Retrofitting

And Climate Adaptation

Gärdet / Stockholm

G7015 Environmental Management in Planning / Group Project

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Foreword

This report is the result of a project work within the course *Environmental Management in Planning* at Stockholm University. The course is a mandatory part of the multidisciplinary Master Programme *Environmental Management and Physical Planning* at the Department of Physical Geography and includes both Swedish and international students. The course comprises ten weeks of study (15EHTC), of which the project part covers five weeks. The aim is to give the students an opportunity to apply their acquired knowledge on environmental management in planning on a realistic and relevant case.

This time we have chosen to study the Stockholm Royal Seaport (SRS) and its surroundings. The different project groups have focused on remediation and implementation of urban gardening in Loudden (the last area to be developed in SRS), retrofitting of neighboring residential areas as well as The Royal National City Park as a green resource for SRS.

The students alone are responsible for the results and conclusions of this report and it cannot be regarded as the position of Stockholm University. The project supervisor has been Ingrid Stjernquist from the Department of Physical Geography.

We want to thank all those who have been helpful in providing the students with information and materials as well as having taken time for interviews. Without your help this project could not have been realised.

Stockholm, March 2019

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Abstract

This project was carried out with the aim to identify climate change risks, adaptation needs and potential retrofitting solutions at Ladugårdsgärdet in Stockholm, Sweden. The assessment of this report is based on scientific papers and literature reviews as well as own collected data through air and soil measurements in the study area. Moreover, was interviews with residents conducted to gain insight of the public opinion.

The selected area was divided in to two separate zones due to the distinct characters – A less densely built area to the North (area 1) and a densely built area to the South (area 2). It was concluded that the potentially most severe hazards arising from IPCC scenario RCP8.5 in the area were: Increased occurrence of flooding due to a wetter climate and more intense precipitation, and increased risk of heat stress due to warmer and longer periods of summer. The most densely built and asphalt covered area showed most potential for "heat-island" effect and may also be in higher risk for flooding due to increasing precipitation.

The interviews revealed that most residents have not experienced any weather related problems until now but do think that it will impact the area in the future. The majority of the residents are also willing to pay and contribute with their time to maintain adaptation measures.

The retrofitting proposal presented in this report includes rain gardens, bioswales, vertical gardens, green roofs, permeable pavements and hybrid PV/T panels. Increased percentage of vegetation cover and surface permeability in the area can decrease the "heat-island" effect as well as mitigate storm-runoff and prevent flooding. Hybrid PV/T panels placed under correct angels on the roofs would contribute to energy efficiency of the buildings.

Previous research indicates that the chosen retrofitting solutions based on their performance capacity are cost-effective in the long-term perspective and complement each other substantially.

Sammanfattning

Projektet genomfördes med syfte att identifiera risker som kan uppstå på grund av klimatförändringar, behov av anpassning och möjliga lösningar för ett bostadsområde vid Ladugårdsgärdet i Stockholm. Undersökningen baseras på litteraturgranskning, luft-och jordtemperaturmätningar i området samt korta intervjuer med boenden. Det specificerade området delades upp i två delar på grund av tydliga karaktärsskillnader: ett tätt bebyggt område i norr (område 1) och ett mindre tätt bebyggt område till söder (område 2).

Från litteraturgranskningen kunde slutsatsen dras att de största riskerna som klimatförändringar kan orsaka för området förmodligen kommer att vara översvämningar och extremvärme. Dessa risker kan komma att vara mest märkbara i område 1 på grund av den högre andelen ej permeabla ytor som täcker området i dagsläget. Intervjuerna med boende i området visade att de flesta inte ännu har upplevt problem relaterat till väder men tror att klimatförändringar kan påverka området i framtiden. De flesta var också villiga att betala högre hyra eller avgift om klimatanpassningsåtgärder skulle behövas.

Förslaget för klimatanpassning av området inkluderar regnträdgårdar, bioswales, vertikala trädgårdar, gröna tak, dränerade ytor and hybrida PV/T paneler. Att öka andelen yta med vegetation och permeabla dränerande ytor bidrar till att minska vattenmängden i avrinningen och förebygger extremvärme i området under sommarmånader. Hybrida PV/T paneler föreslås för att öka energieffektiviteten i byggnaderna. Dessa åtgärder har valts på grund av att de är lösningar till de största riskerna i området, enligt litteraturgranskning är långsiktigt kosteffektiva och även för med sig sociala och kulturella fördelar.

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1. Introduction

Climate change is increasingly putting pressure on cities and requiring adaptation measures to achieve resilience for the future. Many regions are responding to this through implementing climate change adaptation in planning for new developments and retrofitting existing buildings (Williams et al. 2013).

Climate change adaptation is also increasingly included in regional and global legislation and policy, which now have to be implemented. It is for example an integral part of the Paris Agreement and is included in several of the 17 goals of Agenda 2030. It is especially a central part in goal 13.1 (increase resilience to climate change and reduce disaster risks in all countries) and 13.2 (integrate actions to reduce climate change impacts in national strategies and planning). Climate change adaptation is also a central part of goal 11 – Sustainable cities and societies (The Swedish Government, 2018).

In Stockholm, climate change could for example increase the risk of heat stress, flooding, drought, deterioration of green spaces and damage from storms (SMHI, 2019). There is therefore a need for methods to mitigate these impacts for both existing buildings and new development in the Stockholm area. This study investigates the need for climate change adaptation and possible retrofitting measures for existing buildings in the area of Ladugårdsgärdet, located in the North part of Central Stockholm. The area was mainly built during the late 1930 and is therefore relatively architecturally uniform. The area has only to a small extent been subject to new development.

2. Climate Change Scenarios

The severance of the future change impacts will depend on the amount of emissions that will be emitted in the coming years. In order to calculate the alteration over the years, in the Fifth Assessment Report the Intergovernmental Panel on Climate Change (IPCC) illustrates four Representative Concentration Pathways (RCPs). The RCPs are used to produce projections based on greenhouse gas emissions and air pollution (figure 1).

The scenarios are directly linked to a rise of the earth's surface temperature (figure 2). Pre-industrial temperatures are used as comparison. As illustrated in figure 1, the four different scenarios are RCP 2.6, which will likely keep the temperature rise below 2°C, RCP 4.5, RCP 6.0 and RCP 8.5. According to IPCC the probable RCP scenario arising from a lifestyle without any restrictions to emissions will range somewhere between RCP6.0 and RCP8.5. This scope is considered the baseline (IPCC, 2014). However, even if the concentration of greenhouse gases in the atmosphere is stabilized by implementing the RCP2.6 scenario in the near future, global warming is still predicted to continue for many decades after (Swedish Commission on Climate and Vulnerability, 2007).

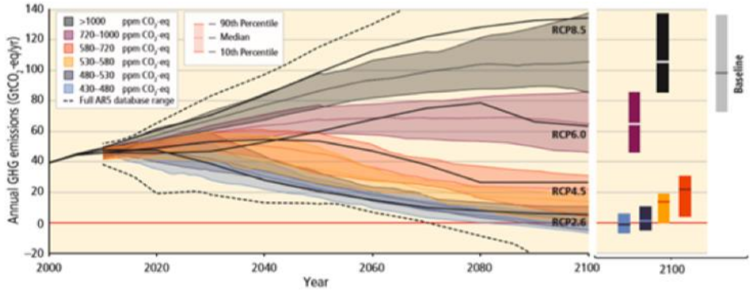

Figure 1: GHG emission pathways 2000–2100 All AR5 scenarios (IPCC, 2014, p. 82)

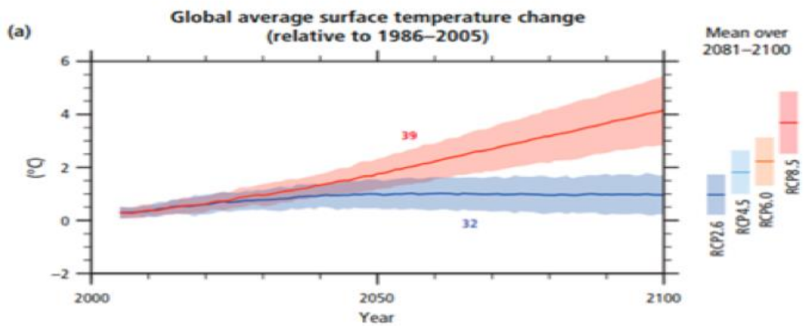

Figure 2: Global average surface temperature change (IPCC, 2014, p. 11)

2.1 Impacts of Climate Change

Climate change has global impacts under all RCP scenarios. Some of the global impacts are; increase of the global mean surface temperature, fewer extreme cold events, more and longer heat waves, changes in precipitation patterns, heavier precipitation events, a global increase of the ocean temperature and acidification, reductions of the Arctic sea ice, decrease of permafrost and glacier extent and a global sea level rise. However, not all of these impacts apply to every location (IPCC, 2014).

Climate change impacts are globally uneven and the northern hemisphere is in some aspects more heavily affected than other places. According to the Swedish Commission on Climate and Vulnerability (2007) the rise of temperature in Sweden will likely be greater than the global average. Observations show significant warming in Sweden since the late 1980s and although Sweden's climate has always varied the changes in temperature and precipitation in the last couple of years have been unusually large (Swedish Commission on Climate and Vulnerability, 2007).

While some aspects of global warming do not have detrimental impacts on the Stockholm region or urban areas in general, some certainly do. Expectations for Stockholm are warmer summers with less rainfall and milder winters with less snowfall but more precipitation in form of rain. The risk of extreme weather events such as heat waves, heavy precipitation and storms is also likely to increase (Swedish Commission on Climate and Vulnerability, 2007). In winter and fall the larger amount of rainfall during shorter periods of time may lead to a higher risk of flooding and more runoff, which will especially affect areas with non-permeable surfaces and a low percentage of green spaces. Higher temperatures and heat waves during summers might result in the need for more cooling in dense areas without mitigation features for natural cooling, such as green roofs. Furthermore, water quality might be affected due to eutrophication and acidification. As storms become more common they will likely cause damages in infrastructure in urban areas that not adequately adapted to the risk. Changes in the climate may also impact biodiversity, as some species might not be able to adapt to the new circumstances (Swedish Commission on Climate and Vulnerability, 2007).

3. The Urban Heat Island effect

The term "Urban Heat Island Effect" describes how an urban or metropolitan area can be hotter than its nearby rural surroundings due to elevated anthropogenic pressures, such as gradual surface modifications (i.e. natural vegetation replaced by roads and buildings) (Hashem, 2005). Because the surfaces of buildings and pavements better absorb solar heat radiation than natural surfaces, the annual mean temperature of the area affected by human activity can be 1–3°C warmer than its surrounding territories (Berdahl et al. 1997). Such "heat islands" can dramatically affect the quality of life of communities by increasing energy demand, affecting water quality, elevating emissions of air pollutants and greenhouse gases, comprising human health and their standard of living. The increased need of cooling in cities can dramatically increase the demand for energy in summer (Hashem, 2005).

Increased daily temperatures, high air pollution levels associated with urban heat island effect can severely affect human health by increasing the risk of diseases related to respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality. Sensitive populations such as children, elderly and those with already existing health problems are especially under risk (Hashem, 2005).

4. What is retrofitting?

Retrofitting as a concept is relatively new in the context of planning and climate change adaptation. The conventional definition of retrofit is to install equipment or parts not available during the original construction or manufacture (Dunham-Jones & Williamsson, 2009). In practice this means an upgrade and transformation for old buildings to become more modern and energy efficient with help of new technologies available on the market. The implementation and transition to retrofit old residential buildings can be done in various of ways and with different methods. The most efficient way to retrofit is yet still open for discussion but there have been attempts to create optimization models to help decision makers to identify the best combination of retrofit options for buildings to ensure policy compliance in the most cost-effective way (Fan & Xia, 2018). However, even though retrofitting often refers to an integrated whole-building process, there are single measures that can be used as key elements of retrofit buildings.

In previous studies on retrofitting of existing buildings it has been found that the most beneficial methods are those that reduce the risk of climate change impacts, and at the same time take the local adaptive capacity into account. For example, the type of suburb, housing type, microclimate, socio economic composition, location, the attitudes of the residents, available resources and methods for governance were important factors to account for to find effective, feasible and acceptable adaptation measures (Williams et al. 2013). To identify the optimal retrofitting measures and extent, there are therefore several aspects that need to be evaluated; the risks to the area that needs to be mitigated, the resources and attitudes of the residents and technical suitability of measures. The attitudes and resources available are likely to be influenced by the income and educational level of the residents (Williams et al. 2013).

5. Nature-based Solutions

Nature-based solutions (NBS) are measures that mimic, are supported by or inspired by natural processes. A NBS measure could for example include rehabilitation of natural ecosystems or creation of artificial ecosystems that bring natural processes. NBS can be implemented in large (landscape) - or small scales. This project will focus on measures in the category of NBS due to the many benefits that are associated with these. NBS measures often include enhancement of biodiversity, disaster risk reduction, food security and water management. Apart from providing climate change adaptation, these measures can also bring additional social, cultural and health benefits to the area (Connor et al. 2018).

6. Aim of the Report

The aim of this report is to present potential retrofitting measures that can contribute to climate adaptation of the selected area in Ladugårdsgärdet, Stockholm. Since the study area contains two different neighborhoods, the retrofitting solutions will be adjusted to the specific areas. The suggested interventions will refer to adaptation for the high emission scenarios of climate change, namely the RCP 8.5 scenario. The report will also illustrate weaknesses of the area, which will help identifying the main risks associated with climate change in the area. The focus of this paper lies on the retrofitting of building technology, ground areas and green infrastructure within urban areas.

The two questions of interest are:

- With an RCP 8.5 scenario, which weaknesses could be found in the two different study areas?
- Which retrofitting measures could be implemented in the area to mitigate negative impacts of climate change?

7. Boundaries

Spatial/physical Boundaries
The study area is located at Ladugårdsgärdet in Östermalm (see figure 8). The closest Subway station is called Gärdet. Within the study area there are two different built parts, one more dense, and one with more green areas. These areas are separated by the street Östhammarsgatan. The northern part will from here be referred to as area 1, and the south area as area 2. The northern boundary for the area is the intersection of Sandhamnsgatan and Tegeluddsvägen and the southern boundary is set by the street Lindarängsvägen. The Royal National City Park is located next to the area to the west and the developing area of the Royal National Seaport lies to the south. Thus, the southern boundary for the study area is Tegeluddsvägen.

Temporal Boundary
The temporal boundary stretches from the planning phase until the year 2030. In perfect conditions all aspects of the project should be finalized until 2030. Regarding the environmental consequences of the project, the time boundary is set until 2050 to fully assess long-term impacts.

Subject Boundary
We limit ourselves to retrofitting measures specifically for climate change adaptation. Different retrofitting measures can be useful for several purposes and retrofitting for climate adaptation can also serve a purpose for economic, social and technological aspects as well. All of the aspects of retrofitting are naturally linked together, but the limit is set to retrofitting measures with very clear connections to climate adaptation challenges for Stockholm and Ladugårdsgärdet, specifically climate changes considering temperature and precipitation patterns.

8. Background of the area

Earlier Land Use

Ladugårdsgärdet is a landscape that has been used and shaped by human interaction for a long period of time. In the middle ages this was mainly a place for keeping livestock and, to a smaller extent, agriculture. This was divided between several different farms and villages and towards the end of the middle ages (early 16th century) most of the land was owned by monasteries. With Gustav Vasa as regent this changed and the royal family took over the ownership of the land. At around this time the name "*Kungliga Djurgården*" was first mentioned for the area, which refers to an enclosure of game which the royal family was keeping.

By the end of the 17th century Karl XI enclosed the whole park with a fence and turned it into hunting grounds. After about a century as hunting grounds and with the change of monarch to Gustav III the park changed with the new ideals of the time and was turned into a place for recreation and a part of the park was turned into an exercise field for the military. The military retrieved in the beginning of the 20th century due to changing needs, but big parts of the park are still used as a recreational space for the population to this day. (Andersson & Jönsson, 2011)

Modern Times

Some of the land was sold to finance the move of the military and it was decided that Gärdet would be developed as a living area. The royal family also contributed with a third of the land to create infrastructure on the condition of high exploitation development. There was a competition for how this development should take form and in the early 1930s the construction of the new neighborhood started, all in the modern style of functionalism. The area stood out due to its modern style, the tall buildings and the high level of standards and became a popular place to live for the young, wealthy and successful in Stockholm. The area kept being developed and the part concerning our project was finished in the 1960s.

In recent years the new "city" of the Stockholm Royal Seaport have been constructed in the sustainability ideals of today. We are facing a changing climate and a growing population which puts a huge stress on Earth's resources. Just as the functionalism era tried to achieve a more efficient and smarter way of living, sustainability tries to achieve a more efficient and wise use of our resources, combined with a design that promotes a high quality of life.

During history, the area had many different functions and we can see that it changed every so often (Andersson & Jönsson, 2011). With the development of the Royal Seaport and the awareness of climate change there is a kind of awakening, that we need to take wise use of our resources which is why retrofitting and climate adaptation of already developed areas might be the next big change that is in store for Gärdet.

Socio-economic circumstances

The project site in Ladugårdsgärdet is located is a wealthy part of the city. The average income for the residents in the area is 394 thousand (SEK) per year in comparison to 363 thousand (SEK) in wider Stockholm. The percentage of residents that have attended higher education is also higher than the average in the city, with 72% that have attended higher education in Gärdet and 58% in Stockholm. The percentage of unemployed residents is 1.75% in Gärdet compared to 2.9 % in Stockholm (Stockholm Stad, 2019).

9. Methodology

Climate Scenarios

In this report we have concentrated on the RCP8.5 scenario by the Intergovernmental Panel on Climate Change (IPCC, 2014). We looked at specific data about temperature and precipitation changes for the Stockholm county published by the Swedish Meteorological and Hydrological Institute (SMHI, 2019). Climate projections in general are never perfect representations of reality. Due to the need for a tremendous amount of data a perfect certainty is never given and biases might occur. The exact changes are harder to estimate the smaller the scale is, so predicting climate changes for the city of Stockholm in particular is rather difficult.

Case Studies

For each suggested retrofitting solution we have referred to a case study in another European city. Climate and circumstances are evidently not the same as in Stockholm, but the studies still give a rough overview of the functionality, benefits and costs of the implemented measures.

Climate measurements

Climate measurements where conducted at different strategic points in the study area. The measurements were soil temperature in °C, air temperature in °C, humidity in % and wind-speed in m/s. The measure points were chosen with the aim to represent areas with different characteristics in development and to see how the impact of the urban heat island effect changes within the area . These are then compared to illustrate where the impact are most apparent.

ArcGIS

With ArcGIS we created an overview map of the suggested retrofitting implementations. For this we used material of land use, buildings and streets provided by Lantmäteriet, a public authority belonging to the Ministry of Enterprise and Innovation, responsible for the real estate division in Sweden and the provision of geographical information and maps for society (Lantmäteriet, 2018). With the help of the already existing maps, projected in SWEREF99 TM coordinate system, we created polygons, polylines and points to visualize the different retrofitting measures.

Interviews

We have conducted a total of 20 semi-structured interviews within our two study areas (*area 1* and *area 2*). The interviews were executed during two different time occasions on the same day, namely 10am and 4pm. All of the respondents in the survey were chosen randomly on the street and then asked the same six preset questions (APPENDIX 1). Semi-structured interviews are fit for these kind of case-studies since they contain theoretically underpinned questions, while still leaving space for the participants to constitute their own narrative and opinion on the topic (Galletta, 2012).

Interviews carry a risk of biases. The questions need to be carefully thought of in order to not manipulate the interviewees opinion. Asking questions that offer a socially volitional answer might result in outcomes that do not represent reality, but rather a common conception of the perceived appropriate thinking. Therefore, the outcomes cannot be viewed as perfectly representative. However, they can still give a rough synopsis of current circumstances.

10. Results

Impacts of Climate Change in Stockholm County

In this report we will be working with the worst-case scenario, namely the RCP8.5 scenario, for the Stockholm county. We will examine measured and estimated annual changes in precipitation and temperature between the years 1961 and 2100. All data is provided by the Swedish Meteorological and Hydrological Institute, an expert agency working under the Ministry of the Environment and Energy (SMHI, 2019). The following figures represent the average projections of different climate models (SMHI, 2019). The standard value used for comparison is in this case the average measurement of the years 1961 until 1990. Considering temperature, the annual mean will continuously rise and result in an increase of about 5°C by 2100 (figure 3).

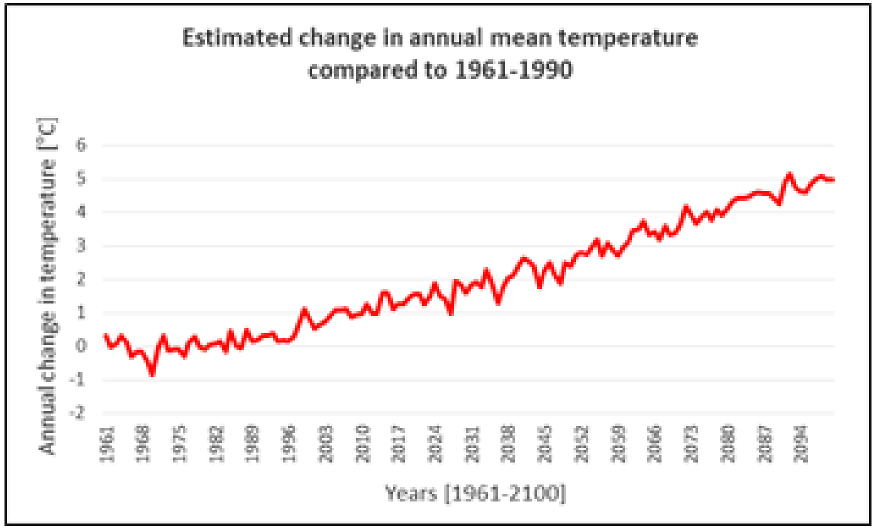

Figure 3: Change in annual mean temperature (SMHI, 2019)

Along with this goes the decline of the annual number of days with temperatures crossing the zero mark. As seen in figure 4 the number of days below 0°C will decrease by almost 40 days per year.

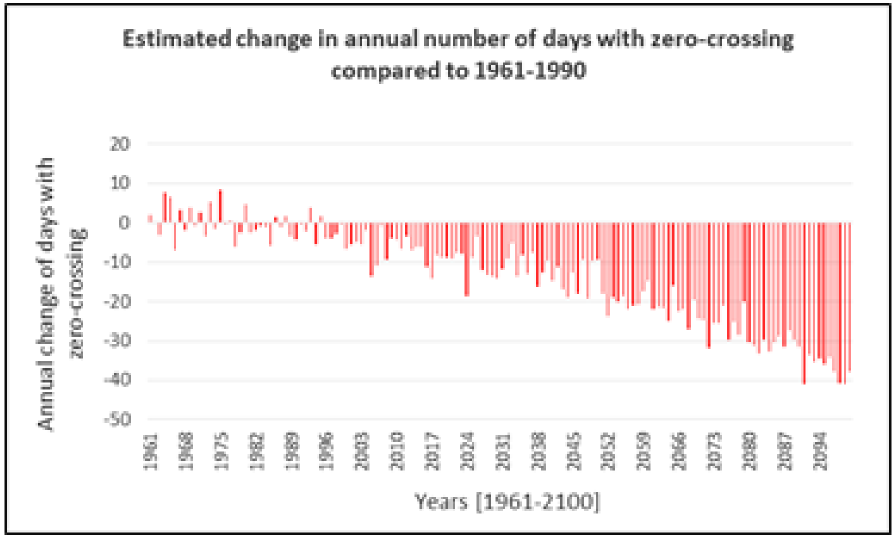

Figure 4: Change in annual number of days with zero-crossing (SMHI, 2019)

The amount of precipitation will progressively rise, resulting in an increase of annual rainfall of 20-30% by the end of the 21st century, compared to the standard value (figure 5).

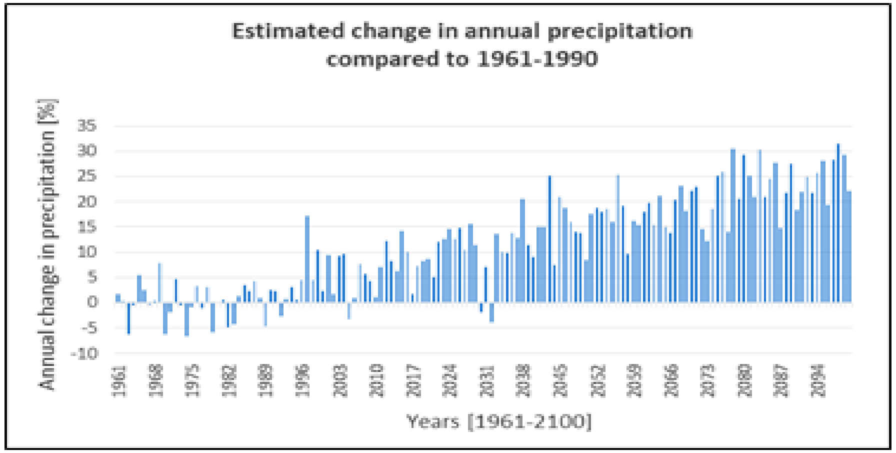

Figure 5: Change in annual precipitation (SMHI, 2019)

Heavy precipitation events will occur more often. Heavy precipitation is in this case defined as precipitation of more than 10mm. Figure 6 illustrates an increase of 6-10 days per year in the Stockholm region.

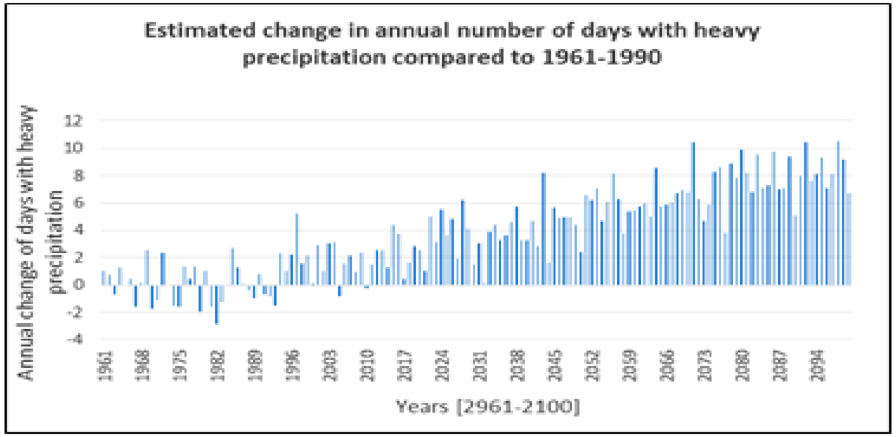

Figure 6: Change in annual number of days with heavy precipitation (SMHI, 2019)

The increase of precipitation goes hand in hand with the decrease of the dry period duration illustrated in figure 7. There has already been an significant decline of the dry period by 1-4 days and this will build up to 2-5 days by the year 2100.

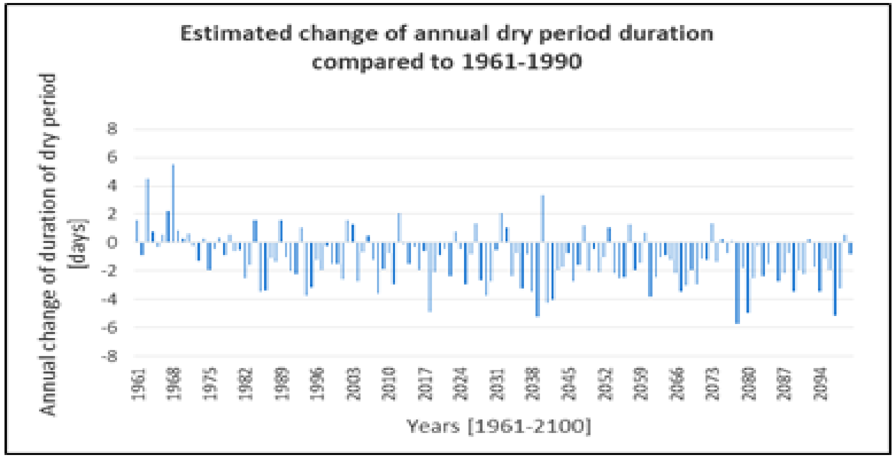

Figure 7: Change of annual dry period (SMHI, 2019)

Overall, calculations with the RCP8.5 scenario in the Stockholm county evince a rise in temperature and precipitation over the course of the years. This will be accompanied by many other environmental consequences, some of them most likely harmful to urban residents.

Measurements from the study area

The results from the measurements (figure 8) indicate that the heat island effect is most striking in the middle of area 2. In general, the results confirm the basic ideas of the heat island effect. Area 2 with tall buildings built closely together and a lot of asphalt "traps" outgoing energy in the form of radiation and the asphalt act as a battery retaining the energy. This combined makes the area warmer and is something that is clearly experienced when walking in the area and can also be seen in measurepoint 3 in table 1.

In area 2 the effect is less due to the lower density of the built environment, but the measurements still indicate a warmer environment in the middle of the area, as can be seen in measurpoint 5 and 6 (see table 1 and figure 8). The results show that it is warmer in the middle of area 1 and 2 (point 3,5,6) in contrast to the peripheral area and crossroad (point 1,2,4,7). The soil temperature is a good indicator, since the soil takes longer to heat up compared the atmosphere. Thus warmer soil temperature indicates a warmer microclimate which also confirms the heat island effect.

Measure point	**Temp. (°C)**	**Humidity (%)**	**Soil (°C)**	**Wind (m/s)**	**Cloud cover (x/8)**
1	6.0	49	0	4.3	7/8
2	7.1	51	none	3.3	6/8
3	8.0	48	4.1	2.0	8/8
4	7.3	50	0	1.9	8/8
5	6.8	50	2.9	2.0	6/8
6	7.0	51	3.2	1.7	4/8
7	6.6	50	0	1.7	7/8

Table 1: Measurements from the study area

11. Suggested Retrofitting Measures

According to IPCC´s RCP8.5 scenario, Stockholm will see an increase in precipitation of about 30% (figure 5) at the end of the century and an increase of days with precipitation over 10mm from 13 to 21 (figure 6), which results in an increase of almost 62% (Asp et al. 2015). 10mm is a measurement that is considered a heavy rainfall and can cause flooding. The measurements also show big variations on a yearly basis, meaning that some years can show a considerably greater amount of precipitation. According to this predictions the region of Stockholm will face an increased risk of flooding due to stormwater and that is why we propose taking adaptation action with the help of green infrastructure to increase the urban stormwater management capacity. There are several types of green infrastructure developed to manage stormwater where most of them uses vegetation and soil to act as a buffer mitigating flooding (USEPA, 2004).

Rain Gardens

Rain gardens or bioretention areas are artificial depressions in the ground with native vegetation that is watered by stormwater. The gardens capture rainwater naturally and provides several ecosystem services. It cleans the water, provides stormwater management, provides biodiversity and have aesthetical values. If there are houses close by, the downspouts from the houses could be disconnected and the water could be lead to the rain garden to relieves the ordinary stormwater infrastructure from stress during heavy rains and helps water the rain garden (Foster et al. 2011).This has been done on an administrative level in Malmö and results show that it have promoted stormwater management and increased the number of green spaces dedicated to water control(Hansen et al. 2016).

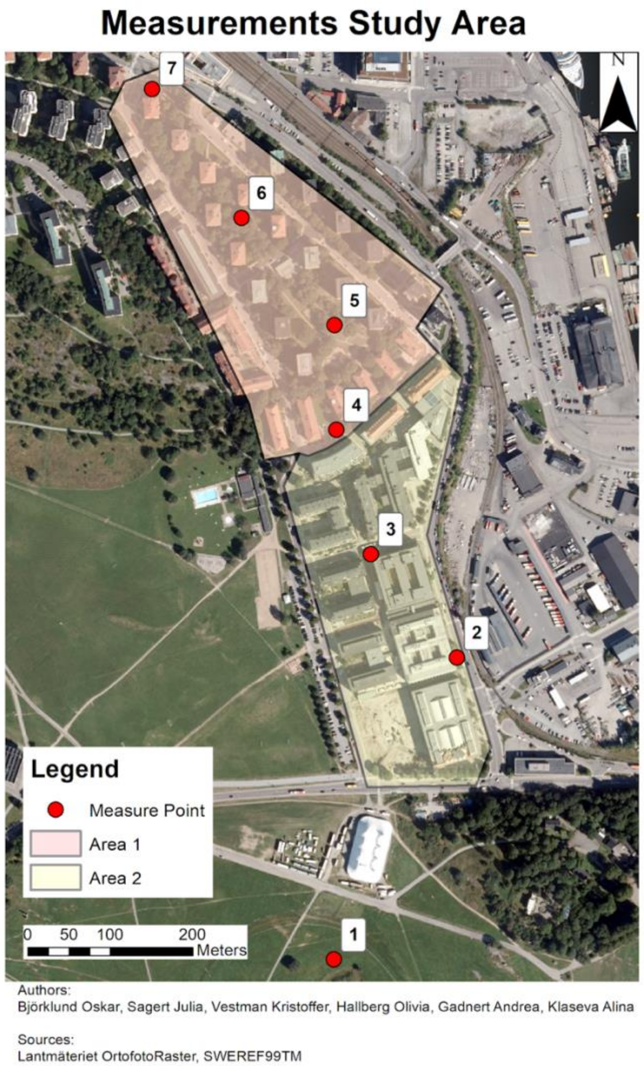

Figure 8: Measurement points in the study area

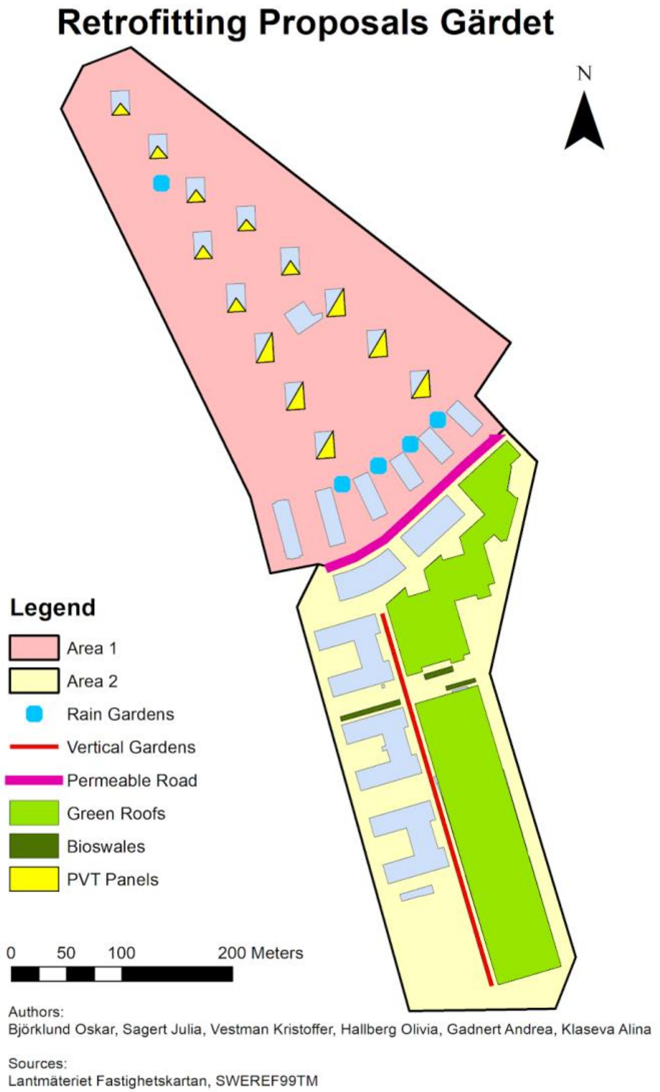

Figure 9: Retrofitting proposals Gärdet (Study area 1 and 2)

Bioswales

Bioswales are constructions similar to rain gardens with the difference that bioswales are created in a linear shape and they have an impermeable drainage pipe in the bottom. They are artificial depression in the ground with a drainage pipe in the bottom which is typically covered with an aggregate to protect the pipe from clogging (e.g. gravel) which is then covered with soil and and vegetation (figure 11). They are typically placed alongside roads and parking lots with the main purpose of managing stormwater and cleaning the water with the help of ecosystem services they provide.

Bioswales work most efficiently if they have dense, heavy vegetation and just as with the rain gardens, native plants are preferable due to their area specific qualities which makes the plants resilient to weather and keeps the maintenance lower. They provide an effective measure to handle pollutants in water runoff before its released in to natural environments. In a case study from outside Toronto where they divided a parking lot to compare water runoff from storms, the results showed that a bioswale created about 60% less runoff than conventional asphalt and cleaned the water from most pollutants except nutrients and copper, traces probably comes from leaching the soil of the bioswale (Van Seters et al. 2006). The cost of installing bioswales is about 50% cheaper than installing a traditional sewer but the cost of maintenance is about 40% more than an traditional sewer (Green-blue Urban Grids, 2019)

Figure 10: Rain garden, Source: https://vaswcd.org/rain-garden

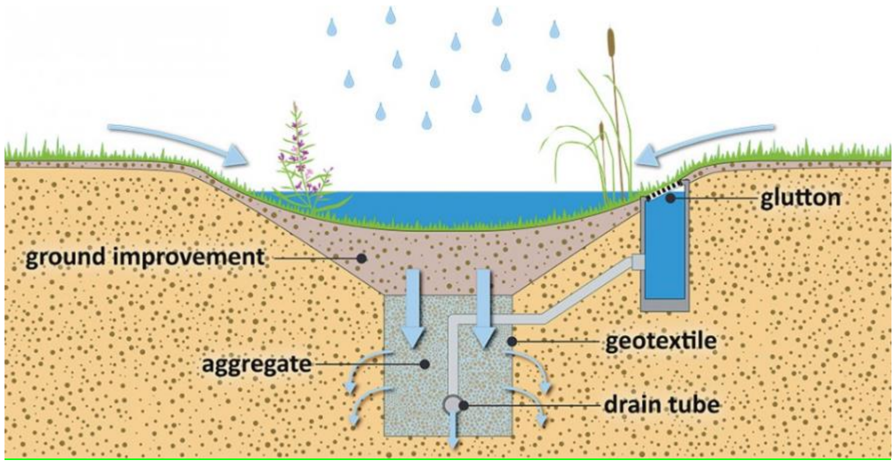

Figure 11: Bioswale © atelier GROENBLAUW, Marlies van der Linden (based on: Boogaard et al, 2006)

Vertical garden

Vertical greenery, also commonly referred to as vertical garden, is a term which refers to all forms of vegetation on wall surfaces with plants rooted in the ground, in the wall itself or in modular panels connected to the façade. Vertical green can be classified as façade greening or a living wall systems according to the growing method employed (Dunnett and Kingsbury 2004). The implementation of greenery on the façade can be done in numerous ways (see figure 12), **a)** direct greening system, **b)** indirect greening system, or **c)** indirect greening system combined with a planter box.

All of the options are using climbing vegetation attached directly to the wall with different setups including advantages and disadvantages.

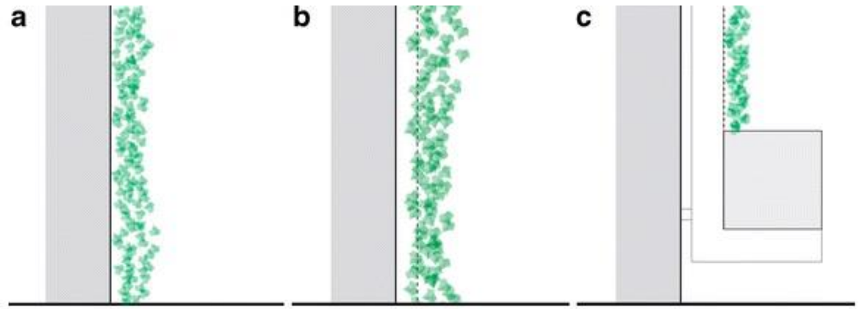

Figure 12: a) direct façade greenery setups and b) and c)indirect
Source: Perini, K., Ottelé, M., Haas, E.M. et al. Urban Ecosyst (2013)

In setup a), the greenery is attached on the ground level and uses the façade directly as primary source for its climbing vegetation. Climbers planted on the base of the building provide a relatively inexpensive façade greening. However, climbers of this setup (a, b, c) imply extra work in the case of damage and maintenance of the façade (Perini, Ottelé and Haas: 2013). The second indirect approach b) is also attached on base level but here is the vegetation supported by meshes or cables. A wide variety of different materials can be used to support the climbing vegetation such as steel (stainless steel, galvanized steel coated steel), different wood types, aluminum or plastic. Each one of the used materials changes the functional and aesthetical properties of the building due to different weight, durability, profile thickness and financial cost (Ottelé et al. 2011). The indirect greening system can also be combined with planting boxes on different heights on the façade, such as setup c). Contributing to more flexibility for the greening system as it doesn't depend on space on base level. However, implementation of planting boxes on multiple levels require nutrients and a watering system and can be rather expensive to maintain properly.

The indirect greenery system can also be defined as living wall system (LWS). This system is constructed out of prefabricated modular panels, which already contain soil and artificial nutrients. They are delivered ready to install at any height on the wall. In figure 13 different types of LWS principles of planning and growing are illustrated.

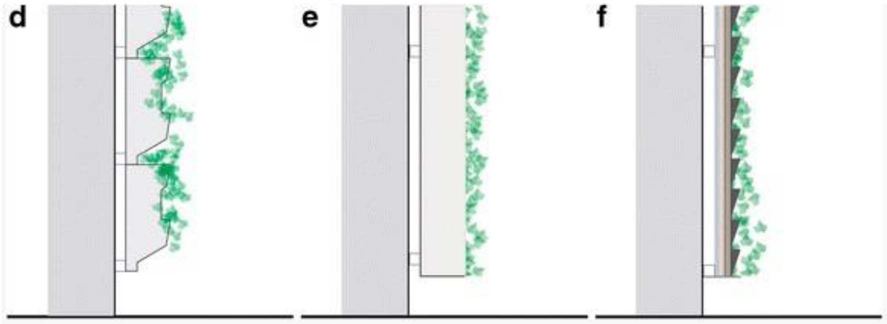

Figure 13: Indirect façade greenery setups
Source: Perini, K., Ottelé, M., Haas, E.M. et al. Urban Ecosyst (2013)

The chosen location for the implementation of the vertical garden is set to area 2 and the parallel walking street (*figure 9*). The location is strategically chosen to run through the whole neighborhood and cover the façades with greenery on both sides of the street. The space between the houses is most likely to absorb incoming solar radiation through the brick walls and concrete pavements. During our measurements in study area 2 we found that soil and air temperature were higher compared to the surrounding measure points. This proves the proposition of the buildings creating an urban heat island effect in the area. To mitigate the effect of urban heat accumulation our study suggests an indirect greening system like example **b)** (see figure 12) in combination with a LWS (see figure 13), including planting modular boxes. The greening system will be supported by steel wires from base level to rooftop. It enables vegetation to climb the wall without using the facade as its primary host. This is an efficient measure, as it does not damage the façade to the same extent as the direct greenery system.

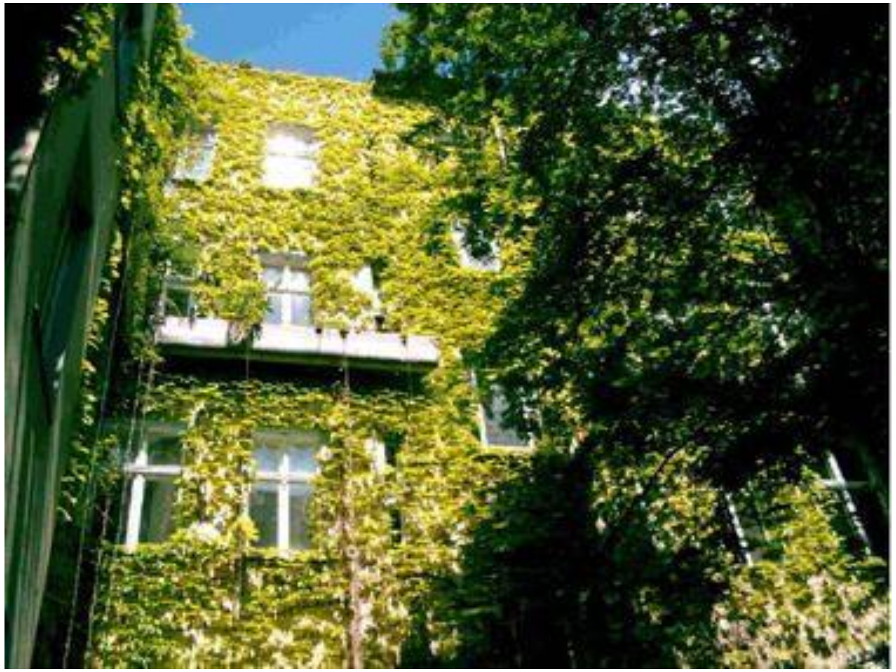

Figure 14, Green facade project "Paul Lincke Ufer" in Berlin 1984
Source: Köhler 2006a, b

The "Paul-Lincke-Ufer research project" was one of the first research projects in Berlin that monitored green facades before vegetation was installed. The project used Boston Ivy in combination with other climbing vegetation which was planted on the ground level and in planting boxes attached on different levels on the wall. After approximately 10 years the façade of the building was covered by the Boston Ivy (*figure 14)* and the survey indicates that the ground base climbers was more successful than the plants in the boxes as they had reached the gutter at the roof. During the temperature measurements that had been taking in the middle of the yard and on different heights along the wall, results shows that the effect of greenery closes to the wall show an increase of insulation value for the building. However, if an area is enclosed with no fresh air flow the greenery has little impact on the surrounding air environment. In an open environment the measurements indicates significant improvements in the air quality. Furthermore, is the Boston Ivy one of the spices which offers the maximum cooling effect; this values are comparable to the shading of trees (Georgi and Zafiriadis 2006). According to architek.com (2019) the costs for implementation of vertical gardens varies depending on the project, but on average cost of the installation for a living wall system, fully complete with plants is, 195-265 $/sq. ft which translates to 19 300-26 200 SEK/m².

Green Roofs

Green roofs are a vegetation cover implemented on roof-tops of buildings, which serves a multitude of benefits to diverse challenges, depending on the configuration (Getter & Rowe, 2006; Oberndorfer et al. 2007; Runhaar et al. 2011). One of the most prominent benefits of green roofs is their ability to retain stormwater (Getter & Rowe, 2006). Green roofs catch rainfall and reduce the amount of runoff with up to 45% due to evapotranspiration. Getter & Rowe (2006) state that the reduction of runoff depends on the character of the green roof, including depth of the substrate, the quantity and variety of plant species and its composition as well as general surrounding requisites; such as the intensity of the rainfall and the microclimate. Green roofs do not only reduce the amount of runoff, but also elongate and delays runoff from the roofs. The substrate of a green roof will retain the stormwater until it is saturated, only after this, the water is released. This delay of runoff and reduced flow rate will ease the pressure on sewage drains, which helps to prevent the risk of flooding. This can especially important in cities where the ground cover is (usually) dominated by non-permeable surfaces.

Getter & Rowe (2006) state that the delay of runoff with green roofs can be from around 1,5-4 hours, again depending on the type of green roof and its fabric.

Green roofs also mitigate the urban heat island effect, lower indoor temperatures and can reduce energy consumption and costs (Getter & Rowe, 2006). Buildings with green roofs have shown to have reduced indoor temperatures of up to 4 degrees with outside temperatures of 25-30 degrees. This decrease reduces the need of air-conditioning and other heating and cooling systems. The energy use can be reduced by around 8% for every 0.5 degree, which can make a significant difference in costs. Buildings use a high amount of electricity and green roofs can be one tool to help neighborhoods and whole cities to reduce their consumption of energy and at the same time reduce costs (Getter & Rowe, 2006). Most of the energy savings will take place during the summer months, but green roofs also acts as insulation in the winter. They keep some of the warmth inside the building, which reduces the energy use for heating. With this being said, green roofs are not the ultimate energy saving measure and other types of insulation might provide better results and may also be cheaper.

However, green roofs serve a diverse purpose for mitigation of weather events challenges concerning climate change. Apart from the management of stormwater, the mitigation of the Urban Heat Island Effect, the followed lowered energy consumption and provision of insulation, green roofs, according to Getter & Rowe (2006) and Oberndorfer et al. (2007) also increase biodiversity and create space-effective valuable habitats in urban environments. They mitigate air pollution, clean the air from different compounds, and reduce noise-pollution to some extent.

Green roofs also provide aesthetical features if they are visible and/or accessible to humans, improving different aspects of human general well-being (Getter & Rowe, 2006; Oberndorfer et al. 2007).

There are two common green roofs known as intensive and extensive green roofs, these are different in several ways, both visually and functionally (see figure 15 and 16). Intensive roofs generally have a deeper substrate (> 20 cm) while extensive green roofs can have more shallow substrates, ranging from 2-20cm, depending on the composition and plant species. The reason for the need of greater substrate depth for intensive green roofs is that the plant species are more demanding and put together in a complex vegetation composition. Due to this they, according to Oberndorfer et al. (2007) also require more irrigation and other regular maintenance like weeding and fertilization. Extensive green roofs on the other side often include succulents which require less maintenance due to their drought-resistance etc. Extensive roofs require little or no irrigation and other maintenance like fertilization and weeding, unlike intensive roofs which have more complex demands (Oberndorfer et al. 2007).

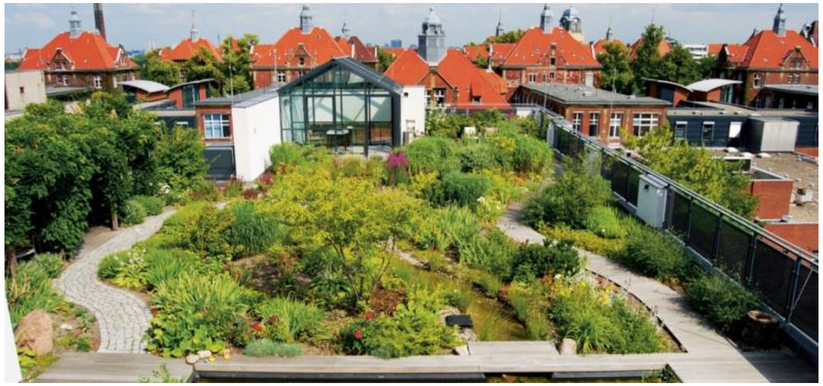

Figure 15: An example of an intensive green roof, unknown location. Source:https://www.urbangreenbluegrids.com/measures/green-roofs/intensive-green-roofs/

Figure 16: An example of a extensive green roof in Stockholm, Sweden.
Source: http://godaexempel.dagvattenguiden.se/project/gront-tak-mitt-i-city/

The purposes of these two types of green roofs are as seen quite different, which gives them different physical and functional attributes. While intensive green roofs focus more on functioning as a recreational and aesthetically pleasing and space-effective gardens in the midst of a city, the extensive green roofs are more focused on functionality towards weather conditions like heat-waves and extreme intense rainfall (Oberndorfer et al. 2007). Buildings have different weight restrictions and carrying capacities, and since extensive green roofs generally are more shallow they also weigh less. Thus, Oberndorfer et al. (2007) mean that extensive green roofs often fit into the weight restriction boundaries of buildings, whilst intensive green roofs might need more structural actions to meet the requirements of the implementation.

When deciding on which type of green roof is fit for a roof, there are many factors to consider, including many place-specific conditions. Getter & Rowe (2006) argue that grass and certain flowers can be hard to maintain during drier summer months, and even present a risk to turn into a fire hazard. These types of species, which are more susceptible to drought, need more irrigation and deeper substrate etc., which implies higher costs of maintenance and for example a higher pressure on the roofs due to the weight. Getter & Rowe (2006) instead argue that different types of succulents are a good choice due to low or almost no need of maintenance, which reduces economic costs. The succulent species of Sedum and Sempervivum are especially promoted by the authors. They can survive longer droughts due to biological feature of storing water. While the may not have the same aesthetical appeal as a flower bed, it serves the purpose of stormwater retention amongst other benefits. Sedum-roofs can also be relatively thin and still maintain their stormwater mitigation capability, which decreases the weight put on roofs.

A case-study done by Rowe et al. in 2006 in the mid-western US prairie showed that succulents could be planted in a shallow substrate (in this study only 10 cm) and survive and grow without irrigation or fertilization during 3 years, whilst most of the non-succulents died during the study and were concluded to need irrigation and a deeper substrate, which results in greater costs and more weight on buildings etc. The non-succulents could also impose a fire hazard in the case of drought (Getter & Rowe, 2006). According to Runhaar et al. (2011) Green roofs, as well as green walls/green façades, cool their near surroundings and thus affect the microclimate. This Dutch microclimate study by Runhaar et al. (2011) showed that the effects of green roofs and green walls decrease when the space between the houses increases.

The study also illustrated that the combination of green façades with green roofs is the best option to mitigate hot temperatures between houses. This applies all the way from a small one-block scale up to the city scale and works best when the area is densely built. Oberndorfer et al. (2007) elaborates on different green roofs and their advantages and disadvantages regarding certain aspects sought for when implementing green roofs. Oberndorfer et al. (2007) state that extensive green roofs can weigh from around 70-170 kg/m² in comparison to intensive green roofs ranging from around 290-960 kg/m². The latter putting more complex demands on the building structure, which can mean further costs.

Green roofs can be relatively expensive, but intensive green roofs are overall more expensive. Again, the best choice to keep costs down seems to be extensive green roofs. The calculations of the area of the roof-tops in area 2 shows that the area is 34 916 m², a third of that is 11 638m² and implementation of extensive green roofs here will probably be about 6-32 million SEK (see table 2). The extensive green roofs are in Oberndorfer et al. (2007) estimated to cost 100-300 dollars/m² which translates to around 930-2800 sek/m². With the cost estimates of Oberndorfer et al. (2007), extensive green roofs implemented on a third of the roofs in area 2 would add up to about 11-32 million kronor in total.

From the Environmental Protection Agency report (2001) it once again stated that the costs of green roofs vary depending on its character, soil depth, plant species, composition etc. According to the report the costs of extensive green roofs starts at 107,64 $/m² which is ca 1000 sek/m². With this cost estimate for extensive green roofs, the cost of the implementation on a third of the roofs in area 2 would be around 11.6 million kr. It is hard to find ant cost estimates of green roofs from Swedish companies, the only rough estimate given is around 500 sek/m² for an extensive green roof (Sundström, 2008). This gives the cheapest estimate of the cost of extensive green roofs on a third of the roofs in area 2. With this price, the price would be approximately 5.8 million SEK

	cost of extensive green roofs (SEK/m²)	Estimated kr/m² on ⅓ of the roof area in area 2 (million SEK)
Oberndorfer et al. (2007)	930-2800	ca. 11-32
The EPA (2001)	1000	ca. 11.6
Sundström, U. (2008)	500	ca. 5.8

Table 2: Costs of extensive green roofs in area 2.

Permeable Pavements

Changes in climatic conditions, such as warmer temperatures and changes in precipitation, can be already globally observed. Considering the uncertainty about future climatic conditions, planning decisions at a local level will require identifying key vulnerabilities of the built environment and promoting adaptive strategies for reducing the risk of damaging impacts (Pyke et al. 2011). One of the main vulnerabilities due to climate change faced in Gärdet is stormwater management. Increased precipitation could worsen the impairment of surface waters due to increases in stormwater runoff. We suggest changing some of the typical asphalted roads that are impervious to a permeable bound recycled glass porous pavement.

Bound recycled glass porous pavement is a mixture of post-consumer glass with resins and binding agents (Green Building Alliance, 2019). The pavement mixture can range from 100% recycled glass to 20% glass and 80% stone for heavier vehicular loads and longer service life (Sustainable Buildings initiative, 2019). This type of pavement has many environmental benefits because it mimics the natural process that occurs on the ground's surface: increased water permeability, trapping of suspended solids and pollutants, reduction of the urban heat island effect due to the increased reflectivity of recycled glass, evaporative cooling, prevention of glass waste from ending up in landfills, aesthetic benefit of beautiful glass colors. Such surface has also many financial benefits: low installation costs, equal or longer life-cycles compared to concrete, eliminated costs for retention basins and gutters, lower requirement of applied deicers in winter (Green Building Alliance, 2019). Drawbacks of such pavements are: infiltration of some pollutants into the groundwater, higher glass mixtures require additional maintenance, more expensive than other permeable pavements (Sustainable Buildings initiative, 2019).

Figure 17: Permeable bound glass pavement, n.d. photograph, viewed 6 March 2019, Source: https://www.stoneset.com.au/popular-permeable-and-porous/

According to the study conducted by Nassar et al. (2012) the use of waste glass as a partial material for permeable pavements results in enhanced durability characteristic, water permeability and pavement's freeze-thaw resistance through improvement in pore system characteristics (Nassar et al. 2012). A 6-year study of long-term effectiveness of permeable pavements in Seattle, USA, has shown very positive results - all rainwater infiltrated through the tested site area with minimum surface runoff during intense rainfalls and that the financial investment paid off in the long run (Brattebo, O., B., et al. 2003). The investigation in California included hydraulic and thermal performance of permeable surfaces in urban areas. The preliminary results showed that the technical feasibility of permeable surfaces was adequate to drain rainwater without generating any surface runoff and mitigate the heat island effect via surfaces reflective properties (Li, H et al. 2013).

Figure 18: Permeable bound glass pavement proposal on Östhammarsgatan, Source: Google Earth [changed image]

The location of the permeable bound glass pavement has been chosen to be implemented on Östhammarsgatan, a low-traffic road in the middle part of Gärdet area. This road had been chosen strategically because it is located geographically on the lowest part of the slope of area 1 and has been recognized as a "vulnerability", which would be mostly affected by storm runoff resulting from climate change increased precipitation levels. This would be a cost-effective stormwater management solution that would enhance the landscape features of the area, as well as increase resilience in the face of extreme weather events.

The construction material (glass from bottles) could be donated by the locals living in the area, who might want to become a part of the retrofitting process. Involvement of the public could stimulate and promote overall environmentally positive behavior and also increase the visual identification and real estate value of the neighborhood.

Hybrid PV/T Panels

In order to achieve the targeted goals Sweden has to cut down on energy use and switch to renewable energy sources. The residential sector consumes 19% of the total energy use in Sweden. A main challenge in order to reduce this is to find effective strategies for reducing the energy use of existing buildings (Mata et al. 2010). One option for renewable energy and a lower energy dependency is the expansion of active solar energy techniques. This can be implemented in newly built houses, but also as retrofitting measure in already existing buildings, such as area 1 of our study area in Gärdet. The residential area was built in the 1960s and therefore does not have a modern energy performance. This part of the report will concentrate on the production of solar energy through the implementation of photovoltaic (PV) and solar thermal (ST) systems. Area 1 has not implemented any form of active solar energy production.

Both PV and ST are used for the production of solar energy, however, there is a difference between those two. Solar thermal systems provide only heat for the heating of water or space. Through a solar thermal collector with an absorber plate the solar radiation gets absorbed and the heat is stored by water or air in a tank (Huide et al. 2017). Photovoltaic systems on the other side directly convert solar energy into electricity. Solar radiation is absorbed by solar cells, which form a solar module or solar panel (Richter et al. 2013).

Whereas PV is only able to operate and provide electricity during sunshine hours and is therefore reliant on the coupling with other power generation mechanisms, solar thermal energy can be stored and is therefore not dependent on continuous sunlight (Danowitz, 2010). The storage potential of the solar thermal system is especially convenient in Northern European climate, where there is a lack of solar radiation during winter (Kanters et al. 2014). On the other side is the power generation capacity of PV greater than of solar thermal (Danowitz, 2010). For this reason we would like to introduce a Hybrid Photovoltaic/Thermal system (PV/T) in our study area. Hybrid PV/T systems provide both heat and electricity. Through the combination of a PV layer and an absorber plate solar energy is used to the maximum (Huide et al. 2017). The heat rejected by the PV cells heats up the working fluid, which can be either water or air. This working fluid is stored and can then be used for heating, while the PV cells provide electricity. The electrical efficiency of PV cells is also higher when excess heat is removed by the working fluid (Sharadga et al. 2019).

The installation of Hybrid PV/T systems depends on several parameters. On one side the installation needs to be suitable within regulatory complaints, performance standards and buildings barriers. On the other side architectural conditions, roof inclination, roof orientation, surface size, density and the amount of solar radiation in the location are important factors (Groppi et al. 2018; Kanters et al. 2014). Whereas one might think active solar energy measures are not profitable in a climate like the one in Stockholm county, Sayigh (2017) states that solar energy is, in fact, viable in Nordic climates. However, Hybrid PV/T systems cannot be implemented throughout all of area 1 in our study area.

According to Statistics Sweden (2006) multi-dwelling buildings in Stockholm county, constructed between 1961 and 1970 and using district heating, have a yearly energy consumption of 158 kWh/m². Electricity prices for Swedish households have been 19,17 cents per kWh in 2018 (Statistika, 2019) and district heating prices were around 8,5 cents in 2015 (Swedish Energy Agency, 2018). The average solar radiation in the Stockholm region is according to the Swedish Meteorological and Hydrological Institute (2019) 975 kWh/m² per year (figure 19).

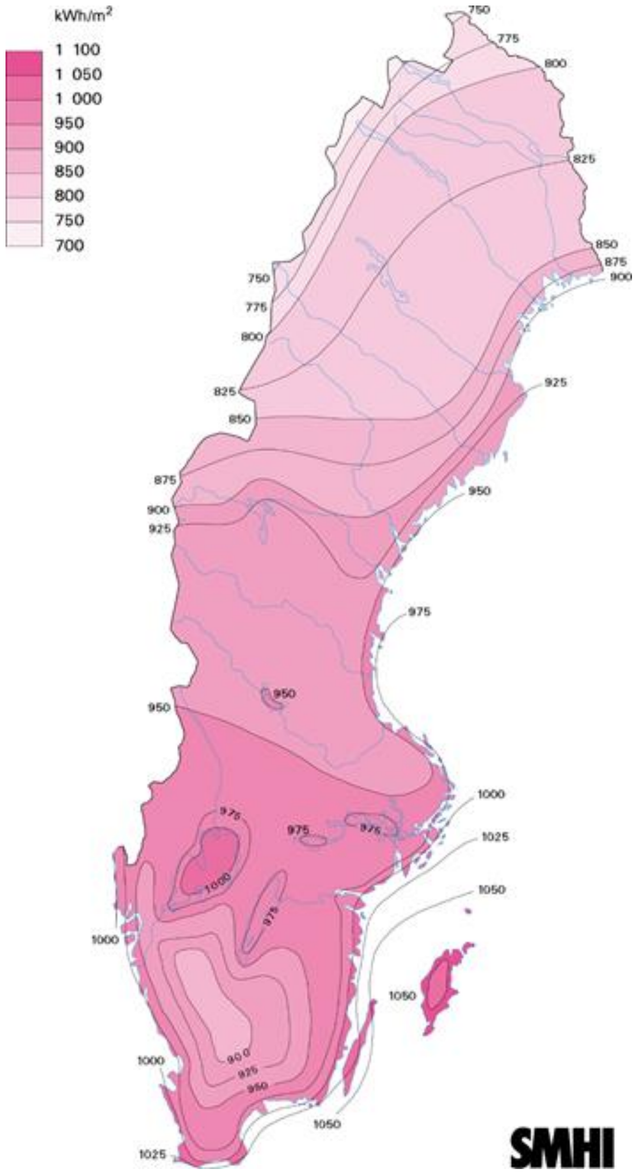

Figure 19: Average solar radiation per year in Sweden

The average Hybrid PV/T module can produce about 250 Wp, the peak amount of energy produced, and an additional average heat energy of 300 W, depending on the solar irradiation (Energie-experten.org Hamburg, 2017). The price for hybrid PV/T systems with current economic conditions range between 290 € and 500 € per square meter, depending on the type of collector (Matuska, 2014).

According to a case study by Matuska (2014) in Würzburg, Germany, Hybrid PV/T was implemented in a residential multi-dwelling building with 45 apartments and 100 residents. Electricity demand was 112,5 MWh/a and heat demand 96,3 MWh/a. However, Würzburg has with 1229 kWh/m²a a different solar irradiation than Stockholm. 100m² of different ratios of PV/T modules were installed on the roof at a 45° angle and orientation to the south.

The case study has been calculated with an electricity price of 16 cents/kWh and a heat price of 8 cents/kWh, those number are however fairly close to the Swedish prices (Matuska, 2014). The largest heat saving through the installation of Hybrid PV/T modules was in the Würzburg study 46 293 kWh/a, whereas the largest electricity saving was 13 361 kWh/a. This translates to 3703 € saved for heating and 2138 € saved for electricity, thus a total of 5841 € per year. The price range for the installation amounts to 29 000 € to 50 000 €. This means that the installation of a Hybrid PV/T system will economically pay off after around 5 to 8,5 years.

Interview results

The interviews conducted in area 1 and 2, regarding the resident's view on climate change and adaptation methods, resulted in the following outcomes.

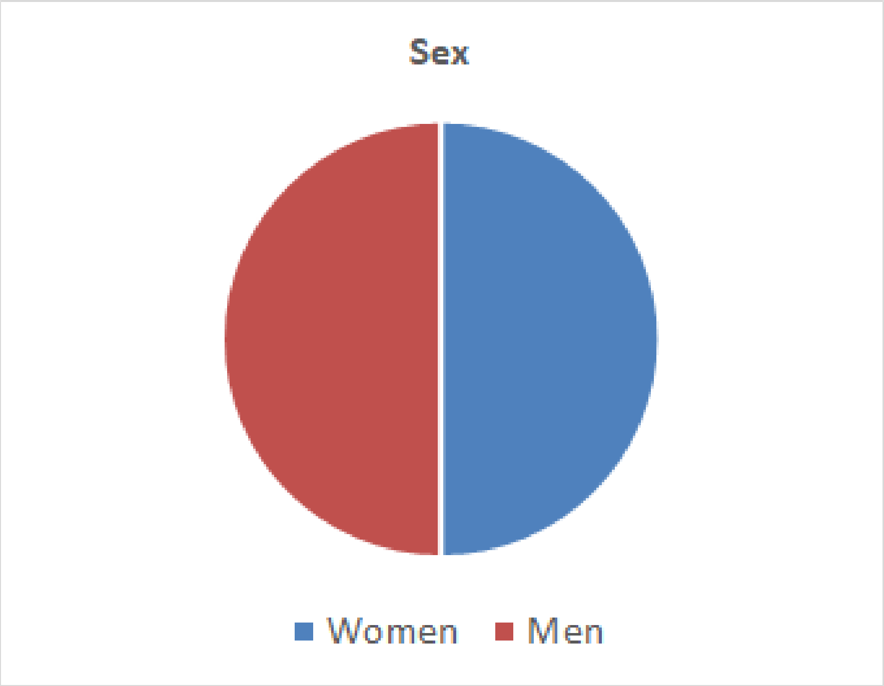

Figure 20: Gender results

10 respondents were women and 10 were men in the survey.

40% of the interviewed were seniors, 62 years and above, 20% were in the age gap between 29-39, 15% were in the age group between 40-50, another 15% were between 18-28 years old and 10% were from 51-61 years old. The distribution is overall quite even except for the 62+ group who was more significantly represented.

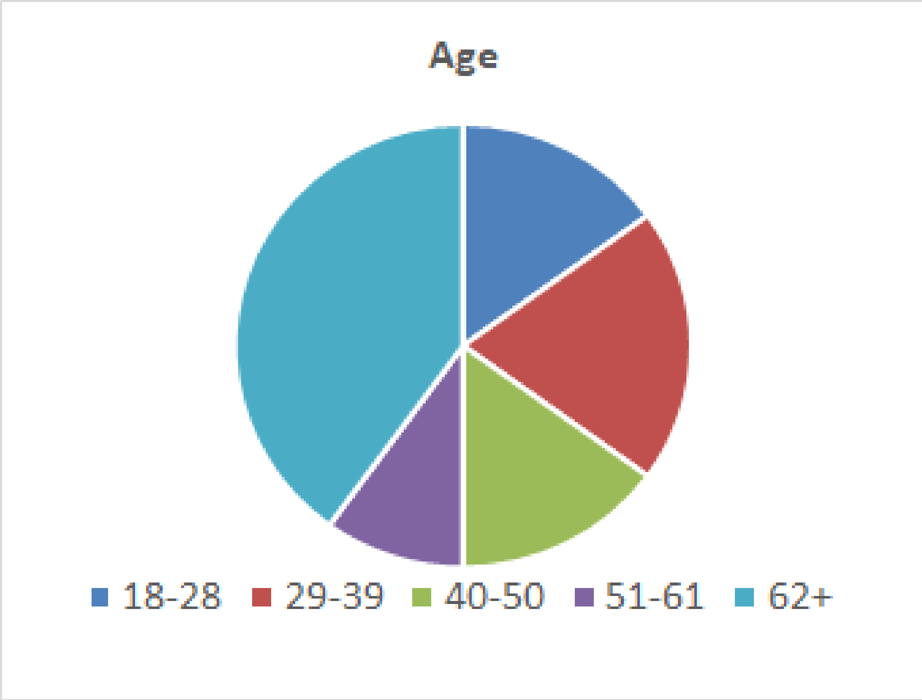

Figure 21: Age results

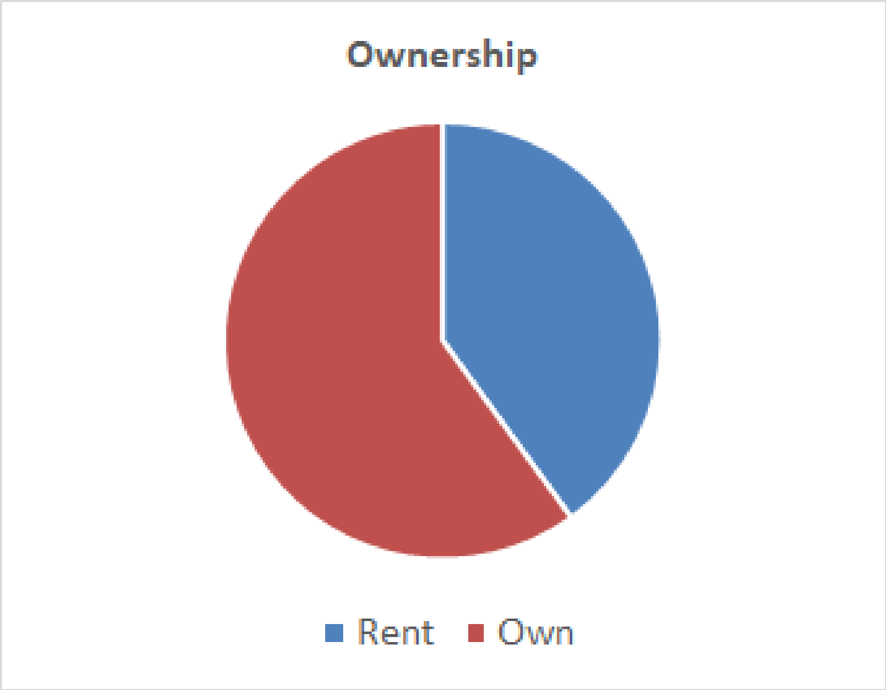

Figure 22: Ownership results

60 % of the interviewees owned their flat and 40 % were renting it.

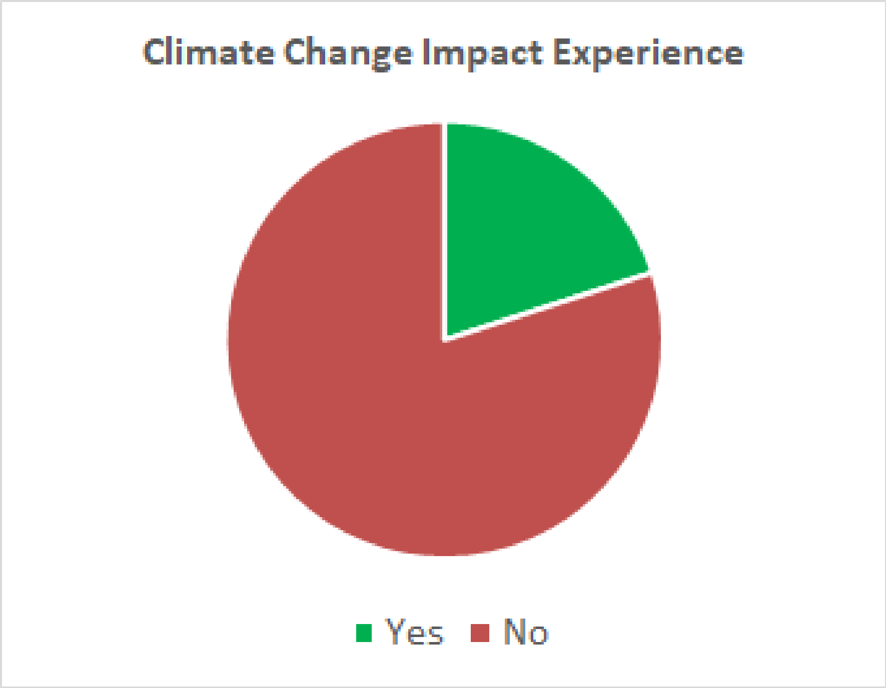

Figure 23: Experiences of climate change

80% of the interviewed claimed not having experienced any weather events related to climate change, and only 20% stated that they did experience atypical weather. Some people had experienced extreme heat waves, others said they had experienced less precipitation in form of snow and more in the form of rain.

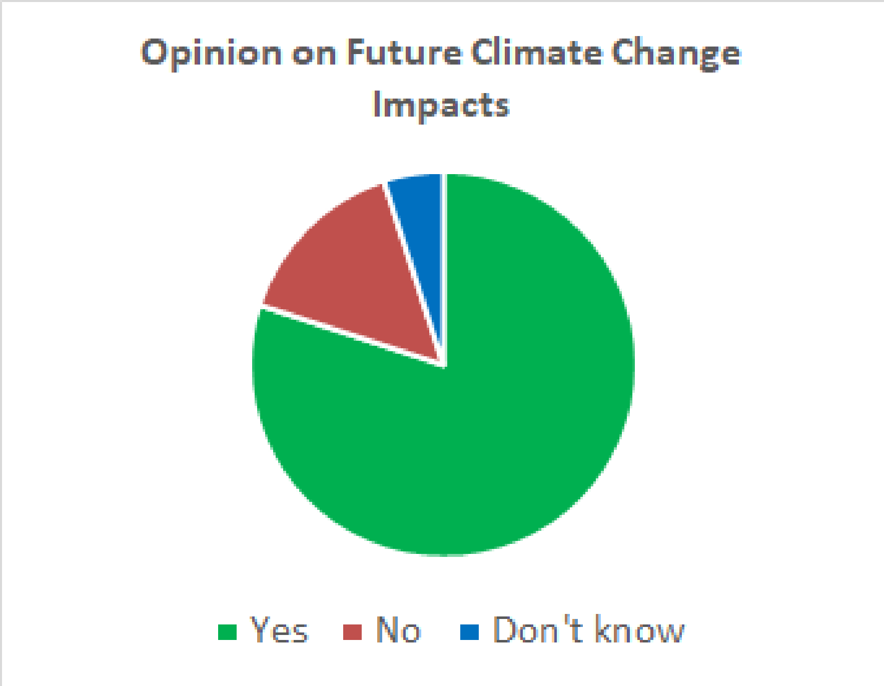

Figure 24: Opinion on future climate change

80% of the interviewees believe that their neighborhood will be impacted by climate change in the future. 15% believe there will be no change in the weather patterns caused by climate change and 5% didn't know if their area would be affected. Out of the 80% that believe that there will be changes in their neighborhood caused by climate change believe that the main change will be rising mean annual temperatures but also rising precipitation rates and an elevated flood risk.

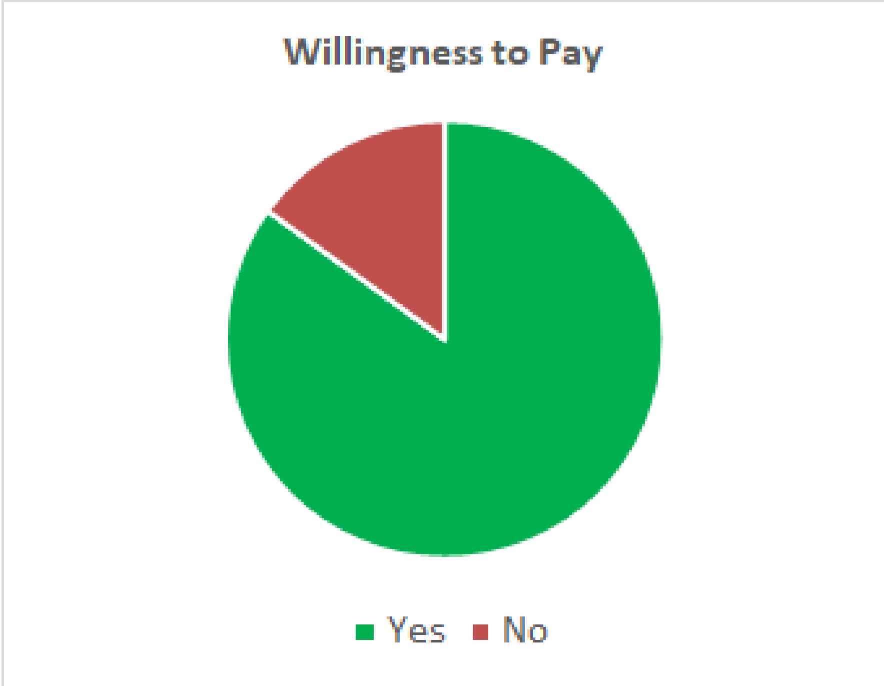

Figure 25: Willingness to pay

85% of the interviewed people were willing to pay for extra measures that would protect their neighborhood from changing weather patterns, while 15% were not willing to pay more. The payments could be in forms of a higher rent or monthly cost depending on if the resident rents or owns their apartments.

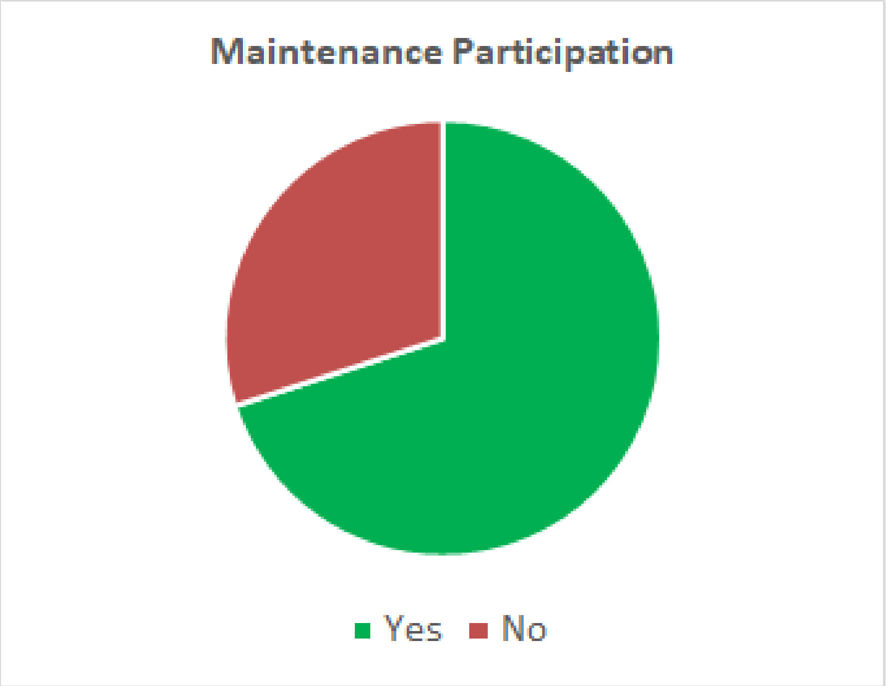

Figure 26: Maintenance Participation

70% of the interviewed were willing to participate in the maintenance work of the rooftop gardens etc., 30% were not willing to do anything in relation to retrofitting measure maintenance.

Discussion

Weaknesses of the Gärdet Area

Even though the Gärdet area has a rather well developed green infrastructure as an urban area it still tends to have higher temperatures than Stockholm's rural surroundings as a result of surface modifications due to the neighborhood's densification. Pollution and physical barriers to root growth can decrease the percentage of vegetation cover in the area and can stimulate the "urban heat island effect". Also other types of land cover such as asphalt roads and pavements can lead to increasing temperatures and lower water infiltration capacity (U.S. Environmental Protection Agency (2008).

Rain Gardens and Bioswales

According to the predicted increase in extreme weather in the future (Asp et al. 2015) Stockholm will see a big increase in number of days with heavy rainfall (>10mm) by the end of this century. This increase has the potential to cause a lot of damage to society, both economic and social and therefor water management and storm water control will become increasingly important as a way to mitigate these damages.

Rain gardens and Bioswales could be a good way to incorporate green infrastructure into neighborhoods which will make the neighborhood more resilient to a changing climate and provide water control. There is also a lot of other ecosystem services associated with rain gardens and bioswales that could benefit the environment and the neighborhood such as cleaning water from pollutants, clean the air from particles, contributes to biodiversity, mitigating the heat island effect and provides social benefits such as aesthetically values

(Demuzere et al. 2014). The cost of creating a rain garden varies quite a lot (Rain Garden Alliance) but it's usually just a little more than a regular garden, the most expensive part is usually the plants. To create a bioswale cost about 50% less than a traditional water sewage system (Green-blue Urban Grids, 2019). They are both relatively cheap to install compared to conventional infrastructure which is a positive quality the problem is the maintenance; both will need to be taken care of continuously.

There is consequently the question of who are responsible for this maintenance and cost? During interviews in the area, 70% of the recipients said they were willing to give up some of their time for maintenance of green infrastructure in their neighborhood and 85% said they were willing to pay for measures which would make the neighborhood more resilient. So there is definitely a positive attitude to these kind of measures but it's also important to remember that this was short interviews in the street. If this measures actually would take place and the rent would go up or people were asked to give a couple of hours of their time each month, it's likely that the percentage of the population that are positive to this would be lower.

However, the implementation and use of green infrastructure is probably going to be increasingly more important in society as a way to adapt to a changing climate and to create resilient and sustainable cities. It is therefore important that measures like these are taken, not only to heighten the local resilience but also to create knowledge, infrastructure and scientific basis which will help in creating a more sustainable society for the future.

Vertical Gardens

The chosen location for the implementation of the vertical garden is set to area 2 and the parallel walking street (*figure 9*). The location is strategically chosen to run through the whole neighbourhood and cover the façades with greenery on both sides of the street. The space between the houses is most likely to absorb incoming solar radiation through the brick walls and concrete pavements. During our measurements in study area 2 we found that soil and air temperature were higher compared to the surrounding measure points. This proves the proposition of the buildings creating an urban heat island effect in the area. To mitigate the effect of urban heat accumulation our study suggests an indirect greening system like example b) in figure 12 in combination with a living wall system (LWS), including planting modular boxes. The greening system will be supported by steel wires from base level to rooftop. It enables vegetation to climb the wall without using the facade as its primary host. This is an efficient measure, as it does not damage the façade to the same extent as the direct greenery system.

The vegetation of choice for the vertical garden will be set to the same as in the case study from Berlin, Germany namely the Boston Ivy. The benefits from this climbing vegetation is proven to be efficient and serves the purpose we are looking for. The Boston Ivy is relatively fast growing and creates proven increased insulation for the building in the winter and cooling effect in the summer.

Green Roofs

With the RCP 8.5 scenario, the temperature in Sweden will be significantly warmer, green roofs with its ability to cool indoor temperatures with up to 4 degrees in a hot summer day with 25-30 degrees (Getter & Rowe, 2006) is one part of a heat-resistant city. Effective energy-consumption will also be a matter in the future with, green roofs have here shown to be able to reduce energy consumption costs with ca 8 % per 0.5 degree indoor temperature (Getter & Rowe, 2006). As Runhaar et al. (2011) showed in a Dutch case-study, a combination of green walls and green roofs was effective in mitigating the urban heat island effect. This combination effect amplified as the space between buildings decreased. This effect guided the proposal of the implementation of these two measures in Gärdet and is proposed to complement each other in area 2 (see figure 9).

The costs of extensive green roofs is hard to estimate, unknown factors such as numbers from Swedish companies, unknown potential structural costs prior to implementation and maintenance costs constitutes much uncertainty. The costs for implementing extensive green roofs on a third of the roof area (11 638 m²) in area 2 would most likely be from 6-32 million SEK. Even if the cost of implementation with the lowest estimated price/m² summed up to ca 5.8 million for area 2 with price estimates derived from Sundström (2008), the price still pretty high. But looking at the price estimate from Oberndorfer et al. (2007) and The EPA (20012), the price will most probably be higher, around 11-32 million SEK. In conclusion, it is hard to know exactly how much the implementation of green roofs would be on a third of the roofs in area 2, but it would probably be around 5.8-32 million SEK from the derived costs/ from Oberndorfer et al (2007), the EPA (2001) and Sundström (2008). This estimate is again hard to apply to today since all the cost estimates are from more than 10 years ago. Additional costs like maintenance, constructional costs for the roofs etc. may increase the cost further although both the EPA (2001) and Getter and Rowe (2006) saw that extensive roofs do need very little maintenance. The EPA writes that extensive green roofs maintenance costs decreases over the years, while the need of care for intensive green roofs stays more constant (EPA, 2001). Oberndorfer et al. (2007) also refers to Germany, where prices are lower due to a common use of green roofs, the price per/m² can be from 800 SEK. If prevalent use in urban planning can make green roofs cheaper as in Germany, the price might be lower in a Swedish context today and keep the costs in the lower perimeters of the estimate of 11-32 million SEK.

Green roofs have a multitude of benefits for climate-related effects and challenges. For some of these challenges, green roofs is not the most effective solution, both cost- and function-wise (Getter & Rowe, 2006). But considering the lack of space in area 2 and that green roofs has several other benefits makes it a good retrofitting measure that benefits several aspects of the environment and helps mitigate climate challenges as higher temperature and more extreme and intense precipitation. Since roofs as a rule is unused, the implementation of green roofs can only make the existing space smarter. The interview questions covered if resident would be willing to pay an amount each month to implement some retrofitting measures to manage future climate challenges, like green roofs and the other retrofitting measures. Since 85 % of the residents answered that they would be willing to pay for the measures and since the area statistics tell us that the residents are more wealthy than the Stockholm average (Stockholms Stad, 2019), some of the payment for the implementation of our measures could be provided by the residents of the area by a higher monthly fee or higher rent.

Another question concerned if the residents would be willing to maintain some of the retrofitting measures themselves, which 77 % would, this lowers the need for paid maintenance of at least some of the measures.

As Oberndorfer et al. (2007) states, the purposes for extensive roofs is mainly functional, while intensive green roofs often aim to create an aesthetic area as an increased living space in the midst of the city. The proposal only includes extensive green roofs and might not hold these values. However, for aesthetic purposes and accessibility of green areas in the city the residents in our study area do have the national city park right beside them. Thus, this proposal for green roof implementation is for functional purposes of climate adaptation and mitigation solely. Maybe the extensive roofs will still provide some recreational benefits, the roofs do have to be accessible for maintenance, so the idea of resident access could be discussed, furthermore, some roofs will be visible for residents in area 1.

Permeable pavements

Urbanization of the landscape has an enormous negative impact on the quantity of runoff being absorbed by soil and vegetation (Davis, 2005). With increased weather unpredictability due to changing climate the Gärdet area faces flood damage risks, diminished recharge of groundwater and increased heat island effect. Use of permeable surfaces was inspired by nature-based solutions (NBS) and they have been designed to mimic natural processes to contribute to the improved water management (Connor et al. 2018). By installing at least one permeable road the neighborhood will benefit from reduced runoff, reduction of some pollutants, cooling down of the temperature of urban runoff, reducing the stress impact on the Baltic sea waters and reduced need to apply salt for deicing in winter time (Houle et al. 2009). This pavement does not require any maintenance work from the inhabitants of the area and as seen in the results part of our questionnaire, the inhabitants are willing to pay the extra fee for installation of nature-based solutions towards climate change mitigation.

Hybrid PV/T panels

When it comes to energy efficiency the assumption is, that the older buildings in area 1, constructed in the 1960s, are lacking implementations for a good energy performance. Especially due to the urban heat island effect and rising temperatures in the summer, residential areas will most likely use more energy for cooling in the future. The multi-dwelling houses will prospectively use and are currently using a lot of energy, that could, amongst others, be reduced by the on-site production of electricity and heat through the sun on the building’s roofs. None of the buildings in the northern part of the study area is equipped with photovoltaic or solar thermal panels. The buildings in area 2 on the other side are more modern and therefore depict a lower necessity for solar power retrofitting. After considering the given circumstances in our study area and the possible solar power implementations, we suggest the installation of Hybrid PV/T systems on the roofs of the multi-dwelling buildings in area 1. The benefits of PV/T modules is the production of both electricity and heating, which means solar irradiation is used to its possible maximum. Flat roofs and gabled roofs with an inclination of 20-40° are suitable for the installation of active solar energy systems. The PV/T surface should face south and be at least 10m² in size (Groppi et al. 2018). Therefore, we suggest the installation of Hybrid PV/T on the southern side of the roofs of the upper area and the southern and south-eastern side of the flatter roofs of the middle area (see figure 9), since shading is less, due to the roof inclination.

The lower area does not provide a large southern roof surface area and will therefore not be considered during the solar energy retrofit. As mentioned in the results the price of PV/T panels ranges between 290€ and 500€ per square meter, which translates to 3 000 and 5 200 SEK/m². Active solar energy systems are a growing retrofit solution in Europe, and we think that especially Hybrid PV/T systems would provide a notable energy saving in our study area

Conclusion

While the mitigation of greenhouse emissions is of great importance for a sustainable acquaintance with and the preservation of the natural environment for future generations, adaptation approaches need to be regarded as well.

> *"Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development."* (IPCC,2014,p.17)

Climate adaptation plays an important role in Stockholm, a city with a great need to provide for its rapidly growing population. One specific challenge in this matter is the adaptation to climate change, whilst also remaining a compact city by implementing the method of retrofitting. With regards to the weaknesses of our study area and the RCP8.5 scenario we have decided on a handful of retrofitting measures, which could be implemented in Gärdet in order to adapt to future challenges.

The identified weaknesses in area 1 are:

- Differences in topography, which steers the water to lower areas, making them prone to flooding that can cause damage to the surrounding houses and their basements.
- Unused solar energy, resulting in low energy efficiency and low energy performance of multi-dwelling houses.

The weaknesses in area 2 are composed of:

- Large proportion of non-permeable ground.
- High building density.
- Dark roofs. (high albedo)
- Sparse amount of sewage drains.

The proposed measures for both area 1 and 2 are:

- **Rain gardens and bioswals**
  Stormwater management, act as a buffer mitigating flooding and relieve stress on the drainage system. Cleans the water from pollutants before its released into streams and sea. Provides noise reduction, cleans the air, mitigating heat island effects, benefits biodiversity.

- **Vertical Green Walls**
  Decrease the façade temperature and provide a green corridor, providing heat reduction for the surroundings. Increases the energy efficiency for the building. Collects stormwater runoff.

- **Green Roofs**
  Mitigates extreme rainfall and the Urban Heat Island Effect. Green roofs reduce and elongates runoff, which eases the pressure on the sewage system and reduces the risk for flooding. Green roofs decrease indoor temperature, resulting in lower energy use for air condition. In combination with green walls, green roofs effectively mitigates heat in dense areas outside as well.

- **Permeable Pavement**
  Permeable pavement is a porous urban surface which catches precipitation and surface runoff, storing it in the reservoir while slowly allowing it to infiltrate into the soil below, minimizes urban heat island effect and acts as a deicing agent during the winter season.

- **Hybrid PV/T Panels**
  Providing both electricity and heat from the solar radiation, lowering the household's dependency on other energy sources and lessening the use of non-renewable sources.

When proposing these retrofitting solutions, an attempt has been made to seek an aggregation of effects, both for each retrofitting solution but also with the combination of these. Cost-effectiveness is always important to consider to be able to implement something, and the research indicates that these complement each other and often have multiple benefits that will be necessary to mitigate the effects on Stockholm by the RCP 8.5 scenario, specifically focused on temperature and precipitation patterns. Some costs have been looked into for some retrofitting solutions, and although they are rather expensive, the focus is again on the aggregated and diverse mitigation benefits for climate change. The climate adaptation measures has been chosen on the basis of their performance and their diverse benefits. If one retrofitting measure provides several climate adaptation benefits, it becomes more cost-effective, not to mention space-effective.

Since 85 % expressed a willingness to pay more in rent or a higher monthly fee, the retrofitting solutions could possibly partly be funded from the residents. With 70 % also expressing a willingness to do maintenance work for these retrofitting solutions, the otherwise more or less regular maintenance costs of some of the proposed solutions can be cut. With the implementation of retrofitting solutions that are more or less self-maintained to begin with, as green roofs with self-sustaining and drought-resistant succulent species, the need for residents to engage in maintenance also decreases.

In conclusion, both areas face significant challenges from the climate change scenario RCP8.5. Area 2 is however in need of more retrofitting measures than area 1 due to existing conditions. The proposed retrofitting measures provide aggregated benefits and mitigating effects for the challenges identified in area 1 and 2.

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