GREEN WALLS IN THE URBAN NETHERLANDS

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2 SUMMARY

The thesis was set out to address how rising temperatures has become more common for the Netherlands (Klok & Kluck, 2015), (Hove et al., 2011). Heat waves and stress are expected to become more common (Hoeven & Wandl, 2015; Hove et al., 2011). In urban areas the urban heat island effect would make these heat waves a larger threat within the Randstad region. It can be that the Netherlands may choose to adopt air conditioning in response to this. While air conditioning is an option to cope with higher temperatures, the demand for energy can be expected to rise if temperatures consistently increase in the future. This can have an effect on the energy savings targets the Netherlands may have in the future. Due to this, the thesis had the aim of finding out how much energy savings can be made with green wall implementation.

A model was developed in Excel to project energy consumption and housing trends in 4 different scenarios for the cities of Amsterdam, The Hague, Rotterdam, and Utrecht. The time period of 2015-2050 was chosen.

The results found were (1) the renovation stock contributes most of the change towards an energy neutral status for all cities, (2) In the cooling season for 2050 at Amsterdam saves 40.7 million kWh, The Hague saves 19.6 million kWh, Rotterdam saves 22 million kWh, and Utrecht saves 17 million kWh (3) For the heating season at 2050 the energy savings was found to be for 2050 for Amsterdam at 4 million kWh, The Hague 2.3 million kWh, Rotterdam 6 million kWh, and Utrecht saves 1.6 million kWh. (4) In the heating season energy savings made with green walls were at 10%, which puts the use of green walls in a questionable place during the heating season. It is concluded that at least for the heating season at the end of the projection period green walls provide limited savings compared to the effect increasing temperatures have on energy consumption.

From the results of the research it is apparent that energy consumption for heating is less than for cooling towards the end of the projection period. This means the cooling season are a greater priority for energy savings. Green walls are capable of bringing cooling energy consumption down by up to 50% and would therefore be seen as an effective energy savings method for Dutch households.

3 INTRODUCTION

Societal Background and Problem

The effects of climate change are real and must be addressed. Although the Netherlands is within a mild maritime climate, extremely hot weather has become more common (Amsterdam, 2015). There is also an expected increase of intense heat waves in the Netherlands of the likes of those that occurred in Western Europe in 2003 and 2006, resulting in the deaths of over 80 000 people (Gabriel & Endlicher, 2011). The urban heat island effect (UHI) means that cities are of a higher temperature than the rural areas around them (Oke, 1988). This is caused by the construction of buildings that tend to have a high thermal capacity, low porosity, and a low albedo with little vegetation. Negative impacts of the UHI effect include increased energy consumption during summer due to higher temperatures, increased air pollutants and greenhouse gases levels due to the increased energy consumption, threat to human health and comfort, and reduced water quality (EPA, 2013). The amount of intense heat waves is expected to occur more frequently towards 2050 and the amount of days reaching over 25 degrees Celsius is expected to double (KNMI, 2014). This means that the UHI and its impacts on urban living are of real concern to the Netherlands and should be dealt with in a timely manner. For instance, in Amsterdam a mapping of the land use in relation to the UHI was conducted and it was concluded that the inhabitants and buildings were not only vulnerable due to high temperatures but by the energy efficiency of buildings, the quality of life, and other demographic factors. Buildings with lower energy-efficiency labels in areas of high employment are expected to increase energy consumption to cool buildings (Hoeven & Wandl, 2015). This would make it more of a challenge for the Netherlands to meet its energy savings targets. It expects to save between 387 and 562 PJ from final energy consumption; from which 87 to 186 PJ will be achieved through new policies (Daniëls & Stutvoet-mulder, 2013). Addressing energy efficiency can be a start in mitigating these effects.

Scientific Background and Previous Studies

In the Netherlands energy efficiency is of interest and an approximation of how much energy can be saved in the built environment was drawn up. Currently the built environment shows an energy savings potential at 120 PetaJoules (Hieminga, 2013). Some examples of (mature) technologies that can help save energy in the built environment are the retrofitting of existing buildings, improved insulation, and smart metering, among other technologies. (Hieminga, 2013).

One energy savings method that has not been mentioned yet but could be used is the implementation of green walls. Green walls are a type of green infrastructure that can be built into new buildings or renovated onto existing buildings. More specifically, they can be built into a new or existing home that contains vegetation that is directly fixed into the wall. In urban areas the potential for green walls is already large due to the high availability of empty wall space, which can be more significant than the potential for green roof space. (Bass, 2007). The main relevant benefit of green walls is the reduction in ambient temperatures that they can provide, which can aid in mitigating the UHI effect and reducing the need for heating during the winter or cooling during the summer (Commission, 2012). Additionally, the implementation of green walls can aid in contributing to urban nature, which can improve the well-being of urban inhabitants (Chiesura, 2004). Urban air quality can also be improved and building energy consumption reduced (Alexandri & Jones, 2004). In the winter, green walls can benefit buildings by lessening the effect of wind speed along the exterior walls and by providing further insulation to the building. (Bass, 2007)

There are plenty of studies in green infrastructure that have already been published. Only recently, however, has there been a literature review compiled on the usage of green infrastructure specific to the exteriors of buildings and energy savings. Pérez et al (2014) summarized the literature on the infrastructure as a tool for passive energy savings, otherwise known as vertical greenery systems (VGS). There is currently no universal standardization of such systems and this has produced research with results that are difficult to compare due to different species of plants being used in different research projects and the lack of attention towards the effects of layers in green walls to energy efficiency. (Pérez, Coma, Martorell, & Cabeza, 2014) hence established their own classification system.

Regarding green walls, it is described that they are made of geotextile felts, panels, and can have vegetation already pre-cultivated. The panels and felts support the vegetation by upholstering them. The green walls are capable of reducing energy consumption between 5% and 50% with most typically reducing at 20% to 30%. Many of the current studies focusing on green walls are currently scoped on Europe and Asia, with the majority of those studies being located in Asia (Pérez et al., 2014). Pérez *et al* (2014) concluded that for green walls, the substrate layer used to support the plants has not been studied in depth. Additionally the majority of studies on green walls with a focus on energy savings are located in a warm temperate climate during the cooling season within the autumn and the summer (Pérez et al., 2014). There are few studies on the effects of green walls on energy savings outside of these parameters. Only two studies were set outside a warm temperate climate, of which were located in an equatorial climate. Perez *et al* also concludes from their literature review that there is only one simulation that analyzes the heating consumption with the involvement of green walls which also concluded that the green walls would induce an *increase* in energy consumption with the suggestion for further different research to be done on green wall thermal behavior for throughout the year.

In the Netherlands there have been initiatives towards green roofs and reaping their benefits in Rotterdam since 2008. Heleen Mees concluded that Rotterdam is making good progress with green roofs, however the incentive of awarding grants cannot be used indefinitely. Rotterdam is already leading in the Netherlands with the creation of green roofs on new and existing buildings and the municipality has recognized the importance of doing so (Mees, 2014). By involving players such as housing associations and making agreements it can be possible to increase the amount of green roofs quickly and in a significant number (Mees, 2014). There is also already an impact on the energy consumption by way of energy bills as the green roofs are cooler than regular roofs, requiring air conditioning units to operate at a lower capacity despite the focus being on water storage. However, more progress is needed in Rotterdam in order to effectively implement green infrastructure. In addition to this there appears to be no equivalent level of green infrastructure implementation in the rest of the Netherlands, especially with regard to green walls and their potential for energy savings.

Internationally there are already government incentives towards green walls and green roofs. The City of Sydney, in Australia, has already stated that there will be support for the growth of quality green roofs and walls by providing leadership; addressing barriers towards implementing green roof and wall technology; supporting research; collaboration with the community and stakeholders; informing and educating on green architecture; supporting local research; supporting green roofs and walls in existing planning systems; installing them on Council areas; and helping to monitor, evaluate, and report on the progress (City of Sydney, 2013). Singapore has also focused on green walls as a part of its “City in a Garden” project. Similarly to the city of Sydney, Singapore is interested in looking to make greenery as a prominent feature of the cityscape (National parks board, 2013). Both Sydney and Singapore recognize the potential for green walls to insulate and save energy in their respective urban environments (City of Sydney, 2013) (National parks board, 2013). It is unknown why this is the case for green walls. Green walls are also not considered among the trends analyzed to help the Netherlands save energy on the long term (Hiemenga, 2013) and hence no indication of how much they can save is given. This means that the amount of energy that can be saved with green walls on the urban level for the country is unknown and hence the potential contribution from cities employing green walls to saving energy on the long term is also unknown. The energy-efficient renovation of existing buildings within the Netherlands would be of large importance as well since there is little participation of actors in diffusing energy-efficient renovation knowledge; lack of energy standardization and a lack of compliance to those standards; public awareness is low; and lobbying is done with futile results (Sauve, 2014).There is already such a city-related green infrastructure implementation incentive for Rotterdam but it only concerns green roofs (Mees 2014). Deep renovation trends are also not very prevalent among EU states and significant efforts are needed to drive them (Nolte & Strong, 2011)**.** However finding literature regarding such citywide implementation that includes green walls for the Netherlands proved elusive to find, giving the impression that no such incentive is being or was announced for integrating green walls.

3.1 RESEARCH QUESTION

Renovation trends in the Netherlands are innovatively impaired (Sauve, 2014) and there is no regulation or initiative for green walls in the Netherlands. With the large potential for energy savings in the built environment it would be of interest to investigate how green walls can contribute to realizing them especially in a future where the Netherlands adopts air conditioning as a primary means of living with higher temperatures. Hence the main research question is:

Main research question: What possible energy savings would green walls provide to the housing sector for urban Dutch cities?

To answer this main research question four sub questions are developed. First the housing trend should be projected for the cities in terms of renovated, new builds, and existing stock as these different build types can vary in how energy is consumed on a house-to-house level and provide insight in how housing trends can affect energy savings in the projection period. The first sub-question is then:

1. **Sub-question: How does the housing stock change over the time period 2015-2050 in terms of renovations and new builds?**

A lack of knowledge in the literature is the contribution of energy savings by green walls in the heating season. As a part of this research and to answer part of the main research question, the second sub-question is:

2. **Sub-question: During the heating season what energy savings are made by green walls with respect to the baseline scenario and of how much use are green walls as a result in the heating season?**

To determine the energy consumption by cooling appliances in the projection period and to show how much the studied cities would consume in a hypothetical scenario where air conditioning is used in all homes, the cooling season energy consumption is answered by the third sub question:

3. **Sub-question: What would be the energy consumption due to cooling appliances in a scenario where cooling appliances is taken up as a countermeasure to increased uncomfortable warm periods during the cooling season?**

Finishing answering the main research question requires calculating the energy savings made with green walls implemented for the cooling season compared with only air conditioning units being used. This will be done by answering the fourth sub-question:

4. Sub-question: During the cooling season what energy savings are made by green walls with respect to the air conditioning scenario?

4 METHODOLOGY

4.1 GENERAL APPROACH

To answer the main research question and its sub questions a scenario analysis is performed. This is done by developing a model to project the scenarios. The model is set up in Excel software.

The scenarios are:

1. Baseline heating scenario
2. Green wall heating scenario
3. Air conditioning cooling scenario
4. Green wall cooling scenario

They are each done for the cities of Amsterdam. Rotterdam, The Hague, and Utrecht.

In order to develop the scenarios and answer the research questions the following is done:

1. The study area for the scenario analysis is chosen and described.
2. Assessment of the housing stock for each city in the chosen study area and the expected changes to the housing stock by their respective municipalities and the national government.
3. The housing stock changes calculated for each city in the period 2015-2050. This also serves the purpose of answering the first sub question.
4. Temperature changes are projected separately for the baseline and green wall heating scenario, air conditioning, and green wall scenarios in the period 2015-2020. This is different for each city.
5. Heating degree days and cooling degree days calculated based on the projected temperatures.
6. Energy consumption due to heating or cooling (depending on the scenario) is calculated based on the heating/cooling degree days. This is the output of the separate scenarios. The output from this is used to answer the third sub question.
7. A comparison between the heating scenarios and a comparison between the cooling scenarios. The comparison is the resulting energy savings for each scenario type (cooling and heating) and answers the 2nd and 4th sub questions and as a result answers the main research question.

The model set up is explained now in further detail in the following sub sections.

4.2 PROJECTION PERIOD

The years 2015-2050 were chosen as the projection period of the scenario analysis. The main reasons for this choice are because:

1. The period is of a long enough period to reflect the changes in housing stock, temperature, and ultimately the energy consumption due to heating and cooling in a long enough period.
2. The Netherlands aims to convert all buildings, including housing to an energy neutral status. Choosing the time period for up to 2050 allows the model to incorporate the

end-target national goal of complete energy neutrality. The time period to 2050 is also chosen by other studies to determine the effects of energy neutral housing and is a popular end-date (Urgenda, 2015).

4.3 STUDY AREA DESCRIPTION

The thesis studies the four largest cities within the Netherlands: Amsterdam; Rotterdam; The Hague; and Utrecht. Together, the cities comprise the megalopolis known to many as the 'Randstad'. The region was chosen due to the relatively high amount of urbanization and population density compared to the rest of the Netherlands. This makes the Randstad an area where the urban heat island effect can be expected to occur at a greater level than for the rest of the country. The region covers 8 282 square kilometers, of which 1 820 km^2 are urban. Approximately 7.1 million people live in the area, making it one of the largest conurbations in Europe (ERRIN, 2015). It comprises of the provinces Utrecht, Noord-Holland, Zuid-Holland, and Flevoland and is of great economic importance to the Netherlands (ERRIN, 2015).

4.3.1 AMSTERDAM

Amsterdam municipality has a population of 2 367 809 in its Metropolitan area (as of July 2015) with a population density of 4923 per km^2 and a dwelling density of 2419 per km^2. (OIS Amsterdam, 2014)

4.3.2 ROTTERDAM

As of 2013 the population in Rotterdam was 616 319 (2.2 million in the metropolitan region). The city covers 325 km^2, giving it a population density of 1896 people per km^2 (Rotterdam, 2013).

4.3.3 THE HAGUE

The Hague city consisted of 500 000 residents as of 2011 and 215 600 homes. The city covers roughly 100 m^2 and is also the seat of the Dutch government (Den Haag, 2014).

4.3.4 UTRECHT

At least 334 000 people live in Utrecht, which is centrally located within the Netherlands. Road and rail networks intersect in and around the city, which houses the largest train junction station of the country (Gemeente Utrecht, 2014).

4.4 MODEL SET-UP

4.4.1 SCENARIO

The model created generates the following for the years 2020-2050 for both the heating and cooling seasons:

1. The change in housing stock in terms of newly built and renovated builds and separated by gallery flats, detached, and terraced housing.

2. A baseline scenario of deep renovation trends aimed at energy efficiency in terms of energy consumption. This is the scenario taking into account the goals the different case study areas have as well as the national goals of the Netherlands.
3. A scenario in which cooling appliances are eventually implemented across all homes and the energy consumption projected, called the air conditioning scenario. High, mid, and low penetration variants of the scenario are generated. The scenario takes place during the cooling season.
4. A scenario in which green walls are implemented instead of air cooling for the cooling season and the energy consumption is projected. For the same scenario the effect on heating energy consumption is also found.

4.4.2 ENERGY CONSUMPTION

Simulating the heat demand for a building is based on the sum of transmission and ventilation losses with the deduction of solar and internal gains. Ventilation losses can include the heat loss from infiltration of air through the openings within the shell of the building as well as the air exchange of air from openings in the shell (also known as infiltration and ventilation losses). The solar gains are mostly due to the solar radiation through windows and the internal gains refer to gains due to heat produced by people within the dwelling and non-heating appliances. These parameters are common to all types of building heat load modelling. The main differences between models are in the chosen complexity.

As the scope of the thesis is on an aggregated level (city wide) a static annual approach is taken. This is considered to be a simplification of dynamic and finite-element models from building science, but is not considered to be any less valid (Kemna & Acedo, 2014).

In the thesis the instantaneous transmission losses are the product of the indoor-outdoor temperature difference, the shell surface area, and the thermal transmission coefficient (also known as the U value). The ventilation losses are a product of the indoor-outdoor temperature difference, the building volume, the hourly air exchange, the specific heat capcacity of air, and the remaining amount after taking the heat recovery of outgoing air.

The end result for each scenario is the energy consumption due to cooling or heating. The energy consumption is based on the following formula, based on that of (Kemna & Acedo, 2014):

$$\mathbf{Q_{heating/cooling} = 0.001 \cdot \Delta T \cdot T_{heating/cooling} \cdot [\ S \cdot U + V \cdot q \cdot (1\text{-}rec) \cdot c_{air}\ ] \cdot H}$$

where

$\mathbf{Q_{heating/cooling}}$ is the total annual building space heating demand for all dwellings [kWh/a],
ΔT is indoor-outdoor temperature difference [K or C] , corrected for solar and internal gains (set at 7)
$\mathbf{T_{heating/cooling}}$ is heating season hours [h],
S is heated shell surface area, built from areas for exterior walls, windows, floor, roof [m²],
U is the average thermal transmission coefficient derived from shell surface area weighted specific U-values [W/m².K],
V is heated building volume [m³],
q is hourly air exchange [$m^3.h_{-1}/m^3$],
rec is the fraction of heat recovered from outgoing air [-],
$\mathbf{c_{air}}$ is specific heat capacity of air [0.343 Wh/m³.K],
H is the amount of dwellings at the end of year
0.01 is the conversion factor from Wh to kWh.

The equation is based on the equation in the final report for the EU building heating demand (Kemna & Acedo, 2014). It is in accordance with the ISO EN 13790 standard for annual space heating demand.

For all scenarios this is the method of calculating the energy consumption. The heating season and the cooling season is considered in all scenarios. The heating season is considered to be the months from 1st October to 1st May. For the cooling season it is considered to be between end March to end August.

4.4.3 HOUSING STOCK CHANGES

The change in the housing stock is the same for all scenarios considered in this study.

Housing type

A challenge in representing the housing stock of the Netherlands is representing it accurately. Assuming that the stock is completely homogenous (of one type of build) would potentially overlook effects specific to different types of stock. Attempting to catalogue all the different types of buildings would also reduce the utility of the model to the high amount of detail. As a tradeoff, it is best to select aspects of the buildings that relate most to energy efficiency sufficiently. In that case, architecture would be a suitable choice as has been done before in the literature (Yücel, 2013).

Houses can be grouped under three subtypes:

1. Terraced
2. Detached dwellings
3. Gallery flats

They are commonly used to classify housing. The distribution of housing stock is also determined as such for the Netherlands: Detached housing at 52%, Gallery flats at 36%, and Town houses at 12% (Yücel, 2013).

It is assumed that all dwellings are homogenous within their respective housing groups. The reference dwellings are based on literature (Klunder, 2005) and reflect the traditional types of dwellings built in the Netherlands. In practicality there can be housing that differ from these traditional builds. To make sure that the stock is represented adequately, the following combination of attributes for the dwelling stock was chosen. In Table 1 the different dwelling subtypes and their dimensions used in the scenario model are given. Each gallery flat building consists of 24 units. It is assumed that the height of each storey is 3 meters. Each unit is considered a separate dwelling (CTBUH, 2015).

TABLE 1: THE DIFFERENT DWELLING TYPES AND DIMENSIONS

	Detached house	Terraced house	Gallery flat
Width	6m	5.4m	7.2m
Depth	10m	9.3m	12m
Height	9m	9m	12m
Storeys	3	3	4

Source for dimensions: (Klunder, 2005)

The amount of doors, windows, walls, and roofs for a dwelling type differ.

A detached house has 4 walls, 10 windows, and a door as well as a traditional triangle roof. A gallery flat has 21 units, each unit containing two windows and a door. The gallery flat thus has 42 windows and 22 doors, alongside four walls. A terraced home can have three or two walls depending on its position in the street. It also has four windows and a door with a traditional triangle roof.

The dimensions of the different house components are according to the building decree of the Netherlands. According to the building decree of the Netherlands from 2012, the minimum width of a doorway is 0.85 metres and a height of 2.1 metres. For windows, the dimensions are 70cm high and the width is 100cm (VROM, 2012).

Even though the housing stock has been grouped into three subtypes, the age of the stock should also be considered in the housing stock changes as the energy consumed for heating by housing of different ages can vary significantly (BPIE, 2015). This difference is highlighted more in the calculation of the separate U-values of the different housing types. Based on literature the following ages are determined for the remaining stock (BPIE, 2015; Yücel, 2013):

1. 2000-2015
2. 1960-2000
3. 1900-1960

Each age comprises the following of the remaining stock:

TABLE 2: AGE DISTRIBUTION OF THE EXISTING HOUSING STOCK OF THE NETHERLANDS AS OF 2000. SOURCE: YÜCEL, 2013

Age distribution of the existing housing stock Netherlands as of 2000 (years)	Terraced	Detached	Gallery Flat	Total
0-20 (2000-2015)	12.00%	52.00%	36.00%	29.00%
20-40 (1960-2000)	12.00%	52.00%	36.00%	37.00%
40+ (1900-1960)	12.00%	52.00%	36.00%	34.00%

As of 2nd July 2015 it was announced that all new buildings built in the Netherlands as of end-2020 must be near-energy neutral. This means all such buildings will have zero net energy consumption i.e., all energy consumed will be roughly equal to the energy generated onsite (RVO, 2015).

Housing that is renovated as of 2020 will also become energy neutral. This will be incorporated into the scenario analysis alongside the city-specific plans for energy efficient housing. The scenario will reflect this by assigning all new buildings as of 2020 as energy neutral and calculating the resulting energy savings from that contribution. The new buildings will comply with these standards in the baseline scenario. The ambition of the Netherlands is to have the entire housing stock neutral by 2050, hence the baseline will reflect this change in the housing stock of the cities studied up to 2050. (Urgenda: NL goals with climate neutrality)

Each city has a different approach to achieving the goal of energy neutrality in the housing stock.

Amsterdam city has an action plan for construction in the years 2014-2018. It wishes to build over 17 000 homes during the period, after which 5000 new homes are aimed to be built yearly from 2018 onwards. No change in this amount is mentioned and the time for how long the increase is expected to take is not mentioned. For the baseline scenario Amsterdam writes in its action plan that it expects an increase of about 3400 homes per year from 2014-2018. Thus for the baseline scenario Amsterdam will increase its housing stock at 3400 homes per year from 2015 to 2017, after which 5000 homes per year are expected to be built. The demolition rate is based on the average mean of the demolition rate for the historical data from the years 1995-2011. (City of Amsterdam, 2014). All new builds from 2015 are to be energy neutral (City of Amsterdam, 2012).

Utrecht has been developing the region Leidsche Rijn on the Western perimeter of the city. It is expected by 2025 that the area will have 30 000 homes. This will be incorporated in the baseline scenario (Gemeente Utrecht, 2015c). The province of Utrecht in addition to this offers land for building new homes, currently in the region of Leidsche Rijn and Vleuten. There are a very limited amount of spaces left for building homes even in Leidsche Rijn, with 40 being the largest in the neighborhood of KubusEiland (Gemeente Utrecht, 2015a). As of 2012 20 000 homes have already been built in the neighborhood. It is assumed that 10 000 more will be built in the course of 2013 to 2025. Afterwards there is no net change in the housing stock.

Rotterdam has published a concept of its housing vision for up to 2030. It is expected that the amount of households in the city to increase to 316 000 by the year 2030. There is a count for how many households are in Rotterdam in 2014 (299 800) but no other information on the rate of increase in households are observed (Gemeente Rotterdam, 2015). It is assumed that the amount of homes increase at a constant rate between these numbers from 2015 to 2030. Afterwards there is no net increase or decrease in the housing stock. This is because there are no plans available from Rotterdam regarding the increase in housing stock after 2030. No net changes to the housing stock would keep the risk of under- or –over estimating the scenario results to a minimum.

The Hague aims for 25 000 new buildings by 2020 as a part of the Wonenprogramma (Living program) for the IPSO. According to the city, this is realistic goal to attain. For the baseline scenario a constant rate of new buildings is assumed for the projection period (Den Haag, 2009). Historical data provided by the CBS up to 2011 finds that the total increase in new builds per year is at 4149, 2276, and 1736 homes. This means The Hague has already achieved 8161 homes of its target. As The Hague still has to build further homes, the target amount of 25 000 new builds from the years 2009 to 2020 will be achieved in the baseline. It is assumed no net decrease of the housing stock takes place. This is because there are no available plans for what The Hague plans to do post 2020.

Input data for housing numbers

As CBS (central bureau of statistics, the Netherlands) only has housing number data until 2011, the years 2012-2015 are projected from the historical data based on trends from 2006-2011. 2006 is the earliest year for which housing stock numbers and changes are available per municipality studied. For the remaining scenarios the housing stock projected per year remains the same, but the new builds and renovation rates are altered so that by 2035 the existing stock consists entirely of renovated and post-2020 new builds. The years 2020 and later are chosen as the starting point for builds to be renovated as the goals of all the municipalities include introducing energy neutral builds into the housing stock as of 2020 (City of Amsterdam, 2012; Gemeente Utrecht, 2015b; Programma Duurzaam, 2015; The Hague Municipality, 2011).

Renovation rate

The central bureau of statistics (CBS) has information on the increase and decrease in the housing stock for the different municipalities of the cities. However on the rate of renovation in the country there is no transparent data. Literature compensates for the lack of information by way of assumption through expert interviews. Since demolition exceeds construction in the Netherlands the importance of renovation for the housing stock is expected to increase in the future (Meijer, Itard, & Sunikka-Blank, 2009). It is thus expected that the amount of dwellings renovated is twice the rate of new builds per year. This is the renovation rate for the housing stock in the projection period.

In the baseline, green wall, and air condition scenarios all existing buildings are to be renovated by 2050. However, the obligation for new homes and renovated homes to be equivalent to energy neutral only begins at 2020 (Betlem, Eck, & Beuken, 2010). Hence the renovated stock as of 2020 is of a different nature than for 2015-2020, as the renovated stock from 2020 onwards only counts renovated buildings after 2020. The new builds per year remain the same for all the different scenarios. Newly built stock is counted from 0 from 2020 and the newly built stock of 2015-2019 is to be renovated. Hence the newly built stock and renovated stock of 2015-2019 is included in the remaining stock amount from 2020 onwards.

Corrections

In the source data for the housing stock changes the end-of-year stock was corrected for the splitting of housing. Splitting refers to the administrative splitting of a home into two or more different homes. This splitting is not made explicit in the data the CBS provide but can be found by taking the stock of the start of the year and adding the new builds and subtracting the decrease in builds. The result from this is the housing stock at the end of the year excluding the splitting increase or decrease. This is done as splitting can distort the results in the sense that the energy consumption can either be over- or undererstimated.

4.4.4 INDOOR-OUTDOOR TEMPERATURE DIFFERENCE

Indoor temperature

It is assumed that the dwellings are heated separately throughout the day. For the purposes of the model it is assumed that the dwellings are constantly occupied throughout the heating season. During the day the living, kitchen, and hall are heated and occupied from 07.00 hours to 23.00 hours. This accounts for 50% of the heated floor area. During the night, the bedrooms are heated 4 hours a day from 19.00 hours to 23.00 hours. This is 40% of the heated floor area. Assumptions are based on those made for heated dwellings in other reports (Kemna & Acedo, 2014).

Solar gains: Solar gains are the useful solar heat entering the homes through the windows and through the walls of the exterior of the building. An estimation of how much useful solar irradiance enters the home is at 2256 Wh/m2 per day for the heating season (Kemna & Acedo, 2014). It is proposed in the final report for the EU heating demand in buildings that a heating gain of 1.2 K can be expected in the heating season from such solar gains if a south-west preference for windows is observed as is the trend in most manuals. This is based on the average dwelling heating use of 100 kWh/m2.

Internal gains: This refers to the heat produced by the inhabitants of the homes and of non-heating appliances. For most building regulations this is set at a 5 W/m^2 of heated floor surface from boilers.

Lighting can produce 500 kWh per year per household and is considered to be effective in adding to the internal gains of the dwelling. This is because lighting is usually turned on at the same period as the heating. In existing households there is an average luminous efficacy of 20 lm/W. This means existing households have an average efficiency of 3.2% where about 480 kWh is the waste heat from lighting that can contribute to internal gains. (Kemna & Acedo, 2014) (Doe, 2013).

Electronic appliances such as monitor displays or television sets also contribute significantly to useful heating, at about 600kWh per year per household. It is expected that the efficiency of the appliances increases over time.

Through these internal gains it is approximated that the average EU building will have its Indoor temperature corrected by 2.3 degrees (Kemna & Acedo, 2014). This is incorporated implicitly in the temperature difference between the outside air temperature and the base temperature. This is because the internal and solar gains have already heated the homes by 2.3 degrees and the base temperature would have to be increased, otherwise too much heating would occur and an overestimate of heating energy use is more likely. For this reason the base temperature is at 15 degrees instead of 18 degrees.

Outdoor temperature difference

For the purposes of the model the overall temperature difference is 7 degrees. This is due to the average building total outdoor temperature in the EU to be 7 degrees. The indoor/outdoor temperature difference for the heating season is hence 7 degrees (Kemna & Acedo, 2014).

4.4.1 TEMPERATURE CHANGES

The temperature difference is the difference between the outdoor temperature and the indoor temperature. This is corrected for internal gains and solar gains during the heating season.

For the projection period in the air conditioning scenario the outdoor hourly air temperature is projected based on the KNMI scenarios and the historical temperature data used for the cities from the same stations in the heating period for the baseline and green wall scenarios.

The KNMI has published 4 different scenarios (G, G+, W, W+) for the future climate of the Netherlands, also known as the KNMI-14 climate scenarios. However, it should be noted that various different models currently produce significantly different results for future changes in the climate. The uncertainty due to this is larger on a regional scale such as for the country of the Netherlands. This uncertainty is due to the circulation patterns in the various simulations calculated for Western Europe (KNMI, 2014). What differs between models and causes the change difference between models is the magnitude and direction of change. This is the reasoning behind the four different scenarios in the KNMI projection, which is based on the global contribution of temperature increase and the regional contribution of atmospheric circulation change. It should also be noted that not any one of the scenarios is more likely than the other to occur but simply represents the different possibilities that a change in these criteria can effect. The climate scenarios are based on the increase in global mean temperature by 2050 in reference to 1990, i.e. an increase of +1 C ("G" scenario) in 2050 in relation to 1990. Additionally, there are variants of each scenario that includes two different circulation regime changes. A "+" denoted scenario would mean that there is a strong circulation change, indicating for warmer and moist winter seasons and drier and warmer summers. A lack of denotation indicates a weak change in circulation. The scenarios are named G, G+, W, and W+. Each scenario provides a change in temperature values including the change in mean, year-to-year variation, and other variables for each meteorological season. For the summer season there is an extensive array of different changes per year, notably for the daily maximum and minimum temperatures as well as the year-to-year variation. This is also the case for the winter period.

The scenario chosen is the W+ scenario where the circulation has a stronger character and temperature increase is highest. This sets the stage for warmer and drier summers as well as warmer winters. This is chosen so that the effect green walls have on energy consumption due to cooling can be seen in a case where heat stress is expected to be highest.

The KNMI defines the summer period to be June, July, and August. The heating period in the thesis includes in addition to these months May and September, hence the corresponding spring and winter changes for these months will be done instead of the summer changes for the remaining months. As the KNMI only calculated the mean increase in temperature for the spring, this will be taken as the increase in temperature for all hours in the day. The temperature increase predicted by the KNMI is increased on a year to year basis.

The changes to the temperatures per year are described in the table below:

TABLE 3: W+ SCENARIO TEMPERATURE INCREASE FOR THE YEARS 2036-2050

Winter Temperature	W+ scenario temperature increase for the years 2036-2050 [C]
daily maximum	+2.5
daily minimum	+2.8
Summer Temperature	
daily maximum	+2.3
daily minimum	+2.2
Spring Temperature	
mean	+1.8
Autumn Temperature	
mean	+2.3

reference period: 1981-2010

Source: (KNMI, 2014)

For the years 2015-2035 the KNMI estimate of change for temperature is taken as the change of temperature in the model as such:

TABLE 4: ESTIMATE OF CHANGE VALUE FOR 2030

Winter	Central estimate of change value for 2030
mean temperature	1.2
Summer	
mean temperature	0.9
Spring	
mean temperature	0.8
Autmun	
mean temperature	1

Reference period: 1981-2010 Source: (KNMI, 2014)

No estimates for daily or minimum temperatures in the seasons were found. Therefore, the mean increase per year will be applied instead to recorded data.

The recorded temperature data come from weather stations around the studied cities. The weather stations are located at De Bilt, Schipol (Amsterdam), and Rotterdam. These stations provide the temperature data for Utrecht, Amsterdam, and Rotterdam respectively. No station temperature data was available at The Hague despite there being heating degree-day data for various stations located throughout the city (Through degreedays.net). Hence the temperature data for Rotterdam apply for The Hague due to its proximity to the city. As the weather stations did not supply hourly temperature data, the hourly temperature was interpolated between the maximum and minimum daily readings of the year before the projection period.

To determine the change of temperature throughout the day for all seasons (winter, spring, autumn, summer), it is assumed the maximum temperature of the day occurs at Time=15.00 and the minimum temperature at Time=5.00 for each day throughout the projection period. This is based on the methods derived by Reicosky et al. (1989) regarding diurnal temperature variations. It assumes a linear relationship between time and temperature.

Green wall-induced temperature changes

For the green wall scenario in the cooling season the temperature change is modified to simulate the effects of the green walls in the urban outside air temperature. n the green wall scenario it is expected that the green wall implementation will affect the outside temperature. The cooling green walls provide has been studied more extensively than the insulation they provide homes and buildings. The effects green walls have on the thermal performance of buildings has been observed to be positive in multiple studies. Especially during the warmest hours of the day, the effect on the temperature difference between the building interior and the exterior air is beneficial (meaning the interior temperature is lower than the outside temperature due to green walls) despite the high thermal resistance of the building components (Olivieri, Olivieri, & Neila, 2014).

Air and surface temperatures are lowered significantly in different climates. In particular the air canyon temperature (the temperature of the space between buildings in a street) is reduced significantly in a canyon where green walls are implemented compared with the situation where there are no green walls. The magnitude of the temperature difference depends on the type of climate the canyon is located in. A more hot and dry climate experiences a larger effect from green wall infrastructure on reducing urban temperature. Colder climates (such as London, Moscow, and Montreal) benefit the least but there still is an expected temperature decrease (Alexandri & Jones, 2008). This is explained by the evapotranspirational properties of the vegetation and lower surface temperatures of the vegetated surfaces. This also has the benefit of lowering the surface temperatures of non-vegetated surfaces, which means that not all surfaces have to be vegetated to achieve a significant decrease in air canyon temperature.

One of the cities studied for the effect green walls have on air temperatures is London. London has a temperate maritime climate (wordtravels, 2015). The case study cities (Rotterdam, Utrecht, The Hague, Amsterdam) are located in the same climate. It is assumed that the temperature differences in a green walls-only case for London also apply for all the case study cities. This difference is taken into account with the temperature projection for up to 2050 within the summer period done for the air conditioning scenario.

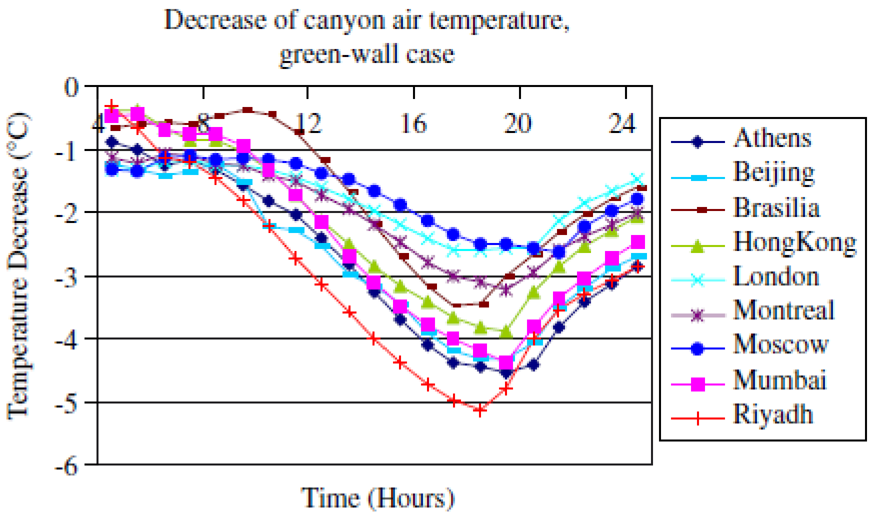

FIGURE 1 TEMPERATURE DECREASE IN CANYONS WITH WALLS COVERED IN VEGETATION

Source: (Alexandri & Jones, 2008)

For the purposes of the thesis is it assumed that the green walls are implemented to the extent that there is a city-wide decrease of the air temperature according to graph 1 in the summer period. It is assumed that the temperature decrease for London is realized in the studied cities in the thesis when all green walls are implemented in 2050.

This is done by assuming a linear relationship between the implementation of green walls in the cities and the temperature decrease they offer. There is no information on how an implementation over time decreases the overall air temperature hence this assumption is made.

4.4.2 VENTILATION AND HEAT RECOVERY

The ventilation rate of different building types has been extensively studied and scrutinized by multiple stakeholders. The different dwelling types of the model hence have different ventilation rates.

According to (Kemna & Acedo, 2014) the ventilation rate for residential buildings is 0.68 m^3 h/m^3. This is taking into account the heat recovered from the ventilation which is at 7%. With a thermal efficiency of 60% this means that rec is at 5%.

4.4.3 HEATED/COOLED VOLUME

For the heating and cooling load the volume V and the shell surface of the cooled/heated volume of the residential dwellings are calculated.

The heated volume is the volume of air heated in the home during the year. As different rooms are heated at different times of the day, the volume heated changes depending on time. The heated surface area also changes in the same way depending on time and where the dwelling is heated.

During the day the living, kitchen, and hallway are heated. These areas take up 50% of the heated/cooled floor area and are occupied 16 hours a day from 7.00 to 23.00. The bedrooms take up 40% of the heated/cooled floor area and are used 5 hours a day from 19.00 to 23.00. This is to reflect how the home volume is used throughout the day. This usage is applicable for both the heating and cooling seasons and is used in the thesis.

4.4.4 U VALUE

It is necessary to calculate the U value of a home for all scenarios. The U value will be calculated using the method proposed in the Building decree under article 3.4 ("Bouwbesluit 2012 | Bouwbesluit Online," n.d.).

$$U_{gem} = \sum_{n=1}^{n=x} (U_n \cdot A_n / A_t)$$

(1.1)

Where x is the total amount of windows and doors; U_n is the insulation value of the window, door, roof, or wall; A_n is the projected surface of the windows, door, roof, or wall; A_t is the total projected surface of the heat loss area.

According to the IEA "Zero energy" is not (yet) a standardized definition. There is currently the consensus that the term applies to any building with a very low energy demand with the majority of renewables supplied by renewable sources ("Energy efficiency," n.d.). However, according to the Dutch plans for the EPBD a definition has been formulated based on the EPC of the building, its renewable energy use, and measures taken as decided by the Dutch government. A zero energy dwelling must have or be near an EPC value of 0. The party building or renovating an existing building is free to choose how to meet the requirements of the EPBD as long as the EPC of the home is 0.4 as of 2015. As of 2020, the EPC of new homes and renovated homes must be near 0. As of 2015 the minimum Rc is 5 m^2K/W. It is assumed that all new buildings and renovated buildings adopt the same mixture of measures as to make comparison with the baseline scenario more transparent. It is also assumed that all energy-neutral homes meet the minimum required Rc of 5 m^2K/W. Because of this there is no focus on the actual combination of materials used in the construction of the housing, as there is already a target R value such homes must adhere to regardless of what is used to achieve that end (Betlem et al., 2010) This means for homes built post 2020, the U value is by default 0.2 as this is the minimum required U value of homes.

The average U value is calculated for each type of dwelling in each scenario. For the case of green walls (1.1) remains the same. However, the U value of the walls considered is varied to take the U value of green walls into account. This is done by converting the U value into its Rc Value (its inverse) and adding the Rc value of the green wall. The inverse of this addition is then taken as the U value of the wall.

For the pre-existing stock the U value can vary greatly. According to the country factsheet for the Netherlands in the data hub by the BPIE for the energy performance of buildings, the insulation values can range from 0.40 to 2.50 W/m2K for walls, 0.40 to 6.60 W/m2K for floors, 0.40 to 3.30 W/m2K for roofs and 0.80 to 4.40 W/m2K for windows (BPIE, 2015). The average of these U values are used for the pre-existing stock in the frozen scenario. This is also used for the pre-existing stock in other scenarios in place before 2015. The transmission value for doors is at 3.4 W/m2K and is based on the reference dwellings as described by Klunder (2005), which they themselves are based on the traditional housing of the Netherlands. The BPIE has published data linking the U values for walls, floors, roofs, and windows to the age of the dwelling. The age and distribution of the current existing stock is based on the work of Yucel and the KWR (KWR, 2000; Yücel, 2013).

Table 5 and 6 summarizes the different U values for the different stock types and their different ages as well as the different home components such as doors, floors, roofs, walls, and windows.

TABLE 5: AVERAGE MEAN OF U VALUE OF HOUSE COMPONENTS IN THE REMAINING STOCK

Average mean of U value

2000-2015 (year of construction)	1960-2000 (year of construction)	1900-1960 (year of construction)
Floor		
0.4	2.55	5.65
Roof		
0.4	0.8	2.45
Wall		
0.4	1.65	1.75
Windows		
0.8	4.95	3.775

Source: BPIE, 2015

TABLE 6: WEIGHTED U VALUE FOR THE REMAINING EXISTING STOCK

Weighted U value	Age (years)	0-20 (2000-2015)	20-40 (1960-2000)	40+ (1900-1960)
	Detached	0.399737319	1.267751359	1.871683424
	Gallery flat	0.339493056	1.212176794	1.603149595
	Terraced	0.407035402	1.474343369	1.474343369

It is assumed that the green walls are all made of the same composition to ensure a thermal conductance of 2 W/m²K. This is based on an experimental study in which the thermal conductance of a 25cm thick plant foliage. This is also equivalent to the effect given by double-glazing or a static air space 7.5cm thick (Eumorfopoulou & Kontoleon, 2009). In the thesis model the thermal conductance is added to the thermal conductance energy neutral homes have, by adding the reciprocal of the Rc value to the U value of the walls of the dwelling. This is the U value of the homes incorporated with a green façade.

Green walls are only installed on renovated and new buildings. Installing a green wall on a building would be considered renovating it, and in accordance with the EPBD policy, this would mean the house has to be updated to comply with its building regulations.

The U values for buildings with green walls installed is summarized below and is used for the green wall cooling/heating scenarios:

TABLE 7: WEIGHTED U VALUE FOR BUILDINGS WITH A GREEN WALL INSTALLED

Weighted U value	Weighted U value w/Green wall
Detached	0.349428744
Gallery flat	0.297575231
Terraced	0.355396806

4.4.5 HEATING AND COOLING DEGREE HOURS

Heating cooling degree hours

To determine the energy use in the different scenarios, the heating degree-days are calculated per year from 2015 to 2050. To allow for comparison with the alternative scenario, the same amount of heating degree-days will be used based on an extrapolation of temperature in the Netherlands for the period 2015-2035.

When modelling the heating degree hours it is assumed that the maximum outdoor temperature for which heating takes place is 15 degrees. This is in other words the base temperature for heating. This was the base temperature chosen by the EU report on heating spaces inside an average dwelling. It was also chosen as the effect from internal gains and solar gains throughout the heating season can make a base temperature of 18 degrees too high. Heat emitted from these gain sources would reduce the need for heating and lower the base temperature for heating (Kemna & Acedo, 2014) ("Choosing a Base Temperature for Degree Days | GreenBuildingAdvisor.com," n.d.)

The heating season in the model is assumed to be the calendar period between 1 October to 1 May. This is the time in which heating is possibly required in the dwelling and energy is consumed to do so.

The heating degree hours are hence calculated as such:

T_{Day} is then summed over all the days of the heating period to provide the annual heating degree days.

The heating degree hours are also corrected for heat use during the 24 hour day according to the assumptions under 4.4.5 regarding the heating volume and room use. These heating degree hours have to be calculated separately according to room use. Hence the heating degree hours are calculated as:

$$HDD_{Day}, HDD_{night} = \sum_{i=7}^{23}(t_a - 15)/24, \sum_{i=19}^{23}(t_a - 15)/24$$

Where

$HDD_{Day} = Sum\ of\ daily\ heating\ degree\ hours\ in\ the\ living, kitchen, and\ hallway$
$HDD_{night} = Sum\ of\ daily\ heating\ degree\ hours\ in\ the\ bedrooms$
$t_a = outside\ air\ temperature$
$i = hour\ of\ day$

For the cooling scenarios and the cooling season the cooling degree hours are calculated instead with a base temperature of 20 degrees.

$$CDD_{Day}, CDD_{night} = \sum_{i=7}^{23}(t_a - 20)/24, \sum_{i=19}^{23}(t_a - 20)/24$$

Where

$CDD_{Day} = Sum\ of\ daily\ heating\ degree\ hours\ in\ the\ living, kitchen, and\ hallway$
$CDD_{night} = Sum\ of\ daily\ heating\ degree\ hours\ in\ the\ bedrooms$
$t_a = outside\ air\ temperature$
$i = hour\ of\ day$

Assumptions made for the cooling season are:

1. The type of AC units installed in the homes are window unit air conditioners. They are capable of cooling individual rooms.
2. For the case of cooling the amount of cooling degree days is expected to increase significantly in the months of March, April, and May. Hence the cooling season in the air conditioning and green walls scenario is from March to end August.
3. It is assumed that the homes are constantly occupied during the cooling season when residents are not away.
4. Some rooms are assumed not to be in use during the cooling season. It is assumed the homes are occupied constantly throughout the cooling season and the bedroom, living, and kitchen are cooled for all cooling degree hours.

5 RESULTS

5.1 HOUSING TREND

5.1.1 AMSTERDAM

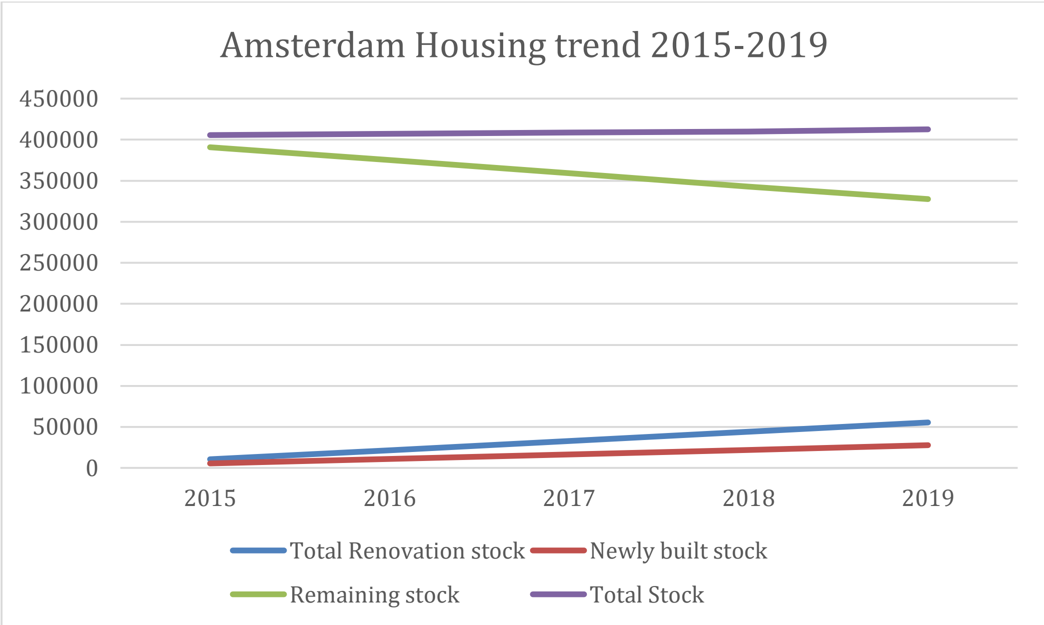

FIGURE 2: AMSTERDAM HOUSING TREND 2015-2019

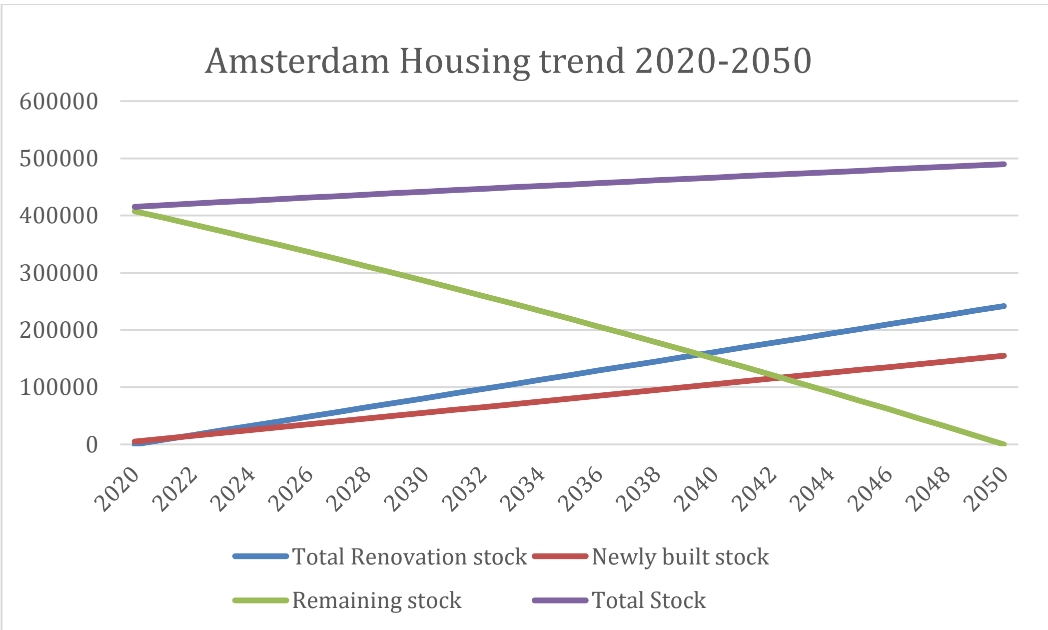

FIGURE 3: AMSTERDAM HOUSING TREND 2020-2050

The housing stock for the cities is presented for the years 2015 to 2050. After 2019 all pre-2019 renovated stock and newly built stock is considered to be a part of the remaining stock for the years 2020-2050. Therefore these time periods are presented separately for each city. Each housing trend for this period for each city took into account the housing visions and plans for the future regarding the housing stock as well as the national goals for energy neutral housing to be fully implemented by 2050. To reflect this means that for the time period post 2019, all renovated and newly built stock are energy neutral.

In Amsterdam for the years 2015-2019 there is a gradual decrease in the remaining stock while the newly built and renovated stock are comparably small, even with an increase. The total housing stock shows an increase in the time period of roughly 12 000 homes. The new builds per year at the start of the time period is at 5000 builds while the renovated builds are at 10 000. These increase to 27 000 and 55 000 builds respectively before energy neutral buildings begin to phase into the housing stock.

This changes after 2020 where the rate of increase for newly built and renovated stock increase sharply until they comprise all of the housing stock at 2050. Overall Amsterdam shows an increase in housing from 415 000 dwellings to 489 000 dwellings at the end of the period. This reflects the expectation of the municipality of Amsterdam to have an increase of 5000 new dwellings a year.

5.1.2 THE HAGUE

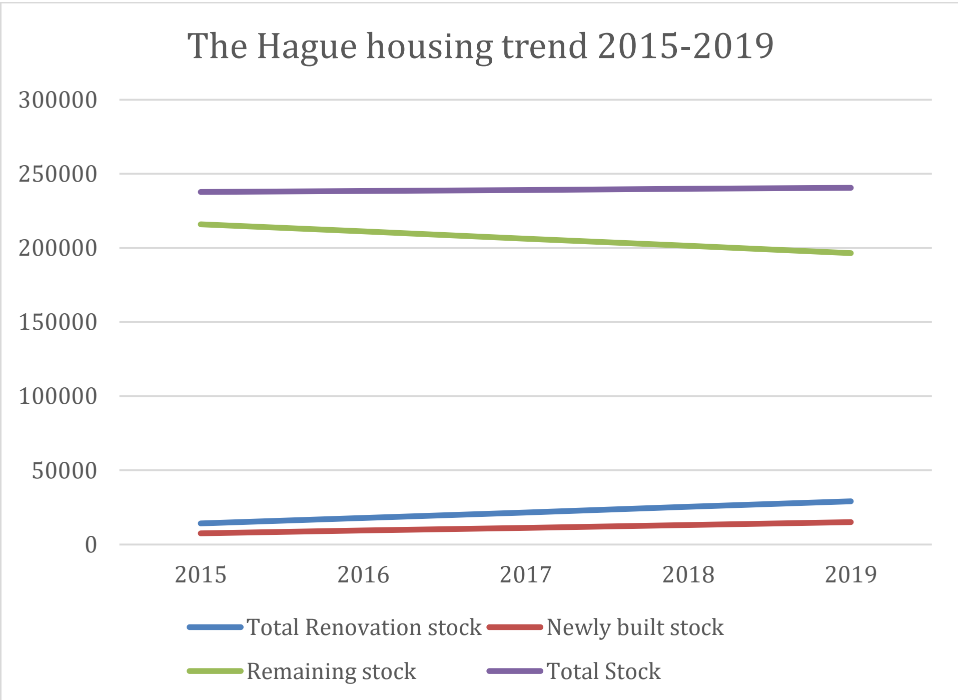

FIGURE 4: THE HAGUE HOUSING TREND 2015-2019

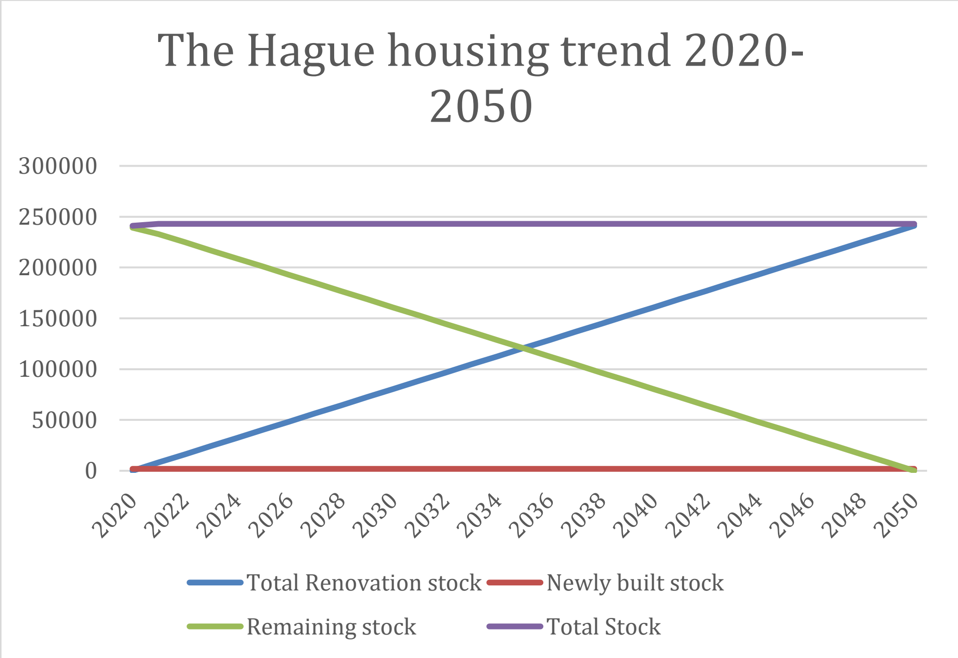

FIGURE 5: THE HAGUE HOUSING TREND 2020-2050

The Hague shows little increase in the total stock for 2015-2019. There is roughly a 3000 dwelling increase while the renovated builds and new builds increases. The new builds increase by the amount The Hague has projected for the time period up to 2020, which is from 7484 to 15 000 builds – an increase of roughly 100%. The renovated builds increase from 14 000 to 29 000 builds.

For the period 2020-2050 there are no new builds as The Hague has no plans for new builds post 2020. The new builds are already projected to be completed before this time and as such these new builds are a part of the remaining stock from 2020 onwards. This results in a constant dwelling amount throughout the projection period for the total housing stock. This also shows that only the renovation is responsible for the transformation of existing stock into energy neutral housing and has a high rate throughout the period. Throughout the period The Hague remains to have a stock numbering at 243 000.

5.1.3 ROTTERDAM

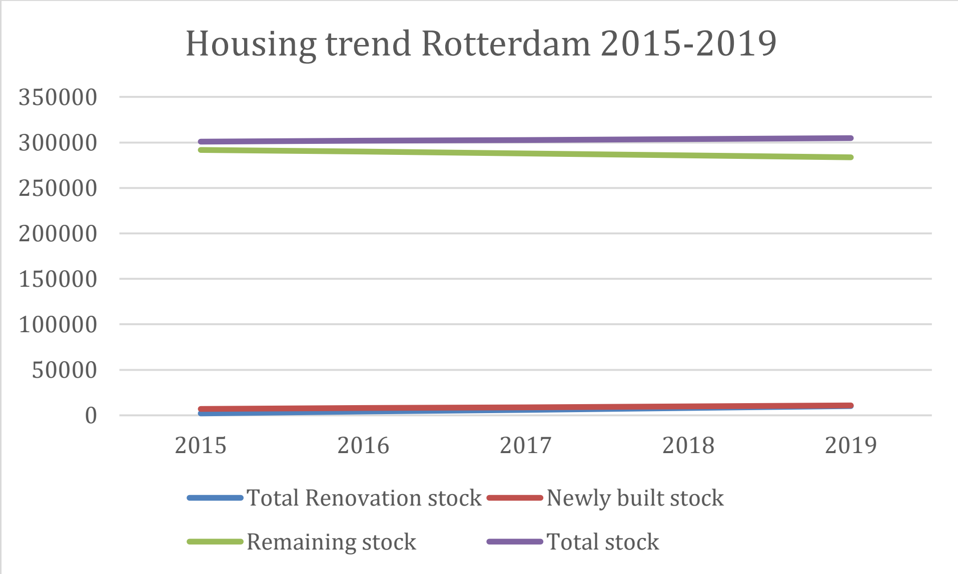

FIGURE 6: HOUSING TREND ROTTERDAM 2015-2019

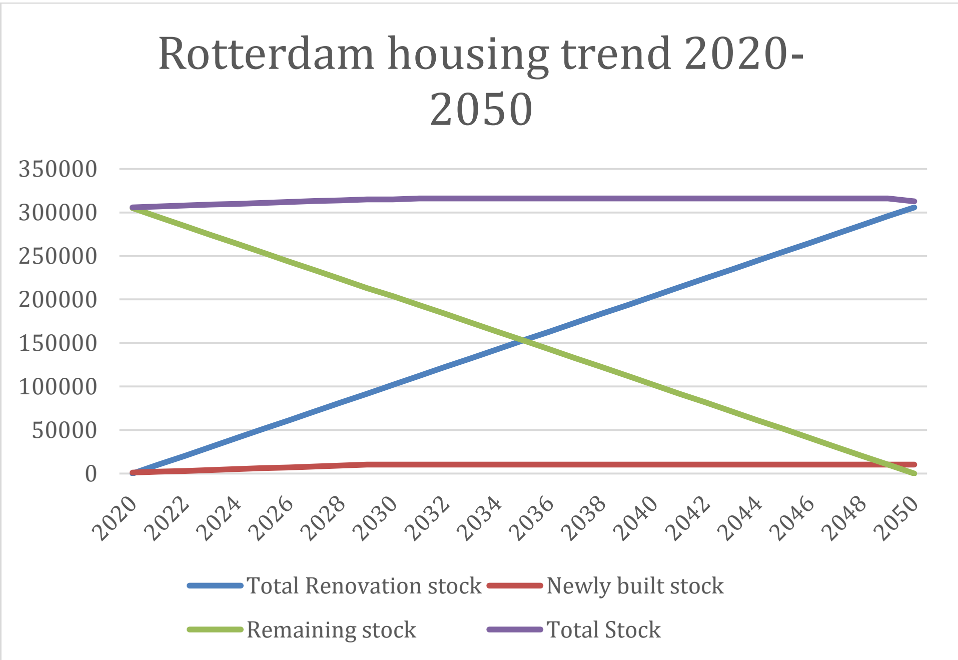

FIGURE 7: HOUSING TREND ROTTERDAM 2020-2050

Rotterdam exhibits an increase of 5000 in the period 2015-2019 in the total housing stock. The renovation and new builds increase also very slightly increasing until they reach a constant stock amount from 2016 onwards. This reflects the assumption that the rate of new builds is kept constant in accordance with the plans set by Rotterdam City. As a consequence the renovation rate is also little and constant. The increase in new builds and renovated builds is at from 2160 and 6915 to 10800 and 11 200 builds respectively.

From 2020 to 2050 the total stock increases to 316 000 from 2020 to 2030. This is to an amount of 316 000 homes as targeted by Rotterdam for this year. Afterwards this amount is constant for the rest of the projection period. The newly built stock hence remains at a constant level while the remaining stock is eventually renovated.

5.1.4 UTRECHT

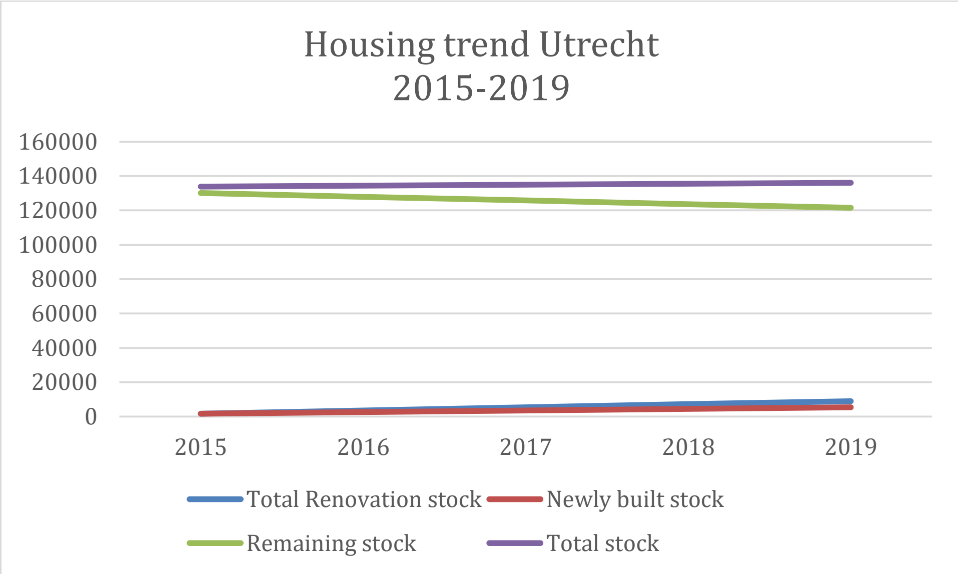

FIGURE 8: HOUSING TREND UTRECHT 2015-2019

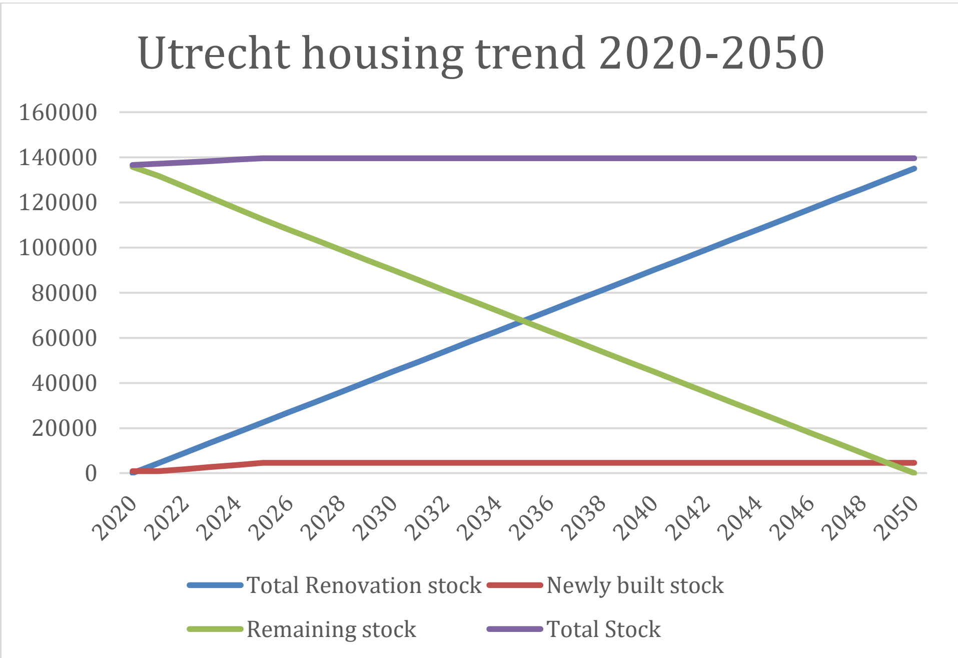

FIGURE 9: HOUSING TREND UTRECHT 2020-2050

Utrecht has an increasing renovation and new build stock in the years 2015-2019. This means a portion of the existing stock is decreased by 2015. After 2020 there is a slight increase in new builds which tapers off at 2025, after which the renovation rate is completely responsible for the transition towards energy neutral builds for the projection period. This reflects the plans of Utrecht municipality regarding the expectation of 30 000 new builds by 2025. As there are no new builds planned post 2025, the new build stock remains constant. Overall the total stock of Utrecht is at a constant 140 000 dwellings after the slight increase in new builds from the Leidsche Rijn development from 2023. Overall the total housing stock at 2050 is at 140 000 dwellings. The renovation stock is at 135 000.

5.2 BASELINE HEATING CONSUMPTION

5.2.1 AMSTERDAM

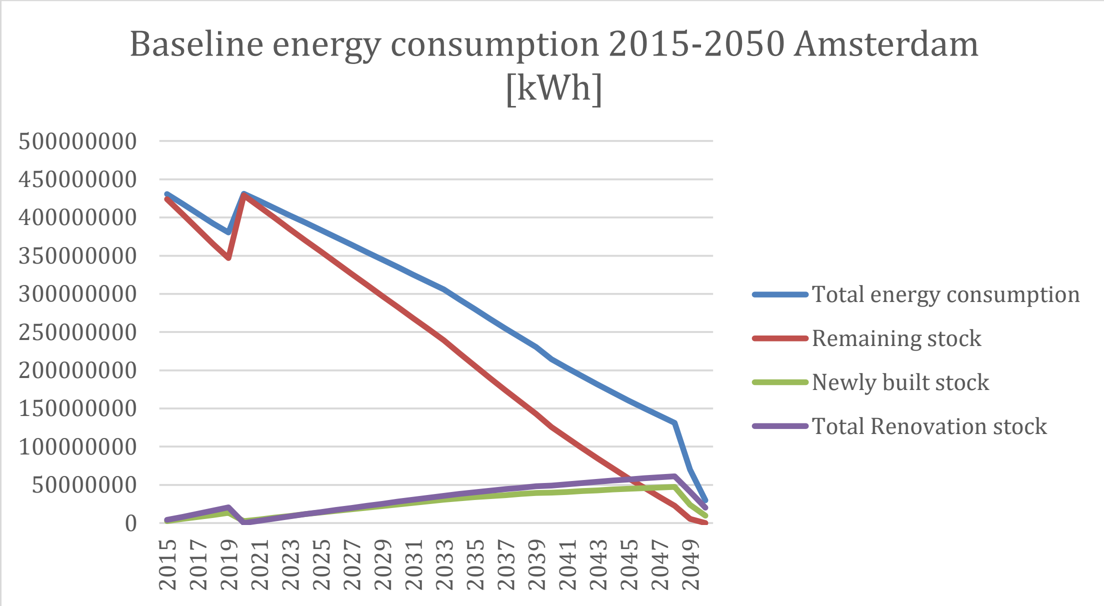

FIGURE 10: BASELINE ENERGY CONSUMPTION FOR AMSTERDAM 2015-2050 [KWH]

For all cities the baseline energy consumption of dwellings was projected up to 2050 for heating. Each type of dwelling stock had its energy consumption calculated and the total energy consumption of all stock types was calculated.

Amsterdam shows a very large decrease in total energy consumption at the end of the period at 2050 compared with the beginning period. At 2049 it is seen that the energy consumption drops significantly from 80 000 MWh to 30 000 MWh. This is attributed to the amount of heating degree hours calculated for 2049 and 2050. At that point the amount of time where the temperature is below 15 degrees has become comparably scarce during the day time due to the significant temperature increase. This is seen for all cities with regards to heating.

The renovation stock energy consumption gradually increases from 2020 onwards at the same level as newly built stock. This is attributed to the increase in heating degree hours and the increase in new builds and renovations. At 2049 the energy consumption of new builds is less than for renovated builds, which is due to the renovated build stock being larger (241 000) than the new build stock (155 000) at that point.

The remaining stock energy consumption decreases gradually over time as the remaining stock is constantly demolished or renovated into energy neutral homes. Overall the total energy consumption is at 30 000 MWh comprised of the renovation stock and new build stock energy consumption.

5.2.2 THE HAGUE

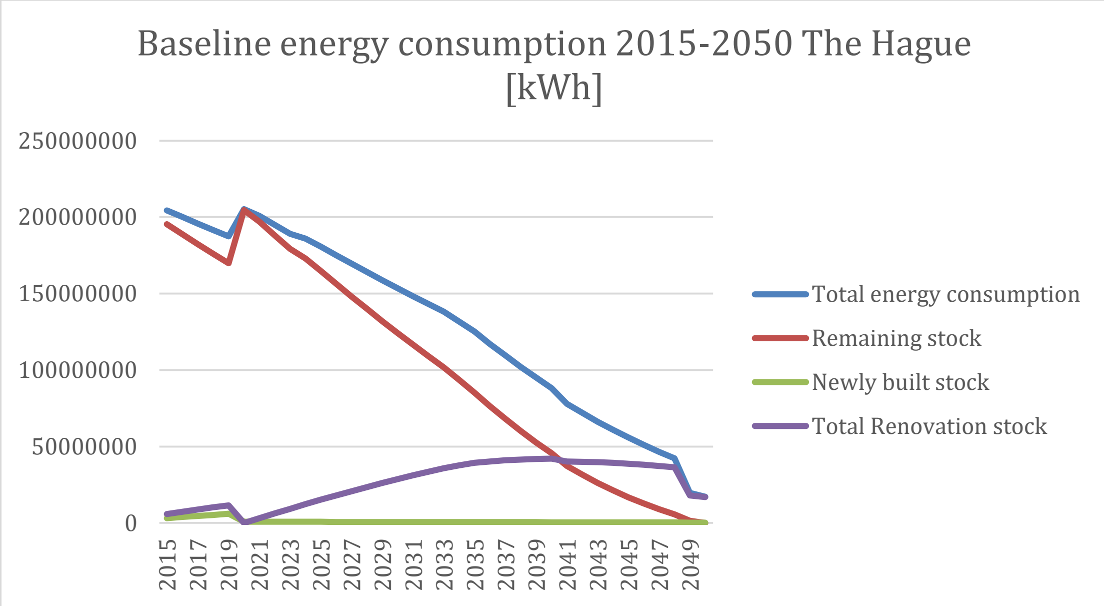

FIGURE 11: BASELINE ENERGY CONSUMPTION IN THE HAGUE 2015-2050 [KWH]

For The Hague the total energy consumption has dropped from 200 000 000 kWh to 20 500 000 kWh in 2050. This has been a gradual decline with some increases and decreases in rate of decline, which can be attributed to the growth of the energy consumption due to the increase in the renovation stock and the accelerating decrease of the remaining stock energy consumption. At 2040 the energy consumption of all the stock begins to level off before the temperature has increased such that there is a sharp decrease in energy use in the renovated stock. The reason for why the energy consumption due to the renovated stock has remained constant despite an increase in renovated stock numbers is due to the increase offsetting the change in temperature and its effect on the heating degree hours in The Hague.

5.2.3 ROTTERDAM

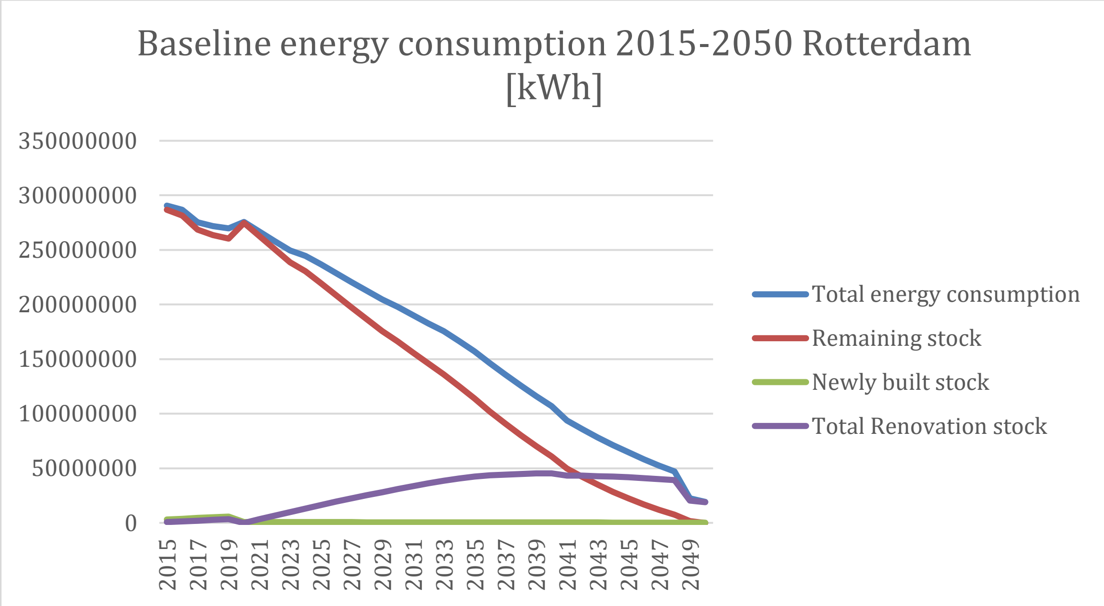

FIGURE 12: BASELINE ENERGY CONSUMPTION 2015-2050 ROTTERDAM [KWH]

With Rotterdam its total energy consumption due to heating decreases throughout the period, except at 2030 (from 280 000 000 kWh to 19 000 000 kWh). This is due to the city achieving its goal of 316 000 dwellings by 2030. Afterwards the housing stock is constant with the renovated stock gradually increasing in energy consumption until hitting a constant level at 2037. Despite the increase in renovation stock, the amount of heating degree hours is decreasing and helps to drive the energy consumption for heating down. The remaining stock meanwhile has its energy consumption decreasing over the time period due to the decrease and replacement of the pre-existing stock into energy neutral housing. The new builds post 2020 have a relatively small energy consumption and is barely noticeable compared with the effect the renovated stock has on energy consumption in Rotterdam.

5.2.4 UTRECHT

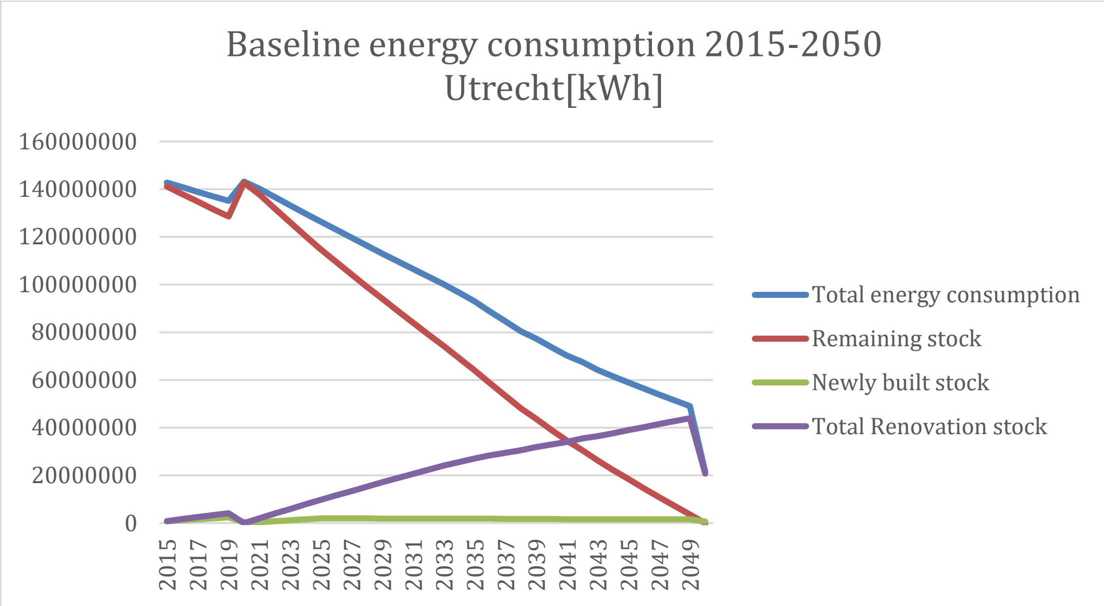

FIGURE 13: BASELINE ENERGY CONSUMPTION 2015-2050 UTRECHT [KWH]

The total energy consumption of Utrecht city decreases throughout the period, from 140 000 000 kWh to 20 000 000 kWh. In this time the remaining stock energy consumption decreases to 0, first being the sole contributer to energy consumption and then becoming overtaken by the renovated stock energy consumption by the end of the projection period.

The renovated stock energy consumption increases throughout the period until it is comprising the entirety of the total energy consumption at 2050. This increase is attributed to the increase in stock falling under renovations despite the decrease in heating degree days for Utrecht. After the drop in heating degree hours in 2049 the renovated stock energy consumption is at 20 000 000 kWh. There is no change in the newly built stock as there are no plans for new build projects by Utrecht post 2020.

5.3 GREENWALL HEATING CONSUMPTION

5.3.1 AMSTERDAM

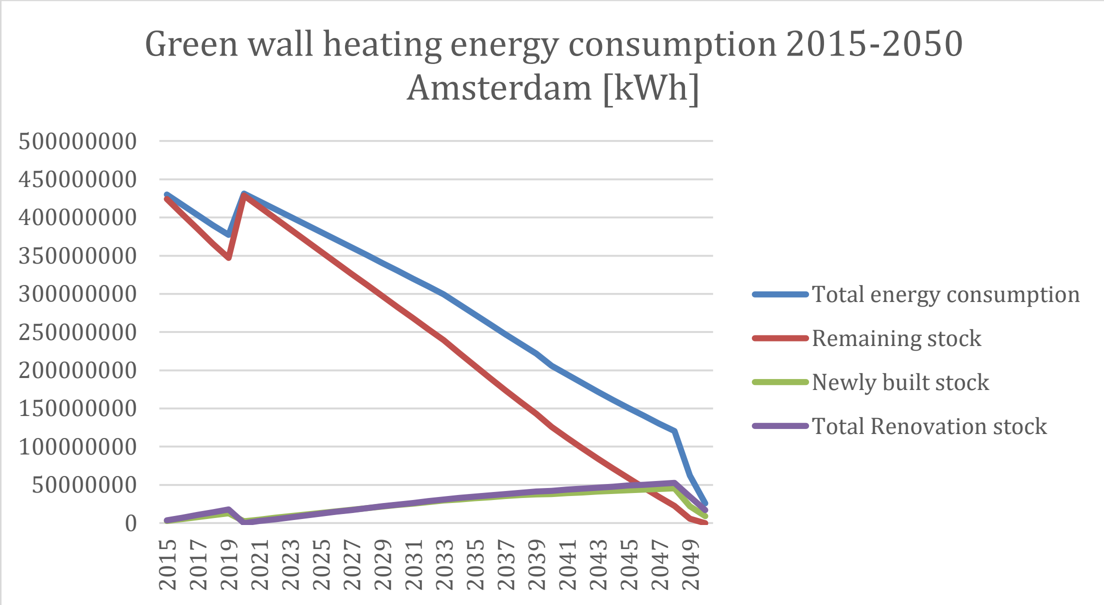

FIGURE 14: GREEN WALL HEATING ENERGY CONSUMPTION IN AMSTERDAM 2015-2050 [KWH]

The green wall implementation in the cities and their effect on heating consumption during the heating season was projected up to 2050 from 2015. This was done by incorporating the u value of the green wall into the total u value of the dwellings considered.

The result is that green wall implementation does not drive down the energy consumption by a great amount in the heating season. The trends for Amsterdam remain the same as for the baseline case, with minor decreases in the energy consumption. The greatest effect is on the energy consumption of the renovated stock: before the drop in consumption at 2049 the energy consumption due to renovated stock is at 52 600 000 kWh while in the baseline it is at 61 300 000 kWh. The green walls were only implemented in the new builds and renovated stock. Hence, the remaining stock energy consumption remains the same as for the baseline. The impact of energy consumption due to green walls is only made more apparent at the end of the projection period at the renovation and newly built stock.

5.3.2 THE HAGUE

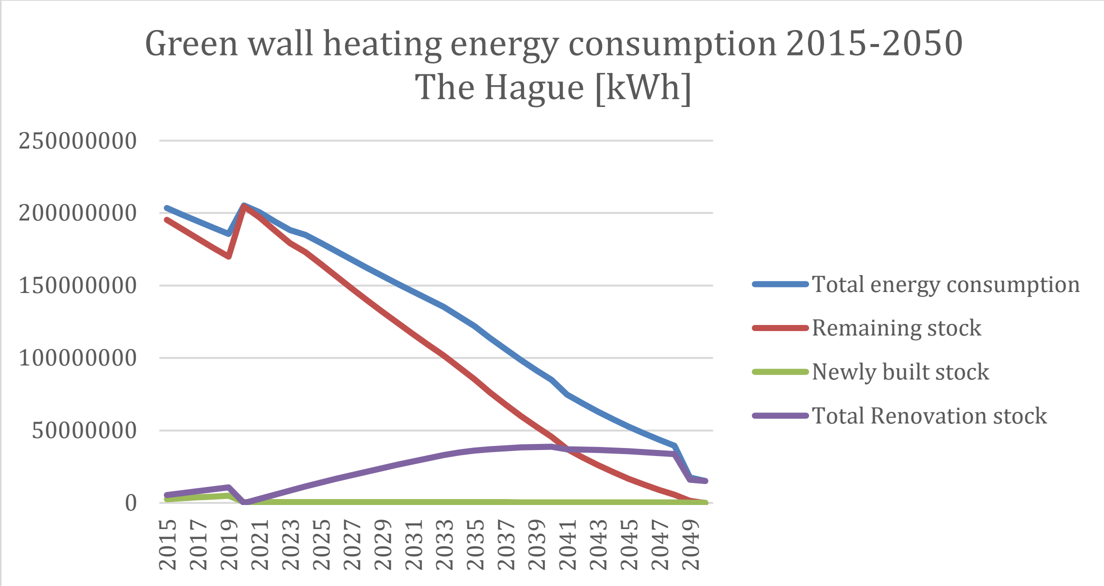

FIGURE 15: GREEN WALL ENERGY CONSUMPTION IN THE HAGUE 2015-2050 [KWH]

The energy consumption for The Hague with green walls implemented follow the same trend as for the baseline scenario. The main difference is in the magnitude of the renovation stock energy consumption. At 2050 the total energy consumption is at 15 000 000 kWh while for the baseline this was at 17 000 000 kWh. This means that introducing green walls reduces energy consumption by at least 2 million kWh for The Hague.

5.3.3 ROTTERDAM

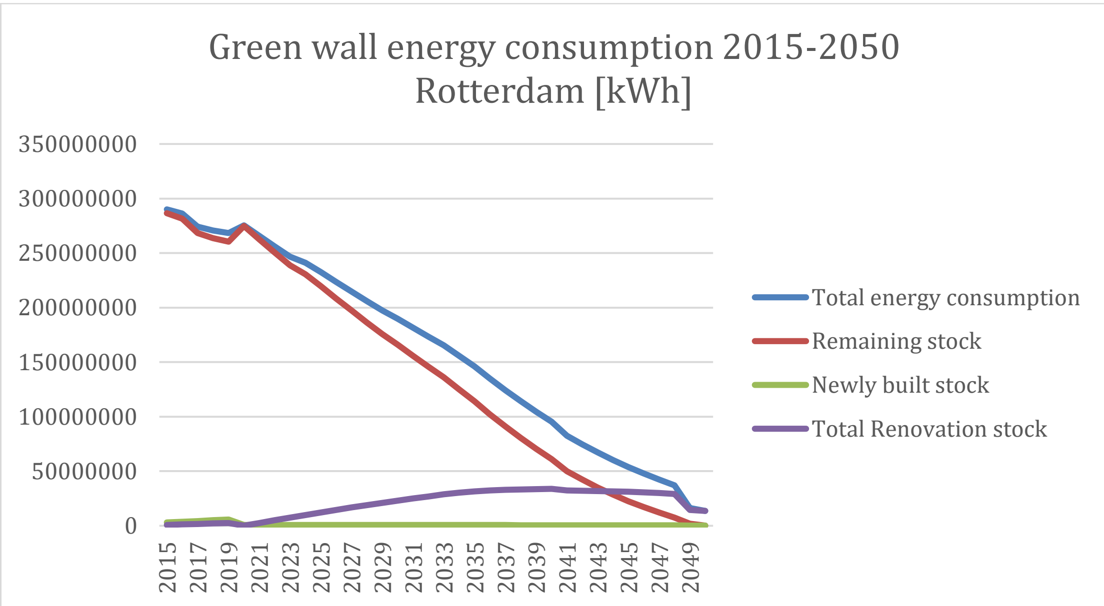

FIGURE 16: GREEN WALL ENERGY CONSUMPTION IN ROTTERDAM 2015-2050

The total energy consumption at 2050 for Rotterdam with green wall implementation is at 13 400 000 kWh. This is a decrease from the baseline scenario with a value of 19 000 000 kWh. This decrease is apparent again in the renovation stock energy consumption. The other stock types remain the same in trend compared to the baseline scenario.

5.3.4 UTRECHT

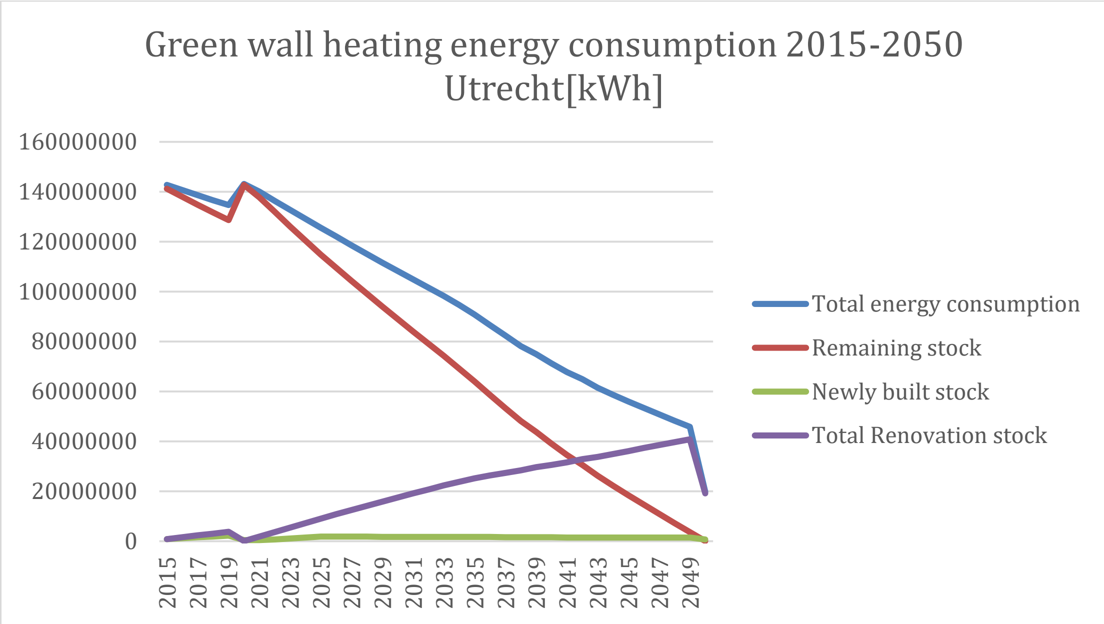

FIGURE 17: GREEN WALL ENERGY CONSUMPTION UTRECHT 2015-2050 [KWH]

The energy consumption for remaining stock in Utrecht remains the same as for the baseline scenario. The main difference is in the total energy consumption where for the green wall scenario the end of period energy consumption is at 19 100 000 kWh while in the baseline it is 20 000 000 kWh.

5.4 HEATING ENERGY SAVINGS

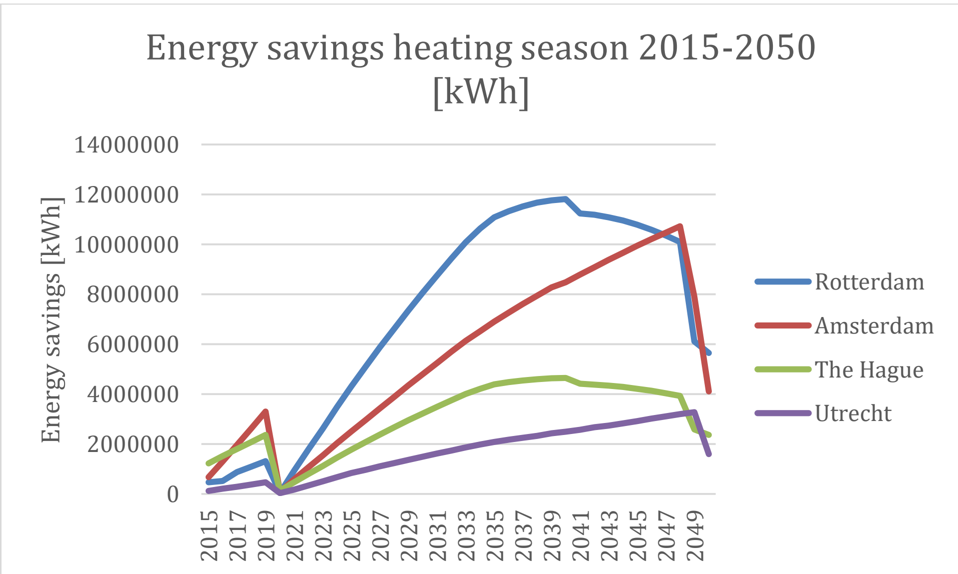

FIGURE 18: ENERGY SAVINGS DUE TO GREEN WALLS IN THE HEATING SEASON 2015-2050 [KWH]

In the heating season the energy savings due to green walls is found by comparing the energy consumption for heating in the green wall heating scenario and the baseline heating scenario.

Rotterdam shows a sharp increase in savings throughout the years peaking at 11 800 000 kWh before dropping to under 6 000 000 kWh. All cities show a similar drop at the end of the projection period and this is attributed to the temperature increase and the resulting decrease in heating degree hours for the heating season. The reason for why Rotterdam has the highest amount of energy savings during the period is due to the temperature increase for the city and the amount of dwellings.

Amsterdam shows the next highest increase, peaking at 10 700 000 kWh before dropping to 4 000 000 kWh for energy savings. Utrecht peaked at 3 200 000 kWh and at the end of the period the energy savings are at 1 600 000 kWh. The Hague peaks in energy savings at 4 600 000 kWh and drops to 2 300 000 kWh.

5.5 AIR CONDITIONING SCENARIO

5.5.1 AMSTERDAM

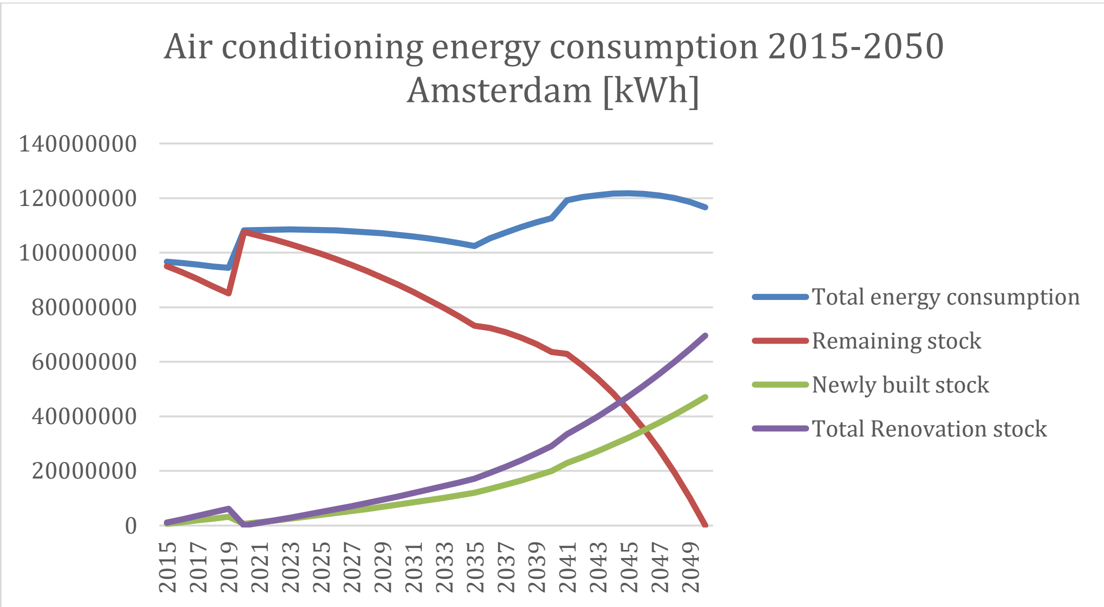

FIGURE 19: ENERGY CONSUMPTION FOR AIR CONDITIONING 2015-2050 AMSTERDAM

For the consumption due to air conditioning the cooling degree hours during the designated cooling season were projected and the energy consumption based on the CDH (cooling degree hours) with a base temperature of 20 degrees. The cooling energy consumption was then projected for the different stock types until 2050.

The total energy consumption in Amsterdam overall increases in the projection period. There is first a decrease from 2019 to 2035, after which an increase is observed and peaks at about 2041, after which the consumption decreases slightly. Overall, start to end, the energy consumption increases from 95 000 000 kWh to 116 000 000 kWh.

The total energy consumption is explained by the changes to the different stock types. The remaining stock energy consumption decreases greatly over the projection at varying rates. After 2035 the decrease has lessened in rate which is explained by the KNMI projection for the temperature during the years 2035-2050. Then the consumption decreases greatly until the remaining stock is completely converted.

The total renovation stock and new build stock energy consumption increases throughout the period as the cooling degree hours increase.

5.5.2 THE HAGUE

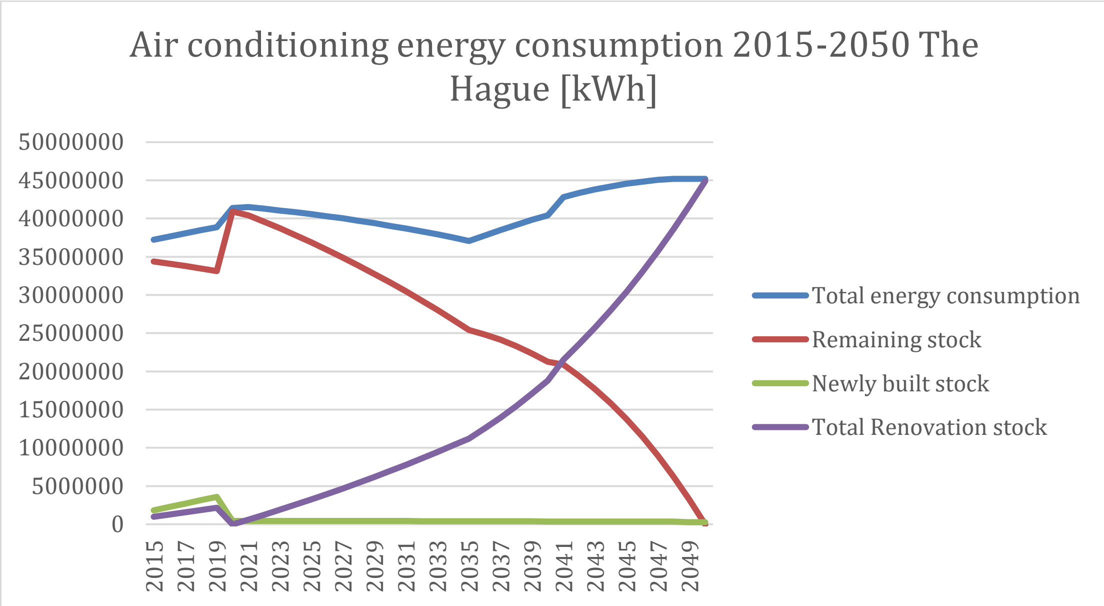

FIGURE 20: AIR CONDITIONING ENERGY CONSUMPTION THE HAGUE 2015-2050

The Hague shows an increase to 44 000 000 kWh from 37 000 000 kWh in cooling in the total energy consumption for the projection period. This is comprised of the remaining stock and renovation stock energy consumption.

5.5.3 ROTTERDAM

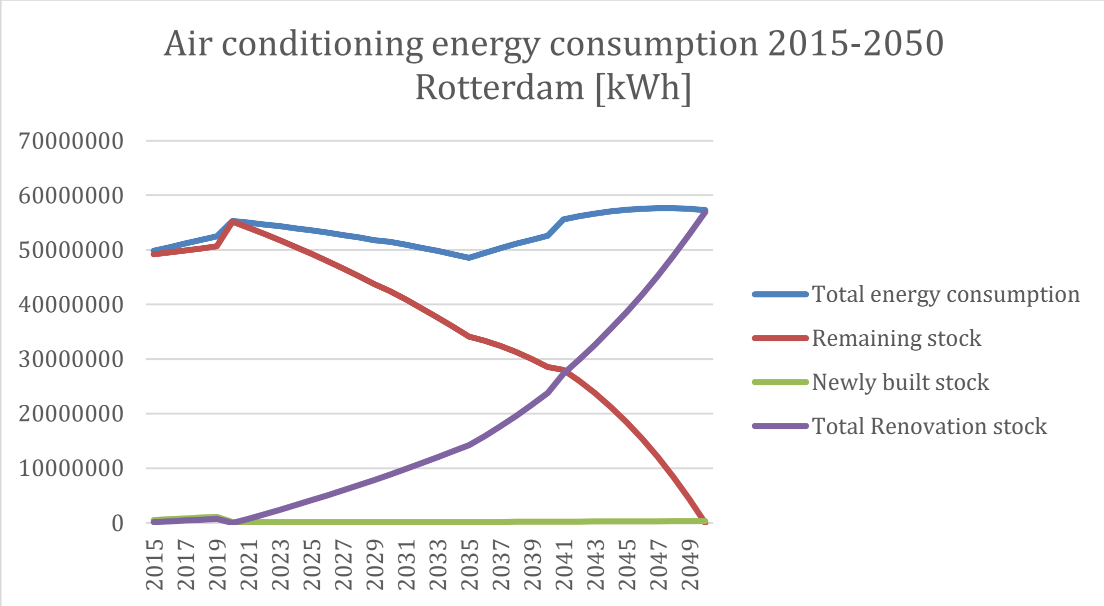

FIGURE 21: AIR CONDITIONING ENERGY CONSUMPTION 2015-2050 ROTTERDAM

The total energy consumption for cooling is at 56 000 000 kWh in 2050 from 48 000 000 kWh. The remaining stock energy consumption decreases after the city reaches its goal of 316 000 homes. The renovation stock energy consumption increases until it is the sole consumer of energy for cooling in dwelilngs.

5.5.4 UTRECHT

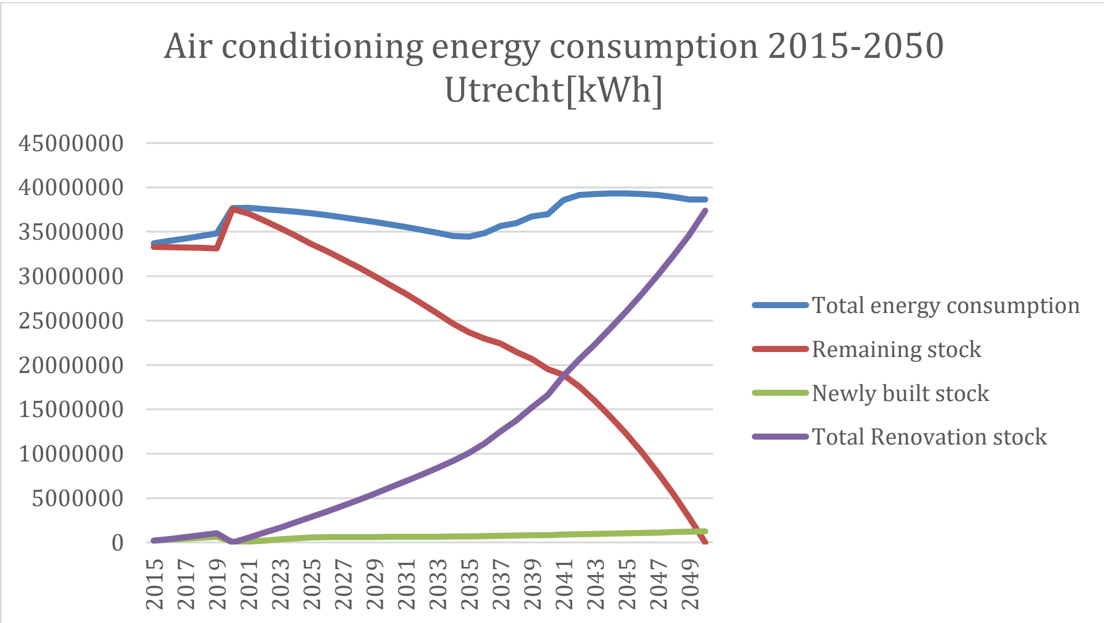

FIGURE 22: AIR CONDITIONING ENERGY CONSUMPTION UTRECHT 2015-2050

In Utrecht the energy consumption due to cooling is at 37 000 000 kWh at 2050. The newly built stock is present in its portion of the energy consumption and slightly increases to 12

500 000 kWh while the remaining stock energy consumption takes up the majority of the total. The remaining stock energy consumption decreases to 0 at the end of the period.

5.6 GREEN WALL COOLING SEASON SCENARIO

5.6.1 AMSTERDAM

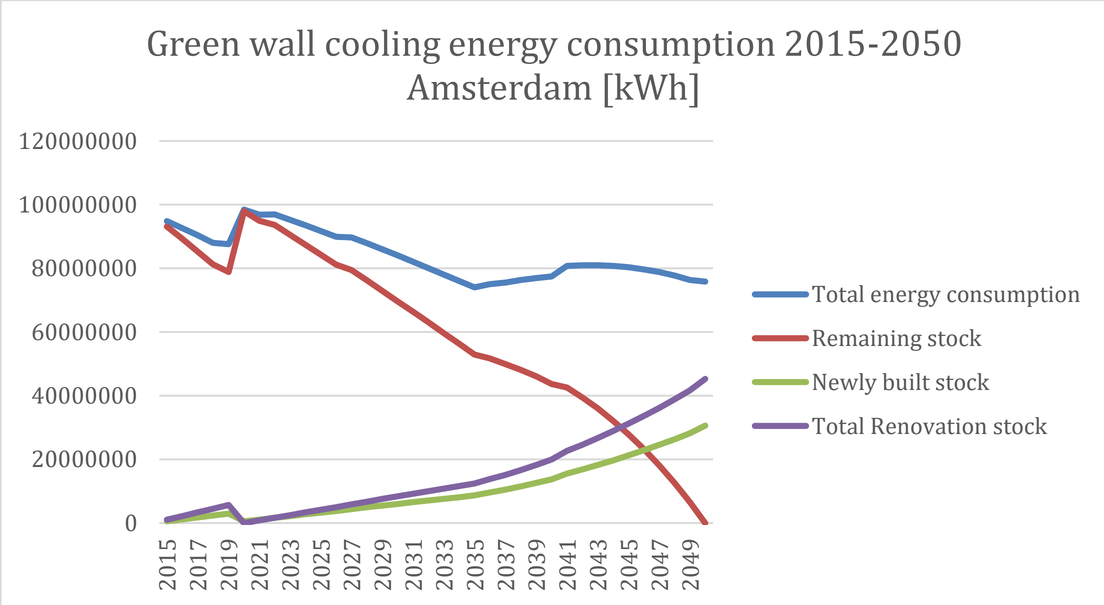

FIGURE 23: COOLING CONSUMPTION DUE TO GREEN WALLS IN AMSTERDAM 2015-2050 [KWH]

The cooling consumption for air conditioning in the green wall cooling scenario was determined by first implementing the effect green walls have on the outside air temperature as they are introduced to the cities.

The effect on this for Amsterdam is a decrease in the total energy consumption due to cooling. This is a decrease to 71 000 000 kWh at 2050 from 93 000 000 kWh. The remaining stock energy consumption also decreases. Compared with the air conditioning scenarios the remaining stock energy consumption still decreases but at a steeper rate. The energy consumption for the other two stock types (new build and renovations) increases as well but at a slower rate. Overall the total energy consumption is lower than for the air conditioning scenario and is in fact decreased while for the air conditioning scenario there is an increase.

5.6.2 THE HAGUE

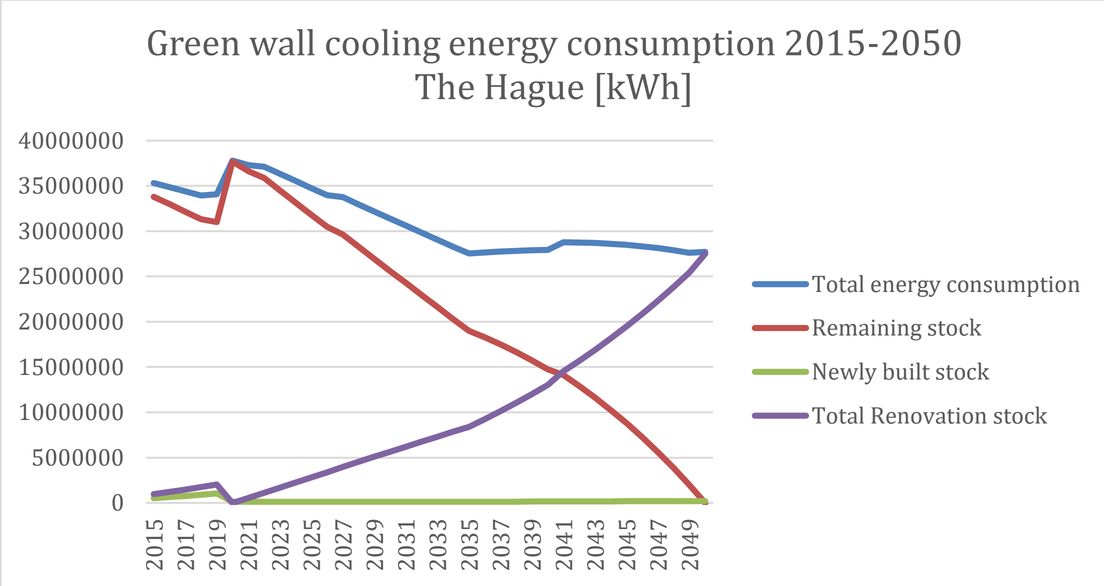

FIGURE 24: GREEN WALL COOLING ENERGY CONSUMPTION THE HAGUE 2015-2050 [KWH]

The Hague shows an overall decrease in total energy consumption due to cooling in the projection period. The energy consumption falls to 27 000 000 kWh from 33 000 000 kWh. The total renovation stock increases in the same manner as for the air conditioning scenario though at a slower rate. The remaining stock energy consumption also decreases but at a lower rate than for air conditioning. The difference between the air conditioning scenario and the green wall cooling scenario is 11 000 000 kWh.

5.6.3 ROTTERDAM

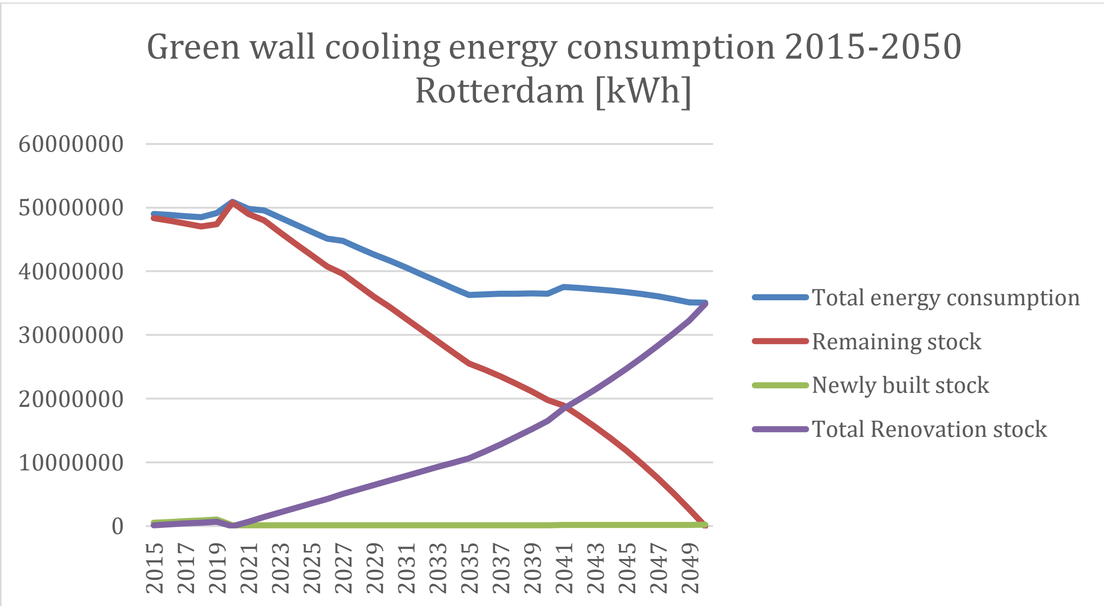

FIGURE 25: GREEN WALL COOLING ENERGY CONSUMPTION ROTTERDAM 2015-2050 [KWH]

Rotterdam shows a decrease in the total energy consumption for cooling as well, from 47 000 000 kWh to 34 000 000 kWh. Energy consumption is up for the renovated stock while the remaining stock energy consumption is reduced to 0 by 2050. All changes to the separate stock types are reduced in rate compared with the air conditioning scenario. The difference between the scenarios is at 22 000 000 kWh.

5.6.4 UTRECHT

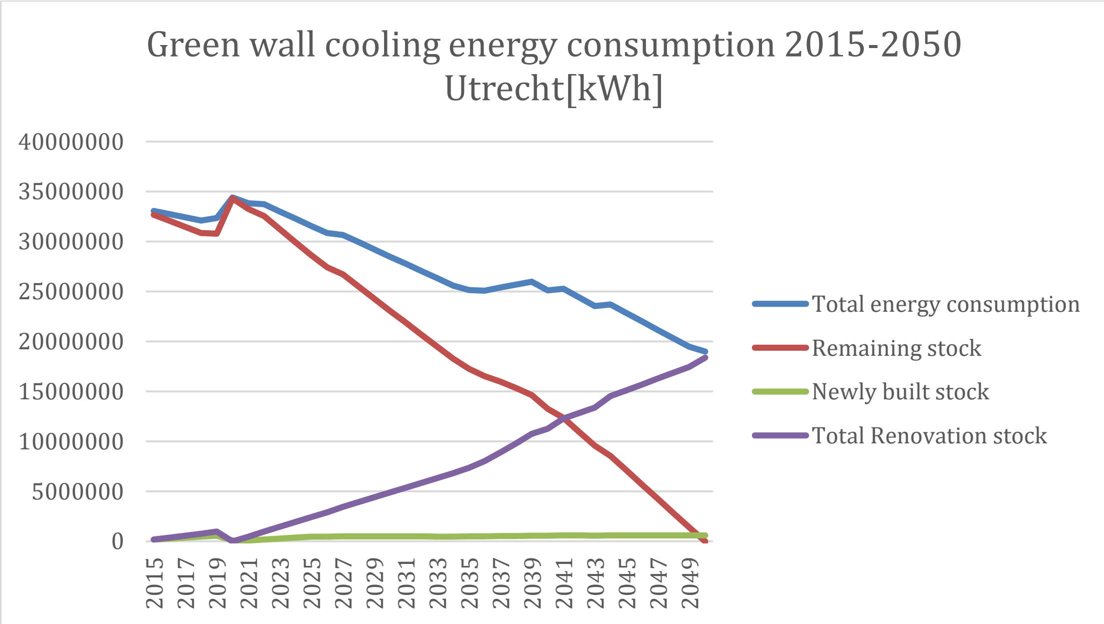

FIGURE 26: GREEN WALL COOLING ENERGY CONSUMPTION UTRECHT 2015-2050 [KWH]

Utrecht has a decrease in total energy consumption to 23 400 000 kWh at 2050 from 32 000 000 kWh at 2015. Like the other cities, the remaining stock energy consumption decreases as the stock goes down in numbers and the renovation stock increases its energy consumption. Compared with Utrecht's air conditioning scenario the energy consumption decreases in total. The decrease between the scenarios is at 20 000 000 kWh.

5.7 COOLING ENERGY SAVINGS

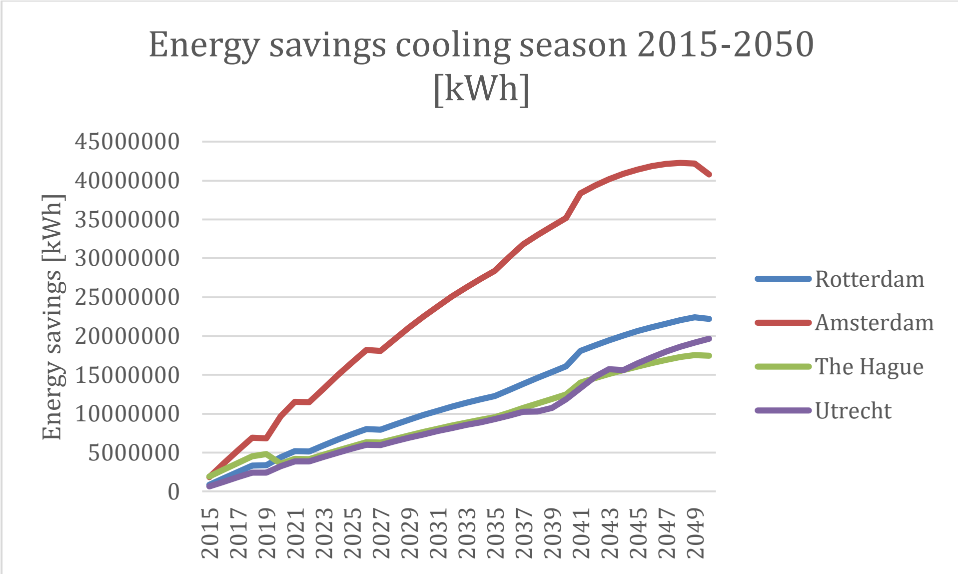

FIGURE 27: ENERGY SAVINGS DUE TO GREEN WALLS IN THE COOLING SEASON [KWH]

Figure 27 shows the energy savings due to green walls during the cooling season for Amsterdam.

The savings increases for all cities throughout the projection period. Amsterdam has the largest amount of energy savings of all cities throughout the entire projection period. This is attributed to the large amount of housing Amsterdam has and the increase in the new builds for the city. Amsterdam saves at 2050 40 700 000 kWh at the end of the projection period, after a slight dip in the savings. This is attributed to a decrease in the air conditioning consumption in the air conditioning scenario.

Rotterdam, The Hague, and Utrecht also show an increase in energy savings though not to the same degree. At the end of the projection period the cities have saved 22 000 000 kWh, 19 600 000 kWh, and 17 000 000 kWh respectively.

6 CONCLUSIONS

The thesis has aimed to answer the main research question:

What possible energy savings would green walls provide to the housing sector for urban Dutch cities?

The results show that these energy savings for the chosen cities to be studied (Amsterdam, The Hague, Rotterdam, and Utrecht) are calculated separately for both the heating and the cooling season.

In the cooling season at 2050 Amsterdam saves 40.7 million kWh, The Hague saves 19.6 million kWh, Rotterdam saves 22 million kWh, and Utrecht saves 17 million kWh with green walls compared to the air conditioning scenario with no green wall implementation.

In the heating season the energy savings with green walls implemented compared to a scenario with no green walls is calculated for 2050 for Amsterdam is 4 million kWh, The Hague 2.3 million kWh, Rotterdam 6 million kWh, and Utrecht saves 1.6 million kWh.

The following answers to the sub-questions aided in the answering of the main research question.

1. **Sub-question: How does the housing stock change over the time period 2015-2050 in terms of renovations and new builds?**

The housing stock changes differently in the years 2015-2019 and 2020-2050 for the studied cities and are presented as follows:

Period 2015-2019:

Renovated builds for Amsterdam are from 10 000 to 55 000 renovated builds and 5000 to 27 000 new builds at the end of the period. There is overall an increase in the total amount of homes for Amsterdam in this period.

In the cities The Hague, Rotterdam, and Utrecht the housing stock changes within the period are very small for the total housing stock. The Hague increases slightly in its housing stock with the renovated and new builds increasing in numbers. Rotterdam increases its total stock until 2016 and has a constant amount of total stock from there onwards until 2019. Utrecht has an increase in its renovation and new build stock for this time period.

Period 2020-2050

After 2020 Amsterdam has an increase in its total stock until 2050. New builds increase during the time period and the renovation of existing stock also increases until all the existing stock prior to 2020 has been replaced or renewed.

The Hague has no new builds in this time period and the only change in the housing stock is in its renovation, which is constant throughout the period.

Rotterdam and Utrecht both have a slight increase in new builds in the start of the period after which no new builds are created. Afterwards for much of this period the main change in the housing stock is the renovation build increase.

2. **Sub-question: During the heating season what energy savings are made by green walls with respect to the baseline scenario and of how much use are green walls as a result in the heating season?**

As a partial answer to the main research question, the heating season the energy savings with green walls implemented compared to a scenario with no green walls is calculated for 2050 for Amsterdam is 4 million kWh, The Hague 2.3 million kWh, Rotterdam 6 million kWh, and Utrecht saves 1.6 million kWh.

Compared to the energy consumption of heating in the baseline scenario the savings take up roughly 10%. However, in the context of the heating consumption changes due to increasing temperatures the energy consumption due to heating decreases greatly especially for the last years of the projection period. This makes green walls less important for making energy savings in the heating season as the temperature increase drives much of the consumption decrease in the baseline and green wall heating scenarios. Green walls have limited use in reducing energy consumption compared to the effect of the temperature decrease.

3. **Sub-question: What would be the energy consumption due to cooling appliances in a scenario where cooling appliances is taken up as a countermeasure to increased uncomfortable warm periods during the cooling season?**

For the cities studied the energy consumption due to cooling appliances are at 2050 which increased for the cities of Amsterdam to 116 000 000 kWh, The Hague to 44 000 000 kWh, Rotterdam to 56 000 000 kWh, and Utrecht to 37 000 000 kWh.

4. **Sub-question: During the cooling season what energy savings are made by green walls with respect to the air conditioning scenario?**

As a partial answer to the main research question the energy savings made with green walls for the cooling season are at 2050 for the following cities: Amsterdam saves 40.7 million kWh, The Hague saves 19.6 million kWh, Rotterdam saves 22 million kWh, and Utrecht saves 17 million kWh.

7 DISCUSSION

7.1 RENOVATION-DRIVEN CHANGES IN THE HOUSING STOCK

The results found that most of the housing stock becomes renovation-driven for the cities of Utrecht, The Hague, and Rotterdam. This implies that the renovation stock for most of the cities studied will be important in realizing the energy neutral goals of the Netherlands and for the implementation of green walls. This is in line with expert opinion that the renovation trend is more important than new builds especially in the Netherlands. The Dutch new build rate is very low yet has a high proportion of existing buildings that are very old and do not comply with the current building standards for heat insulation (Bouwtotaal, 2015), (BPIE, 2015), (Yücel, 2013).

Amsterdam stands out with having a mixture of renovation-driven and new build driven housing stock trend. This is due to the expectation Amsterdam has of new builds being at least 5000 a year from 2018 onwards (City of Amsterdam, 2012). There was no mention if this is an indefinite build rate or if it will change in the future. This means it is possible that the future situation regarding the housing stock in Amsterdam can change if the ambitious goal of 5000 new builds a year is not met.

Other cities in the study do not have a similar ambition and this is the explanation for why The Hague, Rotterdam, and Utrecht have a mostly constant stock amount for housing for the entirety of the projection period. They also share the trait that most of the housing stock change to energy neutral housing at 2050 is due to renovation stock. No projection of new builds were made for any cities other than what was already planned by the cities. As is with the projected stock with Amsterdam the future stock of these remaining cities can be susceptible to change due to decisions taken by the municipality for new housing projects within the city limits in the near future. However, this is not possible to predict as of this moment. With the current expectations and plans that the cities have undertaken, it would be expected that the majority of the shift to energy neutral housing will be done with renovation measures unless there is a clear plan to demolish the existing stock and rebuild or for further housing projects to be developed. Hence the choice was made to not incorporate any new builds that were not approved or in construction by the cities in order to reflect current plans with the certainty that they would be incorporated into the housing stock and to avoid spurious results.

7.2 ENERGY SAVINGS

Heating energy savings
Surprisingly Rotterdam has the largest energy savings for heating despite Amsterdam being a larger city. This can be attributed to the corrected heating degree days found for the cities were higher for Rotterdam at 2050 than for Amsterdam. The Hague and Utrecht show increasingly smaller savings which are attributed to the size of the housing stock of the cities.

The results show that while green walls do contribute in energy savings in the heating season, it is at a 10% rate at 2050. The results also show that before 2048 energy consumption is much higher for all cities for both the baseline and green wall heating scenarios. The reason for the drop in energy consumption at the end was due to the heating degree days suddenly decreasing. This means the temperature becomes high enough to forgo heating and consumption decreases. This has more of an effect on energy consumption in the heating season than the 10% contribution by green walls throughout the projection period.

The contribution hence by green walls on the energy consumption for heating seems to be marginal by comparison even from before the drop in energy consumption due to the decrease in heating degree days. This makes green walls not an attractive option to reduce energy consumption if a city-wide implementation is necessary for a 10% drop across the board for all cities, especially considering how the standards set by the EPBD in the Netherlands for energy neutral homes reduce the energy consumption by a significant amount throughout the projection period in the baseline heating scenario (Betlem et al., 2010). The increase in temperature and the EPBD-induced standards for energy neutral homes plays a much larger role in reducing energy consumption than green walls can based on the results for heating.

It can be argued that the potential to contribute more to energy savings for heating by green walls can be larger if the assumptions involving green walls had been different as the U value of the green walls was incorporated in the green wall heating consumption scenario. This was the main difference in the green wall scenario for heating energy consumption compared to the baseline scenario. It was based on experimental research found in other studies for the insulating properties of green walls. However, these properties are relatively not well known compared to the cooling properties of green walls (such as the evapotranspiration effect on temperature and the shading effect (Pérez et al., 2014)) and it was outside the scope and topic of the thesis to assess these insulating properties. Different species of vegetation can possibly widely affect the U value and there is currently no standard for insulation using green walls.

This means that the results can be affected by the relatively not well understood nature of green walls in winter maritime temperate climates such as in the Netherlands (Pérez et al., 2014). In the meantime, based on the available research which is substantiated by real-world measurement of the U value of green wall foliage, it was decided to use known data to avoid possible spurious results.

Cooling energy savings
All cities show an increase in energy consumption across the board despite the implementation of energy neutral homes while the energy consumption decreases for heating. The energy consumption due to air conditioning appliances used as a coping mechanism in the cooling season was found to be higher at 2050 for all cities than for the baseline heating consumption at 2050. This means the demand for cooling has a much larger role to play in the future of the Netherlands than for heating if air conditioning is implemented to abate thermal discomfort.

Energy consumption due to green walls is vastly different than with the air conditioning scenario. This is apparent in the energy savings found where green walls provide energy consumption savings in the cooling season for Amsterdam at 40 700 000 kWh, Rotterdam at 22 000 000 kWh, The Hague at 19 600 000 kWh, and Utrecht at 17 000 000 kWh. Energy savings are massive for each city which is important when considering how the urban heat island effect is expected to worsen as predicted by studies on the thermal comfort in the Netherlands (Hoeven & Wandl, 2015), (Hove et al., 2011).

The energy savings are in line with other studies on green wall reductions on energy savings which show a reduction in consumption between 5 to 50%, with most falling in between 20-30%. The research here shows a reduction of 35% to 50% for all cities, which matches these findings. These energy savings would help the Netherlands realize its energy savings potential in the built environment, currently estimated at 120 PetaJoules in addition to the more mature technologies already in place (Hieminga, 2013).

An argument to be made here is that energy neutral homes can generate the electricity needed to meet the cooling demand in a renewable manner as the very definition of an energy neutral home is self-sufficiency in energy (Tambach & Visscher, 2012). There, it is a way to conclude that green walls are as an effect made redundant by this in the cooling season. However, green walls can passively cool not only the interior of homes but also the outside air temperature. Using air conditioning as a coping mechanism for increased temperatures especially in highly dense urban areas of the cities of the Randstad would have not only a larger demand from the self-sufficient energy generation of the homes but would not help solve the issue of the urban heat island effect within cities ("Randstad Region | ERRIN Network," n.d.) (Alexandri & Jones, 2004). Additionally, green walls are shown in the results to reduce energy consumption by a large margin and this freeing up of energy can be dedicated to other tasks of the household, or to help meet future energy consumption targets of the Netherlands without the burden of the urban heat island effect.

Limitations

A limitation is in the choice of the source model used for the temperature difference in this research due to green walls, prepared by Alexandri and Jones (2008). The temperature difference was made for London, which was chosen as the reference for the Dutch case due to the similar climate. However, there is a lack of data regarding the green wall effects on the outside air temperature in the Netherlands and this was the reason for the choice to be made based on London. The scope of the thesis was not equipped to determine this. The temperature difference for green walls in the cooling season would best be determined in a separate study with either a dedicated model or an experimental setup meant to measure the temperature differences in the Dutch urban environment, particularly in the Randstad region.

Another limitation was for the historic renovation trends. For future projections involving housing stock or other research involving the Dutch housing stock, renovation trends should be made more transparent in available source data especially as the Netherlands has a goal of becoming energy neutral that would most likely be undertaken in the form of renovations. The renovation trend was in all cases higher in number than for new build trends as the assumption taken was that it would be twice the amount of the new build rate for the time period 2015-2019 and that most cities lacked plans for new builds post 2020. This rate for the initial period 2015-2019 was taken as the renovation rate is not transparent in source data regarding the housing stock of the Netherlands and that this was the rate chosen by expert interviews of the Dutch housing sector (CBS, 2015);(Meijer et al., 2009). It can be that this rate is too generalizing of the cities studied and that the cities can differ in renovation rates, affecting results. However there is no transparency in the source data or in the housing visions of the different cities on what their renovation rates were. Hence, an expertly-informed opinion on the renovation rate was seen as the optimal choice for simulating the housing stock trend.

A major limitation is in the amount of cities studied and their location. They are too few to encompass all of the urban Netherlands (as the cities chosen were the four primary cities of the Randstad region, and not for example a city such as Groningen which is far removed from this area). The results may then therefore not accurately reflect areas of the urban Netherlands not located within the Randstad area and should not be generalized as such outside f Rotterdam, Amsterdam, Utrecht, and The Hague. To further understand the results more cities would have to be studied from within the Netherlands, ideally all of them.

Implications

This research shows that there is indeed energy savings potential for the urban areas and contributes to the lack of knowledge on green walls in the urban Netherlands and to the lack of knowledge on green wall energy savings outside of the cooling season (see Perez *et al* (2014) for a detailed review on green wall literature). This research is one of the few studies on green infrastructure implementation in the Netherlands and it is hoped that there will be further research on how to successfully implement or realize the energy savings green walls can bring to the urban Netherlands.

As of this moment there is no incentive for the implementation of green walls. Rotterdam does have a city-wide incentive plan for green roofs (Mees, 2014) but this is currently the only such incentive in the Netherlands with green infrastructure with a stronger focus on water storage than for energy savings. With the expectation of further heatwaves on the rise in the Netherlands and the impact rising temperatures will have on energy consumption for cooling if air conditioning is taken up, green walls are a recommendation to curb this.

If green walls are adopted, they have the potential to be a passive method of increasing energy savings in a future where energy consumption would be greater due to cooling appliances and increased temperatures than for a future with less demand for heating than for cooling. With green walls, the Netherlands can help itself not only with combating the urban heat island effect within its cities but also with reaching energy savings targets for its built environment on the long-term.

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