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Implementation of Solar Thermal Energy in a Small Residential Area

Case Study Kanalstaden

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Abstract

Implementation of Solar Thermal Energy in a Small Residential Area - Case Study Kanalstaden

Jennie Thunman

This thesis investigates the feasibility of installing solar thermal energy systems on small residential districts and the practical issues that can arise. A residential district, planned to be built in the locality Tierp, has been used as a case study. The residential district Kanalstaden will be designed as a canal residential area, where houses will be constructed alongside three to five artificial canals. The district will consist of small module houses with one basic module that later can be extended by adding one or two similar modules, as well as larger two floor houses. The circumstances of the residential area, the houses and the residents, puts certain requirements and demands on the design of a potential solar thermal system. This does in turn highlight some main factors that have to be taken into consideration when a solar thermal energy system is planned for residential areas. Practical issues like where and how collectors and tanks can be placed has to be considered, but also things like the balance between supply and demand has a great importance. Surrounding circumstances, such as shadowing, can also have a great impact. Social factors, such as the specifics of the residents' heating and water demand, have ultimately also a very important role. The most significant conclusion that can be drawn from the case of Kanalstaden however, is the flexibility of solar thermal energy systems. It can, and should, be implemented differently depending on the actual circumstances existing - it just has to be designed and installed in accordance to it.

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Sammanfattning

Syftet med detta exjobb var att undersöka och kartlägga några av de praktiska problem som kan uppstå vid planering och installation av solfångare i ett mindre bostadsområde. Kanalstaden, ett bostadsområde som planeras byggas i Tierp, fungerade som Case Study. Bostadsområdet kommer precis som namnet antyder att byggas i form av en kanalstad - ett antal tomter kommer att anläggas utmed 3-5 konstgjorda kanaler. Området kommer bestå av dels en modulhustyp med en basmodul som sedan kan kompletteras med en eller två liknande moduler, och dels ett större tvåvåningshus. De förutsättningar och begränsningar som finns för bostadsområdet, husen och de boende, ställer vissa krav på utformningen av ett potentiellt solenergisystem i området. Detta belyser i sin tur några av de huvudskaliga faktorer man bör ha i åtanke när man planerar för ett solfångarsystem i ett bostadsområde. Praktiska faktorer såsom var och hur solfångarna och värmetanken kan placeras måste beaktas, men även faktorer som balansen mellan energibehovet och energiproduktionen är av stor vikt. Externa faktorer, såsom skuggning, är ytterligare en aspekt som kan ha stor påverkan. Sociala faktorer, som de boendes specifika energikonsumtionsmönster, har slutligen också en stor roll. Den kanske största slutsatsen som kan dras från fallet Kanalstaden är dock flexibiliteten i solenergisystem. Trots de många varierande faktorer som kan påverka, finns det nämligen också många möjligheter med tekniken och många olika sätt att implementera det. Solenergisystem kan, och bör, därmed planeras unikt vid varje tillfälle – huvudsaken är att det görs i enlighet med de lokala omständigheter och förutsättningar som råder i just det aktuella fallet.

Contents

1. Introduction

Energy has a principal role in today's society. We need energy for heating and electricity in our houses, for transportation as well as for production and distribution of services and products. But today's energy systems have also a major role in the existing environmental problem, and it is therefore essential that we find solutions to improve the situation. For example, we need to decrease the use of fossil fuels, increase the use of renewable sources and become more energy efficient in general. This is relevant in all of the above sectors - not the least in the residential and service sector, which in Sweden stands for about 40% (166 TWh) of the total energy consumption (Energikunskap, 2012). One way to improve the energy situation in the residential sector could be to make better use of the solar influx constantly reaching our earth. This can be done in a numerous of ways, but the various technologies are often divided into active and passive solar heating. In active solar heating solar radiation is collected to be converted into either heating or electricity (Vinnova, 2009, 11). When it comes to active solar heating systems applicable to the living environment it is mainly PV cells (transformation of solar energy to electricity) and solar collectors (transformation to heating and/or cooling) that are discussed. In this thesis heating through solar collectors - solar thermal energy - will be studied in detail.

The main focus when investigating the potential of a solar energy system is the local circumstances of the solar influx. Only a fraction of the total radiation from the sun reaches the earth atmosphere and equals to 1 370 W/m^2. Much of this is reflected back into space and absorbed by ozone, carbon oxide and oxygen, and the maximal solar radiation that reaches the surface of the earth is about 1 000 W/m^2. The surface around the equator receives the largest amount of energy, average solar insolation of 2 500 kWh/m^2/year, as the incidence angel is almost perpendicular and also has the shortest distance to the sun. In Sweden the number is just over 1 000 kWh/m^2/year. Solar energy in Sweden is often met with skepticism as Sweden is known for not being the sunniest of countries. But even though solar power may be more suitable in places with more sun, solar power should not be disregarded even in northern countries such as Sweden. In fact, compared to central Europe the difference is negligible – the average is in fact the same for Malmö and Paris (1 000 kWh/m^2/year) – and it is only when compared to the Mediterranean region and desert landscapes, where it can reach up to 3 400 kWh/m^2/year, the difference becomes substantial. (Andrén, 2007, 8-9). German, with similar solar influx than Sweden, is in fact the most prominent country in Europe when it comes to solar energy (Vinnova, 2009).

According to Svensk Solenergi, a trade organization for solar energy, there are today about 15 000 solar thermal energy system installed in Sweden and more than 2 000 systems are installed each year. Most of them are installed on small one- or two dwelling buildings, but some are also installed for larger buildings such as apartment blocks and sport facilities, as well as part of smaller district heating systems. (2012). Solar thermal energy (STE) can consequently be interesting for a variety of residential systems – even in Sweden. Worth pointing out, however, is that no building is the other one alike and the solar thermal system applied to the building can therefore be very different. The circumstances for a private small one-dwelling house, for example, can simply be very different from a building with district heating system – and the solar energy system suitable will have to be designed and dimensioned accordingly. In this thesis the conditions and demands of *small scale residential areas* will be studied. That is, the feasibility of installing solar thermal system on a small scale residential area - and what aspects that are needed to be taken into consideration – will be in focus. To make this problem more approachable a residential district in Tierp will be studied as a case study.

Tierp is a locality in Uppsala County, Sweden with a population of about 5 000 people. To make the town a more substantial community the project “Vision 10 000” plans to increase the population to the double in the upcoming years. Kanalstaden (‘Canal-town’) is a residential district proposed to be constructed in the southeast of the town, and is one of the means to obtain this goal. It aims to expand the residential opportunities in the area, as well as attract students and commuters to live in Tierp. Just as the name insinuates the district will be designed as a canal residential area, where houses will be constructed alongside three to five artificial canals on a total area of 450 m^2. The district will mainly consist of small module houses, constituting simple residences, with one basic module of 30 m^2 each that later can be extended by adding one or two similar modules. As a compliment to these smaller houses there will also be the possibility of building larger two floor houses with an area of 198 m^2. To make the residential district more sustainable and attractive there are plans to implement a small scale energy system suitable for the conditions of the project. In this thesis the feasibility to implement solar thermal energy on the district will be investigated; what type of solar collectors could be suitable, where they can and should be placed, what type of storing that could be suitable etc. The project is an initiative from the organization Tierp Rotary, and is now collaboration between the organization, the municipality and the consulting company Ferrivia AB. The thesis is carried out on behalf of Ferrivia AB.

1.1. Thesis objective

The main objective with this master thesis is to study the practical issues that can arise with implementation of solar thermal energy systems on a small residential district. The planned residential district Kanalstaden in Tierp will work as the case study that results will be based on. The questions that will be asked in relation to Kanalstaden are, for example:

What type of solar collectors could be suitable, and where can and should they be placed?

What issues have to be taken into consideration in regards of storing?

What external factors have to be considered in installing solar thermal system in a district such as Kanalstaden, and what kind of impact can they have on the suitability/feasibility?

These questions will be the basis of how solar thermal energy can be applied to residential districts in general, meanwhile as the feasibility of solar thermal energy on Kanalstaden will be studied.

1.2. Limitations

While this thesis was realized the preparatory work for the project of Kanalstaden was still carried out. Due to still existing uncertainties, there have been many assumptions and simplifications in the thesis. Calculations that have been made are furthermore simple in their formation and should by no means be seen as any highly accurate results. Focus in the report has instead been on discussing the practical complexity that can arise in the planning of solar thermal energy in a district such as Kanalstaden. Any thorough economic aspects have, for example, not been included. Ultimately, the thesis should therefore be seen solely as a preliminary work that one could base future, more thorough, studies on.

1.3. Disposition

Initially in this report there will be a presentation of Tierp and its surroundings, the residential district and the potential residents. This is to give a basic overview over the situation and what the conditions are for Kanalstaden, as well as how that can impact the feasibility of installing solar thermal energy.

This will be followed by chapter 3, “Estimated Energy Demand”, where the energy demand that can be expected in the residential area will be presented. The energy demand is divided into heating and hot water, and the numbers the estimations are based upon are limit values new building has to follow regarding energy demand, as well as the average water consumption. As solar thermal energy is especially dependable on the water consumption, the largest focus will be towards this. Discussions have also been made concerning the relevance to the estimated energy demand in Kanalstaden.

Chapter 4 gives a background to the solar thermal energy technology; what it is and how it works, and what elements are needed for a well functional system. A more thorough insight is given to the two types of collectors that are relevant for Kanalstaden: the flat plate collectors and the evacuated tube collectors. The types are compared, and discussions are given around their effectiveness and how it changes depending on certain circumstances. A section is also bestowed to present the short-time storage often used for solar thermal energy. Following this, there will be a presentation of two seasonal storage methods that could work as alternatives to the short-time storage.

In chapter 5 solar thermal energy are applied on the planned Kanalstaden. The chapter is divided into two parts: “Possible scenarios” and “Application of scenarios of Kanalstaden.” In the first part different scenarios are presented that could be possible for the different types of houses that are planned for Kanalstaden, how much estimated solar collectors would be needed, as well as the required tank size. In the next part, these scenarios are problematized and applied on the “real situation” of Kanalstaden, where consideration are taken to where the houses are placed, what type of houses will be shadowing them and the possible placement of the solar collectors, where the tank can be placed inside the houses in regards to the collectors etc.

Chapter 6 will present the results concluded in the study. Suggestion of feasible alternatives for Kanalstaden will be dealt with - by presenting and discussing what type of solar collectors are best in different scenarios in Kanalstaden etc. Also a section will be dedicated to summarize the various losses a STE system in Kanalstaden can expect to have.

Ultimately there will be a concluding discussion, chapter 7, where the circumstances of Kanalstaden will be further discussed and how those will affect the feasibility of using solar energy thermal in the district. Circumstances that will be in focus are the specific architectural circumstances of the Kanalstaden houses, the balance that will occur between the expected energy supply and the residents demand, as well as the proprietary situation that will prevail. A part will also be dedicated to reflection and suggestions on future and alternatives methods.

2. Presentation of the area and residential district

Tierp is a locality situated in the northern part of Uppsala County, with Uppsala in the south and Gävle in the north. It developed from being a railway station village during the last part of the 19th century and is now the regional centre of Tierp municipality. The municipality has a total area of 1 543 km^2, with a predominantly forest coverage. About 30 % takes up by agricultural, and habitation and other land. Within the municipality there are eight localities, and about twenty smaller villages. 63 % of today's existing population in the municipality live in the larger localities, while the other live in more sparsely populated areas. Manufacturing is the largest branch of industry (where Atlas Copco AB and Erasteel Kloster AB are the largest companies), even though the municipality itself is the largest employer. (Tierp, 2012).

The locality Tierp is located in the centre of the municipality, with the river Tämnaren (Tämnarån) running by. The residential district Kanalstaden is planned to be built along the river southeast of, and in connection to, Tierp. The area is lowland and preferentially existing of agricultural land, parts of which is pastureland and parts is about to be overgrown. Tämnarån is a main drainage basin in Uppsala County, draining water from the municipalities of Tierp, Älvkarleby, Östhammar, Uppsala and Heby, to finally flow into Lövstabukten in Bothnian Sea (Bottenhavet) at Karholmsbruk. It is occasionally subjected for flooding which has been taken into consideration in the decision making of the project and where the district should be situated. Other characteristics of the river and surrounding area have also resulted in certain restrictions on the dimensions of the canals. The main idea, however, is to distribute the water in the river into three to five artificial canals and to place a minimum of 100 lots, of 450 square metres each, in between. Each lot will therefore have one long side towards the canal and the other towards the street.

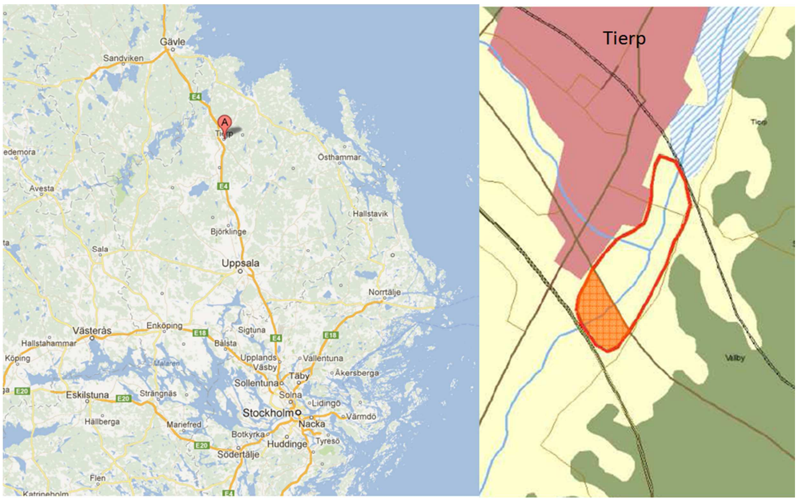

Figure 1. Location of Tierp (left), and planned location of Kanalstaden (right) (Google maps; Tierp Rotary, Civitas Nova, 2011).

2.1. The houses of Kanalstaden

The houses that will be constructed in Kanalstaden exist of two types; one smaller, more flexible, module type and a larger, more traditional, two floor family house. The module house consist of one to three units, each 30 m^2 (5 x 6 m) with a loft of 8 m^2. The idea is that the resident first buys one basic module, consisting of two rooms (i.e. living room and bedroom) with pantry, loft and bathroom. In addition to this, one or two more modules can be purchased either simultaneously or later, in a way to expand the building. The second module consists of a kitchen, living room and loft, whereas the third module is identical to the first basic module. The units will be connected with small glass encrusted passages. Each module will furthermore have a glass sliding door towards the canal on the short side of the house. The roofs of these houses have a gradient of 45 degrees, well suited for solar energy application. In conclusion, the module house can offer a simpler residence of 30 m^2 with 2 possible sleeping accommodations (one bedroom + one loft), 60 m^2 with 3 beds or a larger residence of 90 m^2 with 5 beds. If connected, the pantry's in module 1 and 3 can furthermore be removed since the kitchen in module 2 will then be sufficient.

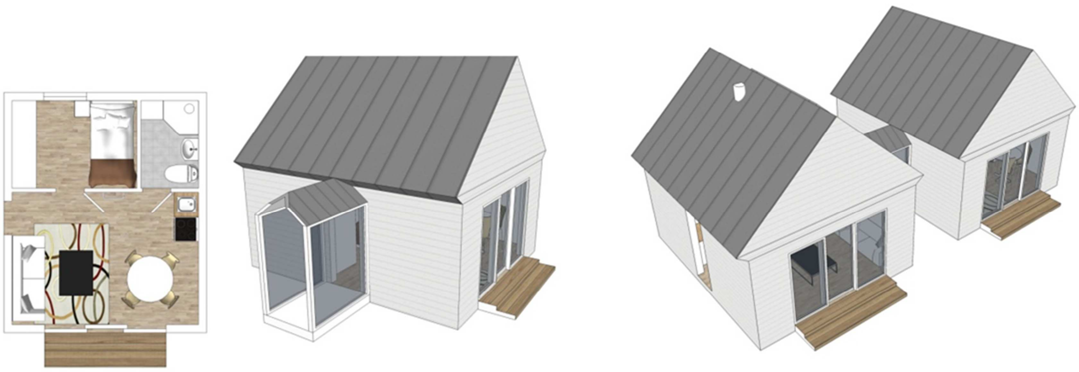

Figure 2. Module houses with one singular unit, as well as two connected units (Tierp Rotary and Civitas Nova, 2011).

The second type of housing that is planned for Kanalstaden, the larger two floor house, is intended as a compliment to the smaller module houses. They are suitable for example families who want to take advantages of the canal environment but not wanting to expand their home in phases. This type of house has a total area of 198 m^2, divided on the two floors (16.5 x 6 m). In a total, it consists of 5-6 bedrooms, 3 shower/bathroom-units as well as some larger common areas. Windows will be placed on the long side of the house, facing the canals. From own calculation it can be determined that the roof gradient of these larger houses will be about 15 degrees (14.03 degrees).

Figure 3. Large house, towards canal (left) and toward street (right) (Tierp Rotary and Civitas Nova, 2011).

The buildings will be prefabricated by a selected building company, and are designed especially for Kanalstaden and to optimize the building costs. No actual changes can therefore be done on the houses regarding energy systems, but has to be implemented externally. For example, no added isolation can be done on the houses to decrease the energy demand. This is especially applicable on the module houses as added isolation material in the walls would make a big impact on the already small area. Changes and alterations may be done, however, on easily changeable segments such as on/in windows, roofs and walls. The design of the houses is also flexible; sizes and placement of doors and windows are changeable and can be constructed in accordance to the design of the solar collectors to achieve most aesthetical design. The measurements of the exterior (walls and roofs) are however fixed.

Figure 4. Kanalstaden, phase 1-3 (Tierp Rotary and Civitas Nova, 2011).

The construction company that will be hired for the construction will take care of the foundation, delivery and mounting of the buildings. They will be installed accordingly to the market demand and a minimum of 100 building are required for the project to reach a break-even. The construction will however be installed in three phases (see figure 4). Phase 1 will be constructed in connection to already existing residential areas and will therefore take advantage of existing road grid etc. This first phase will hold about 30 lots and the canals will be lined in a west-northwest/south-southeast direction (perpendicular to Tämnarån). The houses will in other words be facing a somewhat south-southwest direction (more exactly, 200 degrees) towards the canals and roads. The other two phases, 25 and 50 lots respectively, will be located along canals that will be lined along the river. The houses in these phases will therefore have a perpendicular direction to the first houses, facing the canals in a west-northwest direction. The gables of the houses in these phases will therefore be standing towards 200 degrees. (Tierp Rotary and Civitas Nova, 2011).

2.2. The expected residents in Kanalstaden

The municipality Tierp has around 20 000 inhabitants, and as mentioned, more than 5 000 of these reside in the locality of Tierp today. This number has steadily increased during the past 50 years, increasing from 3 065 people in 1960 (0,041%) to 5 377 in 2005 (0,059%) (SCB, 2009). As mentioned, Kanalstaden is projected to realize a continuing, and increased, trend and aims to attract both single residents and families from other parts of the county/country. Commuters are furthermore a very large target group, including commuting students to Uppsala University and commuters working in one of the nearby cities. In 2010 there were already 3 517 registered outward commuters from the municipality (Tierp, 2012), and with good communication to the surrounding larger cities such as Uppsala, Gävle and Stockholm, as well as to the airport at Arlanda, Kanalstaden may very well increase this number. Along with good commuting times to these cities the pricing for commuting from Kanalstaden is also very competitive. For example, a small student apartment in Uppsala cost about as much as a house by the canal in Tierp will. So while the larger two floor houses are well suited for larger families, the smaller module houses aim to attract students and commuters especially, but also single residents who in the future might plan to increase their household and living space. The individual residents will furthermore be the owners of the property; once they buy the building they will be responsible for the actual house, the lot as well as any installed energy system.

2.3. The energy system in Tierp

In 2010, a total of 85 TWh was used in Sweden for heating and hot water in residences (including both small houses and apartment blocks) and non-residential premises. Of this, about 36 TWh was used for small houses, 27 TWh for apartment blocks, and 22 TWh for non-residential premises - which equals to 42, 32 and 26 % of the total use of energy respectively. (Energimyndigheten, 2011a). In other words, small houses account for the largest part of the energy use in buildings in Sweden.

In Tierp municipality, about 167 GWh was used in 2010 for heating and hot water in small houses. The average distribution of used energy systems can be seen in figure 5. As can be seen, bio fuels and electricity account for the largest part of the energy consumption, but there are also small parts of oil heating as well as district heating. (Energimyndigheten, 2011b). The amount of energy gained from solar energy, as well as other renewable energy sources, has unfortunately not been found. This should however not necessarily mean that they do not exist, or that the amounts are negligible, but nevertheless it can be assumed that solar energy in the area is relatively small.

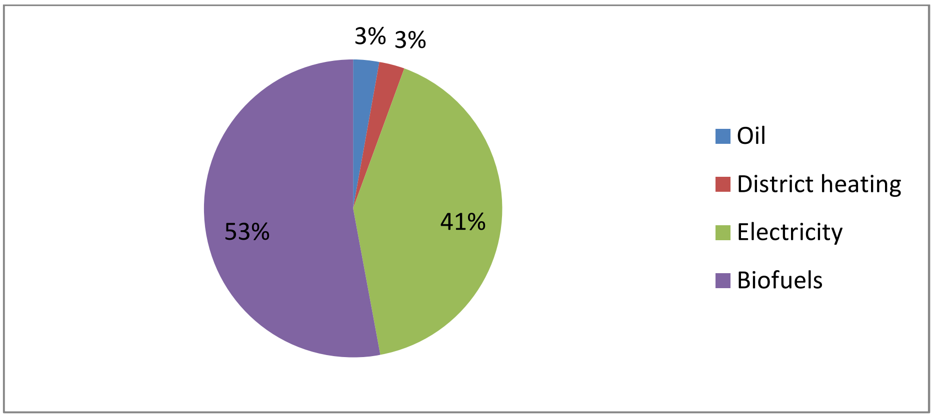

Figure 5. Total use of energy for heating and hot water in Tierp household, 2010 (GWh) (Energimyndigheten, 2011b).

3. Estimated energy demand

Energy consumption in buildings can roughly be divided into three areas: space heating, water heating and household electricity, and for solar thermal energy it is the space and water heating that is of interest. For newly constructed buildings Boverket, The Swedish National Board of Housing, Building and Planning, have put up limits regarding space and water heating that are required to be followed. These limits are created based on the amount of energy that is needed during a normal year, with a normal usage. New rules were set on October 4th 2011 that will take effect during the year of 2012 and be fully implemented on January 1st 2013. Since Kanalstaden is still in the planning phase and it is hard to determine the exact energy demand of its buildings, assumed energy consumption will for this thesis be based on these limit values. Boverket have divided Sweden into three climate zone with varying energy limits. For Tierp, located in climate zone III, the limit is 90 kWh/m^2/year (compared to 110 kWh/m^2/year in climate zone II and 130 in climate zone I). This is applicable on buildings with non-electrical heating, which is assumed to be the case in Kanalstaden. (BFS 2011:26). Applied limits for the houses in Kanalstaden are presented in table 1 below.

As mentioned in previous section, Kanalstaden is planned to be constructed in three stages and the total energy demand will therefore be increased gradually. Vision 10 000's plan is, however, that all 100 lots will eventually be built, but since each house will have their own energy system, it is irrelevant in this thesis to investigate the total energy demand of the entire residential district. Focus will instead be on the demand for each type of house. The values presented in table 1 are furthermore on a yearly basis: the energy consumption will of natural reasons fluctuate over the year. Most consumption will obviously be during winter, when the Swedish households are in need of heating, and little, or no, energy consumption will be needed during summer. This is the case for space heating; when it comes to water heating the situation is different as well as very relevant to distinguish when planning for Solar thermal Energy system.

Table 1. Estimated energy consumption for the houses in Kanalstaden

Type of house	Energy consumption (kWh/year)
Module house (one unit), 30 m^2	2 700
Module house (two units), 60 m^2	5 400
Module house (three units), 90 m^2	8 100
Large house, total area of 198m^2	17 820

3.1. Hot water consumption

The hot water need in Sweden is, on average, often presented to be about 65 l/person/day and compared to the energy demand that increases in winter time, the hot water demand remains more or less static throughout the year. This equals to about 1 000 kWh/person/year and is included in the total energy consumption presented above. (SP and Svensk Solenergi, 2012, 5-19). The average, however, is very fluctuating and various institutions show different numbers. SP and Svensk Solenergi, for example, states in their report "Solvärmesystem för småhus – Kursmaterial för installatörer" from 2012 that it usually varies between 35 to 120 liters. Energimyndigheten showed in a report from 2009 where they investigated the water usage in 44 reference Swedish households that it could vary between 58 to 156 liters/person/day. In other words: the water consumption can vary greatly between different households depending on living habits etc, and above stated average should only be considered as a very generalized guideline.

To get a better picture of the more relevant water consumption it can furthermore be of interest to be aware of some of the factors that can affect. For example, larger households generally use more hot water than smaller households. Studies also show that people living in apartments tend to use more water than the ones living in separate houses (58 liters/person and day versus 42 liters/person and day, according to the study performed by Energimyndigheten (2009). Even technology can have a great part in the amount of water being used in a household. For example, by using efficient shower heads and water taps, as well as energy saving dishwashers and washing machines, the total water consumption can be reduced vastly. Energimyndigheten claims that the consumption can be reduced to up to 20 % with energy efficient appliances (2011c), while SP Technical Research Institute of Sweden states it can be as much as 40 % (Lundh and Hiller, 2011, 10).

Maybe the most significant factor, however, is the inhabitants' lifestyle and habits of using hot water. Some people simply tend to use more water than others. Commonly has been stated that teenagers for example usually takes long showers, and for natural reasons families with young children can have a tendency to use more water. It can also be assumed that people such as students may have a different, and maybe more distributed, water consumption than employed, as students tend to have a more flexible lifestyle – and similar is surely accurate for senior citizens, unemployed and people working from home. Studies have also shown that small scale energy systems, such as solar thermal system, raise people's awareness which in turn tend to change their energy consumption; with a raised awareness, many simply try to decrease their energy consumption (Energimyndigheten, 2009, 46). Any statistics for typical water consumptions behavior for various demographic groups have however not been surveyed and mentioned assumptions should therefore only be considered as unreliable, but perhaps noteworthy, generalizations.

What has been studied more thorough, however, is the general difference in water consumption over time. Overall, there are water consumption peaks in the morning and during the evening when most people tend to spend time for cooking, showering, laundry etc., and a significant decrease during the day and night when people are away/asleep. During the day it is generally very low or inexistent, apart from in households where people are at home (and then there is often some water usage, but usually it doesn't reach the sizes of the morning and evening peaks). Furthermore there are often some households that deviate significantly from the norms, having extremely high peaks or a very constant water usage etc. These specific cases will of course have its impact on the efficiency of using solar thermal energy, but they are, of obvious reasons, hard to estimate on beforehand.

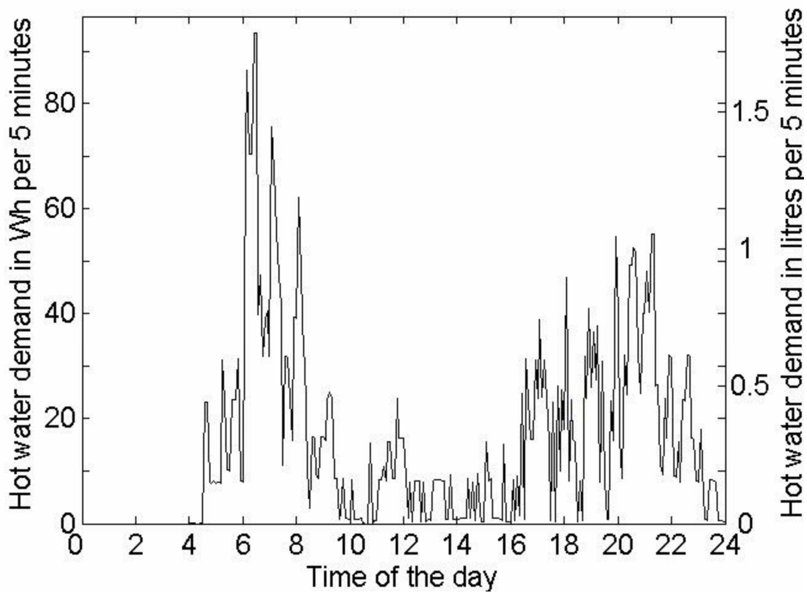

Figure 6. The average hot water use over the day (weekday) (Lundh, Wäckelgård and Ellegård, 2007).

Magdalena Lundh, Ewa Wäckelgård and Kajsa Ellegård showed in their study, "Design of hot water user profiles for Sweden conditions" (2007), that a general difference can also be seen between weekdays and weekends. The average, they concluded, is about 82 liters/person on the weekdays, and 86 liters/person on the weekends. The largest difference, however, is not in the amount but in the time when the peaks occur. Mornings and evening peak can be distinguished both during weekends and weekdays, although in the weekends the morning peaks tend to be later and broader than in the weekends. For weekdays the morning peak are usually also much higher and narrower than the evening peak. This can be seen in figure 6 compared to figure 7.

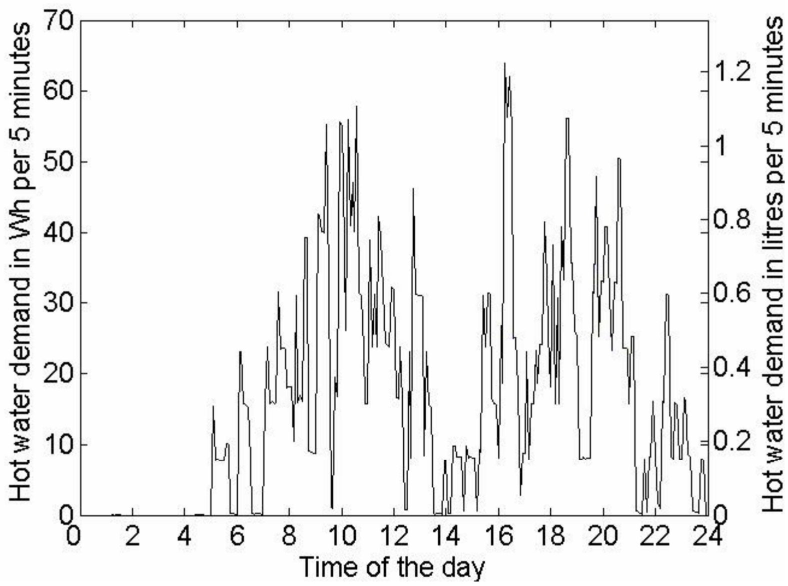

Figure 7. The average hot water use over the day (weekend) (Lundh, Wäckelgård and Ellegård, 2007).

Some difference can, according to Lundh et al, also be distinguished between winter and summer – something that conflicts to the above mentioned statement that hot water demand would be more or less constant throughout the year. What Lundh et al points out though, is the obvious decreased water consumption during summertime – due to the fact that that is often when residents are away. (Lundh et al, 2007). In below table the various factors that can affect the water consumption are summarized.

Table 2. Summary of factors that can affect the water consumption

Factor	Exemplification
Type of housing	Residents in apartments tend to use more water than ones in houses.
Technology	Water efficient appliances can reduce water consumption.
Lifestyle	Teenagers and families with small children tend to use more water.
Water heating system	Small scale energy systems can raise awareness and lessen the consumption.
Time of the day	Peaks in mornings and evenings.
Time of the week	Later and broader morning peaks in weekends than during the weekdays.
Time of the year	Decreased water consumption during summertime.

The significance, then, to map out these water consumption variations and it possible reasons, is to gain an understanding of the impact it has on the efficiency to install solar thermal energy. This is something that will be discussed more thorough later in the report, but what can now be mentioned is that solar thermal energy is the most efficient in households with large water consumption.

As for Kanalstaden it is ultimately impossible to distinguish the exact total water demand that can be expected, as the conditions of the residents (the total amount, their demographics and their living habits etc.) are unknown. What is known, however, is that energy efficient appliances are planned to be installed in the houses and that an energy efficient washing machine will be available for each house. This information will however have little significance without the conditions of the residents, and in this stage of the project only assumption will be possible – but with above mentioned factors kept in mind.

4. Solar Thermal Energy

Solar thermal energy (STE) uses solar collectors to convert energy from solar radiation into thermal energy. The thermal energy can then be used for example residential and commercial heating of air and/or water, and to heat swimming pools. When used for building there are two types of systems: the solar water heating system for heating of water, and the combination system, that in addition to water heating also provide space heating and cooling. In Sweden, where space heating is central in residential energy, the singular water heating system is relatively unusual (approximately 5-10% (Kovács and Petterson, 2002) and in this study only the combination system will be investigated.

The combination system can appear in various ways, but the Swedish standard system with short time storing, function as follows: When solar radiation hits the solar collector a heat transfer medium (often consisting of water mixed with glycol or oil) existing within the collector is heated (pt 1, figure 8). The medium is then transported to the bottom of a water filled accumulation tank, where the heat is transmitted through an enclosed heat exchanger (pt 2). The tap water is heated through two heat exchangers: first the incoming cold water is pre-heated through a heat exchanger in the bottom of the tank to then be heated later in a heat exchanger above (pt 3). The purpose of this is that it creates a beneficial stratification in the tank that would not be obtained if only one heat exchanger would be used. With stratification the cold water in the bottom of the tank will namely decrease the heat losses from the solar collectors, which will in turn increase the degree of efficiency. Hotter water in the top of the tank will also create a reduced need for an additional energy source for the residence’s water heating. From the accumulation tank heat will also be transferred to the radiators for space heating (pt 4). A complimentary energy source, such as electricity or a wood stove, can also be connected to the accumulation tank (pt 5). As solar thermal energy with short time storing can never cover the entire total energy demand, a compliment will be needed. During the summer months, however, and when the energy demand is small and the collected heat from the sun is high, it is often possible to only use an electrical immersion heater as the additional energy source (pt 6). (Formas, 2004, p4-5). This will be discussed further in section 4.1.2.

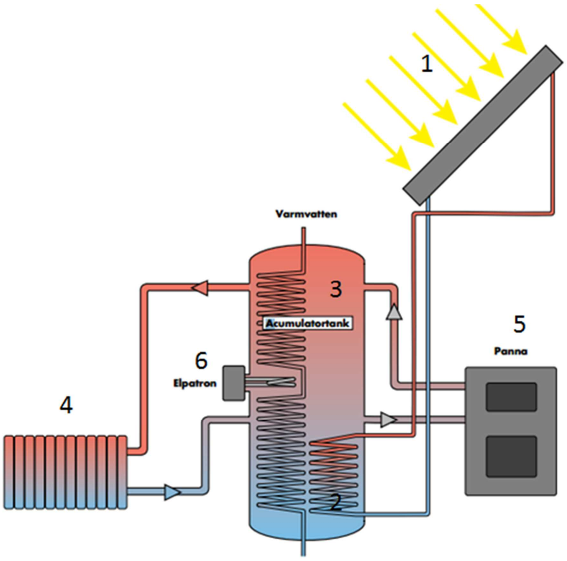

Figure 8. Solar thermal energy system (Formas, 2004, 4).

4.1. Solar collectors

There are mainly two types of solar collectors relevant for domestic solar heating: flat plate collectors and evacuated tube collectors. Other types, such as line focus collectors, have in this thesis been disregarded. The reason for that is, amongst other things, that they are not efficient enough for the Swedish climate (Andrén, 2007, 21).

4.1.1. Glazed, flat plate solar collectors

The glazed, flat plate collectors are the most mainstream collectors worldwide when used for domestic solar water heating and in 2007 it made up for 90 % of the Swedish market. The main reasons for this are that they are relatively cheap, easy to install and have a high reliability. (Boström, 2007, 61). A flat plate collector has the structure of a flat box that consists of a black surface (absorber), a transparent glass cover, a heat-transported fluid and a heat insulating back part. When the solar radiation passes through the glass cover it is absorbed by the black surface at the bottom of the collector, and is then conducted by the heat transfer medium to the solar collector circuit. One main issue in the collector is the potential heat loss and it is reduced by not only the insulated backing, but also the glass cover. The absorber is also glazed with a selective coating to reduce the heat loss. (SP and Svensk Solenergi, 2012, 22).

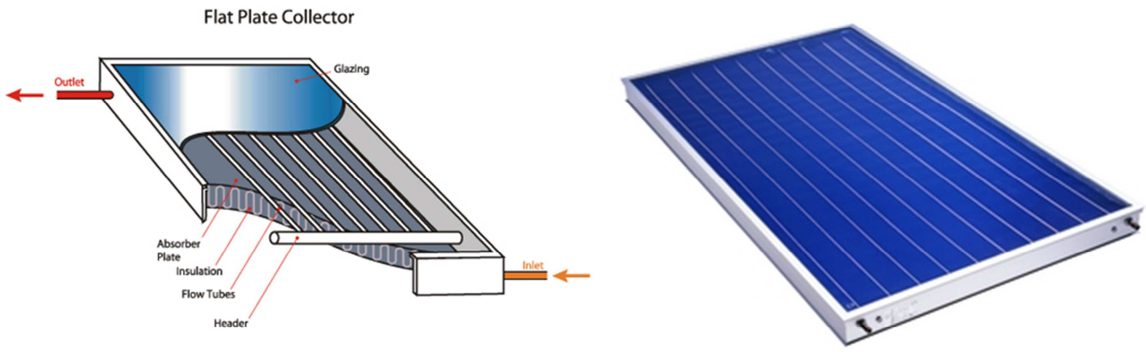

Figure 9. Flat plate collectors (Adam Solar Resources, 2012; Svensk Solenergi, 2012).

When used in residence with short-time storing and for space heating it is generally estimated that 2-3 m^2 flat plane solar collectors are needed/person residing in the building (Kovács and Pettersson, 2002, 13) with a maximum capacity of 400 kWh/m^2/year (Andrén, 2007, 67). This means that, on average, 2,5 m^2 flat plane solar collectors are needed to produce 1 MWh/year. Normally, the optimal location of the flat plate solar collector is to place it towards south (with an acceptable deviation of 20 degrees) and with an inclination angle of 45-70 degrees horizontal. (SP and Svensk Solenergi, 2012, 19). This is the conditions above estimation is based upon. Worth mentioning is also that the higher angle is more suitable for the combination system, while the 45 degree tilt is the optimal angle for system that heat only hot water (SP and Svensk Solenergi, 2012, 27).

The gained energy will furthermore vary depending on the season of the year. For natural reasons most energy can be gained during summer. In fact, of the maximum capacity of 400 kWh/m^2/year as stated above, the capacity during the summer months are estimated to be about 80 kWh/m^2 and month (SP, 2006) – that is, more than half of the total gained energy are gained during the three summer months. This will furthermore affect the most optimal position of the solar collectors, depending on when the assumed production will be. If summer production is planned it is better with a more horizontal tilt, while production throughout the year (that is, also spring and autumn), a more inclined angle is better. Due to the Swedish climate a lower tilt – that is, a more horizontal placing – is less favorable. This scenario is namely most suitable where the sun is higher on the sky and will in Sweden mostly absorb solar radiation during the summer and not much during spring and autumn.

There are also other factors one has to take into consideration considering the position of the collectors. Most importantly, more area is needed if collectors are placed with higher or lower tilt than 45 degrees. The relation between the tilt and the additional needed solar collectors if placed with a tilt differentiating from 45 degrees can be seen in table 3. For example one can see that if the collectors are placed on walls – that is, a 90 degree tilt – 4 % more area is needed compared to if they were placed with a 45 degrees tilt.

There are certain advantages with a deviation however. A steeper tilt will, for example, decrease the risk of snow stacking up onto the collector that can otherwise be a problem and decrease the efficiency. If the collectors are placed on the walls they can also absorb some of the radiation reflected from the ground – something that is especially relevant when there is reflection from example snow, ice or water. The collectors are on the other hand more affected by shadowing when placed on walls. It is therefore especially relevant in these cases to avoid any type of shading from other nearby houses, trees and such to gain maximal utilization of the solar energy facility (Andrén, 2007, 10).

Table 3. Increased amount of collector area needed with various tilts, if collectors are placed toward south (Kovács and Petterson, 2002).

Tilt angle	**Area [m^2]**
15°	1,25
30°	1,06
45°	1,00
60°	0,97
90°	1,04

The flat plate collectors can ultimately be mounted either free-standing, be implemented in the roof/walls, or atop of the roof/walls. One of the great advantages with flat plate collectors are that they are easily customized and implemented in the actual building (Kovács and Petterson, 2002, 27), something that is not as true with the evacuated tube collectors and will be presented shortly. Solar collectors that are implemented in the roofs have the advantage that it replaces roofing material, protects pipes, sensor units and such, and is also more esthetical. The disadvantage is, however, that underlying units becomes less accessible to maintenance. Mounting the collectors atop of the roof/walls can offer a simpler solution as the collectors are often pre-fabricated for this purpose, and they will also be more accessible when maintenance. (Andrén, 2007, 16).

4.1.2. Evacuated tube collectors

Evacuated tube collectors are the other commonly used solar collector type. They are originally developed from fluorescent lamps and have a very similar design to that technology. The collector module consists of several evacuated glass tubes, each of which has an absorber plate down the centre. In between the surface and absorber vacuum exists and because of this there is no thermal conductivity in the tube collectors like there is in the flat plate collectors. The performance of an evacuated tube collector is therefore relatively high, about 30 % more than flat plate. They are also more efficient when there is diffuse radiation (Kovács and Petterson, 2002, 26), as well as when the radiation reaches the collectors somewhat from the side (Landegren and Skogsäter, 2011, 7). Evacuated tube collectors have also a higher degree of efficiency year round – that is, they have a larger income ratio during spring and autumn than flat plate collectors, which have a higher degree of efficiency during summer. (Solenergiteknik, 2012). The estimated amount of evacuated tube collectors needed for STE systems is 1.5-2.5 m^2/resident (placed with a tilt of 45 degrees and towards south). This equals to the fact that, on average, 2 m^2 evacuated tube collectors provides about 1 MWh/year.

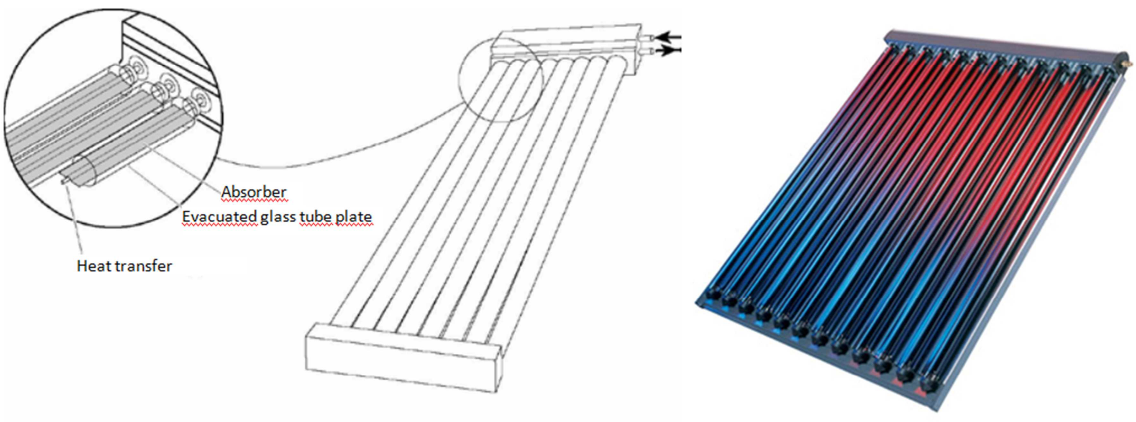

Figure 10. Evacuated tube collectors (SP and Svensk Solenergi, 2012, 24; Svensk Solenergi, 2012).

The most optimal circumstances to place evacuated tube collectors are similar to flat plate collectors: toward south with a tilt between 45 and 70 degrees. (Kovács and Petterson, 2002, 13). Although, evacuated tube collectors should, generally, be mounted with a relatively steeper tilt than the flat plate collectors, up to 65-70 degrees from horizontal. This will not only even up the degree of efficiency between summer and winter, but it will also prevent snow from stacking up on the collectors. Compared to the flat plate collectors, which emit more heat loss and therefore melt potential covering snow, evacuated tube collectors will not be able to melt the snow as efficiently, hence the adaptation. (Andrén, 2007, 18).

Similarly to the flat plate collectors, evacuated tube collectors can also be placed on the walls with the same increased area of the solar panels (4 %).They are, however, not as suitable to be implemented in neither the roofs nor walls, since they don't have isolation. They will therefore have to be placed atop of the already existing roofing/wall material. (Kovács and Petterson, 2002, 26). Other aspects relevant in comparison to the flat plate collectors are that they are easier to exchange when needed, but on the other hand they are more fragile. This can be especially interesting in relation to example vandalism – another aspect than can be worth taking into account. For instance in the case of Storvreta – where a larger solar thermal energy system was installed – the system lost its efficiency and potential when the solar collectors where subjected to rocks thrown at them by the local kids (Åsberg, 2011).

While the implemented flat plate collectors in the roof/wall can, ultimately, be considered more esthetically appealing as they tend to integrate in the house design, the evacuated tube collectors can on the other hand accentuate a more advanced approach and give the residence a green label – seen from an esthetical viewpoint.

4.2. Storing

In all STE systems there is, as mentioned, some sort of storing required to make it possible to use the collected thermal energy at different times from when the sun is shining. This is particularly relevant in Sweden where the largest demand is at those times when the sun is not shining (i.e. winter and nighttime). There are many variations in which the solar heat can be stored, divided into either short-time storing or seasonal storing. The most common type of storing when it comes to small scale STE combination system is the short-time storing in an accumulation tank. This was the technology that was initially presented briefly in this chapter and will also be the technology that will be focused on in this thesis. The main reason for this is because of time limitation. Seasonal storing methods that could be feasible in Kanalstaden will however be presented in short to give a further understanding of the alternatives existing. These methods will consequently not be dealt with beyond this chapter. Instead the focus will be, as mentioned, on the method of short-time storage.

4.2.1. Short time storing

As mentioned, the conventional short-time storing consists of an accumulation tank that stores the heat from the solar collectors. The tank, functioning similarly to a large thermos, is usually constructed in steel, (Andrén, 2007, 40-41) and can store heat from solar collectors for about 2-3 days. During optimal circumstances (with solar collectors placed towards sun, well-isolated tank etc.) a tank of about 50-100 liters /m^2 flat plate solar collectors are required. When evacuated solar collectors are used, the ratio is 75-125 liters/m^2 solar collectors (Kovács and Petterson, 2002, 13). This will, generally, give a capacity of 300-400kWh/m^2 solar collectors/year (SP and Svensk Solenergi, 2012, 17-18).
Short-time storing will in other words not be able to cover the entire energy demand; generally it will be able to cover about 10-35 % (Kovács and Petterson, 2002, 13). This is, however, the yearly coverage and will fluctuate greatly depending on what time of the year it is. Solar thermal can cover over 90 % of the total energy demand during June-August, and be as low as 1% during December-February, according to Formas' report ”Sol till både vatten och värme – Enkla åtgärder kan öka solvärmeutbytet” (2004). During autumn and spring the number is usually around 25-30%.

A compliment system is therefore needed in combination to the accumulation tank. Most commonly biomass (wood or pellets) is used a compliment, but also systems such as district heating, electrical heating or the use of a heat pump are suitable compliments. An electrical immersions heater is also normally connected to the tank and will aid to heat the water when the compliment and/or the collectors won't provide enough energy. For example, in the summer the complimentary system are rarely needed (especially during the summer days with much sun) due to the decreased need of heating as well as the increased solar radiation, and in this case the electrical immersion heater can provide the needed compliment energy. A

compliment system is therefore especially relevant in the winter time when the energy demand is higher, and the solar radiation lower. (Formas, 2004, 5-7).
Apart from the actual size of the tank, it is relevant to consider the placing of the tank. To reduce the cost as well as heat losses to and from the collectors, it is advisable to place the tank close to the connected solar collectors. Preferably the distance should not exceed 5 m (SP and Svensk Solenergi, 2012, 12). If the distance exceeds 5 m, additional collectors should be installed to reach similar income ratio (2 % more for each increase of 5 m) (SP and Svensk Solenergi, 2012, 17). It is also advisable that the tank is placed in connection to the complimentary energy source, so as to reduce the heat loss further. To avoid the risk of water damage, if the tank of some reason would leak, it is also sensible to place the tank in connection to an existing drain, for example in a kitchen or bathroom. For the risk of water damage it is also advised against to place the tank in the attic, where the tank would theoretically be closer to the collectors. (SP and Svensk Solenergi, 2012, 55). Spacing would also have to be taken into consideration to the consumption tank.

Figure 11. Accumulation tanks (Energimyndigheten, 2011d).

4.2.2. Seasonal storing

The principle with seasonal storage is similarly to the short-time storing very simple. Excess heat produced in the summer is stored in some sort of storing unit until winter when the demand is high but the solar radiation low. It can example be stored in a tank above ground, similar to the short-time storing technology, or it can be stored underground in example large rock caverns, natural aquifers or in tubes or pipes that are installed in the ground. What method is best suitable, and if it is even technical feasible, for a certain system depends very much on the geotechnical circumstances of the site where it will be implemented. Two methods that could be geotechnical feasible in Tierp are accumulation tank and storing in clay. The latter, however, is included only on the premises that the ground on the location of Kanalstaden consists of clay - something that was estimated in the pre-study made for the district (Tierp, 2012), but would have to be ensured with a more thorough and exact geotechnical study. Compared to short-time storing, seasonal storing is furthermore only interesting to investigate for larger system, and not for single buildings. To make it economically viable, it is estimated that seasonal storage should only be implemented on systems with more than 100 small houses (Isaksson, Linström, Nordell, 2003).

4.2.2.1 Accumulation tank

Accumulation tank for seasonal storage has the same principle of short-time storage in a tank. The main difference is that it demands a considerably larger tank to be able to store larger amount of heated water and over longer periods of time. The tank is often constructed in concrete or steel, and similarly to the short-time tank it is water, heated from the solar collectors, that is the storage medium. Compared to most other seasonal storing, storing in tank is not dependable on the geotechnical circumstances of the location, but it does, however, demand a relatively high amount of space above ground. Although, even the accumulation tank can be installed underground, something that have been implemented for example in Denmark (Sandborg, 2006, 24).

One of the main issues concerning seasonal storage is the temperatures the storing medium can reach. The higher temperatures (without affecting the efficiency of the solar collectors), the higher degree of covering can be attained. Due to the thermal capacity of water, energy stored in an accumulation tank can reach fairly high temperatures.

Another relevant issue regarding seasonal storage is the time it takes for the storing unit to initially be heated and reach the maximum, and desirable, temperatures. Regardless of the storing method, it can be estimated that it will take 3-5 years until they reach these temperatures and can be considered fully charged. Simulations have shown that accumulation tanks are charged in lesser time than at least clay storing. This fact, together with the higher reached temperatures possible in an accumulation tank, gives the tank higher degrees of covering than example clay storing. (Fryklund, 2010, 42).

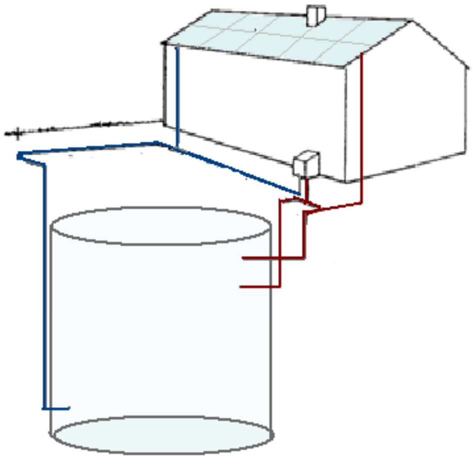

Figure 12. Seasonal storage in tank (Fryklund, 2010, 21).

4.2.2.2. Clay storing

In clay storing heated water from the solar collectors are circulated in tubes that are brought down into the naturally occurring clay ground. The heat are then exchanged with and stored in the surrounding clay. As mentioned, clay storing has high demands on the geotechnical circumstances and even if the ground consists of clay, the efficiency of storage can fluctuate depending on the ground composition. If the circumstances are very favorable to storing the method can be highly efficient, just as the circumstances also can make the method less efficient. (Fryklund, 2010, 11). To get a thorough geotechnical analysis prior to installment is, as mentioned, therefore very advisable when it comes to clay storing.

There are two variations of clay storing: one where the tubes are installed vertical and one where they are installed horizontal. The horizontal system is most common, where the tubes are buried about 1 meter below the surface and with 0.5-2 metes between each tube. In the vertical system the tubes can reach 15-30 meters down the ground. The horizontal system will therefore require less installment effort than the vertical, but instead it demands more surface of the ground. There are however geological prerequisites that also influence the suitability of the systems. (Fagerström, 1991, 8; Landegren and Skogsäter, 2011, 17).

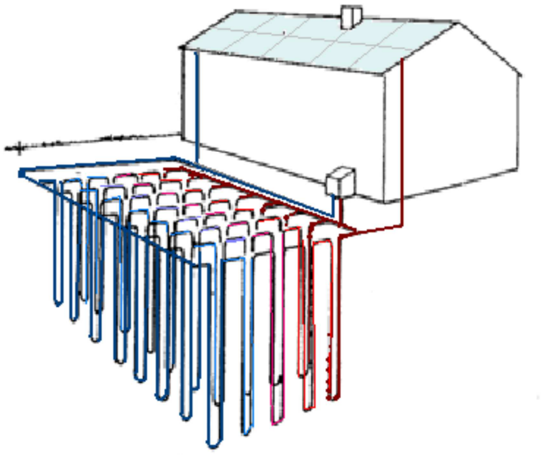

Figure 13. Storing in clay, vertically (Fryklund, 2010, 22).

Compared to the accumulation tank, clay storing takes somewhat longer time to reach its maximum temperature capacity and since the heat is stored in only surrounding clay, the maximum temperature is also lower than the accumulation tank. In fact, storing in clay often requires a supplementary heat pump to reach higher temperatures. Furthermore, clay storing needs more solar collectors area than storing in a tank (about 55-65 % more) to reach similar degree of covering.

Clay storing, however, is the more economical viable solution. This is basically due to the fact where other methods need material for isolation etc., clay storing only needs tubes that are also very easily brought down in the ground. The additional cost, however, is the probable needed heat pump (Sandborg, 2006, 25), and the more thorough geotechnical pre-study that is required.

4.2.2.3. Degree of covering for seasonal storage

Regardless of the size of the system, as well as the storing size and method used, it is difficult to reach 100 % degree of covering using seasonal storage. In fact, many existing examples have usually a degree of covering of less than 50 %. Jenny Fryklund argues in her report *Småskalig säsongslagring av solenergi för uppvärming av bostäder*, however, that it is technical feasible, and economically viable, to cover more than 80 % of the total energy demand by using seasonal storage. The reason why many existing systems don't reach these levels is, she argues, that not enough solar collectors have been used. The dimensions to theoretically reach 80% are according to Fryklund (2012) as follows:

Table 4. Dimensions needed to reach 80 % degree of covering (Fryklund, 2012).

Type of storage	Amount of solar collectors	Volume of storage
Accumulation tank	3,8 m^2/MWh	13 m^3/MWh
Clay storage	5,3 m^2/MWh	20 m^3/MWh

4.3. Dimensioning of STE system (for short-time storage)

Because of the very fluctuating supply, the dimension is very important when it comes to planning of STE systems. Generally it can be stated that the more collectors the more produced energy, and the larger the tank the larger amount of stored energy. The reality is however somewhat more complicated, but most important is that the collectors and the tank is well dimensioned in relation to each other as well as to the local circumstances such as solar influx and energy demand.

In the summer, for example, it is common that short-time storing systems are over-dimensioned (especially if the residents are often away in the summer). It is therefore important that not too much solar collectors are installed to prevent overheating, and that the tank is well proportioned to the actual installed amount. (Kovács and Petterson, 2002, 13). If the tank is too small there is a big risk it will be overloaded which causes the solar collectors to decrease their efficiency, but if it is too large, however, it can instead be difficult for the solar collectors to be able to heat the tank to the desirable temperatures (Formas, 2004, 5). It will also increase the heating losses with a too large tank. If the collectors are placed on the wall, or with a higher tilt than 45 degrees and with an aim to collect more of the autumn and spring sun, more area can be installed without the risk of overheating. Of course, a larger tank can also be subjected to a larger installation cost as well as maintenance, which are unnecessary costs if a smaller tank could be sufficient.

Similarly to the fluctuating demand over the season, the preferable size of the tank also depends on the relation between demand and supply. If the main demand coincides with when the most energy is produced, a smaller tank is needed. If the main demand, however, takes place during evenings, night-time and early morning when the sun don't shine, a larger tank will be needed. (SP, 2006).

It is therefore important to know the estimated energy demand for the actual residence. If there is no demand during summer the relevance to install a STE system decreases, while high energy consumption in the summer would strengthen the argument to use of solar collectors. As was mentioned earlier, it is also most relevant to dimension a STE system after the water demand and not the entire energy demand to avoid the risk of overheating (SP and Svensk Solenergi, 2012). This means that a household with large water demand can save more energy when using a STE system – especially in the summer when the water is more or less the only load. In a study made by Formas, it was presented that a household with a water consumption of 300 liters/day saved 16% of their total energy need, compared to 12% for a similar household that had a water consumption of 100 liters/day (Formas, 2004).

5. Solar thermal energy in Kanalstaden

When it comes to solar thermal energy and how it is applicable on Kanalstaden it can be divided into three variables: which type of solar collectors is most suitable, if the solar collectors should be placed on roofs or south walls, and what type of storing is most suitable. These are furthermore dependable on the varying factors existing for the houses in Kanalstaden: which phase the houses are placed in, what type of house it is, and, in the cases of the module houses, how many units there are. In phase 1 it also depends on whether the house is placed in the north or south row of the canals. This is what will be studied in the following chapter. In 5.1 the possible scenarios of installing solar collectors on the two types of building will be presented (where the collectors can be placed, and how much would be needed) – but without taking any consideration to surrounding circumstances. These circumstances will instead be dealt with in 5.2, where the scenarios of part 1 will be applied in the three phases in Kanalstaden.

5.1. Possible scenarios

As mentioned in previous chapters, the residential area of Kanalstaden is divided into three phases (as presented in figure 4) and the houses will be positioned differently depending in which phase it will be built and on what type of house it is. The houses will, however, never have a cardinal direction directly towards south (180 degrees), but instead towards south-southwest (200 degrees). That is, they will derivate 20 degrees from south, which, fortunately, is the maximum derivation solar collectors can be placed without a considerable loss in income ratio for solar thermal energy. Because of the variations in the houses positions, there will be three different positions in Kanalstaden where solar collectors can be placed towards 200 degrees: on the roofs of the module houses in phase 2-3 with a 45 degree tilt, on the roofs of the larger houses with a tilt of 15 degrees in phase 1, and on the walls of both the modules and the large house in phases 1-3.

Figure 14. Facades towards the canals (south/north in phase 1, and west/east in phase 2-3) (Tierp Rotary and Civitas Nova, 2011).

In this part of the report (5.1) the theoretical amount of solar collectors (flat plate and evacuated tube collectors, respectively) needed for these scenarios are calculated, based on the thumb rules dimensions presented in sections 4.1.1 and 4.1.2. Also the estimated size of the tank that would be needed for each case will be shown. Calculations have furthermore been made for houses with one, three and six residents. This is to give an overview of the possible residential circumstances in Kanalstaden, presenting both the minimum residing occupants (1 person), and the assumable maximum residents in the larger house (6 persons).

The scenario with 4 persons is to show both an estimated average amount of residents for the large house, but also to present an assumable maximum energy demand for a fully extended module house variant (that is, when all three modules are used). There will consequently not be assumed that more than 4 persons will be residing in the module house, due to the space limitation of the living area. In a one unit module it is assumed that it can be a maximum of 2 residents.

5.1.1. Collectors on the roofs of the module houses (45 degree tilt)

Solar collectors placed in a 45 degree tilt towards south are normally a very optimal position, and also the position most recommended calculations are based from. This is the case even in this report. As mentioned in section 4.1., the dimensions for producing 1MWh/year for collectors placed toward south with a tilt of 45 degrees is 2,5 m^2 for flat plate collectors and 2 m^2 for evacuated tube collectors.

For the houses in Kanalstaden these optimal circumstances are only present in phase 2-3, where the 45 degrees roofs of the module houses are placed towards the acceptable south direction of 200 degrees. The required amount of solar collectors and tank size for the relevant scenarios in this case is presented in below tables.

Table 5. Dimensioning for flat plate collectors in 45 degree tilt-scenarios

Scenario	Flat plane solar collectors	Tank volume
1 person /1 module unit (1 MWh)	2,5 m^2	125-250 liters
4 persons /3 units (4 MWh)	10 m^2	500-1 000 liters

Table 6. Dimensioning for evacuated tube collectors in 45 degree tilt-scenarios

Scenario	Evacuated tube collectors	Tank volume
1 person /1 module unit (1 MWh)	2 m^2	150-250 liters
4 persons /3 units (4 MWh)	8 m^2	600-1 000 liters

5.1.2. Collectors on the roofs of the larger houses (15 degree tilt)

Compared to the module houses where the gradient of the roof has been specifically constructed with the benefit for solar collectors, the roofs of the larger houses have not, as it would be too costly and aesthetically unappealing to construct. The gradient is instead approximately 15 degrees. To reach similar income ratio as in 45 degrees, more solar collectors would have to be installed - 25% more according to table 3, section 4.1.1. In a report published of criteria and limit values for solar thermal energy on residences by SP Technical Research Institute (2006), it is however stated that it is not beneficial to place solar collectors with a tilt under 20 degrees in Sweden - regardless of the additional amount of solar collectors installed. The reason is simply that the low standing sun in the autumn and spring will not be able to strike the absorbing plate of the collectors, which will cause a significant decrease in the total energy outcome. These circumstances are, however, optimal for summer production, which means that in the cases where the main demand is during summer – like for pool heating – such low tilt will be considerably more interesting. That is not the case for Kanalstaden.

Instead of installing solar collectors flush atop of these roofs it could theoretically be possible to use a tilt mounting frame to reach the preferred tilt. Although this is something that SP and Svensk Solenergi advise against in their report *Solvärmesystem för småhus – Kursmaterial för installatörer* (2012, 27), as it will assemble snow, leafs and other unwelcomed debris under the mounting frame etc.

Because of these issues, installing solar collectors on the roofs of the large houses in phase 1 will not be advisable and will not be investigated further in this report. Instead the possibility of installing collectors on the walls of the large houses will be explored.

5.1.3. Collectors on the walls (90 degree tilt)

In contrast to the case of placing solar collectors with a 45 degree tilt, placing them in 90 degrees on a wall is relevant in all phases in Kanalstaden, and on both type of houses. In phase 1 it will be the only alternative for both type of houses: for the modules, as they have no roofs towards south, and for the large houses, as mounting them atop of the roofs have been disregarded. In phase 2 and 3 it will mostly be relevant for the large houses, but it may also be interesting to study the possibility of placing collectors on the modules. For example, they could be placed on the wall of the southernmost installed unit of the module residences if shadowing will be an issue (which will be looked into in section 5.2).

According to table 3, 4% more solar collectors will be needed when placed in 90 degrees compared to placing in 45 degrees. Compared to the 25% additional collectors needed if placed in 15 degree tilt, this is not a big difference and can be considered negligible – or at least a possibility worth looking into. The amount needed of respective solar collectors as well as tank, are presented in below tables.

Table 7. Dimensioning for flat plate collectors in 90 degree tilt-scenarios.

Scenario	Flat plane solar collectors	Tank volume
1 person / 1 module unit	2,6 m^2	130-260 liters
4 persons / 3 units alt. large house	10,4 m^2	520-1040 liters
6 persons / large house	15,6 m^2	780-1 560 liters

Table 8. Dimensioning for evacuated tube collectors in 90 degree tilt-scenarios.

Scenario	Evacuated tube collectors	Tank volume
1 person / 1 module unit	2,1 m^2	158-263 liters
4 persons / 3 units alt. large house	8,4 m^2	632-1052 liters
6 persons / large house	12,5 m^2	938-1 563 liters

5.2. Application of scenarios on Kanalstaden

In this stage of the investigation, the scenarios in the previous part will be applied on the conditions of Kanalstaden. Due to the unique circumstances of Kanalstaden there are at least three factors that need to be taken into consideration.

First, there is the issue with the *placement of the solar collectors*. In previous chapter it has already been discussed that the collectors can be placed both on the roof of the modules and on the walls of both type of houses, and how much would be needed to supply various amount of residents. What hasn't been mentioned is where on the roof/wall the collectors should be placed and if there even will be enough space for the required amount. To increase the amount of time the radiation will hit the collectors per day, as well as decrease the risk of shadowing, the collectors should be placed closer to the ridge on the roofs and higher up on the walls. To avoid the risk of destruction as well as snow stacking up and covering the collectors, collectors placed on the façade should be placed 1,5 m above ground. These factors will decrease the available space where the collectors can be placed. The existing windows and doors will furthermore decrease this area.

Then there is also an aesthetic factor that needs to be taken into consideration. To not disrupt the planned design and make the building aesthetically unappealing, certain demand are put on how the collectors are placed on the façade. Preferably they should be placed integrated with the existing windows and doors, for example with relatively similar dimensions. Furthermore they should be placed evenly distributed on the façade/roof to give a more balanced impression. This means that when modules are extended, the additional collectors needed for the increasing demand could be recommended to be placed on the extended module, in a similar fashion to the first one.

Secondly, it is the very relevant issue of *shadowing*. Due to the close proximity of the houses in Kanalstaden shadowing is a main issue when planning STE in this case. The shadowing will, however, vary wildly depending on where the collectors are placed and on which type of building, and whether it is a connected module, a neighboring module or a large house that will be the source of shadowing. Also the distance to the shadowing object has an obvious impact. To calculate the estimated decreased yearly solar radiation various shadowing scenarios will cause in Kanalstaden, a designing method from Solelprogrammet (2012) have been used. The method is originally created for calculation of shadowing effects on PV cells, but as the solar influx is the same for the two technologies the method is applicable also when planning for solar thermal energy. In short, the azimuths and elevation angle from the shadowing object to the placing of collectors are measured which depends on the width and height of the shadowing object in relation to the solar collectors, as well as the distance between them. The elevation angle to the shadowing object depends furthermore on the height of the solar collectors; if the collectors are placed closer to the ground the angle increases and if the collectors are placed further up on the house the angle decreases.

In Kanalstaden average heights of the assumed placement of the various placements are used, and are based on the available space on those facades. Certain facilitative liberties as well as limitations have also been adopted. For example, on the gables of the larger houses only the rectangular surface of the wall have been assumed for collector placement (and not the perpendicular area from the roof) and on the walls with windows the height have been measured with an assumed integration of the collectors to the windows. See figure 15 for a visualization of the elevation angle as well as azimuths that have been calculated (the figure show the case in Kanalstaden when the collectors are placed on the roof of a module house in phase 2-3, and a neighbouring module house is shadowing).

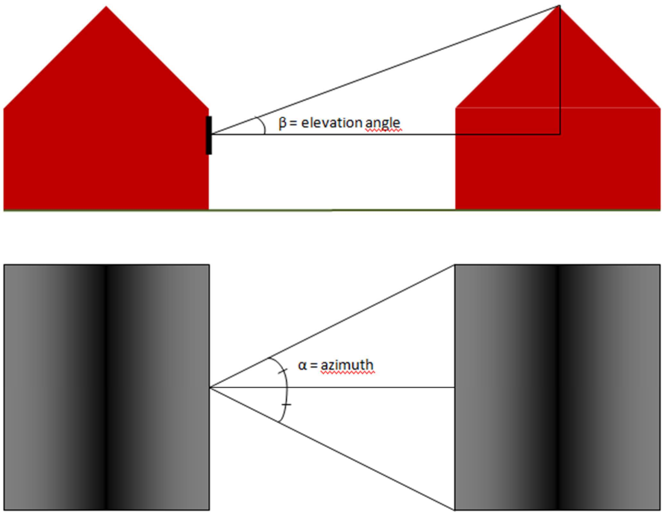

Figure 15. Elevation angle and azimuths, presented from a frontal view (above) and bird's-eye view (below).

The elevation angle and azimuths are then used in a uniquely complied table (table 9) from where the percental loss in solar energy can be deduced: a surface such as the crosshatched surface are drawn based on the elevation angle and azimuths, and the total percental area it covers of the entire table is the percental loss in solar energy. The method provides an estimated loss in the yearly gained solar energy, which means that it will be relatively higher shadowing during autumn and spring when the sun is lower, and relatively lower shadowing in the summer when the sun is higher in the sky.

Worth pointing out is that any additional shadowing (from trees, TV-antennas and such) has been disregarded in these calculations as it is impossible in this stage of the project to know what and where these objects will be. A slightly larger shadowing than presented in this thesis could therefore be expected.

Table 9. Percental loss due to shadowing, when tilt it 90 degrees (a similar table exist for 45 degrees tilts) (Solelprogrammet, 2012).

50°	0,5	4,9	4,5	4,8	4,7	0,6
40°	2,4	3,8	5,1	3,5	3,5	2,5
30°	1,6	2,8	3,3	4,3	2,4	1,6
20° β	1,5	2,8	4,5	4,9	2,4	1,4
10°	0,7	2,2	2,5	3,1	2,3	0,5

-90° -60° - 30° α 0° 30° 60° 90°

East South West

Lastly, there is the issue with the *accumulator tank* and how it is connected to the collectors. As mentioned, the tank should be placed close to the solar collectors to decrease the energy loss (preferably closer than 5 m, as stated in section 4.2.1). This will put certain demands on the placing of the tank – and the collectors – especially in the scenarios when a module house will be expanded and the tank might be placed in one unit and collectors will be placed on the far off module unit. To meet the demand put forward in the previous section, as well as not disturb the design of the interior, it is decided that the tank in the first and third unit of the module units can be placed in the bathroom, and in the kitchen of the second unit. In the large house it should be placed in the utility room, where there is enough space and will be of least disturbance to the residents.

The extensive space in the large house put furthermore no real issue on the maximum size of the tank. This will however be an issue in the module houses, especially in the bathroom of unit 1 and 3. Due to the design of the room, the tank can maximum take up 0,36 m^2 floor area (0,6 x 0,6 m) and reach 1,5 m in height. This leaves a total volume of the tank of 540 liters. On top of this, a consumption tank can be placed. If a larger accumulation tank is needed (i.e. in the cases where other units are connected and more collectors are installed) it is therefore suggested to remove the tank from the first unit and install a larger tank in the kitchen of unit 2, where spacing is not as much of an issue. It cannot reach higher than 2,4 meters in height though. If a third unit is then later connected to this system certain issues arises. With placement of the tank in the kitchen on the side closest to unit 1, the distance from the solar collectors on unit 3 reaches almost 10 meter – and there will be a decrease in the energy gain. In these cases there may therefore be of interest to keep the tank in unit 2 to accumulate the energy from the collectors on unit 1 and 2, and allow unit 3 to be a self-sufficient system with its own tank. One advantage with the houses planned for Kanalstaden is, however, that the interiors of the buildings are flexible; the architectural design presented of the interior in figure 16 can be laterally reversed (compare module 1 and 3 in the case of 3 connected modules). To decrease the distance between tank and collectors the placing of the bathroom and kitchen in the modules, as well as the utility room in the large houses, can be placed on the side most favorable and closest to the solar collector.

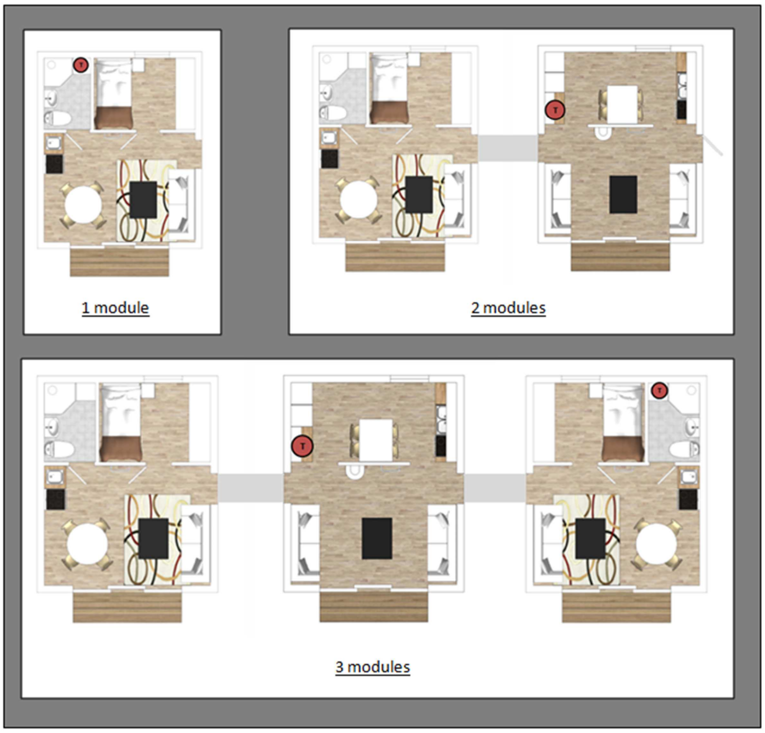

Figure 16. Viable tank placements in the case with 1 module, 2 modules and 3 modules.

These three factors will in following sections be investigated further, in relation to the scenarios of Kanalstaden. It will be presented phase-wise, where first the scenarios with the large house and the module variant in phase 1 will be shown, to then be followed by phase 2-3.

5.2.1. Application of STE system in phase 1

5.2.1.1. Collector placement

In phase 1 the module houses can be placed either on the northern (row N) or the southern side (row S) of the canals (see figure 17), with either the gable with the sliding door towards south or the gable with the small window. These can then be expanded to contain 1-3 units on one lot. The larger house will have the one long side towards south on the northern row and the other long side on the southern row. These walls are the façades where the solar collectors can be placed in this phase.

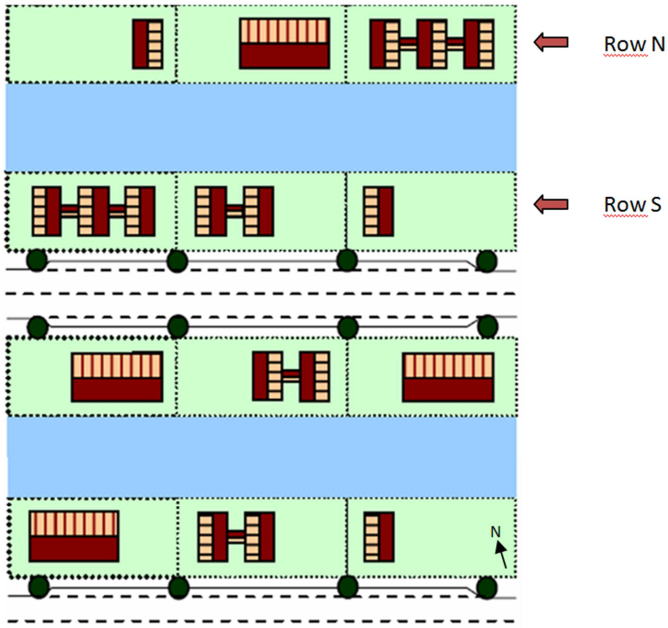

Figure 17. House placement in phase 1.

The large houses have obviously more than enough available space on their long sides for solar collectors, and even the limited space of the smaller module houses have efficient space. The side on the modules with less space – the side with the sliding door – has about 14 m^2 façade. One module wall could therefore theoretically cover the suggested amount of solar collectors needed for 4 persons (10,4m^2 flat plate versus 8,4m^2 evacuated, as stated in section 5.1.3). However, this ignores the requirement that the collectors should be placed 1,5 m above ground which would leave about 10 m^2 available space.

When it comes to the module houses there will, however, not be relevant to have collectors for four persons on one unit as a maximum of two residents are assumed to live in a single module. This would mean that only 5,2m^2 flat plate collectors and 4,2m^2 evacuated would be needed which would fit on the facade. If then the amount of residents increases, another module will probably also be added and more facades will be available to place the additional collectors. Spacing should therefore not be an issue in this case. What could be an issue, or at least worth considering, is the wish of integration with window and door, and to get it evenly distributed on the different units when units are added. For example, if 5,2 m^2 collectors are installed on a one unit module house and it is decided to add another module, and another 2,6m^2 collectors, it has to be considered where these additional collectors should be placed; if they should be placed on the second unit with the risk of giving an unbalanced impression, or if some of the collectors should be removed from unit 1 and be integrated with the new collectors on unit 2 to install the same amount on each module. These matters are in this stage of the project too detailed to investigate further, but still worth mentioning to take into consideration when planning for collectors in Kanalstaden. Examples on how the solar collectors could be placed, integrated with window and sliding door, are presented in figure 17.

Figure 18. Example of solar collectors integrated with window and door respectively, on module house.

5.2.1.2. Shadowing

Due to Swedish buildings regulations the houses will be placed minimum 4,5 m from the waterside of the 6 m wide canal, which will leave 15 m between the façade with the solar collectors on the northern row and the opposite building on the southern row. This is relevant in the calculation of shadowing impact as the closer the shadowing objects, the larger the shadowing impact. The distance between the most southern houses on one street and the northern houses on the parallel street is as much as 39 meters, which gives a negligible loss due to shadowing (0,8 % maximum).

The shadowing effects for the cases when there is 15 m between the houses are presented in the table 10, calculated with shadowing method mentioned in 5.2.

Table 10. Shadowing effects for phase 1.

Type of house - Placed on row N	Object of shadowing - Placed on row S	Decrease in yearly gained solar energy due to shadowing
Module	One module	1,5 %
Module	Large house	5,5 %
Module	3 modules*	< 5,4%
Large house	One module	0,8 %
Large house	3 modules*	<3 %
Large house	Large house	4 %

** When a 3 module house has been the object of shadowing, pathways between the units and the tilting roofs have been disregarded. This means that the actual shadowing affect are less than the presented.*

As can be seen, the large house standing on the south row has, obviously, the most impact on shadowing on the northward placed buildings. When module houses are fully extended - that is with three units – they will also provide relatively large shadowing, while they with only one unit will affect considerably less. The variations between the shadowing are, however, relative small. But even so, the shadowing will have a different impact depending on how, and in which relation to each other, the houses are placed. Therefore, there might be relevant to address the shadowing effect when decisions are being made of where the different houses are placed. To decrease the losses due to shadowing, the larger houses should be placed on row N and the modules on row S. When applicable, module houses placed on row N should preferably also be covered by a module house on row S rather than a larger house. If only certain houses will have solar collectors, regardless of what type, they should preferably be placed on the southern side of the canal.

5.2.1.3. Issues regarding the tank

As mentioned, the placement of the tank in the large houses is no real issue; there are enough and suitable space in the utility room. What is worth considering, however, is while the collectors are always placed on the southern wall the accumulator tank in the large house is always placed on the side alongside the street – that is, the tank and collectors are placed on the opposite side in row N while they are on the same side in row S. See figure 19 for visualization. This means that the distance between tank and collectors in row N is always the length of the buildings (6m). In other words: it reaches the limit when losses from the connections will require additional collectors, and in theory this would mean 0,4 % energy losses.

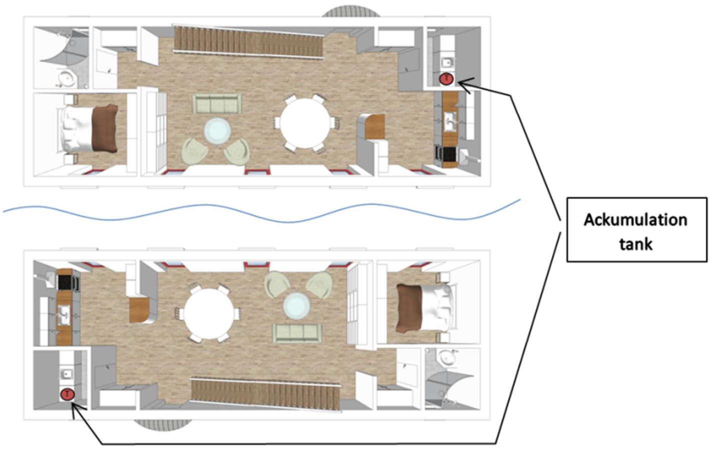

Figure 19. Tank placement in large houses on row N (above) and on row S (below).

Similar case exists for the modules in phase 1. Just as for the large houses, the tank will, due to the interior design of the modules, be placed on the opposite side from the collectors in row N and on the same side in row S (see figure 16 for visualization, which portray tank placement in row N). The distance between tank-collectors in row N will consequently be minimum 6 m also for the modules. In this case the distance will furthermore increase with the extension of several units - as the connections between collectors and tank will have to be drawn between the modules. If a tank sufficient for all three modules' collectors is placed in the kitchen of unit 2, the distance from the collectors on unit 3 will be almost 10 m – which should demand a 2 % addition of solar collectors to reach similar utilization factor, as mentioned in section 4.1.2. In these cases it might be relevant to install a second tank in the third unit to be more or less self-sufficient (that is, a smaller tank in the bathroom of unit 3 that is only connected to the collectors on that unit) and let the larger tank be connected to the collectors on unit 1 and 2 like previously. This would require two tanks and two systems, however (even if they could be connected).

On the southern row the tank and collectors will be placed on the same south side which decreases the risk of loss due to distance. Just as for the modules on the northern row, this distance will however increase when more module units are connected and the same issue whether two tanks or loss due to distance arises.

Regardless, it is obvious that even in the case of the tank the southern row is slightly more beneficial to have STE systems than houses in the northern row. Still, the loss will never be especially vast and might even be considered negligible. Estimated losses and their impact will be discussed further in the results, section 6.2.

5.2.2. Application of scenarios on phase 2-3

5.2.2.1. Collector placement

In phase 2 and 3 the houses will be placed perpendicular to the houses in phase 1: the modules will have their roof tilted against south, and the larger houses their gables. There will consequently not be differences between the streets of the canals as it was in phase 1 and instead the collectors will only be affected by the neighboring house to the south, see figure 20.

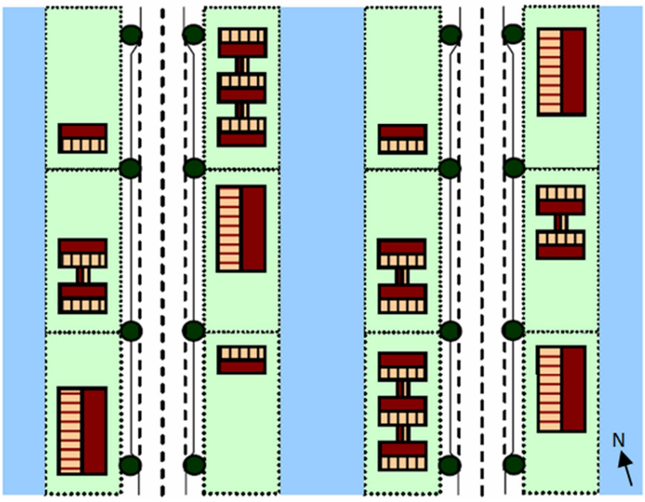

Figure 20. House placements in phase 2-3.

The collectors can in this phase be placed on the wall of the large house, the “long side” of the module houses as well as the 45 degree tilting roof of the modules. And similarly to phase 1, it is only in the module-case that there might be an issue with the available spacing of the façade - if the maximum needed collectors for the household were to be placed on one singular unit. The gable of the large house have more than enough available space for collectors (about 24 m^2 façade), as has the roof of the modules (21 m^2/unit on the side towards south). If the collectors on the other hand were to be placed on the southern wall of a module unit, only 5 m^2 collectors would be able to be installed due to limiting façade area. This would not be able to cover the energy demand for more than 2 persons. If more collectors were to be installed, they would have to be installed on the roof of that unit and/or on the roofs of the other connected units. The possible scenarios for phase 2-3 are, consequently, as follows:

- On module house, south wall (on the long side, either with or without door)
- On module house, all roofs
- On module house, one roof
- On module house, roof/s and south wall
- On large house, wall, short side

Which possibilities are the most favourable are however similar to in phase 1: it depends on the shadowing affects, the tank placement and the desirable balanced distribution of the collectors. Instead of placing all collectors needed for a household of 4 residents on the roof of one module unit, it may perhaps be preferable to distribute them on all three roofs – depending, for example, on how large losses it would cause due to shadowing and distances to the tank.

5.2.2.2. Shadowing

Similarly to the possible placement of the collectors, the shadowing effects are also different for phase 2 and 3 compared to phase 1. What changes most significantly are the fact that while the distance between the collectors in phase 1 remained static, the distance between the houses in phase 2 and 3 varies – and so also the shadowing impact. The distance between the neighbouring houses depends for example what type of houses they are (larger houses will stand closer etc.), and, in the cases of the modules, the distance can decrease when units are added. The shadowing object can, in the case of the module houses, also be a connected unit. In these cases there will only be 2 m between the collectors and shadowing object. Between large houses the distance will be 12 meters, and the minimum distance between a module and a neighbouring house will be 9 m. This minimum distance will be in the cases where the modules are fully extended with three units. It will thus be longer if only one or two units are constructed.

In table 11 the decrease in yearly gained solar energy due to shadowing are shown. In the cases of the modules it is estimated that that the modules are fully extended with the shortest distance to the shadowing object as this will give the "worst case scenario". Shadowing from a connected module - if collectors are placed on a modules wall - have not been calculated as the distance between the units (2 m) will cause the collectors to be shadowed more or less all of the time. Collectors placed on the module wall in phase 2 and 3 is in other words only relevant if they are placed on the most southern unit and won't be shadowed by a connected unit.

Table 11. Shadowing effects for phase 2-3.

Type of house - Placement of collectors	Object of shadowing	Decrease in yearly gained solar energy due to shadowing
Module, roof 45°	Connected module	1,7%
Module, roof 45°	Nearby module	0,4%
Module, roof 45°	Nearby large house	1%
Module, wall 90°	Nearby module	4,9%
Module, wall 90°	Nearby large house	6,7%
Large house, wall 90°	Nearby module	3%
Large house, wall 90°	Nearby large house	3,5 %

Not surprisingly, it is when the shadowing object is a large house that there will be the largest impact on the energy production. Furthermore it can be seen that collectors placed on the wall – regardless of which type of house – are subjected to more shadowing than collectors placed on the roof of the modules. The reason for this is mainly that collectors on a lower tilt will be able to reflect more of the higher standing sun – and therefore have a relatively smaller impact from shadowing objects. Also, it is because the collectors on the roof are placed higher up than collectors on the wall. This is also the reason why collectors placed on the wall on the larger house have a smaller decrease in energy production than collectors placed on a lower placement. The collector have been estimated to be placed, on average, 3,3 m above ground on the gables of the large houses, compared to 2 m on the module wall. Considering that these heights are an estimated average, it will most likely be possible to place the collectors further up – especially if a smaller amount of collectors will be installed – and less shadowing would occur.

Most favourable placement, then, of solar collectors in phase 2 and 3 would primarily be on the roof of the module houses – regardless if the shadowing object is a connected module, nearby module or nearby large house. Most favourable would of course be to have the collectors placed on the most southern module roof. To have the collectors on the southern unit’s wall instead, would only be arguable for possible aesthetical reasons or if there is a definite unbalance in the energy demand between summer and autumn/spring (if there for example would be practically no demand during summer but a considerably higher demand during spring and autumn). As for the large houses the loss is considerably small, but what could be done is, if possible, place the collectors as high up on the wall as possible.

5.2.2.3. Issues regarding the tank

Concerning the placement of the tank in phase 2 and 3 it will be similar to the conditions in phase 1; the distance between tank and collectors can be an issue in the case of fully extended module houses. That is, if the collectors are placed on the third unit and the tank in the first the distance between them might mean losses in gained solar energy and additional collectors could be relevant to install. Similar to the modules in phase 1 it could in phase 2 and 3 also be relevant to install a smaller tank in the third unit and let it be self-sufficient in connection to the solar collectors installed on that unit, as was discussed in 5.2 and presented in figure 16. Due to the 90 degree rotation of the houses, the circumstances will however change somewhat. For example in the case of the large houses the solar collectors will be more centralized on the gable of the house and will never be more than just on the other side of the wall from the tank (see figure 21).

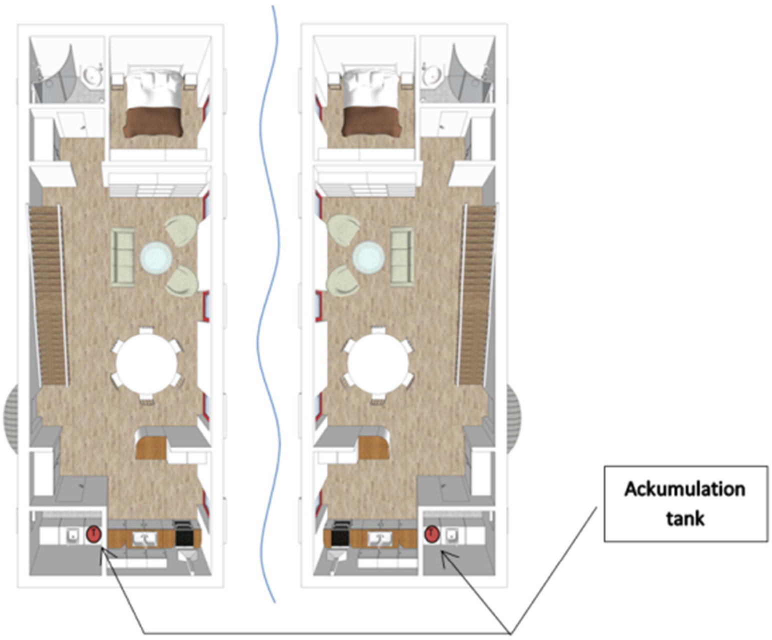

Figure 21. Tank placement in large houses in phase 2-3

6. Results - feasible alternatives for Kanalstaden

In the following chapter suggestions for the design of a STE system in Kanalstaden will be presented. The focus is mainly on what type of collectors is most suited and where they should be placed - depending on the existing scenarios - but a section is also dedicated to summarize the losses that could/can be expected with a STE system in Kanalstaden.

6.1. Evacuated tube collectors vs. flat plate collectors

What type of collectors (evacuated or flat plate) is most suited is very much dependable on the placing and performance of the collectors, but also the esthetical appeal has an impact. For Kanalstaden one main issue furthermore revolves around the correlation that exists between the type of collectors, the placement of the collectors and the expected demand in the summer. Why this is especially relevant in Kanalstaden is the mentioned risk of overheating that may exist if residents are often away in the summers. If there is a low demand, evacuated collectors may for example not be the best solution, and neither is placing on roofs. Evacuated collectors in combination with roof placement would be the least suitable alternative in this case. If there is a high demand, the situation would be the opposite. Which type of collectors are most suitable in which scenario, is presented in table 12.

Table 12. Best suited type of collectors depending on demand and placement.

	Summer demand	Placement	Type of collectors	Comments
Scenario A	High	Roof, 45°	Evacuated	Optimal when high demand
Scenario B	High	Wall, 90°	Evacuated	
Scenario C	Low	Roof, 45°	Flat plate	
Scenario D	Low	Wall, 90°	Evacuated	Optimal when low demand

In Scenario A – that is, when there is a high summer demand and collectors are placed on the roof (on the modules, phase 2-3) – evacuated collectors are well suited. This scenario would indeed be an optimal one, as the supply would be high with both efficient collectors and a favourable tilt meanwhile as the demand would be high. Most saved energy could in other words be gained.

Evacuated collectors would also be suggested to be used whenever collectors are placed on walls (Scenario B and D), and this is basically because evacuated tube collectors are most efficient on steeper tilts. It would especially be a favourable alternative when the summer demand is low, considering the risk of overheating in the summer would be diminished meanwhile as the collectors would take great advantage of the spring and autumn radiation. Evacuated tube collectors on the walls could in other words provide a more even yearly production than collectors on roof – and this is applicable also when the summer demand is high. Evacuated collectors on walls would furthermore be more efficient in the winter as the reflecting factor from the snow would increase, as well the risk of snow stacking up on them decrease. This would however be true also for flat plate collectors on walls, but considering the many advantages of evacuated on walls, these are still the collectors to be advised to use on this tilt. Evacuated tube collectors would also be more efficient when there is diffuse radiation. If the houses will remain to have a cardinal direction of 200 degrees after construction, evacuated tube collectors will also be a better solution as they are subjected to collect radiation from the side better.

When the demand in the summer is low, and collectors are to be placed on the roofs (scenario C), flat plate collectors are the more efficient alternative. Evacuated tube collectors would in this case probably only overheat the system, and would then decrease the efficiency. If there is expected to be no demand during summer, it could furthermore be advisable not to install solar collectors on the roof as it would most likely overheat the system, and instead consider the possibility to install them on the wall even in this case. Since this scenario only exists in the case of the modules in phase 2-3, it would practically mean to place the collectors on the southernmost unit (as the shadowing would otherwise be too great, as stated in 5.2.2.2.

There is, however, a paradox in Kanalstaden with where to place the collectors, and which type of collectors they should be. It is the modules in phase 2-3 that have the best placement for solar collectors in high demand (45 degree tilt), but it is the modules that are also most subjected for low demand, since the target group to reside in these type of buildings are students and commuters – people who often tend to be away in the summer. Similar contradicting situation exist for the large houses. There, the possibility of a low demand in the summer is less likely, and to have collectors on 45 degree tilted roofs would therefore be optimal. But since these roofs have a tilt of 15 degrees, collectors should not be placed on roofs even in high demand and instead be placed on the walls – which then lead to a less energy production. However, this is only an assumption based on the various types of residents' living conditions and would in reality maybe not turn out to be the case. Important to point out is also that regardless of a possible unbalance between supply/demand, collectors on walls – as is the most common situation in Kanalstaden – can provide a more even yearly production.

As for the aesthetical aspect, it is mostly a matter of taste. Evacuated collectors accentuate a more advanced approach and can give the residence a green label. Flat plate collectors are less prominent, and can be appreciated if a more subtle approach is aimed for. If a more uniform approach for the entire residential area is desired, it could be worth considering installing the same type of collectors for placements on both roofs and walls – despite the slight decrease in efficiency that could be expected. It could furthermore be economically beneficial to install the same type of collectors on all houses as it could possibly enable a discount from the supplier. Collectors can also be chosen to be placed in accordance to existing windows, doors and roofs, or distributed in a way that in one way or another integrate with the design of the building (as mentioned briefly in 5.2.1.1). Consideration will in this case have to be taken to the existing market supply of collectors, however. Even if the market provides a wide range of measurements and sizes for the different types of collectors, the supply is still limited.

6.2. Estimated losses

As been pointed out earlier in the report there are other factors that also have to be taken into consideration in the placement of collectors. For example, certain losses from shadowing, long distances between tank and collectors, as well as decrease in efficiency when collectors are placed on walls instead of 45 degrees roofs. Table 13 summarize the losses that can be expected in various cases of solar thermal energy in Kanalstaden.

Table 13. Estimated losses for feasible scenarios in Kanalstaden

Placement of house	House-type	Collector placement	Losses: tilt	Losses: shadowing	Losses: distance tank-collectors	Total losses
Phase 1, row N	Module	Wall	4 %	1,5-5,5 %	0-2 %	5,5-11,5 %
Phase 1, row N	Large	Wall	4 %	0,8-4 %	0-0,4 %	4,8-8,4 %
Phase 1, row S	Module	Wall	4 %	0 %	0-2 %	4-6 %
Phase 1, row S	Large	Wall	4 %	0 %	0-0,4 %	4-4,4 %
Phase 2-3	Module	Roof	0 %	0,4-1,7 %	0-2 %	0,4-3,7 %
Phase 2-3	Module	Wall	4 %	4,9-6,7 %	0-0,4 %	8,9-14,7 %
Phase 2-3	Large	Wall	4 %	3-3,5 %	0-0,4 %	7-7,9%

As can be seen, it is only for the modules, phase 2-3, that have no losses due to tilt as they would be placed in the more optimal tilt of 45 degrees. Just as previously mentioned, placement on walls would however mean a higher efficiency in spring and autumn and these numbers are therefore somewhat misleading. Placement on walls, however, would require about 4 % more collectors, regardless of what type.

As for the losses due to shadowing it is very much dependable on the house that will be situated south of the collectors. That there will be some sort of shadowing, however, have been assumed as Vision 10 000 plan for all lots to be bought and occupied. The numbers presented in above table are the maximum and minimum losses due to shadowing that can be expected, to show both the worst and best case scenario. As was mentioned earlier, collectors on buildings in the southern row S in phase 1 will have no shadowing and would, theoretically, be the best suited alternatives to avoid shadowing. Least shadowing apart from this scenario, would be the case when collectors are placed on modules' roofs in phase 2-3, followed by walls on houses in phase 1 (row N). Even walls on large houses in phase 2-3 have considerably small losses due to shadowing. Of course, collectors (either on roof or walls) on any type of building placed on the southernmost lots in phase 2-3, will also have no shadowing as no house is placed south of it. To place collectors on walls on the modules in phase 2-3 would be the worst alternative. However, considering that the losses fluctuate depending on what type of house is shadowing, more focus should lie on this. For example, in the case where collectors are placed on large houses' walls in phase 2-3, the losses are expected to vary only 0,5 percentage points depending on the type of shadowing house, whereas when collectors are placed on modules' walls on phase 1 (northern row) the losses can vary up to 4 percentage points. In other words: during some favourable circumstances, losses from shadowing can be small and negligible, while under other circumstances losses can reach the limit where it is no longer negligible. Installation of collectors on the buildings of Kanalstaden should therefore be decided only with the knowledge of what type the southern neighbouring house is.

Losses due to storage are mainly from long distance between collectors and tank, as well as heat losses due to a poorly dimensioned system. Losses due to long distance between collectors and tank are the losses mentioned in table 13 and, as can be seen, they have been estimated to be rather small in Kanalstaden, regardless of the circumstances. This is especially relevant in the case of the large houses, where it should be virtually no losses of this reason. In the cases of the modules, it varies depending on the amount of module units: 0 % if there is one module, with an increase up to 2 % if several units are connected. The small losses can be considered negligible in the favour of placing the tank on well suited spaces where it would be in best integration of the design and of least bother to the residents. Losses from poorly dimensioned system are harder to pinpoint, but most important is it to dimension the size of the tank to the expected relation between supply/demand; if there is a difference between supply and demand a larger tank is needed, but if supply and demand is well in lined with each other a smaller tank will be needed.

7. Concluding discussion

From the results obtained in previous chapters, there is one very relevant conclusion to be made: the feasibility of installing solar thermal energy systems on a small residential district such as Kanalstaden depends very much on circumstantial factors. Some of the main factors can, for instance, be divided into architectural circumstances, the balance between supply/demand, and, ultimately, proprietary.

Concerning *architectural circumstances* there are some that are fixed for all houses, and some that varies depending on which house it is and/or which phase the house is placed. One factor that affects all houses is that the cardinal directions of the houses are on the border of making solar thermal energy inefficient. It could, in other words, be preferable to have the houses standing in a slight more direct direction towards south (180 degrees instead of the currently planned 200 degrees) to increase the favourability of solar thermal energy in Kanalstaden. If applicable, this could therefore be worth taking into consideration in the construction of the houses. The architectural circumstances that differ between the houses are mainly the design and their placing in relation to each other. The design puts limitation on where the tank and collectors can be placed, and the placement of the houses affects the shadowing. As been mentioned collectors can be placed on roofs in only phase 2-3 on the modules, and in all other cases they will be placed on the walls. In the case of the modules in phase 2-3, they can also be placed on walls, if that would be found to be favourable. This is something that will be discussed further below.

Due to the various placements, there are more shadowing issues in phase 2-3 for both type of building, which is unfortunate since that is where most buildings are planned to be built. Best place in regards of shadowing is the southern row in phase 1. If it is to be found possible, it could therefore also be of interest to consider where the houses will be placed to maximize the solar thermal yield (by placing smaller houses south of larger houses, and more large houses in phase 1 and modules in 2-3). On the other hand, the variation in shadowing affect has been proven to be rather small (maximum 5,5 % for modules in phase 1 when shadowed by a large house (excluding collectors on module wall in phase 2-3), and it can be discussed whether the loss is worth to be bothered by, or if it is negligible.

The *supply/demand* balance might in the case of Kanalstaden be the most relevant factor for the suitability of a STE system. As has been mentioned it is very relevant to know the actual heating demand in the planning of STE system, and whether the demand is in line with the produced energy. It is especially relevant to know the heating demand in summer, when the collected energy is often high, to avoid overheating. In Kanalstaden the demand is at this time unknown and it is therefore hard to know the feasibility of STE in the residential area. If it will be known that there will be no demand during summer a STE system might not be the most logical solution. Unfortunately, this is a risk in Kanalstaden since the district is especially addressing students and commuters as potential residents – people who might be away in summer. If there will be a demand during summer, similarly to the rest of the year, the feasibility of installing a STE system increases greatly.

Lastly it is the very relevant issue of *proprietary* that may have a significant influence of the suitability of STE in Kanalstaden. The actual cost have however not been taken in to consideration in this thesis, but the impact of proprietary can be discussed already in this stage of the project. Considering the residents of the houses are also the owners, they could in theory have a very significant role in implementation of solar thermal energy on the buildings. They could, for example, be able to choose for or against using solar thermal energy on their houses. They could decide what type of solar collectors should be installed, where the collectors should be placed etc. They will obviously also be able to choose what type of house they want and where they want it to be placed – with or without taking regard if a neighbouring house will be shadowing it. As all these circumstances would have a rather significant impact on the effectiveness of installing solar thermal energy in Kanalstaden, it would have to be decided to what degree a solar thermal energy system would be integrated in the area and what role the owners should have. If the owners will have complete authority of their individual energy systems, only promotion for installation of STE and recommendations of certain types of collectors and placements could be performed. That is, the residents could be well informed of the advantages of solar thermal energy prior to purchase; if it is suitable for their individual estimated energy demand, and if so, how the system should be designed.

Then also the surrounding circumstances, such as possible shadowing houses, could be considered in the decisions-making. This would, however, mean that there is a possibility solar thermal energy might not be as prominent in the district as preferred, or that it would not be designed under the most optimal circumstances. Also, if there are no restrictions on what type of collectors they can use, where and how to place them, the district might also not be able to acquire the uniform approach as previously discussed. If, on the other hand, it will be decided that solar thermal energy will be fully implemented in the district, and that the houses will be fully equipped with collectors and tank according to the most optimal solution, demands could be decided for what type of collectors would be used, where they could be placed etc. This would also facilitate the assumedly preferred uniform design of the area. However, this variant could mean that some houses STE systems would not be optimally dimensioned, as the local demand might not agree with the decided instalment. To address the issue of shadowing, one solution could also be to have a given plan on where the houses can be placed. Instead of giving the residents full liberty on where to place the houses, the large houses could, for example, be directed to the northern row in phase 1 and the module houses on the south. To fully take advantage of the more favourable 45 degree tilt (when the demand agrees), the module houses could also be advised to be placed in phase 2-3. This kind of fixed placing of the houses could furthermore also work as a test to study the variations in collected solar radiation if collectors are placed on roofs or walls. Ultimately it can be said that due to the specific circumstances of the residential district, the issue of proprietary is a very relevant one in the case of Kanalstaden and there are many ways in which one could deal with it. Most important, though, is that it is reflected upon in the decisions-making of the project.

7.1. Conclusion and recommendations

In conclusion, then, it can be said that there are many aspects that has to be taken into consideration when planning a STE-system in residential areas. Practical issues like where and how collectors and tanks can be placed has to be considered, but also things like the balance between supply and demand has a great importance. Surrounding circumstances have also – or can have – a great impact, such as shadowing. A scenario that is optimal for solar thermal energy (i.e. a situation when a high supply concurs with a high demand and where the placement of collectors creates an effective system) can become entirely pointless if the collectors will be subjected to a lot of shadowing. Then social factors also have to be considered. The specifics of the residents' heating and water demand has, as mentioned, a very important role, but also things such as aesthetics may have an influence.

It might, however, be said that Kanalstaden is not the best model to study the issues that can arise in implementation of STE system on the general small scale residential area – Kanalstaden's very unique circumstances are after all not those of the typical residential area. On the other hand, residential areas are never the other one alike and even if Kanalstaden might differentiate more than general, it also shares many of the issues that other, more typical, areas have to deal with - for example the issues regarding demand/supply. In fact, the unique scenario of Kanalstaden, and its very specific circumstances, problematizes the many variables that are – or should be – a part of planning STE systems in residential areas. Also it gives light to the fact that solar thermal energy is a very flexible technology and can be applied on different scenarios; just as it is many factors that has to be taken into consideration, the many variables also gives freedom to design the system differently. STE system can simply be implemented in many ways and depend on many various factors - It just has to be developed and installed in accordance to the actual circumstances existing.

As for Kanalstaden, solar thermal energy could be very suitable – depending on how the residents' demand will turn out to be, and how the houses will be placed. But, as initially pointed out, many of the results presented in this report and the calculations that have been made are very general and assumption-based. If the project is realized, more extensive and thorough calculations are therefore strongly recommended. The fact that the report has focused on very specific issues - and not on all factors that should be dealt with - can also be seen as lacking. That an economic aspect has not been considered, for example, is perhaps one of its strongest weaknesses. Even if this was decided initially, it would have been interesting to integrate it in the study – especially since the economic factors have quite a significant role in STE systems. For example, the price varies greatly between the types of collectors etc. To study the economic aspect should, therefore, be something very significant to study further in a continuing work.

Another aspect that could be relevant to look into in a future study is the suitability of using seasonal storage. Primarily in this report, seasonal storage was considered to be included but due to time limit it had to be disregarded. Seasonal storage could, still, be a viable alternative to the short time storage that has been dealt with in the thesis. This could especially be the case when there is a fluctuating and/or low demand in the summer, as seasonal storage can store energy from when there is a low demand to when the demand increases. However, compared to short-time storing, seasonal storing is only interesting to investigate for larger system, and not for, say, single buildings. Kanalstaden does qualify as a larger system (areas with no less than 100 small houses as mentioned in 4.2.2.), but in some cases it can also have the characteristics of single buildings – and this is where the storing-issue become complicated. If, for example, all houses would be built (including the module-extensions) and it would be decided that all houses would have solar collectors, the residential area's energy system would definitely qualify as "larger" and seasonal storage could be an alternative. It could perhaps be more profitable than short-time storage (and this is what could be investigated in a more thorough study). If, instead, the houses are built successively – just as it is planned in Kanalstaden – seasonal storage would not be as suitable. Then the small scale short storage is very well suited, as each house becomes more independent and more self-sufficient. In other words, the best type of storing could depend very much on how the area would be designed and developed.

When it comes to Kanalstaden, it could furthermore be interesting to study also other solar energy technologies. For example, a method converting solar energy to heating and cooling by a special salt technology, developed by Climatewell, was also looked into initially in this work, and could perhaps be studied more thorough. It might also be an alternative to investigate the feasibility and effectiveness to apply PV cells instead, or together with, solar thermal energy. The problem remains, however, that the demand might not appear simultaneously as the supply. Although, if it could be possible to sell the surplus energy to the national grid the situation would appear different; compared to in the case of short time storage of solar thermal energy, the supply wouldn't have to concur with the demand.

Regardless of what method's being used, and what further studies will be done in the case of Kanalstaden energy supply, it can be concluded that there are many ways in which solar energy can be used – it only has to be designed and adapted to the prevailing circumstances.

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