkeling van dit concept kunnen beperken?
    a. Warmtewisselaars in damwanden
    b. Groengas/biogas
    c. Geothermie
    d. Waterstof
    e. Etc.

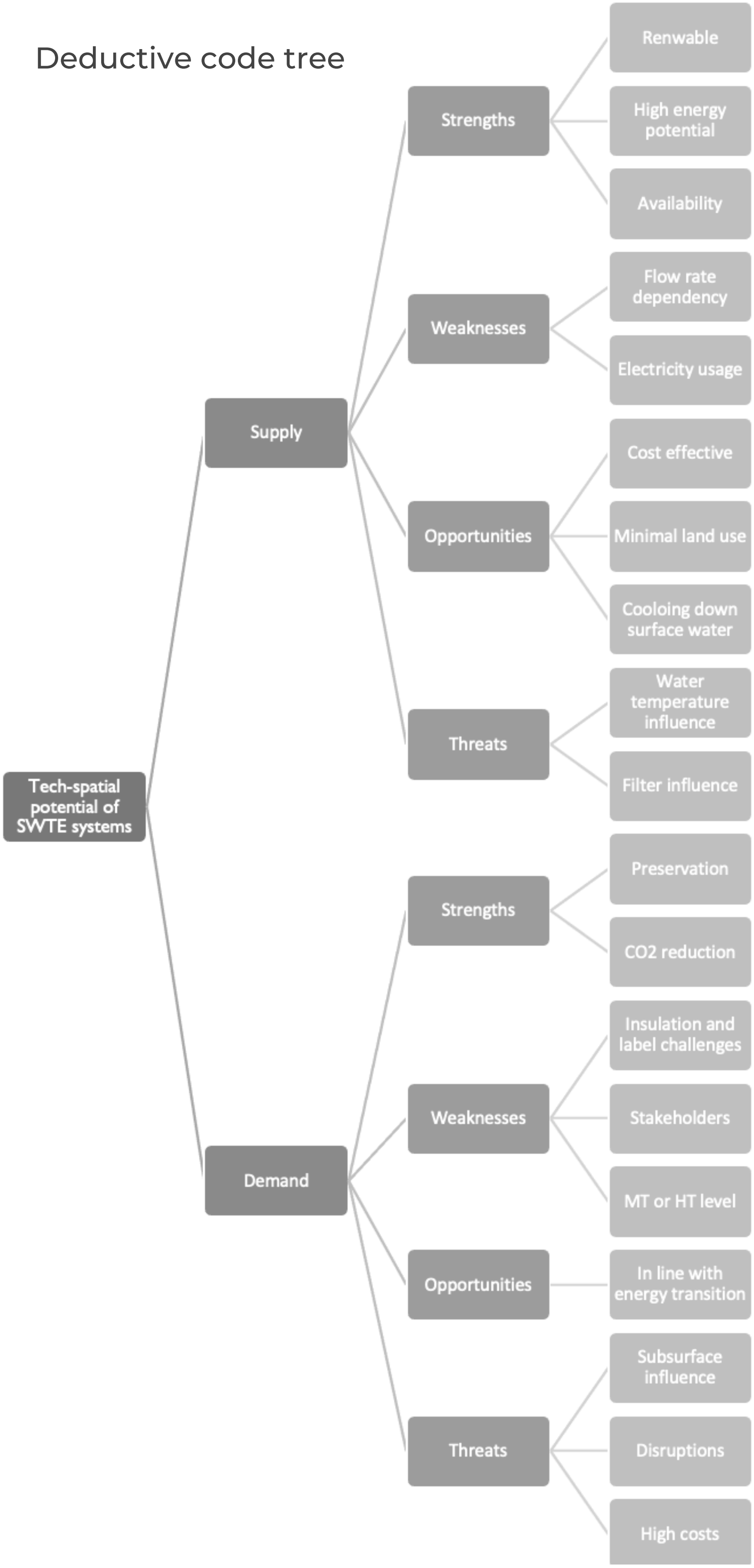
Sluiting

16. Heeft u nog documenten die interessant zijn voor mij om te lezen en mij hier meer in te verdiepen?
17. Verder nog eventuele toevoegingen, of vragen die ik wellicht nog had kunnen stellen?
18. Heeft u verder nog vragen?

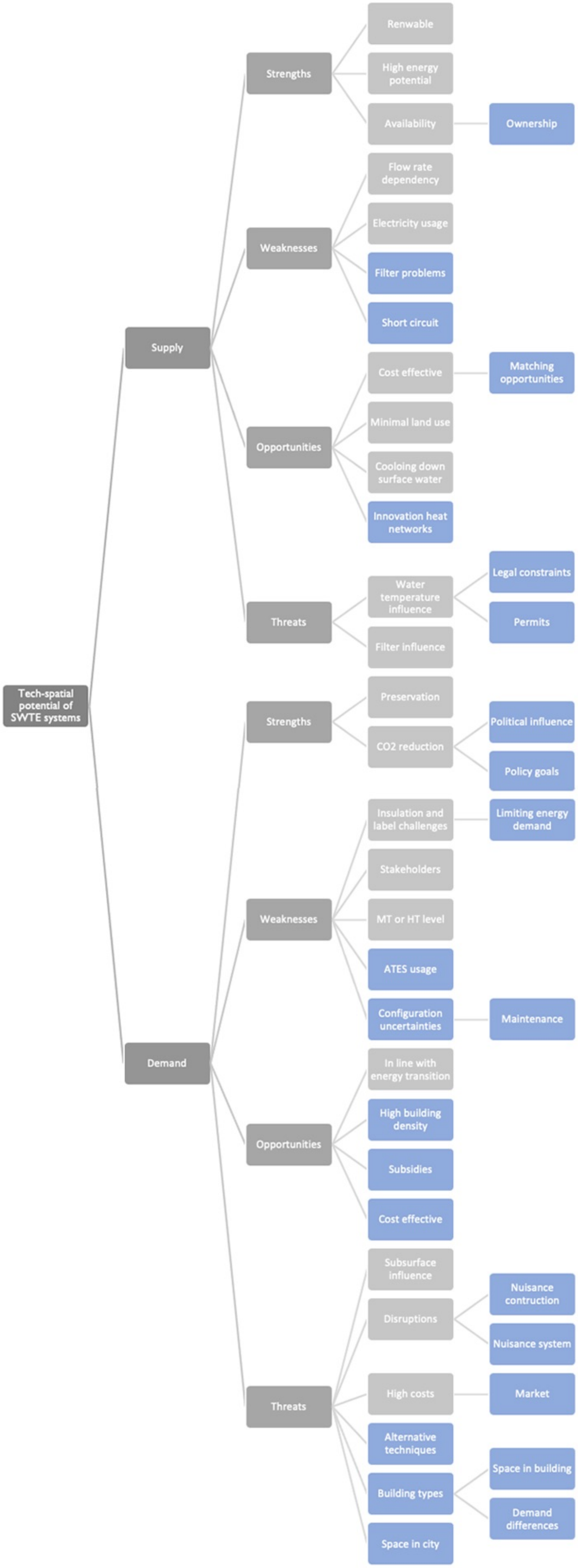
Bedankt voor uw tijd!

Appendix C: Code trees

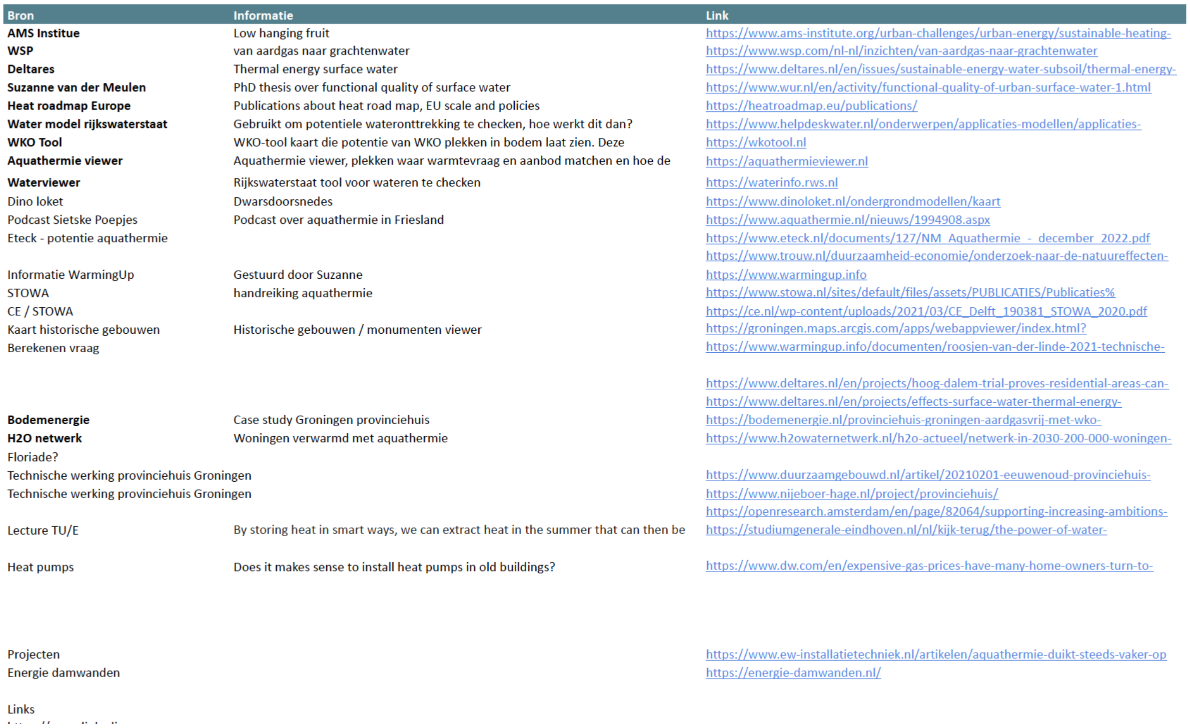
I. Deductive code tree



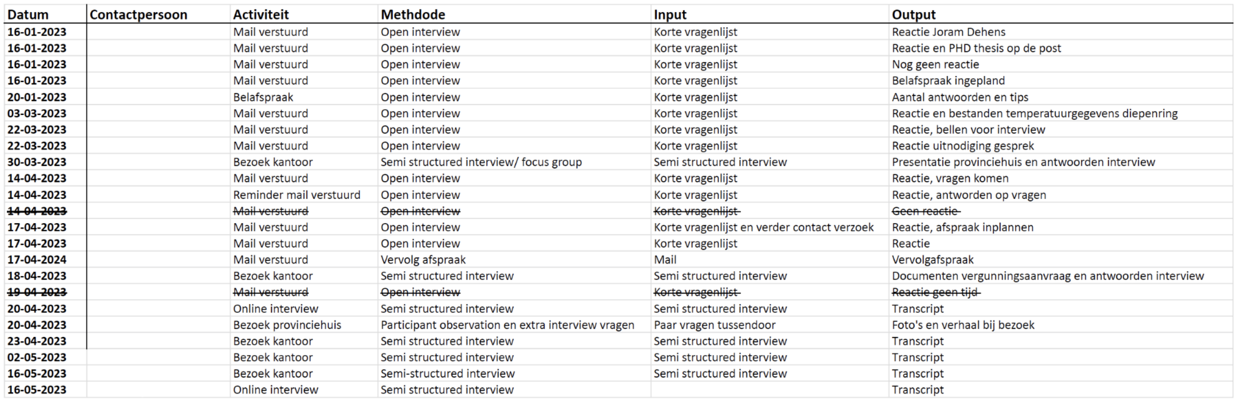
II. Inductive code tree



Appendix D: Documentation desk research



Bron	Informatie	Link
AMS Institue	Low hanging fruit	https://www.ams-institute.org/urban-challenges/urban-energy/sustainable-heating-
WSP	van aardgas naar grachtenwater	https://www.wsp.com/nl-nl/inzichten/van-aardgas-naar-grachtenwater
Deltares	Thermal energy surface water	https://www.deltares.nl/en/issues/sustainable-energy-water-subsoil/thermal-energy-
Suzanne van der Meulen	PhD thesis over functional quality of surface water	https://www.wur.nl/en/activity/functional-quality-of-urban-surface-water-1.html
Heat roadmap Europe	Publications about heat road map, EU scale and policies	https://heatroadmap.eu/publications/
Water model rijkswaterstaat	Gebruikt om potentiele wateronttrekking te checken, hoe werkt dit dan?	https://www.helpdeskwater.nl/onderwerpen/applicaties-modellen/applicaties-
WKO Tool	WKO-tool kaart die potentie van WKO plekken in bodem laat zien. Deze	https://wkotool.nl
Aquathermie viewer	Aquathermie viewer, plekken waar warmtevraag en aanbod matchen en hoe de	https://aquathermieviewer.nl
Waterviewer	Rijkswaterstaat tool voor wateren te checken	https://waterinfo.rws.nl
Dino loket	Dwarsdoorsnedes	https://www.dinoloket.nl/ondergrondmodellen/kaart
Podcast Sietske Poepjes	Podcast over aquathermie in Friesland	https://www.aquathermie.nl/nieuws/1994908.aspx
Eteck - potentie aquathermie		https://www.eteck.nl/documents/127/NM_Aquathermie_-_december_2022.pdf
		https://www.trouw.nl/duurzaamheid-economie/onderzoek-naar-de-natuureffecten-
Informatie WarmingUp	Gestuurd door Suzanne	https://www.warmingup.info
STOWA	handreiking aquathermie	https://www.stowa.nl/sites/default/files/assets/PUBLICATIES/Publicaties%
CE / STOWA		https://ce.nl/wp-content/uploads/2021/03/CE_Delft_190381_STOWA_2020.pdf
Kaart historische gebouwen	Historische gebouwen / monumenten viewer	https://groningen.maps.arcgis.com/apps/webappviewer/index.html?
Berekenen vraag		https://www.warmingup.info/documenten/roosjen-van-der-linde-2021-technische-
		https://www.deltares.nl/en/projects/hoog-dalem-trial-proves-residential-areas-can-
		https://www.deltares.nl/en/projects/effects-surface-water-thermal-energy-
Bodemenergie	Case study Groningen provinciehuis	https://bodemenergie.nl/provinciehuis-groningen-aardgasvrij-met-wko-
H2O netwerk	Woningen verwarmd met aquathermie	https://www.h2owaternetwerk.nl/h2o-actueel/netwerk-in-2030-200-000-woningen-
Floriade?		
Technische werking provinciehuis Groningen		https://www.duurzaamgebouwd.nl/artikel/20210201-eeuwenoud-provinciehuis-
Technische werking provinciehuis Groningen		https://www.nijeboer-hage.nl/project/provinciehuis/
		https://openresearch.amsterdam/en/page/82064/supporting-increasing-ambitions-
Lecture TU/E	By storing heat in smart ways, we can extract heat in the summer that can then be	https://studiumgenerale-eindhoven.nl/nl/kijk-terug/the-power-of-water-
Heat pumps	Does it makes sense to install heat pumps in old buildings?	https://www.dw.com/en/expensive-gas-prices-have-many-home-owners-turn-to-
Projecten		https://www.ew-installatietechniek.nl/artikelen/aquathermie-duikt-steeds-vaker-op
Energie damwanden		https://energie-damwanden.nl/
Links		



Datum	Contactpersoon	Activiteit	Methdode	Input	Output
16-01-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie Joram Dehens
16-01-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie en PHD thesis op de post
16-01-2023		Mail verstuurd	Open interview	Korte vragenlijst	Nog geen reactie
16-01-2023		Mail verstuurd	Open interview	Korte vragenlijst	Belafspraak ingepland
20-01-2023		Belafspraak	Open interview	Korte vragenlijst	Aantal antwoorden en tips
03-03-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie en bestanden temperatuurgegevens diepenring
22-03-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie, bellen voor interview
22-03-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie uitnodiging gesprek
30-03-2023		Bezoek kantoor	Semi structured interview/ focus group	Semi structured interview	Presentatie provinciehuis en antwoorden interview
14-04-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie, vragen komen
14-04-2023		Reminder mail verstuurd	Open interview	Korte vragenlijst	Reactie, antworden op vragen
~~**14-04-2023**~~		~~Mail verstuurd~~	~~Open interview~~	~~Korte vragenlijst~~	~~Geen reactie~~
17-04-2023		Mail verstuurd	Open interview	Korte vragenlijst en verder contact verzoek	Reactie, afspraak inplannen
17-04-2023		Mail verstuurd	Open interview	Korte vragenlijst	Reactie
17-04-2024		Mail verstuurd	Vervolg afspraak	Mail	Vervolgafspraak
18-04-2023		Bezoek kantoor	Semi structured interview	Semi structured interview	Documenten vergunningsaanvraag en antwoorden interview
~~**19-04-2023**~~		~~Mail verstuurd~~	~~Open interview~~	~~Korte vragenlijst~~	~~Reactie geen tijd~~
20-04-2023		Online interview	Semi structured interview	Semi structured interview	Transcript
20-04-2023		Bezoek provinciehuis	Participant observation en extra interview vragen	Paar vragen tussendoor	Foto's en verhaal bij bezoek
23-04-2023		Bezoek kantoor	Semi structured interview	Semi structured interview	Transcript
02-05-2023		Bezoek kantoor	Semi structured interview	Semi structured interview	Transcript
16-05-2023		Bezoek kantoor	Semi-structured interview	Semi structured interview	Transcript
16-05-2023		Online interview	Semi structured interview		Transcript