The potential reduction of household space heating CO2 emissions in the Netherlands
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PREFACE

For this training thesis I got the opportunity to research the interesting subject of household space heating and CO$_2$ emissions. The combination between a technical, a social and a policy oriented approach suited me. The literature study on one side, and the model on the other side, resulted in this report. Therefore I would like to show my gratitude to all the people who supported me with information and guidance. I would like to thank my supervisors for their guidance and support. Especially Dr. R.M.J. Benders supported me with scenarios and models. For the overall progress and technical issues Prof. dr. F.A. de Bruijn was of great support.
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1 SUMMARY

Space heating is responsible for more than half of the total Dutch household energy demand, a large share is based on natural gas. With increasing concern about global warming and depleting gas reserves, energy saving has become an important topic. Energy efficient houses limit fossil fuel use and CO$_2$ emissions, therefore it is important to promote this type of construction. This research focuses on the potential to reduce the space heating CO$_2$ emissions of Dutch households with the following research question.

What is the potential reduction of the space heating CO$_2$ emissions within the Dutch housing stock by applying energy saving measures and which policies and approaches are required to achieve this?

This study is based on a literature review and a scenario analysis. The literature review includes European and Dutch targets, Dutch policy and technological measures to reduce space heating CO$_2$ emissions. The European targets are extended to space heating CO$_2$ emissions in the Netherlands in particular, they comprise 20% reduction in 2020 and 80% reduction in 2050 as compared to 1990 levels.

The main Dutch policy is based on a legal minimum construction standard. The energetic performance of houses is therefore evaluated with the EPG (new houses), energy label (retrofitted houses) and the PHPP (passive houses) methods. However, the above mentioned methods require improvements to become more credible and to get more support by involved parties. A big issue with energy efficiency policies is that they are obscure to involved parties and often temporary.

Dutch policy aims to promote energy saving technologies. Therefore the passive house concept (EPC 0.2) is used as a showcase. Large scale implementation of energy saving technologies will result in a switch from gas based heating systems, to electricity based heating systems. The measures include: extreme air tight building envelope, excellent insulation, balanced ventilation with heat recovery, heat pump and use of passive and active solar radiation. These measures are proven and promising, but there are practical issues. It is hard to get rid of moist and water vapor in the construction of a well insulated house. Also balanced ventilation is still a controversial topic, it is only useful when it is installed and maintained properly. The technology is available, but the offset period is 6-18 years for a passive house compared to low energy houses.

Three different scenarios for household heating CO$_2$ emissions up to 2050 are assembled, first no policy, second current policy and finally stringent policy. MERLiN software is used to assess the energy saving construction measures, related EPC value and heating demand of households. The stringent scenario shows that a substantial CO$_2$ emission reduction of 70% as compared to 1990 levels is possible. In comparison to the current policy it includes higher rates of retrofitting old houses, high energy performance standards for new houses (EPC=0.2) and a large share of green gas (50%) and renewable electricity (80%). This means that the European ambition to reduce total CO$_2$ emissions by 80% in 2050 is unlikely to be met, when applied on household space heating.
2 INTRODUCTION

It is very well possible to have a comfortable indoor climate in our homes without using natural gas. Still space heating is the largest share of our household energy demand. This research focuses on the potential to reduce the space heating demand, and related CO₂ emissions, of the Dutch housing stock. The passive house concept, an extremely energy efficient construction method, is used as a showcase of the technical possibilities. Many studies are conducted about passive construction methods in particular already. Also energy efficiency policies have been addressed in some studies. This study provides the combination of the technological and the policy approach. It aims to provide a large scale picture of the current status of energy efficiency in the Dutch housing stock and its potential for the future. This study includes Dutch energy efficiency policy and European emission targets. Also a technical analysis and a model with different scenarios for the Dutch built environment and related CO₂ emission for 2050 is included. The research question is as follows.

What is the potential reduction of the space heating CO₂ emissions within the Dutch housing stock by applying energy efficiency measures and which policies and approaches are required to achieve this?

Energy efficiency is essential for the mitigation of global warming. Also natural gas stocks are depleting fast. Therefore the European Union sets ambitious targets for reducing CO₂ emissions and natural gas usage in the future. Since energy efficient dwellings limit fossil fuel use and CO₂ emissions (Stahl, 1996) it is important to promote this type of construction.

The emphasis in this study lies on reducing the space heating demand of Dutch households. It accounts for 51% of the total household energy demand (Milieucentraal, 2010). The first chapter addresses EU emission targets and Dutch energy efficiency policy. Also the energy label, EPG and PHPP energy efficiency evaluation methods are analyzed thoroughly. The second chapter addresses the design characteristics necessary to achieve a substantial reduction of the heating demand. The third chapter focuses on the financial and energetic payback time of energy efficiency measures. The last chapter addresses the impact of the proposed measures and policies on the total CO₂ emissions for space heating in the Dutch housing stock. It will be analyzed with the use of three different scenarios for 2020 and 2050.
3 POLICY AND EVALUATION METHODS ENERGY EFFICIENCY
DUTCH HOUSEHOLDS

This chapter addresses the potential of energy efficiency policy to meet EU emission targets. First the European CO$_2$ emission targets will be addressed. Then energy efficiency policy in general is addressed, followed by a closer look at the Dutch energy efficiency policies. The next paragraph addresses evaluation methods for energy efficiency, an important policy tool. It includes the energy label, the EPG and the PHPP. Finally the practical experience with energy efficiency policies will be addressed.

3.1 Policy targets energy efficiency

The Dutch government has a number of agreements with different parties concerning energy efficiency in the build environment. An agreement concerning total energy demand of the Dutch built environment (including electricity) is the "meer met minder" (more with less) agreement. The Dutch government also signed the 20-20-20 European agreement. EU target for all sectors includes: 20% renewable energy, 20% more energy efficient and 20% less CO$_2$ emissions as compared to 1990. Finally there is the European agreement to reduce CO$_2$ emissions by 80% as compared to 1990 levels in 2050 for all sectors. The CO$_2$ emissions for household space heating were 15.4 Mton in 1990. Therefore CO$_2$ emissions should be 12.3 Mton in 2020 and 3.1 Mton in 2050. These targets will be applied throughout this report.

The total household energy demand is expected to level off with business as usual in the next 20 years, as shown in Figure 1. The share of natural gas (NG) will decrease due to global warming and better insulation of dwellings. On the other hand, the electricity demand will increase in the next 20 years. The total CO$_2$ emissions will increase in the next 20 years because the same amount of energy from the current electricity mix emits 2-3 times more CO$_2$ than from natural gas in a condensing boiler (VK, 2006). Still household space heating plays an important role in the achievement of above presented emission targets. (Menkveld, Boerakker, & Mourik, 2005)

Apart from the national energy policy targets there are many regional agreements and targets. But not only is the public sector promoting energy efficiency, also in the private sector there are many

![Figure 1, BAU development of total energy demand (PJ) and CO$_2$ emissions (Mton) Dutch households 1990-2030 (Menkveld et al., 2005)](image-url)
agreements and ambitious goals. For example, social housing corporations are working together on reducing the heating demand of their houses. Space heating is still by far the biggest energy use in households, this means that an improvement in efficiency of space heating is the most important contribution to the overall energy efficiency in households (ECN, 2009). The next part will address what can be done and what has been done so far to reach energy efficiency targets.

3.2 Energy efficiency policy in general
In the last few decades there have been many policies implemented in order to achieve the above presented energy efficiency targets. The policies are aimed at promoting energy efficiency measures. In many cases however, the measures require large additional investments. This is why a well considered and efficient set of policy measures is essential to achieve goals. This paragraph starts with a worldwide view on energy efficiency in the built environment from the IEA energy technology perspectives 2010, in which 3 fundamental issues are addressed. Then the scope is aimed at policies within the Dutch built environment.

The IEA energy technology perspectives 2010, provides an overview of the current status of the worldwide building stock. It also addresses the national energy efficiency goals of governments and policies required to achieve those. ‘Achieving significant energy and CO$_2$ emission reductions in the building sector is technically possible, but a challenging policy goal’ (IEA, 2010). The report concludes with three fundamental issues needed to be addressed by specific policies.

1. Population, household numbers and service sector activity will grow significantly faster in developing countries to 2050, than in the OECD$^1$ and EITs$^2$.
2. Residential buildings, particularly on OECD countries, have very long life spans (80 years or more).
3. Heating loads are large in OECD and the EITs, while cooling loads are much more important in most developing countries.

The IEA report emphasizes that the current building stock in the OECD countries needs to be transformed before 2050. Making this happen requires consumers to invest in energy efficiency measures with potentially higher investment costs. Unprecedented and well targeted policy direction and support are required to achieve this (IEA, 2010). For this kind of policies it is important to be well tuned for local circumstances. For the Dutch situation it means that reducing the heating demand is a key issue. Within the policy process the primary concern is to create sufficient market pull to encourage widespread deployment of the best existing technologies for the built environment. Secondly, still a lot R&D effort will be needed in order to go beyond existing best technologies available and to make it economically feasible. Both approaches however, will have to deal with a number of barriers.

The biggest barriers for energy efficiency in the built environment (IEA, 2010)
- Higher initial costs
- Lack of consumer awareness of technologies
- Split incentives
- Low priority placed on energy efficiency by policy maker
- The fact that true costs of CO$_2$ emissions are not generally carried by consumers

The specific barriers can be targeted with a number of effective polices. The options are: information campaigns, fiscal and financial incentives and minimum energy efficiency standards. They must address financial constraints, industry capacity and boost investment in R&D (IEA, 2010).

---

$^1$ Organization for Economic Cooperation and Development: organization of 34 Countries working together on global development.

$^2$ Economies in Transition
Figure 2 shows the marginal costs of global emission reduction measures. There are two scenario’s used within this study. The ACT scenario envisages bringing global energy CO$_2$ emissions back to 2005 levels, the BLUE scenario envisages halving those emissions (shown on the x axis). Both scenarios are optimistic concerning technological progress. The BLUE scenario however, requires much larger investments. The main message from this figure is that end use efficiency has negative marginal costs. Most measures aimed at reducing the heating demand of houses are found within this category. Therefore in other words, reducing the heating demand of houses will be economically feasible.

Before the Dutch energy efficiency policies will be addressed, it is useful to analyze policies which have been implemented so far. This is the subject of a study by M Harmelink. She made an analysis of 20 energy efficiency policies worldwide and concludes with a number of general success factors and weaknesses (Harmelink, 2005).

Success factors energy efficiency policy (Harmelink, 2005):
- The existence of clear goals and a mandate for the implementing organization.
- The ability to balance and combine flexibility and continuity.
- The involvement of stakeholders.
- The ability to adapt to and integrate adjacent evolving or new policies or develop consistent policy packages.

Weaknesses energy efficiency policy (Harmelink, 2005):
- Energy efficiency policies often lack quantitative targets and clear timeframes.
- Policy instruments often have multiple and/or unclear objectives.
- The need for monitoring information often does not have priority in the design phase.
- For most instruments, monitoring information is collected on a regular basis. However, this information is often insufficient to determine the impact on energy saving, cost effectiveness, and target achievement of an instrument.
- Monitoring and verification of actual energy savings have a relatively low priority for most of the analyzed instruments.
- There is no such thing as the ‘best’ policy instrument. However, typical circumstances in which to apply different types of instruments and generic characteristics that determine success or failure can be identified.
According to above mentioned success factors and weaknesses there are a number of key issues. Many of these issues are found in Dutch policy as well.

### 3.3 Dutch energy efficiency policy

In the Dutch built environment a number of energy efficiency policies are implemented. There are energy performance standards for newly built houses (EPG) and energy labels for the current housing stock (energy index). Also there are a number of polices combined in the *more with less* campaign. It includes tax advantages, subsidies for private investments in energy efficiency and green loans. The government provides loans with low interest rates to finance energy efficiency investments for individuals and housing corporations. A common characteristic of these policies is that they are locally provided and that they are short term. The policies usually last for 1-2 years and they stop when the budget has run out (Meer met minder, ). In this section the most common energy efficiency evaluation methods will be addressed. Then a few examples of Dutch policies are provided and analyzed. Finally conclusions will be drawn and recommendations will be given.

Mainly three different methods are use to evaluate the theoretical energetic performance of houses in the Netherlands. There is the energy label for old houses, the EPG (Energieprestatie Gebouwen) for new houses and the PHPP (Passive House Planning Package) for passive houses. These methods make it possible to evaluate energetic performance of houses and therefore the government is able to set minimum construction standards.

### 3.4 Energy labels

With increasing concern about global warming, depleting natural gas reserves and rising energy prices a high energy label is assumed to be an advantage. Whenever a house is sold, the selling party is obliged to provide an official energy label. The energy label is implemented to provide insight into the energetic performance of houses. The most energy efficient houses are labeled A, and the less efficient are labeled G. The energy label applied in the Netherlands is based on the energy index as shown in Table 1. The core purpose of the energy label is to raise awareness about energy efficiency of homeowners and to stimulate investments. The new energy index calculation method is updated in 2010, therefore it will be possible to compare houses of different types as well.

The calculations for the energy label can only be provided by a specialized and dedicated company. In practice an energy label is calculated with the use of special software. First a schematic projection of the building is entered in the computer program. Secondly the characteristics of the installations are entered. Then the energy index value is calculated. The energy index is not the same as the EPC value because different calculations are applied.

The *ministerie van VROM* did a research about the relation between the heating demand of houses and the energy label. Table 1 shows the average annual gas usage for houses in the Netherlands per energy label. It is important to notice that the range of values is large, 80% of the D label houses has a gas usage between 500m³ and 2,450m³ (Ministerie van VROM, 2006). The large range is caused by the difference between installations, building characteristics and user behavior. This is also the reason that the practical gas usage of the F label houses can be higher than the G label in this study.
Table 1, Relation between practical heating demand and the energy label (Ministerie van VROM, 2006)

<table>
<thead>
<tr>
<th>Energy label</th>
<th>Energy Index (EI)</th>
<th>Practical annual gas usage Average (m³/m²)</th>
<th>Average (kWh/m²) ³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.71-1.05</td>
<td>9.9</td>
<td>97.2</td>
</tr>
<tr>
<td>B</td>
<td>1.06-1.30</td>
<td>11.0</td>
<td>107.8</td>
</tr>
<tr>
<td>C</td>
<td>1.31-1.60</td>
<td>12.7</td>
<td>124.5</td>
</tr>
<tr>
<td>D</td>
<td>1.61-2.00</td>
<td>14.0</td>
<td>137.2</td>
</tr>
<tr>
<td>E</td>
<td>2.01-2.40</td>
<td>14.6</td>
<td>143.1</td>
</tr>
<tr>
<td>F</td>
<td>2.41-2.90</td>
<td>15.7</td>
<td>153.9</td>
</tr>
<tr>
<td>G</td>
<td>&gt;2.90</td>
<td>15.5</td>
<td>151.9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>13.8</td>
<td>131.3</td>
</tr>
</tbody>
</table>

The question is whether energy labels stimulate homeowners to invest in energy efficiency measures. This question was subject of a Belgian research. At the time of the research energy labels where mandatory in Denmark but not in Belgium (2006). In Belgium the energy advice was given by experts on request of the homeowner. In Denmark on the other hand, energy labels are mandatory since 1997 and are similar to the Dutch energy label. Both energy labels include information on consumption of energy and water. The label is used to compare buildings with a similar use and the label also provides an energy plan including proposals for improvements (Laustsen, 2000). To evaluate the behavior concerning energy efficiency investments, ten homeowners from each country where interviewed. The results show that people tend to trust an expert in person more than a labeling methodology. It is also important whether people ask for the information themselves or if they just got it. “They rather are actors that interpret or reject new information on the basis of their previous knowledge and of the norms of their social network” (Gram-Hanssen, Bartiaux, Jensen, & Cantaert, 2007). This means that it is important in which context and in what form the information is presented. There does seem to be a general acceptance that energy advice for homeowners is needed. One could suggest that the message is clear and people would invest in energy efficiency measures. This however is not true. “Even if Belgians trust their energy expert more than Danes trust their label system, both groups do not follow the advice”(Gram-Hanssen et al., 2007).

The research concludes that pieces of advice must be quite simple. But often the energy efficiency measures take time, work and money while homeowners have many other priorities like aesthetics, identity and convenience. Also renovations are often not done because of energy efficiency but for economical reasons. Therefore the advice is to put less emphasis on the payback time but rather on investment costs and possible savings. The research concludes as follows: “This does however not mean that the energy labels on buildings are a bad idea but they should be seen as one input among others to people’s own knowledge and communication about their house and its renovation” (Gram-Hanssen et al., 2007).

In another study by ECN, the effectiveness of the labeling method is considered moderate in the review on Dutch energy efficiency policies (ECN, 2009). If energy labels are not an incentive to invest in energy efficiency measures, possibly a legal minimum energy performance could trigger investments. This is why the EPG and PHPP evaluation methods are implemented in the Netherlands.

³ Correction factor 1.02264 Calorific value 40.0; 1m³ gas = 9.8 kWh (Blom, Itard, & Meijer, 2010)
3.5 EPG

Newly built houses in the Netherlands are obliged to meet strict standards concerning energy efficiency. These regulations are found in the building decree. The EPG (Energie prestatie gebouwen) is indicated by the EPC (Energieprestatie Coefficient). The lower the EPC value, the more energy efficient a house is in theory. The construction standard for houses in the Netherlands was tightened from EPC=1.0 to EPC=0.8 in 2006. Recently from of January 1st 2011, the new construction standard is EPC=0.6. It is expected that the construction standard will be tightened to EPC=0.4 in 2015.

The EPC value is calculated to evaluate energy efficiency of houses. First construction related energy usage is calculated in MJ and divided by the acceptable energy usage. The latter one is related to the total floor area and total conduction area (heat loss through roof, walls and floor). Therefore the same standard can be applied on different houses. One should notice however, that with an EPC = 0.0, it is not per definition an energy neutral house. It depends on the applied definition of energy neutral. It is only energy neutral with EPC = 0.0 when it concerns construction related energy usage and standard circumstances. A few key success factors are mentioned for energy performance standards in the built environment in the research by Harmelink.

When dealing with a target group which is unwilling to act or hard to address concerning energy performance standards, there are a few characteristics that determine the success of the policy. The energy efficiency standard should be well justified, also through the entire life cycle of the house. The target group should be prepared for the standard. For example by information campaigns, demonstration projects, feasibility studies and training programs. Finally the entire housing and construction sector should be sufficiently skilled to apply the standard. (Harmelink, 2005) The overall effectiveness of energy performance standards is considered “high” (ECN, 2009).

Apart from an energy efficiency standard for houses, according to Smeds it is useful to add an appendix to the existing building code. The appendix should describe minimum requirements that have to be fulfilled to achieve a high performance solution. The appendix could then be used as a voluntary option for builders that want to invest in a building with better performance than what the original building code requires. (Smeds & Wall, 2007) This measure would be an incentive for individuals to invest in additional energy efficiency and would prepare all the parties involved for higher energy efficiency standards in the future.

A big issue with the EPG is the fact that there is a big difference between the theoretical and practical energy demand. In a study by VROM, the gas demand for heating in particular was studied, as shown in Table 2. The gas demand for heating was monitored for EPC 0.8-1.2. It shows a difference between the theoretical and the practical approach. This figure shows that the decline of the gas usage goes faster in theory (EPG method) than in practice (PRC Bouwcentrum BV en VROM, 2004). Also the relation between practical gas demand and the EPC value is not proven. These measurements result in large ranges between the practical heating demand for certain EPC values. The large range is caused by differences in user behavior and household composition.

Table 2. Practical and theoretical space heating demand (m³) according to EPG (PRC Bouwcentrum BV en VROM, 2004)

<table>
<thead>
<tr>
<th>EPC</th>
<th>Practical</th>
<th>Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.8</td>
<td>641</td>
<td>418</td>
</tr>
<tr>
<td>0.8-1.0</td>
<td>844</td>
<td>908</td>
</tr>
<tr>
<td>1.0-1.2</td>
<td>997</td>
<td>1180</td>
</tr>
</tbody>
</table>
3.6 PHPP

For passive houses there is a special evaluation method, the passive house planning package (PHPP). The technological characteristics of the passive house will be addressed in chapter 4. In a report by ECN, *the valuation of passive dwellings according to EPG and PHPP*, the PHPP is compared to the EPG (de Boer, Kondratenko, Jansen, Joosten, & Boonstra, 2009). Both methods are models used to determine the theoretical energetic performance of a building. The calculations include installations and the final primary energy demand for space heating, hot tap water, building related electricity (ventilation, heat pumps etc.) and lighting. In the PHPP the residential electricity use is also included. This is an essential difference because the PHPP includes an energy demand influenced by user behavior. It means that the amount and types of electrical appliances has influence on the outcome of the PHPP calculations.

In the PHPP and the EPG there are essentially different input values used as shown in Table 3. The first important difference is that the standard indoor air temperature is 18˚C in the EPG and 20˚C in the PHPP method. Another difference is that the standard hot tap water usage is higher in the EPG (37 l) compared to the PHPP (25 l). There is however some doubt if the 25 l hot water usage per person per day used in the PHPP is not too optimistic. The biggest difference is the internal heat load which is almost 3 times as much in the EPG calculations. The internal heat load involves the heat production by domestic appliances and inhabitants’ activity. Finally the improved air tightness in a passive house is only partly included in the EPG calculations. In the PHPP more input values are separately adjustable e.g. the average hot water usage per person and the amount of lamps installed. The EPG uses standard input values for these parts and will therefore limit the accuracy.

Table 3. Standard input values EPG and PHPP method (de Boer et al., 2009)

<table>
<thead>
<tr>
<th>Input values</th>
<th>EPG</th>
<th>PHPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Indoor temp.</td>
<td>18 ˚C</td>
<td>20 ˚C</td>
</tr>
<tr>
<td>2 Internal heat load</td>
<td>6.0 W/m(^2)</td>
<td>2.1 W/m(^2)</td>
</tr>
<tr>
<td>3 Ventilation</td>
<td>170 m(^3)/h</td>
<td>100 m(^3)/h</td>
</tr>
<tr>
<td>4 Hot water</td>
<td>Circa 37 l pp per day</td>
<td>25 l pp per day</td>
</tr>
<tr>
<td>5 Condensing boiler power</td>
<td>25 kW</td>
<td>15 kW</td>
</tr>
</tbody>
</table>

The study by de Boer (de Boer et al., 2009) shows that the effect of energy efficiency measures applied in a passive dwelling are under appreciated when the EPG method is used in comparison to the PHPP, as shown in Figure 3. The main reason is that the internal heat load is relatively higher (for both the EPC=0.8 as well as the passive house) according to the EPG than according to the PHPP. Therefore the heating demand for both dwellings is much lower according to EPG than according to PHPP. Energy efficiency measures aimed at reducing the heating demand in the passive house will therefore have little influence on the EPG value anyway. In the study an “in between” terraced house (EPC=0.74) is compared to a passive house and both are evaluated according to the EPG and the PHPP. The total primary energy demand for the EPC=0.74 and the passive house are shown in Figure 3 (de Boer et al., 2009).
Figure 3 shows that the heating demand of both the EPC=0.8 house and the passive house are lower according to the EPG method (respectively 22 and 7 kWh/m$^2$) as compared to the PHPP (respectively 63 and 15 kWh/m$^2$). The maximum heating demand for a passive dwelling is 15 kWh/m$^2$/a. According to the EPG method, a house with EPC=0.8 should almost reach a heating demand of 15 kWh/m$^2$/a while with PHPP the heating demand would be almost three times as large. Figure 3 also shows that more energy is used for hot water for both houses in the EPG method (41 and 41 kWh/m$^2$) compared to the PHPP method (25 and 27 kWh/m$^2$). The passive energy efficiency measures result in total energy savings of 42% according to the PHPP and only 16% according to the EPG (de Boer et al., 2009).

This analysis shows that the application of different evaluation methods results in significantly different outcomes regarding the theoretical energetic performance of houses. Additional research is necessary to improve the accuracy and reliability of the energy label, the EPG and the PHPP methods. Additional refinement of the methods will be necessary for strengthening trust in the methods by involved parties.

### 3.7 More with less campaign

Apart from energy efficiency labeling and standards, also a number of policies are applicable for homeowners. Some are available for rented houses as well. The website meer met minder (more with less) provides an overview of policies for homeowners.

- **Tax reduction on labor from 19% to 6% for renovation and insulation measures.**
- **Subsidy insulation glass (€35/m$^2$).**
- **Improving Energy Index with 0.50 points €300 subsidy and €750 for 0.75 points.**
- **Subsidies for solar boiler, heat pump or CHP.**
- **Subsidies for producing decentralized renewable energy.**
- **Loans with small interest rates for energy efficiency investments.**

For housing corporations there are special policies.

- **Subsidy for the installation of a CHP system €4000, a heat pump max €5000 and solar boiler €200 per gigajoule energy gain**
- **Green mortgage, 1% discount on interest rate**
- **Tax reduction on labor from 19% to 6% for renovation and insulation measures**

Above mentioned policies are specifically aimed at reducing the heating demand of houses. However, it can be confusing to select the right policy because many policies are temporary and locally oriented. Some of the above mentioned policies are withdrawn already because the budget has run out. Still the entire “more with less” campaign is evaluated as highly effective (semi-quantitative impact) in the ECN review on Dutch energy efficiency policies (ECN, 2009).
3.8 Practical experience with policy

In theory energy efficiency policies appear to be effective. In practice however, this is not always the case. Energy efficiency regulations are often not complied by constructors and real estate agencies in practice. Also many regulations are not enforced by authorities sufficiently. Hence, the EPG calculations prove easy to manipulate by varying input values. Because of this the credibility of the EPG method is low by involved parties. (Vrieze de, 2010)

A few studies where conducted about the practical energy savings of tightening the EPC value. The energy efficiency standards for houses where tightened from EPC=1.0 tot EPC=0.8 in the Netherlands in 2006. The policy change had consequences for architects, contractors, housing corporations, project developers, municipalities, consultancy companies etc. ECN did a practical evaluation of the policy and interviewed the concerned parties. Architects indicate that the policy change did not stimulate integral design, but the energy efficiency measures are becoming part of the design phase earlier than it used to be. Consultancies as well as installers state it would be good to be involved earlier in the design process, integral design is mentioned often. Many parties question whether a more stringent EPC leads to innovation. An EPC of 0.8 is in most cases achieved with traditional technologies which are a bit further developed e.g. CHP (combined heat and power), balanced ventilation with heat recovery and heat recovery in showers. All parties indicate that they rarely receive feedback from municipalities on the EPC calculations. Supervisors from municipalities give priority to safety on site and fire safety instead of EPC and energy efficiency measures during onsite inspections. There is also a big difference between municipalities concerning the assertion of regulations. Every involved party uses its own quality standards and inspections. Consultancies and architects are not involved in the onsite construction process at all. (Menkveld & Leidelmeijer, 2010)

All parties and inspectors doubt the correlation between the EPC value and the energetic performance in practice. Weak points in the EPC calculation and insufficient inspections are important issues. Also user behavior can influence the effect of energy efficiency measures and therefore limit the support for the EPC. When inhabitants leave windows open while having balanced ventilation or have longer showers because they have heat recovery in the shower (rebound effect). Most parties are critical for further tightening the EPC. Special attention should be paid to safeguarding indoor health conditions and comfort. (Menkveld & Leidelmeijer, 2010)

The practical energy savings from tightening the EPC to 0.8

The practical energy use for heating is influenced by the installation characteristics and the inhabitant’s behavior. Therefore the ECN collected gas meter data of 248 houses and invited inhabitants to a panel. Figure 4 shows the trend of the annual gas use (m$^3$) of the houses in the ECN research. Including the big uncertainties the switch from EPC=1.0 to EPC=0.8 results in 1-15% reduction of the gas use. This is less than the theoretical expected 20% reduction of gas use. (Menkveld & Leidelmeijer, 2010)

![Figure 4](image-url)

Figure 4, Trend of the practical gas use (m$^3$/year) compared to EPC value (Menkveld & Leidelmeijer, 2010)
The experience with tightening the EPC to 0.6

Only recently houses are constructed with an EPC of less than 0.6. Therefore only an explorative study by DGMR Bouw B.V. is available. The study focuses on a number of different houses which reached an EPC of less than 0.6 by improved construction and installation measures. The most important measures are HR++ glass, extra insulation of the envelope and doors, ground source heat pump, solar panels for pre heating water, balanced ventilation with heat recovery with CO₂ controlled ventilation lattice. In 75% of the cases the inhabitants are satisfied with the installations. In some cases there are complaints about draught, the ventilation system and heating. The complaints are not proven to be related to the energy efficiency measures. For the practical energy savings and costs analysis there is not sufficient data available yet. The CO₂ emissions are generally higher than what one would expect according to EPC calculations. (van der Loos & Vlot, 2009)

The experience with energy efficiency policies in practice are in line with conclusions drawn by (Harmelink, 2005). The energy label does raise awareness about energy efficiency of houses, but it should be seen as one input among others to people’s own knowledge and communication. Also tightening the EPG is a step in the right direction. However, a reliable energy efficiency evaluation method is missing. The EPG needs improvements to get more support and credibility by involved parties. For private parties the energy efficiency policies are often unclear and subsidies are only temporary. Often inspections by authorities are conducted insufficiently. Finally monitoring of the practical energy savings in houses is missing. The next chapter will address the design characteristics which are necessary to reduce the heating demand of houses.
4 DESIGN CHARACTERISTICS FOR REDUCING THE HOUSEHOLD HEATING DEMAND

A suitable showcase of a house with an extremely low heating demand is a passive house. This type of dwelling is extremely energy efficient due to the implementation of an air tight envelope, extreme insulation, balanced ventilation, heat pump and use of solar radiation as shown in Figure 5. In some cases also a ground source heat pump is applied. Therefore passive dwellings can make a significant contribution to a more sustainable housing stock in the Netherlands. The space heating demand of passive dwellings should be less than 15 kWh/m²/a, which is 15-25% of the current Dutch average. (Blom et al., 2010) The total primary energy demand should be less than 120 kWh/m²/a. In the Netherlands space heating accounts for 51% of the energy demand of dwellings in 2010 (Milieucentraal, 2010). Measurements indicate that a passive apartment consumes 65% less energy for heating. Therefore the CO₂ emissions are 25-40% lower than for energy efficient buildings. (Mahdavi & Doppelbauer, 2010) Passive dwellings are available in Europe already. However the current share of passive dwellings in the Dutch built environment is small. This chapter describes into which extend the above mentioned technologies can add to the reduction of the heating demand.

Figure 5, Passive house concept (55 Wolfgang, F.)

The first step to reduce the heating demand of a house is to minimize conduction through walls, roof and windows by applying insulation. Second heat loss caused by ventilation is reduced by applying balanced ventilation with heat recovery. Key features are given by J Smeds and M Wall for the reduction of the heating demand within the built environment (Smeds & Wall, 2007).

The first key feature is area to volume ratio. It describes the relation between the area of the building envelope and the building volume. The optimum ratio is the one for a globe, so the closer the shape of a building comes to a globe the smaller the thermal losses.

The second key design feature is the application of thermal insulation. From the first stage in building design the wall insulation should be included. Also insulation of windows and doors is very important. Double or triple layer glass can reduce thermal losses substantially. Special attention should be paid to avoiding thermal bridges. (Smeds & Wall, 2007)

The final key design feature is a balanced ventilation system with heat exchanger. It is applied to reduce heat losses from ventilation. Before warm air leaves the building the heat is exchanged to the cold fresh air entering the building. The heat exchanger should have an efficiency of at least 80% and should be equipped with a bypass to avoid over heating in summer periods. Because air should only
pass through the heat exchanger it is essential that the building envelope is very air tight. (Smeds & Wall, 2007) In warm periods the heat exchanger can be used for cooling the incoming air as well. The above mentioned features will be further explained in the following paragraphs.

The above mentioned key features are included in passive house designs. It results in an extremely energy efficient building as shown in Figure 6, a typical energy balance for a passive house. A common unit to express the amount of energy is kWh/m²/yr this will be used throughout this report. The left column shows the heat losses which are mainly caused by the windows and for a smaller extend by walls and ventilation. The heating demand is 15 kWh/m²/yr, which is 15-25% compared to a conventional house with a heating demand of 70-100 kWh/m²/yr. (Voss et al., 1996) The rest of the heat gains come from internal sources which includes rest heat from electrical appliances and inhabitant’s activity. Finally an important heat source is the gain of passive solar radiation through windows (mainly south). The energy balance for a conventional, energy efficient and a passive dwelling are compared in chapter 5.

Currently effort is put into the construction of energy efficient apartments. In a study by Mahdavi and Doppelbauer the heating demand of two energy efficient apartments and two passive apartments in Vienna were monitored. (Mahdavi & Doppelbauer, 2010) The results are shown in Table 4.

Table 4, Annual energy demand for passive houses (PH1&2) and energy efficient houses (LH1&2) (Mahdavi & Doppelbauer, 2010)

<table>
<thead>
<tr>
<th></th>
<th>Area (m²)</th>
<th>Inhabitants</th>
<th>Heating kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH1</td>
<td>59.4</td>
<td>1</td>
<td>8.4</td>
</tr>
<tr>
<td>PH2</td>
<td>89.5</td>
<td>3</td>
<td>15.2</td>
</tr>
<tr>
<td>LH1</td>
<td>51.6</td>
<td>1</td>
<td>22.4</td>
</tr>
<tr>
<td>LH2</td>
<td>84.5</td>
<td>5</td>
<td>46.4</td>
</tr>
</tbody>
</table>

The passive house apartments were shown to consume approximately 65% less energy for space heating as compared to low-energy apartments. Moreover, the CO₂ emissions for passive apartments were approximately 25–40% less than low-energy houses. These studies show it is possible to
construct a house with a low heating demand compared to modern energy efficient apartments. The next part addresses the installation measures required to reduce the heating demand substantially. The analysis is based on a study by Badescu V. In this study the Primasens passive house in Chemnitz, Germany, is monitored throughout January, and is well documented (Badescu & Sicre, 2003a). The total living area is 150m² divided over two floors as shown in Figure 7. It is suitable for a four person household.

Figure 7, Primasens passive house in Chemnitz (Badescu & Sicre, 2003a)

Figure 8 shows the characteristics of the heating and ventilation system. It includes a 36m long, single tube subsoil heat exchanger, a high-efficiency heat exchanger built into the ventilation system, a 9 m² solar thermal collector combined with 600 l layer water tank, and a wood pellet stove acting as backup heater with a heating loop to the water storage tank. (Badescu & Sicre, 2003a) The heating and ventilation system will be further addressed throughout this chapter.

4.1 Total heat loss
The total heat loss is the sum of the energy losses of both conductance and ventilation, multiplied by the temperature demand. The temperature demand depends on the thermostat settings and the degree days for a certain area. If e.g. the indoor temperature is 20°C and the outside temperature is 12 °C for a period of a week, it results in (20-12)*7=56. The temperature demand is for a big part determined by the thermostat settings of the house as shown in Figure 9 on the left. (Mackay, 2009) The city of Groningen in the Northern part of the Netherlands has e.g. 2777 degree days when the thermostat is set at 18°C. Degree days for cooling at the same location are 271 with the thermostat set at 20°C. (BizEE Software,)

Figure 9 shows on the left the degree days for cooling and heating in Cambridge, Great Britain. It also shows (on the right) that lowering the thermostat settings from 20°C to 17°C reduces the temperature demand for heating by 30%. Raising the thermostat from 20°C to 23°C reduces the temperature demand for cooling by 83%. (Mackay, 2009) By analyzing degree days it can be concluded that user behavior has a big impact on the heating demand. The second determinant of the total heat loss is conduction. It can be reduced by applying insulation. This will be addressed in the next part.
4.2 Insulation

The second determinant of the total heat loss is conductance. To reduce the heat loss as much as possible the building envelope should be extremely air tight and well insulated. And second there is the heat transfer by ventilation. In a typical house the heat loss by conductance has a larger share in the total heat loss than the ventilation. (Mackay, 2009)

Insulation measures limit heat loss through walls, windows and doors. The heat transfer is proportional to the temperature difference between the inside and the outside of the building. The rate of conduction is the product of the wall area, the U value and the temperature difference. The U value is a characteristic property for a certain material. Bigger U-values mean bigger losses of power. The thicker a wall is, the smaller its U-value. A number of U values for construction materials are given in Table 5. The table shows that improving the insulation makes a significant difference regarding heat loss. The table also shows that windows cause the biggest heat loss if compared to walls, roofs and floors. The table distinguishes old buildings, modern buildings and best methods. Triple layered glass and the best wall, roof and floor insulation available are necessary to meet passive construction standards.

Table 5, U values (W/m²/K) construction components (Mackay, 2009)

<table>
<thead>
<tr>
<th>Component</th>
<th>Old buildings</th>
<th>Modern standards</th>
<th>Best methods</th>
<th>Passive standard (Knoops, 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid masonry</td>
<td>0.45-0.6</td>
<td>0.12</td>
<td>&lt;0.15</td>
<td></td>
</tr>
<tr>
<td>11 inch brick-block cavity, unfilled</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 inch brick-block cavity, insulated</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>0.45</td>
<td>0.14</td>
<td>&lt;0.15</td>
<td></td>
</tr>
<tr>
<td>Suspended timber floor</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid concrete floor</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roofs</td>
<td>0.25</td>
<td>0.12</td>
<td>&lt;0.15</td>
<td></td>
</tr>
<tr>
<td>Flat roof with 25 mm insulation</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitched roof with 100 mm insulation</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>1.5</td>
<td></td>
<td>&lt;0.8</td>
<td></td>
</tr>
<tr>
<td>Single-glazed</td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-glazed</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-glazed, 20 mm gap</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triple-glazed</td>
<td>0.7-0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Applying insulation appears easy in theory, in practice however there are some issues. Applying thicker and better insulation leads to a major technical issue. One of those is overheating in summer periods. It is difficult to get rid of heat in a passive house because it is very air tight and thick insulation layers are applied. Another key issue concerning insulation is dealing with vapor pressure from warm to cold. Therefore vapor restraining layers are necessary within the construction in summer as well as winter periods. During summer periods water vapor tries to enter the construction. Preventing the moist to condensate inside the construction proves very hard in practice. Moist within the construction materials reduces the insulation levels and can cause serious damage to the construction. This is a major challenge during the construction of passive dwellings. Insulation companies are working on special layers of material which allows water vapor to enter the construction only one way direction (Halbertsma, J., 2008). Ron de Vrieze emphasizes in an interview that more research on this topic is required (Vrieze de, 2010). Besides conductance also ventilation is an important determinant of the total heat loss of a house. In regular houses heat is lost when windows are opened for ventilation purposes.

4.3 Balanced ventilation with heat recovery

The third part of a buildings’ total heat loss is determined by ventilation losses and air leaks. Fresh air is required for a healthy and safe indoor climate. However, in most cases the fresh air entering the building is colder and dryer than the indoor air. When the warm and moist air is extracted the energy is lost. Therefore balanced ventilation with heat recovery is applied to provide enough fresh air and limit heat losses through ventilation. Figure 10 shows a schematic picture of balanced ventilation. As shown in the picture additional heating is provided by the electric heating coil. In many passive houses additional heating is provided only on the coldest days throughout the year and will be provided by natural gas fired condensing boilers. On the long term additional heating could be provided by renewable electricity or green gas fired condensing boilers.

Figure 10, Balanced ventilation with heat recovery (Nyman & Simonson, 2005)

The application of balanced ventilation led to fierce discussions about bad health conditions caused by poor indoor air quality in the past. Some issues where raised about high CO$_2$ concentrations and inhabitants showing signs of building sickness. (VROM & vereniging eigen huis, ) Therefore the filters are very important. In the performance comparison between a passive and a low energy building by Mahdavi and Doppelbauer, as shown earlier, the balanced ventilation system was evaluated. The results suggest that both passive and low-energy apartments performed well in view of thermal conditions and indoor air quality. The use of a balanced ventilation system clearly contributed to lower levels of carbon dioxide concentrations in particular during cold periods and especially in multiple-occupancy apartments. The level of acceptance regarding the ventilation system was quite high. And none of the interviewees showed any sign of building sickness. The inhabitants of both buildings were generally satisfied with indoor conditions and building systems.(Mahdavi & Doppelbauer, 2010) Most problems with balanced ventilation occur when inhabitants turn the system off due to high noise levels. Therefore close attention should be paid to proper installation, system use and maintenance of balanced ventilation to guarantee a safe and healthy indoor climate.
The correlation between balanced ventilation and the EPC value was studied by ECN. (Menkveld & Leidelmeijer, 2010) The EPC value indicates the energy efficiency of houses, it will be further explained in the next chapter. In this study the experiences and complaints of inhabitants with balanced ventilation are compared to the ones with mechanical ventilation. This ECN study is less promising than the Mahdavi and Doppelbauer research. The ECN study proves there is no correlation between the EPC of houses and the health of inhabitants. However, there are correlations concerning the application of balanced ventilation. An enquiry shows that inhabitants with mechanical ventilation are satisfied with the ventilation system of the new house (62%), but for balanced ventilation only (49%) is satisfied. The most common complaint is the noise level, followed by the limited possibilities for adjusting the ventilation level. Also the impossibility of natural ventilation is mentioned and the air is experienced by inhabitants as “not fresh” in some cases. The share of inhabitants that find the indoor air too dry is two and a half times larger with balanced ventilation than with mechanical ventilation. Also 19% of the inhabitants with balanced ventilation find indoor temperatures in summer periods too high in comparison to only 7% for mechanical ventilation. In this case a bypass in the heat exchanger could solve a part of the problems.

Finally the research shows that there are more health issues with balanced ventilation than with mechanical ventilation. Often mentioned issues are sore throat, irritation of the skin, irritation of contact lenses, fatigue, colds and infected eyes. There is a strong suspicion that inhabitants tend to turn down the ventilation system (balanced as well as mechanical) when they experience noise. (Menkveld & Leidelmeijer, 2010) Both studies suggest that balanced ventilation does not necessarily cause health problems. They do show however, that there are more health issues reported and complaints concerning noise in houses with balanced ventilation compared to houses with mechanical ventilation. Noise is seen a big problem because it is one of the main reasons for improper use of balanced ventilation and therefore causing health issues.

In the case of the passive house in Chemnitz the temperature is kept at 20˚C by regulating the air temperature released by the balanced ventilation. The indoor air temperature is shown in Figure 11 and the temperature of the released air by the ventilation system is shown in Figure 12. (Badescu & Sicre, 2003a)

![Figure 11, Indoor air temperature Chemnitz passive house (Badescu & Sicre, 2003a)](image)

![Figure 12, Air temperature at heater exit Chemnitz passive house (Badescu & Sicre, 2003a)](image)

The figures above show that between 9 am and 4 pm little additional heating is required. At these times other heat sources like passive solar radiation, rest heat from appliances and occupants’ activity are sufficient to maintain comfortable indoor temperatures.
As an example the air temperatures are given for the Chemnitz passive house (Badescu & Sicre, 2003b).

- The exterior temperature is -10°C and is filtered.
- The ground temperature at 2 m depth stands between 7 and 10°C even during cold winters.
- The fresh air is warmed up to 7 °C, in the earth-to-air heat exchanger.
- In the cross-flow heat recovery unit, around 80% of the heat of the outgoing stream is transferred to the incoming stream.
- The fresh air is heated up to 18°C.
- The air post-heater (supplied with heating water from the solar tank or fossil fuels), warms up the supply air to 40°C. As shown in Figure 12.
- Due to heat transmission and heat radiation, supply air comes into the rooms with a temperature of 22 °C.
- Exhaust air leaves with a temperature of 7 °C.

To analyze the effect of applying balanced ventilation on the total energy demand, a study was conducted by Blom et al. Different apartments (84.24m²) in a conventional seven story residential building where compared as shown in Table 6. It was built between 1966 and 1988, it does not regard a passive building.

Table 6, Comparison of balanced ventilation with conventional (mechanical) ventilation (Blom et al., 2010)

<table>
<thead>
<tr>
<th></th>
<th>1 Conventional</th>
<th>2 Balanced ventilation with HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system</td>
<td>Condensing boiler</td>
<td>Condensing boiler</td>
</tr>
<tr>
<td>Efficiency</td>
<td>107%⁴</td>
<td>107%⁴</td>
</tr>
<tr>
<td>Temp. supply (°C)</td>
<td>90/70</td>
<td>90/70</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Collective mechanical exhaust</td>
<td>Individual balanced with heat recovery</td>
</tr>
</tbody>
</table>

The effect of the application of balanced ventilation with heat recovery on the total annual energy demand of a single apartment is shown in Figure 13. It shows that for apartment 2 with balanced ventilation, the heating demand almost reduced by half to 2362 kWh/a compared to apartment 1 with conventional ventilation. The additional electricity demand is 226 kWh/a for apartment 2.

Figure 13, The effect of the application of balanced ventilation in a cold climate{{19 Blom, I. 2010}}

Correction factor 1.02264 Calorific value 40.0 and 1m³ gas = 11 kWh. Electricity includes system components like circulation pumps and ventilators. Electricity demand for domestic appliances is not included.

⁴The efficiency of a condensing boiler is related to the lower heating value (LHV) of gas. Since a high efficiency condensing boiler recovers heat from combustion gases, an efficiency of more than 100% is gained.
The studies presented above show that balanced ventilation is an effective method for reducing the heating demand for houses. It accounts not only for passive dwellings (Badescu & Sicre, 2003b) but for conventional houses as well (Blom et al., 2010).

4.4 Passive solar radiation

The final key feature for energy efficient buildings is the use of passive and active solar energy. To optimally use passive solar energy, the orientation of windows is important. Generally, the window area should be moderate to reduce thermal losses. Shading devices are recommended to avoid overheating in summer periods. (Smeds & Wall, 2007) The shading devices are usually installed such to block sun around noon and in summer time and allow sunlight in the morning, afternoon and in wintertime when the stance of the sun is low.

![Figure 14](image1.png)

![Figure 15](image2.png)

Figure 14 and Figure 15 show the relation between the global solar irradiance $G$ (W/m$^2$) on a horizontal surface and the passive solar gain inside the passive house. In both figures it shows a peak between 6 am and 5 pm. The passive solar gain depends on the orientation, the transmittance and the area of the windows. Utilizing passive solar energy is often considered less suitable for northern European countries. Yet the average annual solar irradiance in the Netherlands is only 40% less than in central Spain (European Commission, ).

The biggest issue with solar energy is the fact that the irradiance is lowest in wintertime when the heating demand is highest. Therefore seasonal heat storage would be necessary. One of the possibilities is a ground source heat pump or hydrogen storage. The drawback of these options is that they require more technical installations and therefore increase financial and material investments. Another possibility might be to reduce window sizes to reduce heat loss by conduction in winter time.

The classic approach for a passive building is to minimize the window areas facing north (to prevent heat loss in cold periods) and to maximize window areas facing south (to maximize heat gains from solar irradiation). There is a tradeoff between the gain of heat by solar irradiation and the heat loss by conduction through the windows. There are a few studies conducted on this topic, key elements in the analysis are window area, window orientation, floor area- window area ratio, type of glass and type of shading device.

A Swedish study focuses on the influence of window size on the heating demand of low energy houses (Persson, Roos, & Wall, 2006). The study focuses on 20 terraced houses built in 2001 with the best construction techniques available. The houses have a relative small window area facing north and a relative big window area facing south. The houses are equipped with balanced ventilation with heat exchanger and 900W backup heater. Also solar collectors are installed on the roof to cover 50% of the hot tap water demand.
The main conclusion is that the size of energy efficient windows does not have a major influence on the heating demand in winter periods, but does have influence on the cooling demand in summer periods. This means that the window size facing north can be enlarged in comparison to prior passive designs to optimize lighting conditions in the dwelling. Another conclusion is that to minimize the cooling demand and the risk of overheating in summer periods the window area facing south can be designed smaller than in the traditional passive designs. As a rule of thumb it is stated that the window area should be around 10% of the floor area to provide enough daylight. (Persson et al., 2006)

![Figure 16](image-url)

Figure 16. The influence of window size on the heating and cooling demand (Persson et al., 2006)

The influence of window size on the heating and cooling demand in a passive house is shown in Figure 16. Different configurations of window area, window orientation and type of glass where simulated. An optimum regarding space heating demand can be found somewhere between a reduced area of 20-50% in comparison with the conventional window size for passive houses. The figure shows that the heating demand with energy glass is lower than having no windows to the south at all. This is because windows can collect and use solar energy in periods when the sun is shining and the indoor temperature is higher than the outdoor temperature.

Another study by van der Loos focuses on the orientation of windows of common houses. The study concludes that orientation to the south in an apartment building or “in between” terraced house with condensing boiler increases the energy efficiency substantially (it reduces the EPC with 0.05). (van der Loos & Vlot, 2009)

### 4.5 Active solar radiation

Apart from passive solar radiation also active solar radiation is utilized as a heat source. It is called active since it requires the use of technical equipment (pump and control unit). In the case of the Chemnitz passive house, solar panels (9m²) with 600l water storage tank are installed (not to be confused with photo voltaic cells).

![Figure 17](image-url)

Figure 17. Heat gain of the passive solar panels in January (Badescu & Sicre, 2003a)

When the passive solar energy (through windows) is sufficient to meet the heating demand, the active solar system (solar thermal collector) is considered as excess energy. The heat gain of the active solar...
panels in January is shown in Figure 17. One of the solutions applied in the Chemnitz passive house is a 600l water tank. (Badescu & Sicre, 2003a) The active solar energy is used to heat water in this tank and will be used to pre heat hot tap water. Calculations indicate that 63% of the demand for hot tap water is met by active solar heat. (Badescu & Sicre, 2003b) This system can be optionally used to assist the space heating system. Also heat is contained within the buildings’ structure. Seasonal heat storage however, is still an issue. To solve the problem of seasonal heat storage a heat pump can be installed.

4.6 Heat pump
A renewable alternative for the conventional condensing boiler for space heating is a heat pump. In most cases it is either a ground source or an air source heat pump. The ground source heat pump consists out of a number of tubes deep in the ground (50m). Every tube in the form of a loop carries a liquid up and down to uptake heat. The heat is then released in a heat exchanger to the hot water circuit of the heating system in the house. In summer time the heat pump can be used for cooling by storing the heat in the ground. An issue with heat pumps is that low temperature heating is applied (< 55 °C), it requires floor –or wall heating. Therefore for retrofit project it is a less suitable technology. The biggest advantages are that it is a reliable system and that heat can be stored over the seasons. (Hwang, Ooka, & Nam, 2009)

4.7 Micro combined heat and power
A micro combined heat and power (CHP) system produces heat as well as electricity inside the house. Similar to a condensing boiler is runs on natural gas. The efficiency of the CHP system, as applied in this study, is 88% for heat and 12% for electricity. In conventional power plants (natural gas and coal) a lot of energy is lost as excess heat when electricity is produced. With the CHP system the excess heat can be used directly for space heating and hot tap water within the household. (De Paepe, D'Herdt, & Mertens, 2005)

4.8 Package of measures with related EPC value
The question that now arises is which energy efficiency measures are necessary to achieve certain EPC values. For the scenarios in chapter 6, a number of packages of energy efficient measures are assembled with the use of MERLiN software. There are different packages for newly constructed houses and retrofitted houses, all including an EPC value as shown in the appendix on page 53. It is important to notice that different configurations would also be possible for a certain EPC value. The different packages will be further addressed in paragraph 6.1.2.

This chapter shows that there are many options to substantially reduce the heating demand of houses. The first essential step is to minimize the total heat loss of the house. A number of technical measures where addressed throughout the chapter. Firstly the total heat loss is determined by the temperature demand, the conductance and the ventilation losses. Secondly applying good insulation reduces the total heat loss significantly. Thirdly the application of balanced ventilation with heat recovery minimizes heat loss by ventilation. Finally a heat pump and a micro CHP provide efficient energy. When the total heat loss is minimized the last step is to utilize passive and active solar energy.

Still there are a number of issues with these technologies. In air tight and well insulated houses it is hard to get rid of moist. Also overheating is an issue. Finally balanced ventilation should be installed - and maintained properly, to guarantee a safe indoor climate.

The next chapter will address the entire life cycle of an energy efficient house. There will be a subdivision between the energetic payback time and the financial payback time of energy efficient construction methods.
5 LIFE CYCLE ANALYSIS OF ENERGY EFFICIENT HOUSES

Within life cycle studies a few definitions are used. Therefore this chapter starts with an overview of definitions according to the literature studied.

Definitions:

- **Operating energy**: Energy used in buildings during their operational phase, as for: heating, cooling, ventilation, hot water, lighting and other electrical appliances. It might be expressed either in terms of end-use or primary energy. (Sartori & Hestnes, 2006)
- **Primary energy**: Energy measured at the natural resource level. It is the energy used to produce the end-use energy, including extraction, transformation and distribution losses. (Sartori & Hestnes, 2006)
- **Total energy**: The sum of all the energy used by a building during its life cycle (total embodied energy plus operating energy multiplied by lifetime). (Sartori & Hestnes, 2006)
- **Embodied energy**: the energy utilized during manufacturing phase of the building. It is the energy content of all the materials used in the building and technical installations, and energy incurred at the time of erection/construction and renovation of the building. Energy content of materials refers to the energy used to acquire raw materials (excavation), manufacture and transport to the building site. Embodied energy is divided in two parts: initial embodied energy and recurring embodied energy. (Ramesh, Prakash, & Shukla, 2009)
- **Initial embodied energy**: The sum of the energy embodied in all the material used in the construction phase, including technical installations. (Sartori & Hestnes, 2006)
- **Recurring embodied energy**: The sum of the energy embodied in the material used in the rehabilitation and maintenance phases. (Sartori & Hestnes, 2006)
- **Direct energy**: energy used for construction, operation, rehabilitation and demolition. (Sartori & Hestnes, 2006)
- **Indirect energy**: the energy used for the production of the materials (embodied energy). (Sartori & Hestnes, 2006)
- **End-use energy**: energy measured at the final use level. (Sartori & Hestnes, 2006)

We have seen in the previous chapters that there are many options to substantially reduce the heating demand of energy efficient houses. These measures however, require extra financial and energetic investments in most cases. This chapter addresses the energetic and financial life cycle analysis of energy efficient houses and passive houses. The first part of this chapter concerns the energetic payback time. This part focuses on the embodied energy. Embodied energy is the energy that was used during the production process of building parts including raw material extraction, transport, construction, manufacture and deconstruction. Studies that consider energy required for construction, demolition and transport of materials all show that the sum of the energy needed in those phases is negligible or around 1% of the energy required for the entire life cycle of a house. (Sartori & Hestnes, 2006) When also energy included in the materials and installations are added, the total embodied energy is found. This represents in general 5-10% of the total life cycle energy use. (Ramesh et al., 2009)

The second part of this chapter focuses on the financial payback time of the additional investment. Higher construction costs are generally caused by the ventilation system, high performance windows and the additional thermal insulation. Studies show that the financial payback time of a passive house is 6-18 years compared to a current newly constructed house (Mahdavi & Doppelbauer, 2010). It is important to make sure that energy efficiency investments (financial as well as energetic) make sense over the entire life cycle of a house.
5.1 Energetic life cycle analysis

In Figure 18 the life cycle of a house is shown. Energy is required in every part of the life cycle. The cycle starts with the extraction of raw materials, building material production, transport and construction. The second part is the use phase where energy is required for heating, ventilation, air conditioning, hot water, electrical appliances and lighting. The final part is the demolition phase including the transport and recycling of waste and building materials. In most literature the lifetime of a Dutch house is assumed to be 80 years. The ratio between operating and embodied energy use varies between different types of houses. This will be further addressed throughout this chapter.

![Life cycle of a house (Ramesh et al., 2009)](image)

First it is necessary to find out what the energetic life cycle is of a passive house compared to other types of houses. A number of studies where conducted on this topic, some will be addressed here. A study by Feist (1996) compares six different types of buildings on end use energy as shown in Figure 19. It shows that a passive house is four times more energy efficient on the entire life cycle than a conventional house (ordinance 1984). In this case the operating energy was expressed as primary energy and a lifetime of 80 years was considered. The self sufficient solar house does not have operating energy requirements but the initial end use energy and recurring end use energy requirements are considerably higher. This increase is caused by the extra energy requirements for technical installations (PV panels and energy storage systems) and maintenance. Therefore the total life cycle energy requirements of the passive house are lower compared to conventional, low energy and self sufficient solar houses.
A literature review about the life cycle energy use of 60 different buildings from nine countries was conducted by Sartori et al. (2006). The study revealed a linear relation between the operating and the total energy through all cases. (Sartori & Hestnes, 2006) The operational energy requirements prove to be by far the largest energy requirements over the entire life cycle of a house. This is one of the reasons why the focus in many studies lies on reducing operating energy.

In a review by Ramesh et al. the life cycle energy use of 67 cases including residential and office buildings where analyzed. In this study the ratio between embodied and operating energy is 10-20% to 80-90% respectively. Despite the fact that application of passive (and active) technologies leads to increased embodied energy, it reduces the operating energy significantly. However, an excessive use of passive (and active) features in a building may be counterproductive (Ramesh et al., 2009). The study emphasizes that low energy houses perform better than self sufficient houses in the life cycle content.

In a study by Mahdavi et al. the additional investments of two passive apartments are compared to the construction of (current) energy efficient apartments. The amortization time for additional energy is around 1-3 years with respect to embodied energy and 2-5 years regarding CO$_2$ emissions (Mahdavi & Doppelbauer, 2010).

A study by Blom et al. (Blom et al., 2010) focuses besides the energetic and financial life cycle, also on the total environmental impact of houses. They conclude that decreasing energy consumption by decreasing the heating demand in houses is the most effective option to limit the environmental impact concerning heating and ventilation systems. On the one hand improving the energy efficiency of the climate systems (balanced ventilation with heat recovery) will reduce the environmental impact. But on the other hand the more systems added, the higher the operating energy and material content are. This situation might shift the impact categories that are affected most in the LCA. They emphasize that it is important to focus on the development of climate systems which reduce gas consumption without increasing operational electricity consumption. One of the options mentioned is to improve the service life, the durability and adjustability of climate systems so that less replacement and maintenance is needed (Blom et al., 2010).

Above mentioned researches all agree on the fact that operating energy is much larger than the embodied energy considering the total energetic life cycle of a house. The ratio between both depends on user behavior, type of construction and installations. Finally the articles emphasize that a balance should be found between increasing the amount of energy efficient installations and limiting operating energy because of additional electricity usage and material usage. The energetic payback time of the additional investments for a passive house compared to current standards is 1-3 years. The financial payback time of additional passive measures is considerably higher than the energetic payback time (Ramesh et al., 2009). This will be further explained below.

Figure 19 Total primary energy demand six types of houses (Feist, 1996)
5.2 Financial life cycle analysis

Besides the energetic payback time of houses, the financial payback time might be even more interesting. This part addresses the financial feasibility of energy efficient measures for Dutch households and passive houses.

A passive house is more expensive than a conventional house. An average price for a passive house is €225,000, it was calculated in a survey among 15 passive house owners. The average price of a conventional house was considered €185,250. The additional costs are €39,750 (Knoop, 2006), which is 21.5%. In these calculations the price for land is not included. There are also possibilities for subsidies for municipalities housing corporations and developers. Subsidies are not included here and depend on the type of project.

Figure 20 shows the financial consequences of energy efficiency measures compared to a reference house with a space heating demand of 100 kWh/m²/a (conventional house). The figure shows that the additional construction costs increase slowly at first but then increase faster when the limit of zero heating is approached. The capitalized energy costs decrease almost linearly. The sudden reduction of the total costs at specific space heating demand of 15 kWh/m²/a is caused by the replacement of a conventional heating and hot water system (expensive) by e.g. a less expensive small heat pump. The heating system can be replaced because the heating demand is low enough to be covered fully by a different kind of heating system. The total costs show a minimum for current low energy houses between 40-50 kWh/m²/a of 70 €/m². For passive houses the minimum of the total costs is at 15 kWh/m²/a with also 70 €/m². (Feist & Schnieders, 2009) This study shows that passive houses are a cost efficient way of reducing the heating demand in the built environment.

Above mentioned study shows the total costs for different heating demands of houses. It would be interesting to move the point where the common heating system (condensing boiler and radiators) is replaced to a position more to the right (15-50 kWh/m²/a). The question that arises then is whether the total costs will be lower than when a conventional heating system is applied. This depends on the type of heating system and its required power.

The study by Mahdavi et al., mentioned earlier, concludes that the additional costs for the construction of passive apartments was 5% compared to the (same type) low energy apartments. The payback time was calculated to be 6-18 years. The range depends greatly on the user’s behavior. Also rising energy prices are not included here. (Mahdavi & Doppelbauer, 2010)
Both studies conclude that the financial payback time of additional passive measures is considerably longer compared to the energetic payback time. The period depends greatly on user behavior and future (gas) energy prices. A big financial advantage of a passive house is the fact that no conventional heating system is required.

In the above mentioned cases the additional financial investment of a passive house will offset within 18 years maximum. On the life cycle of a house which is eighty years or more, this period might seem not that long. From a personal point of view this kind of investment is however quite large and considered as long term. People tend to move to a different house usually within those 18 years. The additional investments are in many cases not added to the total value of the house when it is sold, which means that a part of the investment is lost.

The next chapter will address three different scenarios to evaluate the potential of Dutch policy to meet the European CO₂ emission targets for household heating in 2050.
6 SCENARIOS HOUSEHOLD HEATING AND CO₂ EMISSIONS

The main focus of this research is to analyze the potential of Dutch policy to meet the European CO₂ emission targets for household heating in 2050. Therefore three different scenarios are calculated with an Excel model. The scenarios differ in the ambition level to reduce the household heating demand and corresponding CO₂ emissions. Scenario 1 represents the current situation with no future policy. The scenario 2 represents the current situation with current ambition levels (current policy). And scenario 3 represents a situation with a high ambition level. The analysis shows that current Dutch policy is insufficient to meet European emissions targets for 2050.

6.1 Method scenarios

The scenarios are calculated with an Excel model, based on three main parts. First the characteristics of the Dutch housing stock are analyzed. Secondly the theoretical space heating demand of different types of houses is analyzed. Finally the CO₂ emissions per MJ of gas, as well as for electricity are determined. The three steps result in the total CO₂ emissions for household space heating as shown below.

\[ \text{Total CO}_2 \text{ emissions household heating} = \text{no. households (sum n1, n2, n3) \times heating demand (MJ for gas and electricity) \times CO}_2 \text{ emissions for gas and electricity (kg CO}_2/\text{MJ)} \]

6.1.1 Characteristics Dutch housing Stock

The first input for the model is the future characteristics of the Dutch housing stock. There are a number of trends noticeable (Jeeninga & Jelsma, 2002).

- More floor area and volume per inhabitant
- Increasing attention for safety and health
- Continuing quality improvements
- More complex shapes
- Automation, more electrical controls and appliances

The CBS prognosis of the Dutch housing stock for 2050 is shown in Table 7. The total number of households is applied as an absolute value within the model. The size of the housing stock is related for a large part to the population size. According to CBS statistics the Dutch population grows on average with 235 persons per day, which are 85775 persons per year. With a total population of 16.5 million people in 2010, the growth rate is therefore 0.51% per year (CBS, ). The expected growth of the population will cease in 2040 (Duin, 2009). Another factor is changing composition of households, an average household exists out of 2.22 persons in 2010 and is expected to be 2.06 persons in 2050.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total population</th>
<th>Average household size</th>
<th>Total households</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>16536423</td>
<td>2.22</td>
<td>7354720</td>
</tr>
<tr>
<td>2020</td>
<td>17013720</td>
<td>2.14</td>
<td>7860148</td>
</tr>
<tr>
<td>2030</td>
<td>17380345</td>
<td>2.09</td>
<td>8195689</td>
</tr>
<tr>
<td>2040</td>
<td>17473632</td>
<td>2.07</td>
<td>8271998</td>
</tr>
<tr>
<td>2050</td>
<td>17342447</td>
<td>2.06</td>
<td>8229146</td>
</tr>
</tbody>
</table>

Within the total number of households a number of changes will occur in the future. The development of the housing stock includes the construction of new houses (n1), the retrofitting of old houses (n2) and the old stock (n3). The share of these three categories changes over time. The new share (n1) and the retrofitted share (n2) will gain, while the share of the old stock (n3) will gradually reduce. Therefore the efficiency of the total housing stock will improve.
6.1.2 Heating demand households

The second input for the model is the household heating demand. It determines for a large share the CO₂ emissions of a household. To link the heating demand to Dutch policy, the EPC value and corresponding heating demand are calculated for different types of houses. The EPC value and heating demand depend on the type of house, heating system and insulation as shown in the appendix on page 53. This was calculated with MERLiN computer model. The results are shown in Table 8. The first column shows the package of measures. The average 2010 represents the current average Dutch household. Then 4 different packages for newly built houses are assembled. New 4 is the most energy efficient configuration possible in MERLiN software, this is considered a passive house. Finally 2 different configurations for the retrofit of old houses are assembled. The total heating demand is the sum of gas demand and electricity demand for space heating.

Table 8, Total annual single household space heating demand and EPC (MERLiN), end of the row/2 under one roof 134 m²

<table>
<thead>
<tr>
<th>Package of measures</th>
<th>EPC</th>
<th>Gas (MJ)</th>
<th>Electricity (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Balanced Ventilation</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>Average 2010 (134 m²)</td>
<td>1.06</td>
<td>40174</td>
<td>0</td>
</tr>
<tr>
<td>New 1</td>
<td>0.79</td>
<td>18816</td>
<td>2289</td>
</tr>
<tr>
<td>New 2 (standard 2011)</td>
<td>0.61</td>
<td>0</td>
<td>2289</td>
</tr>
<tr>
<td>New 3 (standard 2015)</td>
<td>0.39</td>
<td>0</td>
<td>2289</td>
</tr>
<tr>
<td>New 4 (passive)</td>
<td>0.22</td>
<td>0</td>
<td>2289</td>
</tr>
<tr>
<td>Retro 1 (good ins)</td>
<td>0.85</td>
<td>24670</td>
<td>0</td>
</tr>
<tr>
<td>Retro 2 (good ins+CHP)</td>
<td>0.62</td>
<td>30838</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 8 shows that the average Dutch household has an EPC value of 1.06 and space heating is based on gas. Balanced ventilation is applied on all new construction (new 1-4). A heat pump is applied on new 2-4, the electricity demand for the heat pump depends on the insulation level. In retrofit 1, only additional insulation will be applied. In retrofit 2 also a combined heat and power (CHP) system is applied. No balanced ventilation or heat pump is applied on retro 1 and 2 because of practical difficulties with installing these systems in existing houses. Because the balanced ventilation and heat pumps run on electricity, a switch occurs from gas to electricity.

6.1.3 CO₂ emissions for electricity and gas

The third input for the Excel model is the CO₂ emissions for 1 MJ of gas and 1 MJ of electricity. The considered emissions for the different scenarios are shown in Table 9. The CO₂ emissions of 1 MJ of gas depend on the type of gas (green gas and natural gas) in the national grid. The share of green gas is considered to increase in the future. When green gas is considered CO₂ neutral, the total CO₂ emissions of the gas mix will decrease over time. The share of green gas depends on the ambition of the EU and the Dutch government. Different ambition levels for the different scenarios where assumed within this study, as shown in Table 9. SC1 has the lowest ambition level and SC3 has the highest ambition level. SC3 is according to the EU target, 10% green gas in 2020 and 50% in 2050 (Wempe & van der Drift, 2007).

Table 9, CO₂ emissions for electricity and gas mix

<table>
<thead>
<tr>
<th></th>
<th>Gas (kg CO₂/MJ)</th>
<th>Electricity (kg CO₂/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2050</td>
</tr>
<tr>
<td>SC1</td>
<td>0.051</td>
<td>0.051</td>
</tr>
<tr>
<td>SC2</td>
<td>0.051</td>
<td>0.039</td>
</tr>
<tr>
<td>SC3</td>
<td>0.051</td>
<td>0.027</td>
</tr>
</tbody>
</table>

A similar situation is there for the CO₂ emissions of electricity. As shown in Table 9, the CO₂ emissions for 1 MJ of electricity are much higher than for gas. This is caused by efficiency losses during production in the power plant and losses during transport in the electricity grid. The emissions for electricity depend on the share of renewable electricity within the national grid. Renewable
electricity is considered CO₂ neutral within this study. Similar to gas, the share on renewable electricity depends on the ambition level of the EU and the Dutch government. Different ambition levels for the different scenarios where assumed within this study, as shown in Table 9. SC1 has the lowest ambition level and SC3 has the highest ambition level. SC3 is according to the EU target, 80% renewable electricity in 2050.

It is important to notice that only direct CO₂ emissions are considered in the scenarios. Bio gas is subject to a lot of discussions. These discussions comprise mainly the indirect environmental impact of various forms of biogas production. The main topics are eutrophication, acidification, air pollution, changed land use and handling of organic byproducts. Such indirect effects are seldom considered in environmental analyses of biogas systems, though they can affect the results significantly (Borjesson & Berglund, 2007).

6.1.4 Assumptions scenarios

- EU emission targets include the reduction of CO₂ emissions (20% in 2020 and 80% in 2050 reduction) for all sectors in the Netherlands. For the scenarios the targets are applied on household heating only, not total household energy demand.
- Total number of households is based on the CBS prognosis until 2050 and is an absolute value in the model. Only the ratio of different types of houses (n1 new, n2 retrofit and n3 old stock) changes over time.
- Demolition is always followed by the same rate of new construction.
- Value for natural gas applied is 32 MJ/m³, as applied in the MERLiN model.
- Natural gas CO₂ emissions are considered 0.051 kg/MJ in 2010.
- Electricity CO₂ emissions are considered 0.130 kg/MJ in 2010.
- House is considered “passive” with EPC of 0.22.
- End of row house/ 2 under one roof with 134 m² is considered the average Dutch house within the model. The other types are an apartment (average 75 m²), a row house (average 111 m²) and a single house (average 194 m²).
- The average EPC value for the Dutch housing stock is 1.06 in 2010.
- Gas usage for cooking and hot tap water is not included in scenarios.
- In the model a house built after 2010 will not be replaced or retrofitted.
- The EU target for the share of renewable electricity in the national grid is 80 %.
- The EU target for the share of green gas is 10% in 2020 and 50% in 2050 (Wempe & van der Drift, 2007).
- Green gas is considered CO₂ neutral since carbon is stored in the biomass before it is released into the atmosphere.
- Renewable electricity is considered CO₂ neutral.
- For the annual electricity demand of balanced ventilation a standard value is considered of 2289 MJ. In MERLiN the electricity demand for BV is not considered in the category for heating, it is derived from the total household electricity demand.
- The CHP system applied in the model: Blauwe Engel II, ATAG BV, with electrical efficiency 12% and heating efficiency 88%.

6.1.5 Input scenarios

Three different scenarios are assembled to investigate the potential of Dutch policy to meet the European CO₂ emission targets for household heating in 2020 and 2050.

Table 10 shows the input values for the different scenarios.

<table>
<thead>
<tr>
<th>Table 10, Input values scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SC1, no policy</strong></td>
</tr>
<tr>
<td>Share green gas/ electricity mix 2050</td>
</tr>
<tr>
<td>n1 New Stock</td>
</tr>
<tr>
<td>electricity mix 2050</td>
</tr>
</tbody>
</table>

37
Scenario 1 is characterized by the current situation with no policy concerning energy efficiency. It includes the current electricity and gas mix and they do not change until 2050. The new houses will be built according to current construction methods, leading to EPC=0.8. The annual rate for retrofit is 0.8%. The old stock will remain the average of 2010 with EPC=1.06.

Scenario 2 is characterized by current policy. The electricity and gas mix change according EU targets but the targets for green gas and renewable electricity are only met half. SC2 results in 25% green gas and 40% renewable electricity in 2050. For new construction the EPG is tightened to EPC=0.4 in 2015. The retrofit part is similar to SC1. The old stock will remain the average of 2010 with EPC=1.06.

Scenario 3 is characterized by stringent policy. The electricity and gas mix change according EU targets for the share of green gas and renewable electricity. In contrast to SC2 the targets are fully met in SC3, resulting in 50% green gas and 80% renewable electricity in 2050. For new construction the EPG is tightened even further to EPC=0.22 (passive standard) in 2020. The retrofit part is more thorough than for SC1 and SC2, the EPC=0.62 instead of EPC=0.85. Another difference is that the annual retrofit rate is 1.3% instead of 0.8%. The old stock will remain the average of 2010 with EPC=1.06. The results of above mentioned scenarios are shown in the next paragraph.

6.2 Results scenarios
The results of the three scenarios are shown in
Figure 21. The red dots indicate the CO$_2$ emission level necessary to meet the EU emission targets when applied on household space heating in particular. The first target is 20% reduction of CO$_2$ emissions for household heating in 2020 as compared to 1990 levels. The second target is 80% CO$_2$ emission reduction for household heating in 2050 as compared to 1990 levels. The figure shows that changes in the housing stock are very slow and that current Dutch policy is insufficient to meet any of the two EU emission targets for household space heating.

Despite scenario 1 represents a situation with no policy concerning energy efficiency, the total CO$_2$ emissions still reduce to 11.5 Mton. The reason is that the newly built houses have a lower EPC and heating demand than the old stock. Also a part of the old stock is retrofitted which results in a lower heating demand. Scenario 2 represents the current policy. The graph shows that this scenario will meet the target for 2050 only for two third, at 7.3 Mton. It shows that current policy is effective, but still is not sufficient to meet the target. Finally scenario 3 shows that despite more stringent policy and a situation where targets for the share of green gas and renewable electricity are met, the emission target for 2050 will be still out of reach. The reason why in 2040 the line for SC3 flattens is that the old stock (n3) will be retrofitted completely. The effect of retrofitting old houses on the total CO$_2$ emissions is therefore lower. Scenario 3 will therefore result in 4.6 Mton, still 1.5 Mton short for meeting the target in 2050.
The trend from gas to electricity for space heating is shown in Figure 22. The first column represents the situation in 2010 where the share of electricity in the total CO\textsubscript{2} emissions for space heating is negligible. The next columns represent the three different scenarios in 2050. SC2 has a larger share for electricity because heat pumps and balanced ventilation are applied on a larger scale than in SC1. In SC3 the share of electricity is smaller because in this case the newly constructed houses are more energy efficient than in SC2.

Scenario 3 results in surplus electricity, as shown in Figure 22. The surplus is generated by the combined heat and power system (CHP) in the retrofitted part (retro 2). The CHP system has an efficiency of 88\% for heating, which is lower than the condensing boiler. Therefore the gas demand is higher for retro 2 than for retro 1, as shown in Table 8. However, when heat is produced in retro 2, the remaining 12\% is used to produce electricity. The electricity is considered a surplus because it is not used for heating in the same household. A good option would be to use the surplus for household appliances. Therefore the total emissions of SC3 will be lower than presented in Figure 22.
CONCLUSION

For this study the European ambition to reduce total CO₂ emissions by 80% in 2050 as compared to 1990 levels, is applied on household space heating in particular. The space heating CO₂ emissions where 15.4 Mton in 1990 and should therefore be 3.1 Mton in 2050. The most effective step to meet the target is to improve the insulation level of houses. Insulation has negative marginal CO₂ emission reduction costs. The next step is to apply balanced ventilation, heat pumps, combined heat and power and utilize solar radiation. The technology is available but the financial offset period is longer compared to current construction methods.

Within the European Union and the Dutch government there are many policies in order to reduce household space heating CO₂ emissions. A big issue with policies is that they are obscure to involved parties and often temporary. An important policy measure is minimum construction standards. However, current evaluation methods (EPG, energy label and PHPP) require improvements in order to become more credible. The EPG evaluation method, as applied in this study, evaluates the theoretical space heating demand only. Technological energy performance measures result in larger CO₂ emission reduction in theory than in practice according to the EPG method.

Three different scenarios show the potential reduction of the space heating CO₂ emissions within the Dutch housing stock. The scenarios show that the emissions targets will not be met with current policy. A substantial emission reduction of 70%, as compared to 1990 levels, is only possible with stringent policy. It includes: higher rates of retrofitting old houses, high energy performance standards for new houses (EPC=0.2) and a large share of green gas (50%) and renewable electricity (80%). In order to meet the EU emission target, changes and developments in the housing stock should be faster. Also the share of green gas and renewable electricity should be larger than aimed by current policy. Therefore the potential reduction of the space heating CO₂ emissions depends on the implementation rate of energy saving technologies and the share of green gas and renewable electricity in the future.
8 DISCUSSION

With many assumptions there are issues to discuss. The implementation of green gas into the current distribution network in the Netherlands has a major impact in the total CO\textsubscript{2} emissions. Gas is the main energy source for household space heating and will still be a large energy source for the scenarios in 2050. Green gas is considered CO\textsubscript{2} neutral within this study. However, since energy is required for the production of green gas (from biomass) it can be argued that green gas results in 100\% CO\textsubscript{2} reduction when compared to natural gas. A similar issue is the implementation of renewable energy sources (wind energy) within the fuel mix of Dutch electricity. It can be argued to which extend renewable electricity is CO\textsubscript{2} neutral. These assumptions obviously influence the results of the scenarios. When e.g. scenario 2 would be applied in one case without green gas and renewable electricity in 2050, and in the other 50\% green gas and 80\% renewable electricity in 2050, the difference would be 2-3 Mton of CO\textsubscript{2} emissions.

EU emissions targets for 2050 will not be met according to the scenarios. A few issues would make it even harder. Firstly only direct CO\textsubscript{2} emissions for natural gas are considered (0.051 kg/MJ gas). The indirect CO\textsubscript{2} emissions would be 0.060 MJ/m\textsuperscript{3} gas. (Heslinga & Harmelen, 2006) If also indirect CO\textsubscript{2} emissions from e.g. the extraction of natural gas and transport are included as well, the EU emission targets are harder to meet. Secondly it should be noticed that the theoretical heating demand is lower than the practical one when the EPC is lower than 1.0 as was shown earlier in Table 2. Therefore the emissions target will be harder to meet in practice than in theory. Thirdly in practice it can be argued that old houses will be retrofitted first. The classical and monumental houses often remain in original condition while the houses built in the seventies are retrofitted on a large scale.

However, there are also reasons which make it easier to meet emissions targets. Firstly EU targets are based on emission levels in 1990. Since the natural gas demand for heating shows a mitigating trend already it will be easier to meet the target than when targets would be based on 2010 levels. Secondly the input for the model is based on the current best technology available. It is possible heating system efficiency and insulation materials will improve within the next 40 years.

For further research it would be interesting to find out more about the financial life cycle of the different scenarios for 2050. The difference between life cycle costs for retrofitting existing houses and the construction of different types of new houses would add valuable information about the feasibility of the scenarios.
9 ABBREVIATIONS AND DEFINITIONS

BV: balanced ventilation

CB: condensing boiler, produces hot water for space heating and hot tap water

CHP: Combined Heat and Power, decentralized heat production and electricity production powered by natural gas

Direct energy: energy used for construction, operation, rehabilitation and demolition. (Sartori & Hestnes, 2006)

Embodied energy: the energy utilized during manufacturing phase of the building. It is divided in two parts: initial embodied energy and recurring embodied energy. (Ramesh et al., 2009)

End-use energy: energy measured at the final use level. (Sartori & Hestnes, 2006)

EPG: Energieprestatie Gebouwen

EPN: Energie Prestatie Norm

EPC: Energie Prestatie Coëfficiënt

EIT: Economies in Transition

HP: Heat pump

IEA: International Energy Agency

Indirect energy: the energy used for the production of the materials (embodied energy). (Sartori & Hestnes, 2006)

Initial embodied energy: The sum of the energy embodied in all the material used in the construction phase, including technical installations. (Sartori & Hestnes, 2006)

OECD: Organization for Economic Cooperation and Development: organization of 34 Countries working together on global development

Operating energy: Energy used in buildings during their operational phase, as for: heating, cooling, ventilation, hot water, lighting and other electrical appliances. It might be expressed either in terms of end-use or primary energy. (Sartori & Hestnes, 2006)


Primary energy: Energy measured at the natural resource level. It is the energy used to produce the end-use energy, including extraction, transformation and distribution losses. (Sartori & Hestnes, 2006)

Recurring embodied energy: The sum of the energy embodied in the material used in the rehabilitation and maintenance phases. (Sartori & Hestnes, 2006)

Total energy: The sum of all the energy used by a building during its life cycle (total embodied energy plus operating energy multiplied by lifetime). (Sartori & Hestnes, 2006)
REFERENCES


IEA. (2010). Energy Technology Perspectives. IEA. OECD.


Mackay, D. J. C. (2009). Sustainable energy, without the hot air. Cambridge England:


VK. (2006). *CO2 emissions 1 kWh gas.*, 2011, from [http://www.vkblog.nl/bericht/93563/Meten_is_weten](http://www.vkblog.nl/bericht/93563/Meten_is_weten)


11 APPENDIX

11.1 Meeting with Ron de Vrieze
Researcher and staff member Hanze University Groningen
He is working on a PhD research on integral (sustainable) design of school buildings with the emphasis on the psychological aspects.
Groningen, 24-01-11

Research question
What is the potential future reduction of the heating demand within the Dutch built environment by applying passive construction methods and which policies and approaches are required to achieve this?

Summary
Passive construction methods can contribute to a reduction of the heating demand in the Dutch built environment. However there are many issues involved.

At this moment passive construction methods are not applied on a large scale in the Netherlands. The passive methods are more expensive than current construction methods. People tend to focus on cost reduction on the short term rather than savings on the long term (10 years). Therefore rental agencies have difficulties getting support for extra investments in energy efficiency measures from their customers. A major issue in this situation is that rent and energy costs are a separated bill. An incentive for the rental agencies to invest in energy efficiency is the risk that their customers can’t afford to pay the rent when the energy bill becomes too large.

Another issue is that the installations, in contrast to constructive measures, require a lot of attention. The quality of the installation work is essential and also the amount of maintenance required on the long term will determine if the energy efficiency measures are successful. When balanced ventilation e.g. is not installed and maintained properly it can cause serious health problems and noise. In practice people dislike balanced ventilation systems, “they simply do not like the idea of living in a plastic bag”.

Another technical issue concerning passive construction methods is overheating in summer periods. It is difficult to get rid of heat in a passive house because it is very air tight and thick insulation layers are applied. A key issue concerning insulation is dealing with vapor pressure from warm to cold. Therefore vapor restraining layers are necessary within the construction in summer as well as winter periods. During summer periods water vapor tries to enter the construction. Preventing the moist to condensate inside the construction proves very hard in practice. Moist within the construction materials reduce the insulation levels and can cause serious damage to the construction. This is a major challenge during the construction of passive dwellings. Insulation companies are working on special layers of material which allow water vapor to enter the construction only one way direction. (Source: dhr. Halbertsma fa. Dubomat) More research on this topic is required.

The energy index for the current housing stock is a useful tool to raise awareness about energy efficiency. However, energy efficiency regulations are not complied by constructors and real estate agencies and neither enforced by authorities sufficiently.

The EPG method is applied on newly constructed houses. This method however, is easy to manipulate by varying the input values. Therefore the confidence in the EPG calculations by professionals is reduced. Another issue with the EPG is the emphasis on installations rather than constructive measures (HR++ glass and insulation). An EPC of 0.6 is almost more difficult to achieve without energy efficient installations (heat pump and balanced ventilation). Finally there is no inspection afterwards to determine if the EPC values are actually achieved in practice.
To conclude, there is only a small percentage of people who are concerned about energy efficiency of houses and willing to invest. The large share of the people simply does not care or have other issues on their minds. In general the attitude of people will only change when they feel pain or pleasure. Pain will have the strongest effect so after a disaster or enormous raise of energy prices we should witness a change in behavior and attitude towards energy efficiency. The biggest gain in energy efficiency should come from improving the energetic performance of the existing housing stock because the rate of replacement is simply very low. The cheapest and most efficient option is applying insulation measures and HR++ glass.

Finally Ron de Vrieze is working on integral design methods. Not only architects, constructors and users should be included in the design phase, but also other areas of knowledge like ICT and psychology.

Energy and Environmental Sciences, IVEM, Rijksuniversiteit Groningen  
Wiebe Engelmoer
### 11.2 Package of energy efficiency measures and EPC value (MERLiN software)

End of row house/ 2 under one roof with 134 m$^2$ and south oriented is considered the average

CB=  condensing boiler    HP=  heat pump
BV=  balanced ventilation  CHP=  combined heat and power

#### Current average

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<td>Heat system</td>
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<tr>
<td>Solar boiler</td>
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#### New construction

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<td>HP air source</td>
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<td>Solar boiler</td>
<td>2m$^2$ 180l storage</td>
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#### New construction passive

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#### Retrofit

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