Design of an affordable and sustainable house concept for the Netherlands

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Preface

Prof.ir. Rutten and dr.ir. Loomans (coaches of this project) initiated to develop a new research area within Eindhoven university of Technology which integrates knowledge on Sustainable Energy Technology in the Built Environment. Students from 'Sustainable Energy Technology' (SET, department of Mechanical Engineering), Physics of the Built Environment (PBE, department of Architecture, Building and Planning) and 'Building Services' (BS, department of Architecture, Building and Planning) are brought together and companies are also requested to set research questions and assist in coaching. Through this initiative, we (from PBE and SET) came together in this project while collaborating with engineering firm Arup and material supplier Kingspan.

This project was initiated by the request from Arup and Kingspan to find the possibilities for sustainable house concepts comparable to Kingspan Lighthouse (on which both UK branches of these firms collaborated) in the Dutch market. The scope shifted from this particular house concept to an average terraced house to most comply with the future housing demands. In order to become familiar with the current practice in sustainable housing, a preliminary study (as M3 and SIPII project) was conducted between September and December 2009 that focused on assessment of sustainable houses. The conclusions were applied for the graduation project with the goal to design an affordable and sustainable house concept for the Netherlands. This was executed from January till October 2010.
Thanks to our internship at Arup Amsterdam and intensive contact with Kingspan, we were able to meet several experts in the sustainable building sector. Experience from them and visits to their (own) houses/projects gave a lot of insight, mainly in the applicability of several technologies.

Also the contact we got with building costs consultants from IGG Bointon de Groot helped us in finding our ways in cost assessment methods and estimation of prices.
Reflection on the process of collaboration during this graduation project gives a positive view. Although sometimes struggling with personal approaches in work and communication, the learning points were numerous and the quality of work was high. We were able to discuss difficult decisions, getting or giving feedback and visiting people and projects as a team.

We would like to take the opportunity to thank the people who supported us in this project: first of all Paul Rutten and Marcel Loomans for supporting integrated design and these combined projects at TU/e. We want to thank Bart Kramer (Arup Amsterdam) for his efforts, contributions and detailed criticism of the project content. Although they are not part of the graduation committee, Jeroen de Wilde and Vincent van Sabben (IGG) put a lot of effort to advice us on building costs and revised our work in detail. We are grateful to Frank Donkers and Léon van Maurik from Kingspan for their contribution on the excursion to London and their support in arranging meetings with experts in the field. We also thank the speakers during the trip to London: Chris Twinn (Arup), Bob Giles, Paul Newman (Kingspan) and Justin Wimbush (Arup).

The people who gave their time and effort to share their knowledge were valuable to us: Renz Peijnenborgh for his thoughts on ecological building, Jan-Willem van de Groep for his view on building processes, Stefan van Uffelen for his interest in our work concerning BREEAM-NL and Thomas Dieben for his architectural view on sustainable design.

And we want to thank the MEP services team in Arup Amsterdam who helped us with many questions and created a cool and friendly environment for us to work in. Our family and friends have supported us during the whole project and we are grateful to them.

Sinan and Filique

Summary

This research is focused on the analysis and design of sustainable and affordable house concepts in the Netherlands, specifically based on the terraced house typology.

The growing concerns about impending global warming and scarcity of energy sources lead to efforts to use different energy sources and more efficient use of available resources. The building sector is responsible for about 40% of the energy use, and almost 10% of this is used in residences. So, (re)construction of the 'sustainable' residential building stock plays an important role for preventing the possible problems in the future. Next to the energy use, the definition of sustainability is broadened to other subjects such as health and safety, material use, water use and waste management. The goals for improvement are described in Dutch environmental policy plans. This broadened scope leads to the goal for sustainable housing with a broad perspective of sustainability.

Both renovation of the existing stock and the sustainable design of the new-built houses are crucial to achieve these goals. This study is specifically focussed on the new-built houses since they will be demanded in the short term. According to housing prognoses, there will be a significant demand for new built low priced single family houses in the next 20 years. The designed house typology is therefore a single family terraced house, based on the design as given by SenterNovem reference houses. The design of this typology will enhance the applicability and the broad effect of sustainable design. The 'affordability' is defined in this study based on the selling price boundary predictions.

The topics that are addressed within this study to describe sustainability are deducted from a preliminary study which focused on the current practice in sustainable housing projects and concluded the lack of attention in several sustainability aspects, especially the economics. As a conclusion, the scope of this project is extended to the analysis on thermal, visual, acoustic and spatial comfort, indoor air quality, CO_2 emissions, user behaviour, water use, waste management, building materials, and economics. To evaluate the performance in all topics, BREEAM-NL (residential beta version) was chosen as guideline for assessment. The applicable criteria were extruded and credits were assigned per topic and weighted on importance.

Each topic of interest is analysed based on the criteria as prescribed by BREEAM-NL (if available) and the current practice levels are checked for defining the improvement areas. For each topic, the measures are compared or advised based on literature to improve the current situation and to achieve a higher sustainability level. All partial analysis resulted in recommendations for two lines of thinking for the concepts, defined as the 'passive' and 'active'.

The two concepts are equally differentiated from the reference house in terms of spatial planning, water use, waste management, efficient lighting and appliances and the daylight availability. The passive design is based on the 'passive' strategies to reduce the energy demand which includes solutions such as the improvement of thermal quality of the building skin. Whereas the active concept was designed to achieve the goals with the 'active' measures such as a ground source heat pump which will cut down the primary energy

consumption. For both concepts and the reference house the user behaviour is assumed to be ideal such that they are comparable in terms of use. Robustness study indicated the influence of user behaviour on the total performance of each.

The reference, passive and active concept were all assessed on their performance by means of specific tools per topic and by use of BREEAM-NL criteria to score them on their level of integral sustainability. All concepts achieved the demands for thermal comfort, indoor air quality and acoustics. The active and passive concept scored higher than the reference on CO_2 emissions and flexibility and only the active concept scored higher on building materials. Extra points were scored by the passive and active concept on accessibility, waste and daylight.

None of the suggested concepts was able to achieve the set boundary for affordability, nor do the additional investments pay back in the mortgage period (considering predicted energy prices), compared to the reference house. The score in sustainability was much higher than the reference house, which resulted in a low value of the investment per achieved sustainability score. The passive concept resulted in the best performance in terms of energy use, achieved BREEAM-NL credits, affordability and robustness (for changing energy prices). Therefore this concept was chosen for improvement into the hybrid version. Although the affordability and feasibility criteria were not achieved, most of the measures which resulted in this concept are the best in their category and therefore kept while designing the hybrid version. This concept was improved by a different choice in ventilation system (balanced) and changing the type of façade cladding. It resulted in a selling price exceeding the boundary by 13%, but 6% lower CO_2 emissions than the passive concept. This resulted in the lowest selling price per weighted BREEAM-NL credits so this concept is the most advisable for implementation in affordable and sustainable single family housing.

Although the project focused on affordability and sustainability, it can be concluded that improvement in environmental sustainability generally results in an increase in costs, which is not paid back assuming the predicted energy price changes. In terms of sustainable energy technologies, it can be concluded that the small scale applications are not financially feasible considering the current financial conditions and the energy price predictions. So, the solution to achieve the sustainability goals in a financially feasible way can be found in the large scale applications. Recommendations are given for further study on efficiency in the building process to reduce costs and on building materials, spatial planning and user behaviour to enhance the level of sustainability. Although the BREEAM-NL tool is useful to value several topics of sustainability in one figure, it lacks the impact of economic value and the character of assessment does not assist the designer in order to achieve a balanced concept with high performance.

1 Introduction

Growing concerns about impending global warming and scarcity of energy sources lead to the efforts to use different energy sources and use the sources more efficiently. Since the energy consumption of the building sector constitutes for about 40% of the energy demand (US DoE, 2008), buildings have become one of the focus points of these efforts. Introduction of sustainable energy technologies and reducing energy demands have been in the heart of the endeavour to improve the environmental performance of the buildings. This study is one of the many efforts to mitigate or solve this problem. The introduction indicates the details of this problem and explains the cause for the project.

Trends in 'Sustainability in the Built Environment'
Sustainable building design has been a topic of discussion from about the oil crisis and the Club of Rome publications in 1972. The focus on sustainable building design started mainly on the reduction of energy demand during use. With the outcomes of the Brundtland report ('Our Common Future', from the World Commission on Environment and Development) in 1987 the focus has spread to a broader perspective of sustainability, also including social and economic values. In the Netherlands, these developments have been observed in governmental programs which started with a prescriptive approach by giving lists of measures which could be used for achieving credits in sustainable building assessments (DuBo). Performance based design and assessment methods drew attention when it became clear that prescriptive methods sometimes did not lead to better overall performance and by that, not to a higher level of energy reduction.

Although in some fields the focus on sustainable development has become broader, the regulations in the Netherlands still focus on energy reduction in buildings, by use of the energy performance coefficient (EPC) and by using the energy label to show this performance. This regulation is linked to the European Performance of Buildings Directive, which demands an assessment method on energy performance and minimum requirements to this performance for new buildings and buildings with major renovations.
This description of the trend in sustainable building is based on the findings in the preliminary study of this project: *Assessment of sustainable housing projects* (Nijenmanting & Senel, 2010).

Broadening the Perspective of Sustainability
The Netherlands
As was found in the trends of preliminary study, the attention for sustainable building design is rising in the Benelux and also in other parts of Europe. Each country has made different progress while the Netherlands being somewhere in the middle. It is ahead of Belgium (as can be found in the energy performance demands), but initiatives in Germany and the United Kingdom are in a further stage of progress. The goals for the Netherlands to tackle the environmental problems are high, so it is important for the building sector to be able to comply with these demands in practical solutions. Therefore, this country will be taken as the practical basis of this project. This will also contribute to the assessment since one set of regulation can be used.

Broadness of sustainability in policy

To describe the significance of broadening the perspective of sustainability in the Netherlands, the Dutch governmental policy and their studied basis have been taken as a starting point. Sustainability policies are constructed from the National Environmental Policy Plans (NEPP) (in Dutch: Nationaal Milieubeleids Plan = NMP), of which the latest version is NEPP 4, dated in 2001 and considers the strategy until 2030. This report gives an overview of the governmental policy to mitigate the environmental burdens on future generations. This was stated to be necessary, since the way of producing and consuming as it was in 2001, still shifted the environmental burdens to the next generation.

The plan concludes on the positive effect of environmental policy, because it resulted in the dissolving or manageability of environmental problems. It discusses 7 environmental problems which need to be handled in the coming years (topics and explanations are quoted from VROM 2001, chapter 2):

1. **Loss of biodiversity**
   Biodiversity, the presence of a wide variety of biological species, is a precondition for the processes that make life on earth possible: food, nitrogen and water cycles, the production of clean air and Biomass, and the regulation of the climate system.

2. **Climate change**
   Human actions are a significant cause of global warming. The increase in global prosperity results in ever growing energy consumption and, if policy is unchanged, disproportionate CO_2 emissions.

3. **Over-exploitation of natural resources**
   Natural resources are all those resources people use during the course of their lives. A distinction is often made between renewable natural resources (such as wood, fish, fresh water, clean air, soil fertility) and non-renewable resources (such as ores, minerals and fossil fuels).

4. **Threats to health**
   Many people have concerns about the health effects of chemical substances and products used on a large scale.

5. **Threats to external safety**
   The vulnerability of the population is likely to be increased.

6. **Damage to the quality of the living environment**
   In the Netherlands, the quality of the living environment is under constant pressure from increasing traffic and combinations of housing, infrastructure and employment.

7. **Possible unmanageable risks**
   The world can be roughly divided into two systems: one system driven by people (the world economy) and a system driven by the rest of nature (known as the ‘life support system’). The life support system keeps the water cycle going, for example, and regulates the earth’s temperature. Today’s greatest problem is that the two systems have taken on

similar proportions. Dramatic changes in one system can easily lead to instability in the other. The question is whether today's solutions might not lead to unmanageable problems in the future.

This list shows that energy reduction is not the only topic to which attention should be given. It also considers the depletion of resources, general health, safety and quality of life. The NEPP 4 indicates strategies to follow in order to attack these problems and to reach a sustainable society, which is defined in qualities of life. These strategies are defined in clusters of 4 transitions and 4 policy programs. Some programs have been written to handle the practical solutions of these problems. Two of these programs indicate the importance of change in the building industry explicitly: the transition to sustainable energy generation and the sustainable use of biodiversity and natural resources. The first one is translated into the *Energy Transition* platform. This is a platform which combines the efforts from government, business, research and social organizations to make the shift to a different approach of energy use. The built environment is one of the items for improvement according to the roadmap defined by the platform (see Textbox 1).

Built environment

Our ambition is to achieve an energy-neutral built environment in which houses and buildings will be supplied only with sustainable energy. This goal will be reached by drastically reducing the energy used for heating, cooling and powering household appliances.

Textbox 1: definition of energy transition for the built environment. Source: Energy Transition Task Force (2006), More with Energy, opportunities for the Netherlands.

In order to specify the goals of the NEPP 4 in the field of over-exploitation of natural resources (problem 3), a report has been constructed which *quantifies the environmental goals for building materials* (Krutwagen e.a., 2004). The request by the Dutch Ministry of Housing, Spatial Planning and the Environment for this report indicates the importance of this sector in the share of reaching the NEPP 4 goals.

Specifically, the residential part of the building sector has a lot to gain. If the aim of 40-60% CO_2 reduction should be reached in 2030 (as is described in NEPP 4), the built environment should be improved since the share in the total energy consumption is significant as presented in the pie chart in Figure 1 (19% by residential sector).

Division of energy use in the Netherlands, 2001

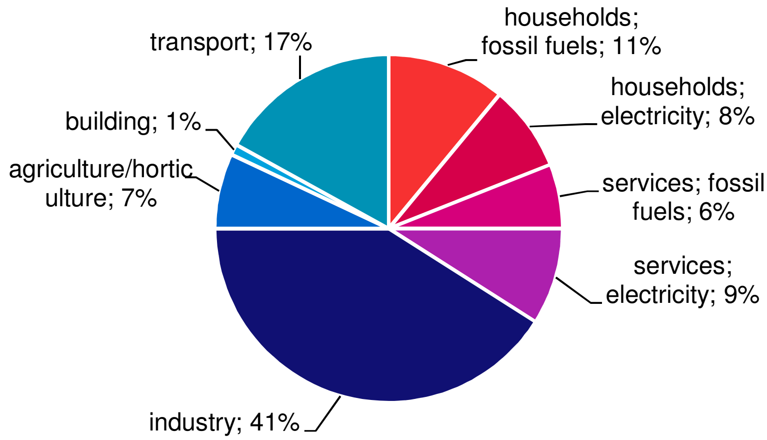


Figure 1: Division of energy use in Netherlands, 2001. Source: Monitweb, translated

House-building for demands

A report by Novem on the Strategical Frame of the Built Environment published in 2002 (Novem, 2002), describes the trend in house-building in the Netherlands till 2030. According to this report, the amount of houses will increase. This results from a small amount of new built homes, and a low amount of demolition. By this, the amount of houses is expected to increase from 6.2 million in 1996 to about 8.3 million in 2030. From 2020 and further, the production of new built homes is predicted to decrease tremendously, in order to prevent the excessive number of houses compared to households. It is expected that in 2050 about 34% of the houses will be 'new' (built after 2000) and two-third will be about 50 years 'old'.

The Primos Prognose 2007 (den Otter and Heida, 2007) concludes that the house shortage will need to be recovered until 2019, with a number of new built homes 384,000 between 2009 and 2014 and 339,000 between 2014 and 2019. This also indicates the decline in new-built houses as was predicted by Novem in 2002. The Primos Prognose is a model to predict future developments in composition of the population, composition of households and the housing demand on national and regional level in the Netherlands. It predicts these parameters based on current knowledge and uses the prognosis of population as given by the Central Bureau of Statistics. The future new built homes are depending on the level in which the current housing stock complies in quality with the demands of consumers and the national government. The quality of housing is defined as the level to which the supply of housing stock complies with the demand. To comply with the demands, the conclusions of the WOon 2006 (Poulus and Heida, 2006, p.4-8) research as described in the housing market explorations (which covers the housing demands of the Dutch population) are summarized:

The housing needs will shift from rental homes to owner-occupied properties. These are mainly wished in urban and compact living environments. An increase in demand in the rural areas for houses is noticed too. The demand for houses in green urban areas will remain high, but not as high as it used to be. For new built houses, the demands request less rental but still a major amount. The shift will be found in the mid-expensive owner-occupied property.

The demands in quality for homes will increase in the coming years, the chances for success for consumers to find an appropriate home will not improve' (Poulus and Heida, 2006). This quality is specified within the studied report in location, size, type and price per surface of the home.

One can notice that sustainability or low-energy is not part of these decision parameters. This is part of the conclusions which can be found in a graduate thesis on the 'willingness to pay' for low-energy new housing developments (van Eck, 2008). Van Eck concludes that consumers do not mention these values if they are asked for their criteria for the choice of house. But when specific labels are given for several house options which include the energy reduction and financial consequences, they are willing to pay up to 10% extra for the best A++ rating. Overall it can be concluded that a higher level of sustainability has to be included for an affordable price in order to reach a large impact.

1.1 Preliminary Study and Results

As the first step of the graduation project, trends in sustainable houses were researched. For that purpose, several projects, in the Netherlands and regions with a similar climate in the world, were studied. In this section of the report, the results and conclusions from the preliminary study are summarized and discussed in order to find the concrete goals for the graduation study. These results will lead to main research question of the study.

1.1.1 Aim and Methodology

In order to compare the projects objectively and comprehensively, a comparison method was developed based on BREEAM-NL (BREEAM-NL v1.0, 2009) and the model of integrated building design as presented by Rutten (Rutten, 1996). The criteria for comparison were interpreted from BREEAM-NL scheme, but these criteria were simplified to simple yes/no questions since detailed information was required to assess the criteria. The structure of this assessment tool was improved using model of integrated building design and BREEAM Communities (BREEAM Communities, 2009).

The comparison method was developed to evaluate the projects based on a certain topic/criterion whether it is addressed (in a positive way) or not. So, considering the limited information, the projects were not evaluated based on their performance but on the design strategies. The output of the evaluation was considered as a strategic overview of the projects.

As a result of the comparison and evaluation of the projects, it was aimed to interpret the design strategies and find out the field of focus of the design. Hence, general trend in the building sector could be predicted from these results and improvements for the design strategies could be recommended. These results lead to the determination of the goals and strategies for the new design of a building.

The methodology for the preliminary study can be seen in Figure 2. It displays the description of the case studies in six level of the building system, which form the total design. This design was evaluated by the criteria based on value domains and BREEAM-NL. From that, conclusions could be found on the fields of focus in these case studies and the design strategies which were used in each total design can be interpreted.

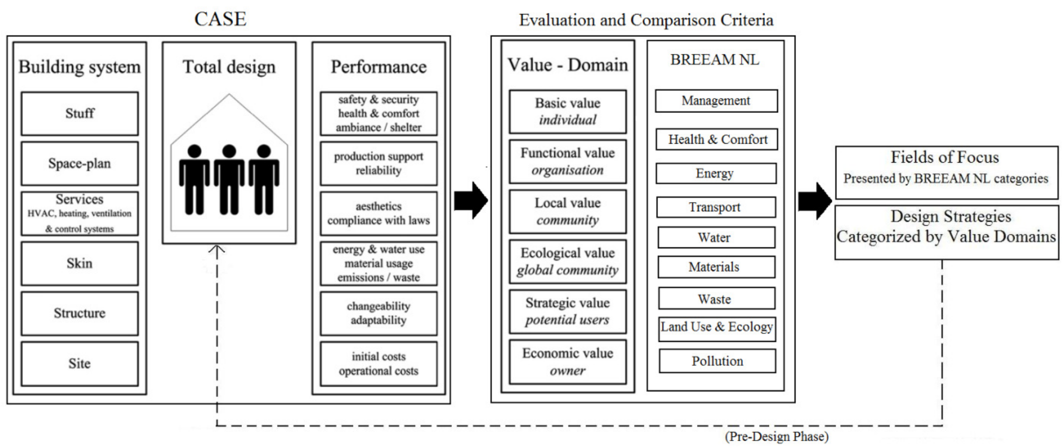


Figure 2: Methodology for the preliminary study

As indicated before and in the figure, additional criteria for the comparison were interpreted from the model of integrated building design. Design strategies were defined using value domains as proposed by the model, in order to have a better overview representing all necessary values of a building. These are categorized under six value domains which are explained as (Mallory-Hill, 2004);

Basic value (Individual) is determined from a building's relationship with individual occupants and their sense of psychological and physical wellbeing.
Functional value (Organization) is concerned with how activities taking place inside the building are supported.
Economic value (Owner) is based on the relationship with people concerned with the ownership and marketing of the building.
Local value (Community) is based on special conditions that are unique to a particular place; anything that may prevent a building from being constructed in the most straightforward way.
Ecological value (Global community) considers the relationship of the building to the global environment.
Strategic value (Future users) is an abstract human-building relationship as it considers performance requirements associated with time and the future.

Fields of focus in sustainability are presented by charts which are determined by achieved criteria under categories of BREEAM-NL. These categories and their weighting are:

Weighting of BREEAM-NL categories

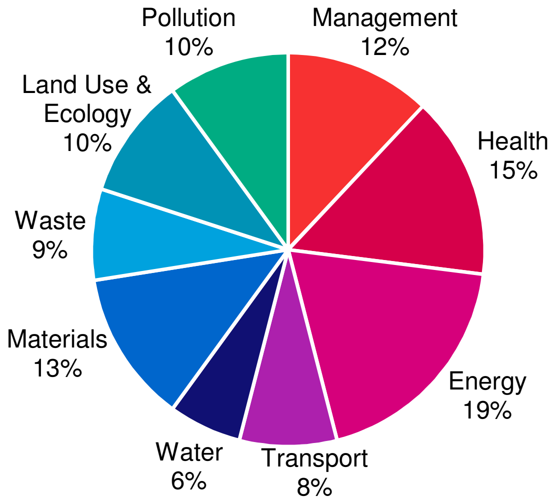


Figure 3: Weighting of BREEAM-NL categories

Results for each case were compared for each category separately and overall scores, which were calculated by using the weighting factors determined by BREEAM-NL, were evaluated as well.

Within the scope of the preliminary study, seven projects were evaluated and compared using the comparison method as explained above. The cases were selected to represent different scopes of sustainable house design. The projects are presented in the following table.

Table 1: Selected Projects for Preliminary Study

Benelux	
Woonhuis 2.0	It is a project built by the home owner (architect). The house has a passive house certificate and material choice is based on C2C theory.
Kaswoningen Culemborg	These homes are part of the district EVA lanxmeer. This is built from an ecological view.
Powerhouse Leusden	This very traditional looking house is producing more energy than it uses. This makes it an interesting case study.
World market	
Zero Carbon House, Shetland	The reason behind choosing the 'zero carbon house' in Shetland as a case study is that it presents a real time experience about the micro generation technologies and other aspects of sustainability.
Kingspan Lighthouse	Kingspan Lighthouse has been chosen as a case study, partly because it was the starting point of this research. It is achieving the highest level of the UK Code for Sustainable Homes, so it is a good example of how to achieve regulation standards.
NREL Zero Energy House	It's one of the typical examples in US market, which only deals with energy aspect of sustainability and represents also passive house

Colorado USA	concept.
Beddington Zero Energy Development	This development project includes sustainability perspectives ranging from energy to transport, local food production and even quality of life in the neighbourhood.

1.1.2 Results

The results of the preliminary study were discussed in four topics based on comparison results, design strategies, usefulness of methodology and learning points from the preliminary study.

As interpreted from the results of comparison, in most of the projects Management, Energy and Health & Comfort categories are well addressed. This means the designers tried to achieve decreased energy demands, healthy indoor environment (thermal comfort, daylight levels) and low technical risks of technologies. Most of them are illustrative and educative projects for sustainable house building practice, so the designers implemented sustainable energy technologies for energy supply.

It is evident that the designs are focused partly on categories Transportation, Material, Water and Waste. This means in most of the projects, environmental friendly material use, decreased water consumption, sustainable transportation of residents (bicycles, electric cars, public transport) and waste recycling facilities were taken into account.

The least addressed categories were Land Use & Ecology and Pollution. From this, it could be concluded that projects are not focused on the improvement of ecological environment, low impact on land, flood risk of the land, and only some projects addressed pollution by surface water run-off.

On top of these results, the design strategies of the projects were interpreted either from the solutions implemented or by the explicit statements in the reports, interviews. As a result of this strategic analysis, several issues for extra attention during the design process were pointed out. They are presented in six value domains. Each value domain has some parts which were already well addressed, such as energy and comfort. But some points were missed and they should get extra attention in future design. These topics are presented below for each value domain.

Basic Value
Typical strategies for improved basic value, which were pointed out in all case studies, associated with this value domain focus on thermal comfort in the house, daylight levels for visual comfort and air quality regarding fresh air supply to habitable rooms. The lack of strategies were observed for **acoustics, spatial comfort** and **internal air quality.**

Suggested strategies can be listed as follows:

- Acoustical comfort should be improved in the house by implementing simple design solutions such as placing all the noise producing equipment in an acoustically insulated room or preferably out of the house.

- Spatial comfort in the house should be given special attention and local perception of spatial comfort should be implemented in the design.
- Internal air quality goal should be clearly defined in terms of pollutant and CO2 concentration. Strategy for fresh air supply with non polluted air by internal and external factors should be explained.

Economic Value

In most of the projects, the focus was on minimizing energy demand and producing energy on site, operational costs related to energy bills are decreased. However, lifetime costs of the building are not mentioned, which may be due to the difficulty of calculating it. Strategies regarding **initial, maintenance & operational and demolition costs** should be defined.

Suggested strategies can be listed as follows;

- Selection of proven, robust technologies in cooperation with the suppliers will decrease the design risks and costs.
- Life cycle cost analysis should be made by giving details about initial, maintenance & operational and demolition costs
- Design decision should be made according to the design goals or limitations in initial and operational costs. Choosing a solution with low initial cost is not always preferable so life cycle costs should be considered for decision making.

Ecological Value

Ecological value was the most improved value in all the projects since all of them are about improving the environmental or energy performance of houses. However, strategies regarding **low embodied energy**, **construction (site)**, **land use** and **existing fauna/flora** are not adequately emphasized in the projects.

Suggested strategies can be listed as follows:

- Design the house such that waste during construction would be minimized, which depends on material selection, excavations required and site selection.
- Material selection should be based on low embodied energy criteria and calculations of CO_2 emissions and energy consumption related to the pre-construction phase of the material should clearly display the environmental impact of the material.
- Selection of renewable energy technologies according to the local conditions
- Incorporating sustainable solutions for transportation of inhabitants according to the local conditions will help to achieve not only sustainable houses but also sustainable life styles. Similarly, growing own food is another way of promoting self sufficient, sustainable life styles.
- The process of demolition of the house should be taken into account during design phase such that, the house should be demolished after use with minimum waste and effort possible.
- Building site should be carefully selected and the ecology around the location, if there exists any, should be protected from the consequences of building a house.

Strategic Value

Most of the projects did not mention and implement strategies to improve the strategic

value of the building which ensures the value/function of the house in the future.
Suggested strategies can be listed as follows:

- Implement design solutions for different and possible future users considering the predicted life time of the house. For example house design should allow old or disabled people to live in the house comfortably.
- Technical and spatial flexibility of the house should be considered in the design phase. Addition or modification of systems, changing spatial planning of the house should be relatively easy. For example, house should be easily modified to be used in a neighbourhood or an urban development project.

Functional Value

Manageability and ease of operation and maintenance in the houses were improved by user manuals, operation and maintenance manuals and also monitoring systems. Therefore, for the new design some advices and strategies can be concluded from the case studies:

- Selection and design of simple systems will make the house more manageable and easier to maintain.
- Preparing detailed and easy to understand user guides will increase the efficiency of the systems and awareness of users.
- Domotica systems should be placed in visible areas
- Control of the systems should be easy for the users.

Local Value

Since in most of the projects, local value of the building was well addressed and improved, following strategies and advices can be interpreted from the case studies;

- A design based on local know-how will increase the ease of construction and also the local value of the house
- Choice of the systems and solution during design process should be based on local conditions including micro climate, best and typical practices, know-how of the labor.
- In order to design according to local conditions, interaction with the local community should be effective such that some decisions should be made based on the local experience.

'Learning points'

Lastly, several learning points from the preliminary study have been interpreted. These were the highlights that were observed in the case study and literature search and these will be the points that the design team has to bear in mind while achieving the final goal. Learning points can be listed as:

- Define design criteria and strategies clearly in the beginning of the project try to stick with these criteria throughout the whole project so that scope and focus of the design will not shift.
- Estimate the user behaviour based on the local way of living and preferences. Checking the sensitivity of the solutions to possible behaviour changes will give indications of possible consequences or problems which can be faced in practice.
- The new design should create possibilities for urban development and should be technically flexible to be modified for projects with larger communities.
- New design should promote the sustainable way of living for residents such that ecological footprint of the community will decrease by improving environmental

performance of not solely buildings but also residents.
- Choice of the systems and solution during design process should be based on local conditions including micro climate, best and typical practices, know-how of the labor.

1.2 Research setup

The environmental problems which are described in the introduction, the trends in the built environment and the policies which are set out for the Netherlands have lead to the goals for this project as they are described in detail in the following chapters. On top of that, the conclusions from the preliminary study helped to determine the objectives and the scope of the study more in detail. In this section, specific topic and the objectives of the study are discussed.

1.2.1 Topic of study

Since the amount of energy and materials which is used by the residential buildings is significant, it is important to improve the performance of new built houses in this field in order to reach the goals which were set in NEPP 4.

As the preliminary study concludes the lack of a broad sustainability perspective in the field of sustainable housing and the lack of feasibility in the projects which do consider this broad scope. Therefore, the main objective of this study is to find a solution for the design of an affordable and sustainable house for the Netherlands.

The specific demands are set during this study, but the general aim is to maximize its performance on the environmental, economical and comfort values to satisfy the consumers (residents), policy makers (Dutch government) and the producers (economic feasibility).

The project will consist of several steps in this design process and will result in a design of an affordable and sustainable home for the Netherlands. Parts of this study will be the setting of scope, the specification of demands and the choice of assessment method. The design process will be organized in such a way that an integrally designed end product will result from it. The specification of this integral design process will be given in detail, in order to be an example for future designs of different housing or building types with comparable aims (sustainability, comfort and affordability).

1.2.2 Main research question

A main research question has been formulated in order to address this challenge:

What is the optimum combination of the design strategies and measures to achieve high basic, environmental and economic value in the design of a ‘sustainable’ and ‘affordable’ single family house in the Netherlands?

This main question consists of several parts:
- The ‘optimum combination’ refers to the intended design process, in which different topics and resources will be combined in order to reach a solid and integral design.
- The design strategies indicate the main roads to follow in order to reach a satisfying

product in terms of the basic, environmental and economic values. The measures that can be found to match these strategies will be used in the design to translate it to a practical design concept.

- The terms of 'sustainability' and 'affordability' are both results from the current Dutch situation (aimed policy) as described in the introduction and will be the target points for the final design. The definition of these terms will be given in the boundary conditions and the design will be assessed on these terms afterwards.
- The single family house is a major concurring type in the Netherlands. This is one of the reasons to choose this house for study. Further argumentation will be given under the boundary conditions.
- The Netherlands will be the location of the concept, as it was earlier discussed in paragraph 1.2, which is the activity area of the contributing firms and was also topic of the preliminary study. The design will be made applicable for this country (and its regulation), but it must be noted that the main concept could probably also be translated to other countries in the same climate region.

1.2.3 Sub-questions

The main research question as given is broad and directs the answer of it into design decisions based on reasoned argumentation. In order to lead this design process into satisfying results which include all goals in the research question a methodology has been described and is presented in a list of partial research questions.

The general methodology which they form is presented in Figure 4. It is based on the primary definition objectives (as deducted from the preliminary study). From here some specific topics of interest can be defined. These objectives and specific topics will be studied within the boundary conditions which will define the house typology and costs implications. In order to guide the design process into an integral attention for sustainability, the same tool as in the preliminary study will be used. The (adapted) unique way of using this tool within the boundaries of this specific project will be explained. Guided by this framework, each specific topic of interest will be analyzed in order to find the current practice and possible improvements. The combination of these analyses will result into recommendations for a set of concepts in different directions which will be explained in further detail.

The concepts will be assessed according to the defined assessment method and will be compared to a concept that represents the current building practice (the reference concept). The comparison of these concepts and analysis of the results will lead to recommendations for improvement of both based on the set of topics as defined in the introduction chapters. These recommendations will be combined into a third concept that will represent the concessions that result from all influencing topics of interest.

This concept of concession will represent the strategies to use in order to design an affordable and sustainable house for the Netherlands and will thereby be an answer to the main research question.

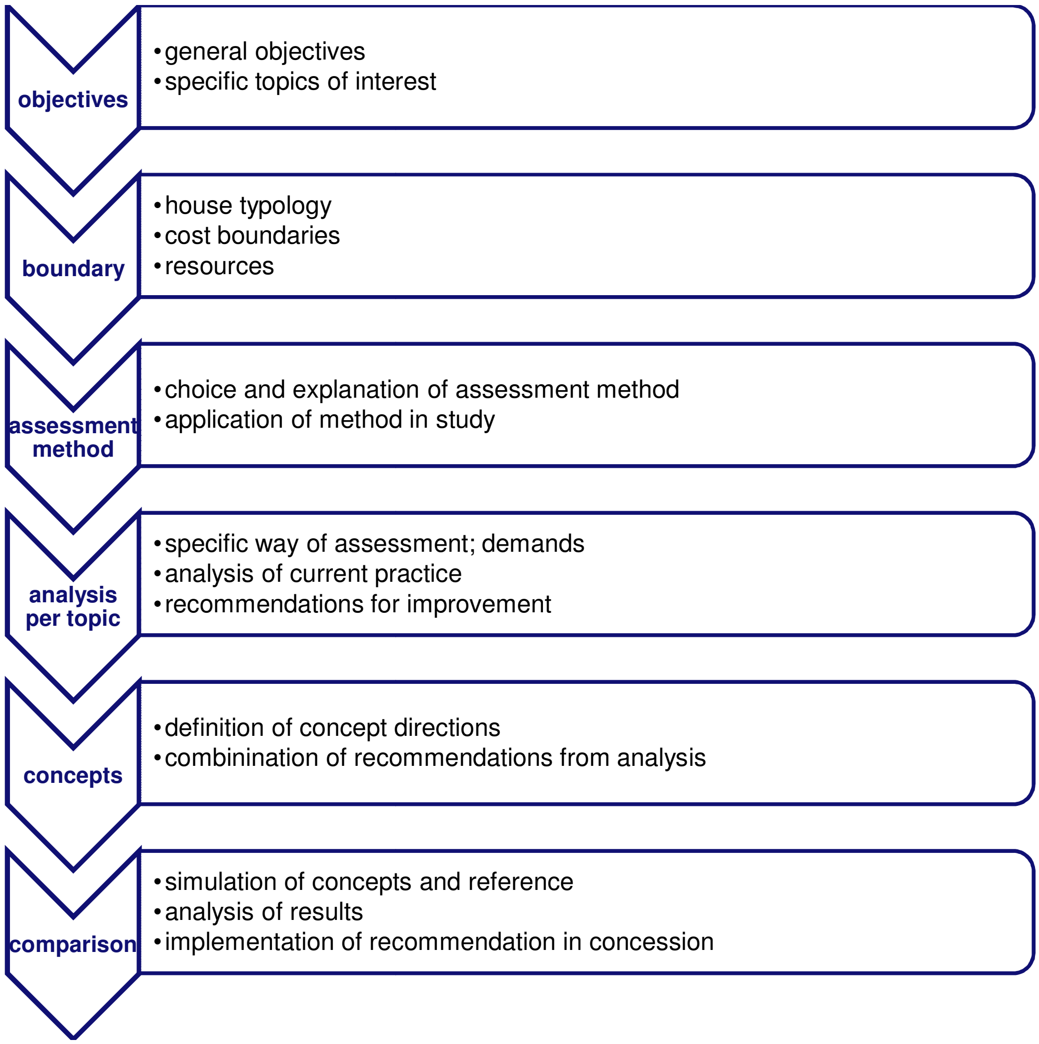


Figure 4: Graphical representation of project methodology.

Objectives: Which objectives are taken into account in order to achieve the main goal and how can they be translated in specific points of interest?

Aim of this research question is to define the objectives of the project in general terms such as sustainability, health and comfort, affordability, flexibility etc. The input for these objectives consist of the outcomes of preliminary study, background scope of the study, external parties, time limits, location boundaries and general knowledge.
The specific topics of interest for this project are divided in concrete parameters which have to be achieved and assessed. These parameters should also be compatible with the skills of the design team such that they can cope with the challenge of achieving goals.

Boundary: Which conditions will form the boundary of the house design to make it applicable to the Dutch house market?
In order to fulfil the aim to achieve a high impact of sustainability, the house typology will be deducted from house demand prognoses and the cost boundaries will be deducted from this house typology.

Assessment method: Which assessment method can integrate the performance level of all topics of interest as defined in order to give an integral score on sustainability for the house concepts?

The aim is to find the assessment method that can combine the individual performances per topic in order to weight them in an integral approach of sustainability. The choice of the most optimum method will be based on its compatibility with the building type, the boundary conditions and the presented specific points of interest. The actual use of this method within the project will be described.

Analysis per topic: How is each topic addressed by previously defined assessment method, and how should the current practice be improved to achieve a higher level of sustainability?
For each topic of interest, an analysis will be presented which includes the specific demands from the assessment method, the performance in the current practice and by help of short (literature) studies advice will be given for improvement in several concepts. A definition of concepts directions will be given in order to direct the solutions into a specific direction.

Concepts: Which combination of measures per topic of interest could be suggested in order to achieve sustainability within the given concept definitions in the presented house typology?
By help of arguments from the analysis per topic, the boundary conditions and the given assessment method the concepts will be designed.

Comparison: Which of the presented concepts can be defined as most feasible and sustainable, and how can this concept be improved in order to find a concept of concession?
The designed concepts will be assessed according to the presented method which will result in the performance that can be compared to the reference concept and to the other concepts. All concepts will be analysed to find the strengths and weaknesses in order to find the combination of measures that can lead to the concept of concession.

1.2.4 Structure of the project

This project is conducted within the scope of a combined graduation project; two students have been working on the content of this study which is represented in this report. For well assessment and definition of the work, a division of main tasks is presented in Appendix 1.
The project has been conducted within the scope of ‘Sustainable Energy Technology’ and ‘Physics of the Built Environment’ master programs at the Eindhoven University of Technology. The project work has been conducted as part of an internship at the international consultancy firm Arup, located in Amsterdam. Also, intensive collaboration with material supplier Kingspan (Tiel, the Netherlands) took place and assistance on building costs was given by IGG Bointon de Groot (Wassenaar, the Netherlands).

Table 2: Graduation committee

Members of the graduation committee	
First Coach	prof.ir. P.G.S. Rutten Faculty of Architecture, Eindhoven University of Technology
Second Coach	dr.ir. M.G.L.C. Loomans

	Faculty of Architecture, Eindhoven University of Technology
Third Coach	ir. B. Kramer Sustainability consultant at Arup Amsterdam
Member	dr.ir. A.J.H. Frijns Faculty of Mechanical Engineering, Eindhoven University of Technology

1.2.5 Layout of the report

This report describes the methodology and results of the conducted research. It also includes the findings of the preliminary study which lead to this study. The summary and main conclusions of this are given in this first chapter (**Introduction**). This chapter also describes the main- and sub- research questions which form the general methodology. It is explained in the next major part of the report (**Methodology**). This describes which goals should be reached in the next phase and which boundary conditions are taken as starting point. Also the assessment method to be used will be introduced. The **Analysis and Design** part describes, for several topics of interest, separate studies which address the demands for that topic, the performance in current practice and the suggested improvements in design. This section as a whole forms a design guideline for different concepts. In **Concepts and Comparison** the design strategies per topic are combined to integral concepts which are assessed according to the defined assessment method.

All findings in the project are concluded in the last part which will also answer the main research question as presented under Background and Methodology.

The appendices as referred to are compiled in a separate document, which among them includes a list of definitions in Appendix 2.

2 Methodology: Main approach and assumptions

2.1 Topics of interest

In this chapter, the topics which are significant and interesting for this study are introduced and their influence on the project is discussed. These are interpreted from findings from the preliminary literature study, interests of contributing parties and learning points from the meetings/interviews with experts. Although purpose is to achieve the overall objectives based on the specific points of interest, some of the points/parameters will not be studied in depth due to the capabilities and the limitations of the design team.

The general focus which is to be followed throughout the project and the specific points that the design team considered throughout the design process are presented. It should be noted that these are not the requirements of the final concept. So the points which will be mentioned below should be considered as the context to take into account certain aspects in the design process.

As explained above, in addition to the preliminary study, meetings with the experts working in the field of 'sustainable' building give ideas to determine the general objectives and the design parameters. This includes an excursion to BRE Innovation Park in London, a summary of which can be found in Appendix 3. It represents the speeches of several experts from Arup and Kingspan in the United Kingdom and the visit to the BRE Innovation Park in Watford.

It is taken into account that this study is conducted through Building Physics and Sustainable Energy Technology (mechanical engineering) backgrounds, therefore the main focus (and knowledge) lie in these fields. If the goals which are set exceed the capabilities and knowledge of the design team, the external parties are introduced for integrating their knowledge into the design.

Throughout the chapter, firstly main focuses of the project are defined in value domains which are explained previously and under each category specific points of interests are given since the whole domain can be extensive to work on. After having explained the objectives, boundary conditions of the project are specified.

2.1.1 Integral sustainability

The preliminary study focuses on sustainability from an integral perspective and points out the significance of integral approach to achieve sustainability in a building. It was also addressed by several speakers from building practice, who gave presentations during the excursion. All these stress that designing an 'energy efficient' house is not the only solution to deal with the problems of climate change depletion of sources. The importance of the integral sustainability was also stated in the introduction of this report: the Dutch government aims to spread the focus, away from only checking the energy performance in buildings. Therefore, one of the main objectives will be to integrate this topic in a house design.

2.1.2 Specific topics of interest

Although sustainability is addressed in an integral way, specific topics are studied in depth and remaining parts will be discussed but the level of the analysis is not the same as the mainly focused ones. If integral sustainability is defined in value domains (see definition in chapter 2), the domains with the major focus in this project are 'basic value', 'ecological value' and 'economical value'.

The choice for these values results from the findings in preliminary study, the capabilities and interests of the design team and the external parties.

Value Domains

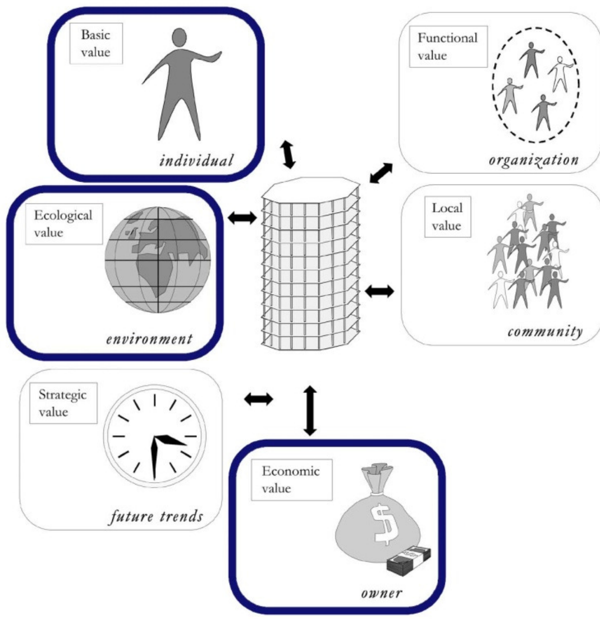


Figure 5: Illustration of value domains for integral design. Source: (Mallory-Hill 2004)

For the sake of broad perspective of the sustainability, local, functional and strategic values of the house are also discussed in this study to some extent. The limitations in the considerations in all categories are explained in the following part.

2.1.2.1 Basic value

The basic goal of building a house design is to give the inhabitants protection from the outdoor environment and assure a safe and comfortable place to live in. Therefore, for a house design, as for all the buildings, basic value of the building, as the name implies, is the most fundamental requirement to meet. In order to achieve a high basic value, in addition to the health and comfort in the indoor environment, safety and ease of use are essential to consider.

Considering the health and comfort in the house, the preliminary study results pointed out the attention which is given to the main aspects of this function (thermal and visual comfort). The fresh air supply in the houses was addressed, but could be improved in ways of CO_2 directed input and the decrease of pollutants. Also some extra attention on acoustical comfort within and on the border to neighbour houses could be given as well as a reconsidered division of rooms to improve the spatial comfort of a house.

In the preliminary study, the significance of safety and ease of use in the house have been stressed out in several projects. By achieving these, well-being of people will be improved in the house.

Since this study is a graduation project for the faculty of Physics for the Built Environment, the health and comfort aspects of the design receives a high and detailed level of attention and will take a large share in the results.

Health and comfort in the indoor environment

As mentioned previously, assuring health and comfort in the indoor environment of the house will be considered as one of the major objectives. In order to achieve this objective, parameters should be clearly defined. Following points, which constitutes different aspects of health and comfort, will be specifically taken into account during the design process:

- **Thermal comfort**
  An internationally-accepted definition of thermal comfort, used by ASHRAE, is 'that condition of mind which expresses satisfaction with the thermal environment' (ISO 7330). Thermal environment is affected by the air temperature, relative humidity, air velocity and radiant temperatures. For this study, the indoor air temperature will be considered to represent the thermal comfort in the house.

- **Indoor air quality**
  In most of the projects, the air quality is claimed to be achieved in the houses. Since this is an important measure for the health and comfort in the house, this should be taken into account during the design process. Generally, the air quality is represented by the fresh air availability in the indoor environment. This criterion can be interpreted by the CO_2 concentration in the room and air exchange rates which is supplied by the ventilation system (natural or mechanical). As mentioned in the preliminary study, volatile organic compounds emitted by the materials should be taken into account for satisfactory indoor air quality. But volatile organic compounds are mostly emitted by the furniture placed in the house not by the structural materials, so it is not in the scope of this project since this is a study for a conceptual design.

- **Visual comfort**
  Although visual comfort in houses is not strictly regulated as in office buildings, considering the possible use of the house as a 'home office' and to assure the comfort in the house, visual comfort becomes an important criterion to be taken into account during the design process. This criterion will be interpreted by daylight levels in the rooms and type of artificial lighting will be evaluated. Any measures to prevent glare will also help to improve the visual comfort in the house considering the possible use of the house as 'home-office' but it is challenging to predict 'glare' and design accordingly. So preventing glare will not be in the scope of this study.

- **Spatial comfort**
  Spatial comfort in a house is hard to measure and it is a rather subjective criterion. Also it depends on the way of living and preferences of the target group. In order to achieve high spatial comfort in the house local practice and conventional living spaces can be used as a guideline and so this will also add to the local value of the house which will be discussed later.

- **Acoustic comfort**
  Acoustic comfort is one of the points that were not addressed with adequate attention in the projects that were evaluated in the preliminary study. However, it is an important measure to assure the comfort in the indoor environment and efficient operation of the systems. So it will be calculated as sound levels in the rooms caused by appliances, ventilation and insulation levels.

Ease of use

As stated previously, people's well being is dependent on the good control and understanding over the activities around them. So, the house should be designed such that users, which might include a wide variety in terms of capabilities, should be able to cope with the environment in the house.

Ease of use will be evaluated mainly based on the control and monitoring systems in the house. Control strategy and availability of monitoring and control devices can be the main criteria to evaluate if the residents have a control over the activities in the house.
This may affect the efficient operation of the house and thus performance of the house in addition to the improved comfort of the residents. The study will include analysis of temperature and lighting control systems as well as the monitoring systems, which in general are referred to as 'domotica'. This analysis will be included in the 'User Behaviour' section as explained in the next sections.

2.1.2.2 Ecological value

Increasing the ecological value is one of the most important objectives of a 'sustainable' house project because it is related to the effect of the building to the global environment, in other words 'planet'. Problems of focusing the design strategies only in the energy efficiency of the house have been pointed out in the preliminary study, which were explained previously in this report. Therefore, to achieve high environmental performance, more points should be studied.

Since the CO_2 is the main contributor to the global warming among the greenhouse gases, reductions in CO_2 emissions has been a measure to show the environmental performance of the buildings. Therefore, high ecological value of the house will be achieved by meeting the requirements to reduce CO_2 emission due to building and operation of the house. Limitations to this analysis will be given in the corresponding part.

In addition to the CO_2 reduction, attention will also be given to the water consumption and waste management as they are in many of the sustainable housing projects and in BREEAM-

NL as part of sustainable house design strategies.

As was learned from the preliminary study and the experts during the excursion (see Appendix 3), the user behaviour has a significant effect in the environmental performance of the house and residents have a personal carbon footprint which includes their activities in and out of the house, which can be decreased. Therefore, decreasing carbon footprints of the residents due to activities in the house and the transportation will be considered as part of design strategies.

Since this project is topic of graduation for the faculty of Sustainable Energy Technology, the energy performance of the design will be given high attention and will be studied in detail. The material aspects will be taken into account, but detailed calculation on e.g. the embodied energy will not be made.

CO_2 emission reduction

In order to reduce the CO_2 emission and achieve zero energy consumption over a year, energy demand of the house should be minimized and the remainder should be met by renewable energy sources and/or efficient energy production systems. CO_2 emissions due to operation of the house will only be taken into account, since emissions throughout the whole lifetime of the house is complex and beyond the scope of this study.

- **CO_2 emission**

  Calculating the CO_2 emission in the whole life span of the house, including the building and demolition of the house, is complicated and unfeasible considering the capabilities of the design team. So this target will be considered for only the emissions related to the use of the house. On the other hand, CO_2 emissions due to the construction, material selection and demolition of the house may be reduced by proper material and building method selections.

  Achieving energy neutrality as part of the design strategy will be evaluated under this category and will not be taken as a main objective because the purpose of the project is not to find the most energy efficient house design but to find the optimum of ecological and economic value of the design.

  Since the common practice is to use electricity from the grid and the electricity is generated mainly by fossil fuels (as explained previously by energy mix of the Netherlands), it is essential to reduce the electricity demand of the house so that both energy neutrality and net zero carbon goals will be achieved.

  Considering the heating and the cooling loads are important causes of energy consumption in houses, it is essential to reduce the loads. The house will be designed for the Netherlands, so decreasing the heating load will be the main challenge of the project. However, the balance between the two should be taken into account because decreasing heating load would possibly mean increasing the cooling load.

  As explained previously, lighting is one of the main items in energy demand of a house and so minimizing the energy consumption by artificial indoor and outdoor lighting is an important criterion to meet to achieve net zero energy consumption in a year.

By increasing the thermal quality of the building skin it is possible to reduce the heating and cooling loads of the house. This includes the improved thermal properties and air-tightness of the building skin. Therefore, material selection and the design details will be critical to meet this criterion.

However, low/zero carbon technologies are undergoing a development phase and implementation of these technologies has not become common practice yet. So application of sustainable energy technologies becomes a challenging part of the project and for the purpose of satisfying both ‘sustainability’ and ‘affordability’ it is one of the most critical criteria to meet. This can be evaluated by checking the amount of energy supplied by these systems compared to the total energy demand. Since the design team is interested in the application.

- **Embodied energy**
  Although the whole lifespan of the house will not be taken into account for CO_2 emission calculations, embodied energy of the materials is an important parameter and selecting low embodied energy materials decreases the carbon footprint of the house. It should be noted that ‘embodied energy’ is a broad topic and a detailed analysis is beyond the scope of this project, only available information through manufacturers, material databases etc. will be used to estimate the environmental costs of using the specific building materials.

User Behaviour
It is one of the main objectives of the ‘sustainable’ housing concepts to reduce the ecological footprint of the residents so that the community will be sustainable as a whole. On the other hand, the user behaviour is influential on the environmental performance of the house. Therefore, it becomes a critical issue to affect the occupants’ behaviour in a positive way.

In order to achieve the overall objective of decreased carbon footprint of the residents, user behaviour inside and to some extent outside the house will be studied. Although this is a wide area of research, only the occupants’ energy consumption behaviour and transportation preferences will be taken into account in this study.

Depending on the selected systems/solutions to be used in the house, efficiency of these systems will depend on the user behaviour and as can be seen from the preliminary study results it is a quite influential on the environmental performance of the house. In the literature and the projects, some solutions and ways are pointed out to affect the user behaviour and increase the awareness of the residents to environmental issues. These will be studied and effectiveness of the solutions in the proposed conceptual design and local circumstances will be questioned.

Transportation of the people is another contributor to the CO_2 emissions as a result climate change. So to mitigate the impact of transportation occupants of the house should use low/zero carbon emitting ways of transportation. The house design should stimulate/allow the residents to choose the low carbon alternatives of transportation. This issue also includes the possible future perspective of the transportation industry but this will not be studied in depth because the conceptual design does not have a specific location.

Decreased water consumption
Water is a precious matter which is expected to be scarce in the coming future due to global warming effects. Therefore, reduction in water consumption has been considered as an important parameter for sustainable house design and dealing with the possible impacts of the climate change.

- **Water consumption**
  'The reduction of water consumption by the appliances is considered as the main strategy. Therefore, the ways of decreasing the water consumption will be analyzed in terms of applicability, costs and effectiveness. Since this is not in the scope of the capabilities of the design team, only available products in the market will be studied.
- **Water Recycling**
  As the second step for the reduction of water consumption process, recycling of the water for different use in the house may be used so that the remainder of the water consumption can be met by either recycled water or rain water which might be considered as the renewable supply of water. This section will not also be studied in detail but available solutions will be evaluated.

Waste management
Waste collection and management in centralized facilities are carbon intensive processes and to decrease the environmental impact due to the household waste, recycling and on-site treatment has been applied in several projects. Two different issues will be pointed out in this subject, which are waste recycling and on-site treatment.

To decrease the material and resource use waste recycling is a critical means so the households should be able to collect different types of recycled waste in a convenient place in the house so that they will be fostered to recycle their waste. Although this is a relatively simple point to consider and achieve, the significance of it should be anticipated in the design phase.

On-site management of household waste is useful to mitigate the efforts of transporting and processing waste, so implementing a composting facility in the house will reduce the environmental impact due to waste management. However, the feasibility of this system should be questioned during the design process. It should also be mentioned that the design team does not have the necessary skills to run a detailed analysis on this matter.

2.1.2.3 Economic value

In order to make 'sustainable' housing widespread and increase the impact of the efforts, the concept should be applicable in terms of costs as well. It was shortly indicated in the introduction that costs are an important aspect in the quality assessment of a house, so it is important to take this aspect in account in an early stage of the design. Therefore, the optimum between the environmental performance and the costs related to the improvement will be sought throughout the project.

So as one of the main aims of the project is to design an 'affordable' house, it is critical to improve the economic value of the house. In order to achieve this, specifically initial and operational costs and return of investment will be analyzed.

Since economics of the project requires background in this field, for this domain the input of external parties is used in order to help the designers to make sensible decisions in their choice on strategies. The level of detail in cost analysis will therefore also be general, but based on practical knowledge from experts, so the results will be valuable.

Calculating only the investment cost of a product is not sufficient to express its real costs/ savings in the life time of the product, so the investment costs of the building will not reflect the benefits of savings either during the use or the demolition of the house. Therefore, it is important to estimate the lifecycle costs of the building. However, calculating lifecycle costs of a building is a complicated process with elaborate assumptions and cost predictions which may include (Whole Building Design Guide website):

- Initial Costs—Purchase, Acquisition, Construction Costs
- Fuel Costs
- Operation, Maintenance, and Repair Costs
- Replacement Costs
- Residual Values—Resale or Salvage Values or Disposal Costs
- Finance Charges—Loan Interest Payments
- Non-Monetary Benefits or Costs

The lifecycle cost analysis is beyond the scope of this study considering the background of the design team. According to the experts from the building practice, in the building sector there seems to be lack of understanding of lifecycle costs of a building and currently investment are considered as the main parameters. On the other hand, the design of the house may result in cost savings in operation of the house, which might show the advantages of the design. For this study, only investment and wherever possible operational costs of the house will be calculated.

Initial and operational costs
Initial costs may include capital investment costs for land acquisition, construction or renovation and for the equipment needed to operate a facility (Whole Building Design Guide website). However, investment costs will include only building costs, and the ground costs will be excluded because the design will not be based on a specific location.

For the operational costs, only the energy and (if possible) water consumption costs will be presented because the operation, maintenance and repair costs can be difficult to estimate, which can be obtained from the manufacturer data. For the energy costs, the future projection of energy prices will also be incorporated in the calculations.

Return of investment
Return of investment shows how long it will take for the investment to payback the corresponding costs. For the systems in the house, especially installations, it is necessary to calculate the return of investment so that the advantages of installing energy efficient

and/or energy saving solutions in the house.

2.1.2.4 Strategic value

The possibilities for the future use of a house could extend its lifetime and therefore spread the impact of material use over a longer period. The changeability of space, systems, skin and structure could improve this strategic value and by that it is useful to consider the separation of these building levels.

The concept of a house is a building function which is not likely to change to many other functions, only for different types of inhabitants. Therefore the focus on this value will be less than on the first three which were specified, but the possibilities for future users and ease of changeability will be taken into account. Some assumptions and general design guides will be taken but no detailed study will be conducted on this topic.

As stated above, the design of the house should allow possible changes in the house to take place with minimum effort. This strategy should be incorporated in the building services design and also in the structural and spatial design of the house.

Technical flexibility
This point is relevant for the building services used in the house and possible (future) expansion and/or change of the systems should be taken into account to cost a minimum effort. This item includes also the possible application of the housing concept in the district level. The impact of the efforts to achieve 'sustainability' increases as the design allows the future technologies to be applied in the building.

Usability by different (future) users
To design a house for different users with different demands like disabled, elderly, families with children etc. is a difficult to achieve and mostly an ignored design strategy. In order to improve the flexibility of the concepts and to preserve the value of the house over years, the concepts are designed to be suitable for elderly or disabled and easy to modify for future changes if necessary.

2.1.2.5 Functional value

This value domain is related to the management of the activities in the buildings, so it is more relevant for utility, office buildings which require building management. However, ease of operation and maintenance is critical for houses as well considering the fact that more installations will possibly be available in the houses in the future.

While choosing the systems and solutions to use in the house simplicity and easy maintenance should be one of the focus points so that inhabitants will be able to maintain the ongoing operations in the house and/or will need minimum effort to keep the house functioning.

Since this study will result in a conceptual design and it is not possible to run performance tests, it is necessary to rely on the manufacturer information or field reports from the previous applications (if any). At this point, use of proven and previously applied technologies can be helpful to decrease these risks.

2.1.2.6 Local value

As specified previously the design will be suitable for the Netherlands but the project will not be based on a specific location within the Netherlands. So studying and improving the local value of the building in depth will not be possible. However, local practice and k now how in the Netherlands can be influential in the design decisions, which might be useful to take into account throughout the design process.

Local practice and local know-how can be defined and studied by the literature study and meeting experts from the field. This consideration also includes building regulations, local climatic and environmental conditions which may affect the applicability of the design in the local circumstances.

2.1.3 Integral design

The outcomes of the preliminary study show the difficulty in reaching the goal of integral sustainability. It mainly depends on the design strategies which are chosen at the start of a project and it was learned that holding on to these strategies gives the best chances of indeed reaching the set goals. The difficulty of reaching this goal lies in the concessions which are mostly done during the design process. Therefore, an integral design approach is favoured and is applied in this study as far as possible. As could be learned from the preliminary study it is valuable to take all different demands into account from the start of the process and include them in all building levels. The collaboration of students from two faculties, the contribution of cost experts and input from architects will contribute to the design process to reach a design which complies with all demanded values in a high level.

2.2 Boundary conditions

2.2.1 Location

As was already stated in the introduction, the Netherlands is chosen as building region. It is the aim of the contributing parties to find a housing concept for this country, and therefore the preliminary was also focused on this. The boundary conditions will be defined for the Netherlands as a whole, which accounts for the climate and the national building regulations. General assumptions will be taken for the specific climate, urban planning, (ground) costs etc. The assumptions will be presented in the relevant chapters. This non location bounded (within the Netherlands) design will result in higher applicability as is one of the objectives.

Figure 6: Location: The Netherlands

2.2.2 House type

Since it is the aim to increase the impact of this housing concept, it is chosen to use the most built housing type (by help of governmental prognoses) as a representative example. The type, size and cost range as well as the finance type (rental or owner-property) are specified. This will also lead to the target group for which this house will be built, though the objective holds that it should be applicable for different user types within this group.

Population

There will be a decrease in population growth. The amount of people will increase from 16.3 to 17.0 million in 2034, but the growth will be about zero between 2020 and 2034. Despite of this, it is expected that the amount of households will increase compared to the 2006 level due to increasing individualization. The trend of the aging population will continue which results in more elderly and less middle aged people (in their working years). Den Otter and Heida (2007, p. 12) present a higher increase in households than population, which implicates a decrease in the amount of people per household. This is predicted to shift from 2.26 in 2006 to 2.07 in 2030.

The demand for amount of houses will therefore increase in the coming years (with about 50,000 a year between 2006 and 2020). This demand could be filled in by new built homes. They are not only necessary to supply the demand, but also to replace some parts of the existing stock which is out-of-date or mismatches the demand for quality.

Demands for new housing developments

The type of houses which needs to be built in the near future is described in the prognosis report of Housing market Exploration, Socrates 2006 (Poulus and Heida, 2006). This report concludes in a decreasing shortage of housing (but still a shortage) and an increasing mismatch in types and qualities of the current housing stock for the population demands. In order to meet the house wishes of the consumer, it is needed for the market of new built houses to deliver the types of houses which are not released in the current stock. This results in a 55% of new houses for owner-occupied property and 45% for rental property, mainly in the Green Urban and Rural (Villages) sectors (see Figure 7).

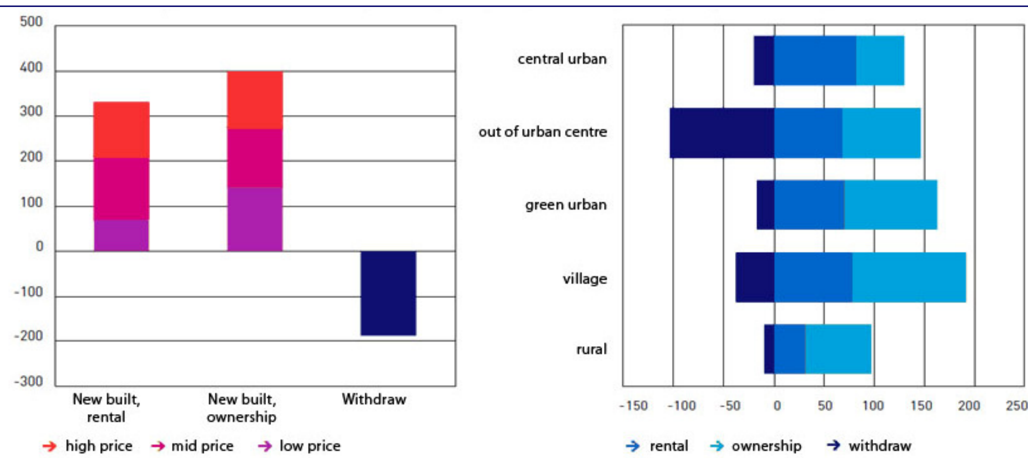


Figure 7: New housing developments and withdrawal development by ownership and price (left) and by ownership and living environment (right); (amount x 1000), 2006-2015. Source: (Poulus and Heida, 2006, p.7).

The demands for new housing developments are higher than before in the mid- and low-priced owner-occupied properties, and many of them in the green urban and most in rural (villages) areas. General expectations point out the continuous pressure on the housing market which will result in more ambitious qualitative house demands. The chances for success will probably not increase for the consumer. The main quality parameters for consumers are the space in the house, the building type and the price.
The type of houses which is demanded is also deducted from Socrates 2006 (Poulus and Heida, 2006, p.22-23). The main demand is found in single family homes in the living environment of a town. In these environments, the focus for the price range of the new housing developments is mostly in the low- and mid-price range of which the latter one is the biggest.

This demanded type coincides with the location and price range in which the demand is highest. For example, terraced houses are seen as acceptable for the low-priced sector (59% accepted, in rental and owner-occupied property), but less acceptable for higher price sectors (40% for mid-price and only 11%). As can be expected, the percentage of people which is interested in a house decreases when the price increases.

Conclusions
The most demanded house type is a single family home, in the owner-occupied property in the low-price cost range. Following the figures in Socrates 2006, the specifications are summarized in Table 3 and Table 4.

Table 3: Specifications of the house type for this research. Source: summary of details from (Poulus and Heida, 2006)

House specifications, deducted from Socrates 2006	
Ownership	Owner-occupied property
House type	Single family house
Building type	**Terraced house** / coupled house / detached house
Price range	Low-price
Price range (selling price)	Below 200,000 euro (2006) Below 215,000 euro (current level 2010)
Living environment	Rural: Villages Centre
Amount of rooms	4,0
Surface of house	126 m^2
Surface of living room	35 m^2
Price per m^2	1540 euro
% of homes accepted in terraced structure	59%

Table 4: Typology of living environment: Villages Centre. Source: summary of details from (Poulus and Heida, 2006)

Typology of living environment: Villages Centre	
% of pre-WOII houses	15,4%
% of single family houses	88,3%
% of detached houses	18,2%

Density of living area	23,2
Total density	2,9
Shops per 1000 households	20,6
% of families	40,8
% of low incomes (below 9,249 euro in the year 2000)	38,9

2.2.3 Reference house

A reference house is used to compare the several possible concepts which direct to an affordable sustainable house. Costs, energy, materials, health and comfort can be compared to this reference house to check the performance of the new designs.

2.2.3.1 SenterNovem

SenterNovem has presented a set of reference houses (Referentiewoningen nieuwbouw, 2006) in order to make new houses comparable in their energy efficiency by EPC. The houses are based on the house building demands of January 1st, 2006. The main starting point for these is the Energy performance Coefficient of 0.8. For calculation of this EPC, NPR 5129 version 2.02 of April 2006 is used.

Houses with a balanced ventilation system and heat recovery and self regulating grills with mechanical exhaust are applied quite much in the Netherlands, so both are presented for each house type. These both options give a different result in EPC (0.78 for mechanical exhaust and 0.74 for balanced ventilation). The best performing option on energy is chosen in this study as a starting point, so the version with balanced ventilation, which is also the one without energy producing features like a solar collector.

The houses are designed to fit the common building practice in the Netherlands, so input is used from the monitor new houses (Monitor Nieuwe Woningen).

The choice on the typology terraced house is partly based on the VROM Socrates 2006 study and the considerations presented in the SenterNovem reference house publication, which specifies the amount of terraced houses in the Netherlands.

Terraced houses represent almost 50% of all housing production in the Netherlands. Of this 50% almost one quarter exists of end of terrace houses (so in between). In total, about 36.5% of all new built houses are not end of terrace houses. 20% of terraced houses is found in rental sector and 80% in the owner-occupied sector. A terraced house contains generally 3 bedrooms and occurs with flat or sloped roof structures (Referentiewoningen, p. 10). The house design is given in Figure 8 below. In Appendix 4 details of the house are summarized.

Drawings of SenterNovem reference house

Figure 8: Drawings of SenterNovem Reference terraced house

2.2.3.2 Considerations

The house size differs by 2 m^2 (less) from the VROM Socrates 2006 outcomes. It is therefore convenient to use the SenterNovem characteristics, since it comes with a whole set of figures about energy use and costs besides just floor plan surface and selling price.

Incorporating the trend of lower demanded EPC values in the future years (0.6 in 2011, 0.4 in 2015) might be possible when choosing one of the concepts from the SenterNovem website. But the choice of one of these concepts as a reference house would be quite random and therefore the more funded one will be used, since it will be more representative for the housing stock.

2.3 Assessment method

The project goal has been defined as to design an affordable sustainable house which will be applicable in the Netherlands. The objectives which have been defined in the first sub-question give the scope and focus of this project, in short terms: a terraced house in the mid price for owner-occupied property, which performs very well on health and comfort and even high on many topics of sustainability. The specific topics of interest have given a more detailed focus on several design parameters in the project. The overview of overall and specific topics with the current boundary conditions is given in Table 5.

In order to translate these objectives and parameters into a satisfying end result, it is necessary to specify the demands which have to be met. These demands can be based on national building regulation, scientific studies or building practice, separately. A more efficient way to collect this set of demands is to use an assessment method which includes the demands from these fields. It can also help in assessment of the final product, to check if it meets the demands which are set in the beginning to fulfil the objectives.

The choice of assessment method will be described in this chapter. This will be chosen based on the specific demands and by help of studies which have been conducted on the comparison of sustainable assessment tools for the Netherlands. When chosen, the content of the method will be described and use in this project will be explained in general. The next chapter will focus on the use of this method per parameter. If the overall method cannot be used for some parameters, the argumentation will be given to use a different approach and the content of that approach will be described.

Table 5: Overview of objectives and boundary conditions

Overall objectives		
Sustainable design	Affordable design	Integral design
Boundary conditions		
Region: the Netherlands	House type: single family terraced house	Price range: Low price, owner occupied-property
Specific points of interest		
General topic	Specific topic	Level of study
High basic value: Health, comfort, ease of use and safety.	Thermal comfort Indoor air quality Visual comfort Acoustic comfort Domotica Safety - accessibility	High High High High Medium Low
High ecologic value: CO_2 emission by use or built, water consumption, waste management.	CO2 emission during use Embodied energy Carbon footprint of residents Water consumption Water recycling Household waste	High Medium Medium Medium Medium Low
High economic value: Affordability	Building costs Return of investment	Medium Medium
High strategic value: Flexibility	Technical flexibility Useability of different users	Medium Medium
High functional value: Operation, maintenance	Use of proven technologies Choice of low maintenance solutions	Low Low
High local value: Applicability	Use of local know-how Compatibility with local regulation	Low Medium

2.3.1 Choice of overall assessment method

Demands for the method

The method should be able to assess the specific topics by quantitative numbers, to reach a certain level of sustainability and affordability in a performance based way. In order to assess the specific topics, it should give attention to these and it should be able for the user to filter the topics which are not of interest. The level of depth to study certain topics should be variable by use of this method. These demands are included in the total list of demands:

- It should *at least* comply with the Dutch building regulation (the Building decree 2003).
- The theoretical background of the method should be clear for all users.
- The way of accreditation of credits should be open for all users.
- The method should include most of our specific topics of interest.
- Most of the topics in the method should be performance based.
- The users must be able to select their specific topics of interest and still be able to give a final grade for the integral design concept.
- The level of depth to address a certain topic should be variable.

Types of methods

The methods which can be found are defined in general as prescriptive of performance based tools.

- Prescriptive based tool: a tool which gives a list of practical measures for the designer, which can be chosen and combined in order to reach a certain amount of credit points
- Performance based tool: a tool which sets quantitative demands for several topics, but does not describe the practical measures by which these demands can be reached.

Also, the available tools can be divided in single-topic and a combined set of sustainability topics which result in a single degree.

Choice of method

Some studies have been done on the description and comparison of several sustainable building assessment methods. Based on those conclusions, the best method is chosen for this project. In 2008, under the authority of SenterNovem, DHV has done a study on 'Instruments for assessment and promotion of sustainable office buildings' (Clocquet, Boonstra and Joosten 2008). Another report by TU Delft gives a model of comparison for the Dutch Green Building Tool (Dobbelsteen, 2008).

Both studies give an overview of available tools for assessment of sustainable buildings, and conclude on the applicability for the Netherlands. The demands which are set for the project mostly cohere with the demands which are set for the research project by Dobbelsteen. It was done in authorization of the Dutch Green Building Council, in order to find a good basis for a Dutch tool which integrates many sustainability topics. Dobbelsteen focuses on a comparison between LEED, BREEAM, Eco-Quantum and GreenCalc+. The choice of these tools for study was based on the DGBC needs: performance directed, objective, robust, simple, transparent, qualified, international, harmonizing, affordable and complete.

The only two really interesting tools seem to be LEED and BREEAM, since these are integral assessment methods with a multicriteria analysis based on a simple checklist, though also including advanced calculating tools behind it. EcoQuantum and GreenCalc+ are missing the integral aspects. The reason to choose for BREEAM as basis for the Dutch green building tool is the use of Life Cycle Analysis, good adaptation possibilities per country and that it's scores are based on reference scores of other buildings. BREEAM is mostly used in the United Kingdom, though LEED is known and used all over the world.

Since BREEAM is an advanced checklist, it could very well be used in combination with GreenCalc+ or EcoQuantum, since these tools give well calculated and specific environmental analysis of buildings. This was stated by Dobbelsteen in 2008, but meanwhile the textual description of the credits for material use do include the advice to use one of these tools for calculation of the score. The acknowledgement is given that a BREEAM-NL certificate should be given with a year of assessment attached to it, to show the state of comparison while assessing the building.

The DHV study (Clocquet, Boonstra and Joosten 2008) concludes on the topics of focus for these assessment tools.

- Communication about sustainability is one of the main driving forces behind the development of these tools.
- The scales to describe the level of sustainability in most of the tools are not influenced by the changes in innovation, standards or other development. This was also indicated by Dobbelsteen, who advises to rate the buildings by year to a reference building of that period.
- When comparing international known methods for the Dutch market, BREEAM is more favorable over LEED, because the latter one is explicitly based on American regulation and references.

BREEAM-NL v1.2 (Residential)

Both studies by DHV and by Dobbelsteen conclude in a positive result for the use of BREEAM in the Netherlands, if a broad spectrum of topics needs to be handled. In order to show the compatibility with the demands in this project, some explanation of BREEAM-NL will be given here.

In 2008, the Dutch Green Building Council (DGBC) started translation of BREEAM to BREEAM-NL. For this purpose, five working groups consisting of retail, residential, office, industrial and regional stakeholders were asked to give feedback for the scheme. Since October 2009, BREEAM-NL has been published and become operational for new buildings including offices and homes (BREEAM-NL, 2010). Since March 2010, a beta version for residential buildings is published. When 'BREEAM-NL' is mentioned further in this text, it refers to this residential version. The assessment of a building is based on a list of credits (given in Appendix 4). This list is based on the BREEAM Europe 2008 Credit list and translated to the Dutch law and regulation, practice guidelines and building practice. All credits are divided in several categories, which are weighted by importance and the achieved level is expressed in percentages as shown in the list below:

- Pass 30%, also the minimum requirement for the granting of a license
- Good 45%
- Very Good 55%

- Excellent 70%
- Outstanding 85%

Some credits are mandatory, this amount increases with the aimed level (more mandatory credits for ‘outstanding’ than for ‘good’). The categories and their weighting for the current version of BREEAM-NL are equal to the presented division in Figure 3.

Achieving a credit is based on reaching sustainability targets and meeting the given set of criteria. The sustainability targets outreach the legal minimum, as they are described in the Dutch Building Decree or other laws. This accreditation results in a combination of prescriptive and performance based assessment.

Advantages within this project
In order to address and to assess the topics of interest in this project in a satisfying way, BREEAM-NL seems to be a good method. It is based on the Dutch building regulation and it addresses 9 topics of sustainability. There is a high focus on energy, health & comfort and materials which complies with the set demands for basic and ecological values.

- The method meets the current building regulations, so practical implementation is possible.
- The method is open in its assessment: all criteria to achieve credit points are communicated in detail, so a clear insight is possible in the theory behind it.
- This method complies with the aim of this project to address sustainability in a broad perspective. It handles many topics, besides energy reduction.
- Because of the checklist structure with mandatory and tradable credits, a choice can be made on which topics to focus. The criteria can be chosen on their usefulness and be assessed separate from each other.

Market value
Besides the practical feasibility of BREEAM-NL in this project, the external party Kingspan finds the use of BREEAM-NL for housing assessment interesting for the market value of the end result.

Drawbacks within this project
Though affordability is a major point of interest in this project, it is not awarded in any of the credits of BREEAM-NL v1.2 (residential). The economic value of the project could not be assessed by this method, therefore an alternative is found as described in the next paragraph.

Some of the credits in BREEAM-NL are not performance based, but prescriptive. In the topics which will not be studied in far detail, this is not a problem. These prescriptive criteria will be adopted as a guideline. In the topics which will be basis of detailed study, these credits will be filtered out in order not to conflict with the analytic study to be conducted.

2.3.2 Application of BREEAM-NL in this project

Selection of credits

One of the reasons to choose BREEAM-NL as an assessment method is the division into topics and criteria. By this, the applicable topics for the project can be chosen and the ones which are not applicable can be left out. Topics are left out for different reasons, being the phase of design (conceptual, not being built yet) the lack of exact location details, the scope in the objectives or the capabilities or time available in the design team. Appendix 5 shows the reasoning for choice of topics, the amount of credits available in the original version of BREEAM-NL and the amount of credits available in this study. The total amount of criteria reduces thereby from 39 to 13 and the amount of maximum achievable credits reduces from 89 to 37. Not all topics are taken into account in the quantitative assessment of this study; therefore the share of topic weight is changed as can be seen in Figure 9.

Topics in BREEAM-NL and in study

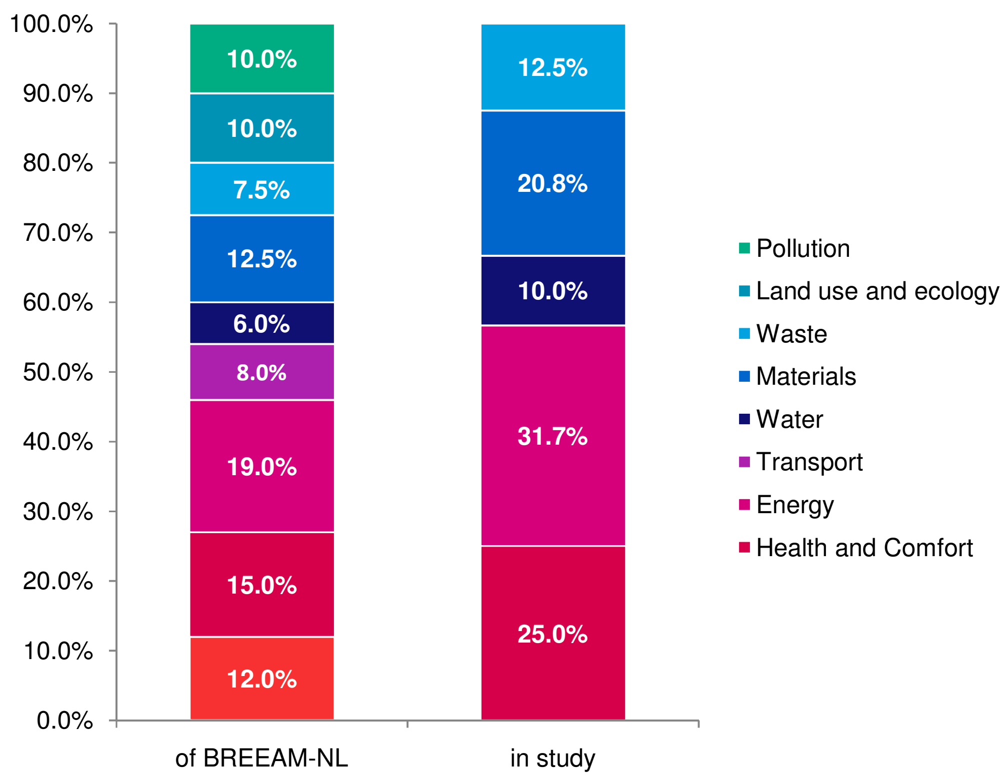


Figure 9: Share of topics in BREEAM-NL and in adapted version for assessment in study

Although not all credits are included in this study, this selection could give insight in comparison of conceptual houses which are not designed for a specific location. When the remaining credits (mainly on management, land use and ecology, transport and pollution) of BREEAM-NL would be added to the calculated value, the achievable real value of BREEAM-NL could be predicted for the specific concept. The left out topics are location bounded and therefore could not be included in a conceptual design for a non specified location. The concepts by themselves can be compared since they are assessed within the same scope.

The demands and awarding of credits will be followed in this study as they are described in BREEAM-NL. In the next chapter, each topic is analyzed in terms of BREEAM-NL demands, assessment methodology and possibilities for improvement.

Assessment on all topics of interest

Unfortunately, not all value domains and topics of interest as described in the objectives chapter can be expressed in BREEAM-NL credits. Some of them are implicitly taken into account by use of BREEAM-NL as guideline, for others a specific assessment method has to be developed.

Economic value

Although economic value is one of the main objectives, this topic is not addressed in any of the BREEAM-NL criteria. The assessment of economic value for the concept will therefore be based on the partial tests:

- **Selling price**: in order to fit within the boundary conditions, each proposed concept should have a selling price below the limit that was given for this house typology as a 'willingness to pay'. This is the selling price including ground costs and VAT which is <1,688 euro per m2 user area (< 215,000 euro for a 125 m^2 house). If a proposed concept shows a higher price, it does not comply.
- **€/BREEAM-NL credit**: in order to show the difference of approach to achieve sustainability, the total selling price of the house will be devided by the amount of awarded credits to find the difference between concepts in profitability of sustainability achievement.
- **Payback of investment:** although the selling price of a concept can be below the allowed selling price as mentioned under the first partial test, the additional investment compared to the selling price of the reference house might not pay itself back within the mortgage period of 30 years. Therefore the payback period of each concept will be calculated compared to the reference house.

More detailed description of this assessment, the used model, resources and assumptions will be given in the next chapter under Economic Value.

Functional value

As the goal is to achieve flawless operation and low maintenance addressed in the management topics of BREEAM-NL, but the assessment is based on performance after built. Design principles for this can therefore not be rewarded by BREEAM-NL. By choosing proven technologies and by reduction of the amount of systems in the concepts, big steps are taken to improve the operation of the total. This topic will not be further part of assessment.

Local value

Since the aim for local value is to make the house applicable to its location, this goal can be achieved by use of local know-how and technologies and by taking into the count the local building regulations. This is done by using the BREEAM-NL tool as framework, by using Dutch suppliers and consultation of experts in Dutch building practice. Further assessment will not be done on this topic.

2.4 The Performance Assessment Tool

Next to the overall assessment method, the concepts are compared in terms of their performances especially for the energy use and the thermal comfort. For this purpose, using a dynamic building simulation tool is the most effective way of analyzing the concepts at a satisfactory level.

Several simulation packages are evaluated for the selection of the most appropriate tool for this study. These include Ecotect, TRNSYS, IES VE, eQUEST, ESP-r and HAMBASE. It should be noted that there exist more tools but these tools are considered based on the availability and suitability for the study. The simulation tools are evaluated in the following table and the reasons for discarding the tools other than eQUEST are presented.

Table 6: Simulation tools comparison for the purpose of this study

Tool	Strengths	Weaknesses	Why not?
Ecotect	Suitable for concepts evaluation with different level of details*	Thermal analysis may not be reliable and certain type of analysis requires too detailed input.*	The reliability of the calculations is questionable.
TRNSYS	Extensive systems library especially for renewable energy systems*	No assumptions for the components, detailed input information required. 3D visualisation is not available*	It lacks visualisation, especially for the building geometry. It is not user-friendly and limited know-how in TU/e and Arup to consult
IES VE	Complete analysis of the building is possible. Reliable calculations for 'passive' measures.	Systems library is limited, especially for renewable energy systems.	Due to limitations on the systems side, coupling of the 'passive' and 'active' solutions is limited.
ESP-r	ESP-r is flexible and powerful enough to simulate many innovative or leading edge technologies.*	The extent of the options and level of detail slows the learning process. Specialist features require knowledge of the particular subject.*	It is difficult to learn and the level of details is beyond the scope of this project. Only expertise in TU/e is available.
HAMBASE	A complete building simulation is possible, any kind of solution can be modelled.	Scripting is necessary for modifications/new models. A new system/solution should be modelled from scratch, including the mathematical model.	It requires considerable time to build new models and even modifying existing models. Limited sources of help from TU/e and no other source of expertise.
VABI	Based on Dutch practice and regulation. Strong in heat demands and overheating.	No complete building simulation: no electricity use, low level of detail in operation schedules, no	Since it only focuses on heating and cooling loads, this tool is not applicable for total

	daylight dependency.	simulation in this project.

*source: Building Energy Software Tools Directory, DoE.

The chosen software for the dynamic simulation is ‘eQUEST’ building performance modelling software which is developed by Department of Energy (DoE) in USA. This software is selected based on the following factors and advantages:

- Reliability and the speed of the calculations
- Completeness to evaluate the passive and active design of the concepts
- User friendly interface
- Adequate depth of details for conceptual design phase
- Availability of expertise within Arup to consult.

The disadvantages of using eQUEST can be listed as follows:

- It does not yet support SI units (I-P units only), so the conversion of units takes time.
- The tool is developed for the US market, therefore the default applications mostly are not suitable for European practice.
- Default components have a number of assumptions which have to be reviewed.
- Infiltration/natural ventilation models are simplified and limited.
- Scripting may be necessary to modify the input parameters in detail.

Considering the advantages of using eQUEST and being capable of simulating both the ‘active’ and the ‘passive’ measures at satisfactory level of details, it is the most reasonable software tool to use for dynamical simulation of the concepts considering the purpose and the scope of this study.

3 Results: Analysis and design

Due to the large amount of parameters to be included in the study, the amount of concepts will be kept at a limited number. The concepts will therefore be given a specific direction, to be diverse in their basis.

All of them will be located in the Netherlands, so a general (site) analysis will be conducted for all. The different options which result from that will be divided over the three concepts to their best match as predicted.
The concepts will be differentiated, based on their typology of:

- Passive design strategies
- Active design strategies
- Strategies which combine both passive and active principles.

With these directions in mind, the analysis of the chosen parameters will be focused in such a way that strategies will be given in these three directions, in order to make these applicable in the next phase of design.

Passive and active definitions
From the design philosophy based on the Trias Energetica, the distinction between passive and active design lays in the steps of the process: first to design a building by passive methods to reduce the need for energy and afterwards use active technologies efficient to either supply energy in a renewable way or to decrease the use of fossil fuels by efficient conversion.

This distinction in strategies level is made by Ochoa and Capeluto (2008), who investigated the difference between active and passive designed office buildings in hot climates. They define them as:

Passive	early smart architectural design; ‘‘‘passive design’’ refers to a series of architectural design strategies used by the designer to develop a building in order to respond adequately to climatic requirements, among other contextual necessities.’ [p.1]
Active	later intelligent technological devices; ‘‘‘active features’’ are the elements through which buildings self-adjust to changes initiated by their internal or external environments. They can be both automatic and manual and do not need to include sophisticated electronics.’ [p.1]
Intelligent	"Intelligent buildings’’ are those that combine both active and passive intelligence, active features and passive design strategies, to provide maximum occupant comfort by using minimum energy’ [p1]. ‘The primary functions that must be performed by intelligent systems were considered: perception, reasoning and action. This corresponds in robotics to sensors, control processors and actuators’ [p.2].

They made a comparison between several active, passive and combination of passive and active strategies for an office building in a hot climate. This resulted in high energy savings for the combined strategies, intermediate savings for the passive strategies and lowest for the active ones.

Though active measures in the façade were able to provide good visual comfort, passive strategies lacked user control and quick response and the combination gave comparable results for different orientations.

This lead to the main conclusion that: a successful intelligent building, as seen from the results, cannot be just a collection of smart active features. It needs to be a product of a design process that incorporates intelligence in all its stages, including the schematic, early ones, while taking advantage of technological innovations.' [p.11]

Similar to the definitions given above, distinction has been defined in systems level by Wachenfeldt and Bell (2003) in their study where they compared passive and active building integrated energy systems. According to this study:

Passive systems are characterized by their direct interaction between the building fabric and the environment. They do not produce power and do not need any mechanical devices or significant mechanical energy in order to operate.

Active systems are designed to utilize the environment to avoid or meet a significant proportion of the residual demand. These systems either produce power, or they operate in conjunction with some mechanical devices to utilize renewable energy to provide heating/cooling.

After having made the distinction between passive and active strategies, the line of thinking for designing different concepts can be defined. Based on the definitions above three concepts can be designed; namely passive, active and hybrid. The basic philosophies of these concepts are given. It should be kept in mind that in none of these concepts health and comfort in the indoor environment will be compromised, which means all the concepts will achieve the same minimum level of health and comfort in the house.

Basic philosophy of the 'passive' concept

Basically this concept will be designed to illustrate the effectiveness of the passive design strategies (solutions/systems) to achieve the predetermined goals. The steps to design this concept are;

1. Decrease the energy demand of the house using the passive principles, as low as possible such that requirements from the active systems are minimized.
2. Remainder part of the energy demand should be supplied by either sustainable energy technologies or efficient fossil fuel based technologies, determined by other parameters.

Following this approach, the economic cost of the concept design will be mostly due to the passive measures. So, decisions on active systems should be made based on the cost effectiveness of the systems so that the concepts will be comparable in terms of costs.

Basic philosophy of the 'active' concept
Basically this concept will be designed to illustrate the effectiveness of the active systems to achieve the predetermined goals. It should be noted that the passive measures will still be taken into account but to a certain extend. The steps to design this concept are;

- Keep the energy demand of the house at regulated levels by utilizing the passive measures to comply with the regulations.
- Relatively larger energy requirement of this concept should be supplied mostly by sustainable energy technologies.

Different than the passive concept, the active systems will play the most important role in terms of economic costs of this concept. Therefore, decisions can be made based on the improvement of the environmental performance of the house by the use of active systems.

Basic philosophy of the 'hybrid' concept
As the name of the concept implies, this concept will be designed using the combination of passive and active strategies/systems to achieve the predetermined goals. The steps to design this concept are:

1. Passive design measures should be determined according to their effect on environmental performance of the house and costs. Some of the parameters can be compromised based on their effectiveness.
2. The energy demand of this concept is expected to be higher than passive and lower than active concept, so active systems can be determined in terms of the contribution to the environmental performance of the house versus the corresponding costs.

So the hybrid concept will seek for the balance of passive and active strategies/systems in terms of environmental performance and corresponding costs.

Although for all the concepts the decisions seem to be based on evaluation of costs and energy reductions, integral design of the systems/solutions will be taken into account. For example, some passive solutions may limit the possibilities to apply some active systems in terms of resulting performance.

On the other hand, some measures should be applied in all the concepts so that they will be comparable and the comparison will be objective.

3.1 Analysis per point of interest

Per point of interest, the assessment method and appending demands are primary sought in BREEAM-NL category to increase consistency. The topics are described on their assessment possibilities. Table 7 shows all main objectives, the specific topics of interest, the chosen assessment method and appending demands and the method for analysis.

Most of the parameters could be expressed in BREEAM-NL assessment and demands. This references to the specific credit is given in the table. Where BREEAM-NL does not give an assessment (with demands) for a specific point of interest (example: costs), an alternative method was found. For these deviating topics, the assessment method is described under the analysis of the topic in the coming paragraphs.

For each topic of interest, the analysis will therefore consist of:

- General aim
- Assessment method (or specific part of that method)
- Methodology of analysis
- Results: comparison of demands and supply
- Conclusions: gap size between demand and supply
- Recommendation: strategies for design: passive, active and combinations
- Used sources

Table 7: Overview of assessed parameters, the assessment method, the demands and method of analysis

TO ACHIEVE	BY SPECIFICALLY FOCUSING ON	BASED ON	BY CHECKING (quantity)	SPECIFIC DEMANDS (value)	TOOL FOR ASSESSMENT	METHOD OF STUDY
Health and Comfort in the Indoor Environment	Thermal Comfort	BREEAM-NL Hea10: Thermal Comfort	Overheating hours per year for Predicted Mean Votes	GIW-ISSO 2008 demands PMV <+0,5 TO <300	Dynamic thermal simulation tool eQUEST	Literature: strategies for thermal comfort; Analysis: outdoor temperatures compared to heating set points; PMV influencing parameters
	Indoor Air Quality	BREEAM-NL Hea8: Indoor Air Quality	Ventilation capacity per room (dm^3/s)	Building decree demands	Hand calculations: Excel	Literature: common ventilation principles; values from regulation; current quality in houses
	Visual Comfort	BREEAM-NL Hea1: Daylight	Average Daylight Factors (ADF) in rooms	DF > 2,0% for 85% of user area	BRE calculation: Excel	Analysis: influence of design parameters on ADF; artificial lighting demand
	Acoustic Comfort	BREEAM-NL Hea13: Acoustics	Sound Levels caused by services; Noise insulation levels	Building decree; BREEAM-NL Hea13 demands	Building details; supplier information	Regulations: search for surrounding sound values, leads to insulation demands. Literature: search for general solutions
	Spatial Comfort	BREEAM-NL Hea14: Outdoor space, Hea15: Accessibility; Hea16: Flexibility	Sizes in the space plan and smart design of partitions for flexibility	Accessible ground floor, outdoor space, options for change/expanding	Measurement in drawings	Literature: finding examples for accessibility in design Analysis: possibilities of adapted space plan

Low CO_2 Emission and Energy Neutrality	CO_2 emission	BREEAM-NL Ene1: CO_2 emission reduction	Energy Performance improvement	1-100% Energy Performance Improvement; set EPC on 0,4 (2016 goal) and try to reach zero CO_2	eQUEST	Literature study to find the available sources in the region and the proven and feasible technologies to use these sources. On the other hand describe the general energy pattern of Dutch households and conclude in options for reduction.
	Embodied Energy/ Environmental impact	BREEAM-NL Mat1: Building Materials	'Shadow-price' per building material per m^2 gross floor area (GFA)	10-20-30-40-50-60% lower than shadow-price of 0,8 euro/m^2 GFA	Greencalc+ V2.20	Literature study to find the general use of building materials in the Netherlands and possibilities for change. Analysis of solution impact using Greencalc

TO ACHIEVE	BY SPECIFICALLY FOCUSING ON	BASED ON	BY CHECKING (quantity)	SPECIFIC DEMANDS (value)	TOOL FOR ASSESSMENT	METHOD OF STUDY
User Behaviour	User Preferences	HVAC preferences	Measures and possible savings	Availability of monitoring devices and specific assumptions for calculations	Hand calculations and results from literature	Literature study for preferences of Dutch households and specific strategies
	Domotica	Lighting Control	Daylight dependent control and savings			Literature study to find out possible strategies for using monitoring devices and possible effects on the user behaviour
		Temperature Control	Possible set points and savings			
		Monitoring Devices	Possible savings			
Decreased Water Consumption	Water consumption	BREEAM-NL: Wat4: Water consumption	Water flows of appliances	BREEAM-NL Wat1 demands: flows of water in several taps	Manufacturer data	Short analysis on water consumption in residences and saving measures.
	Water recycling	BREEAM-NL: Wat5: Water recycling	Rain or grey water collection measures, options for reuse	Rain water collection tank/ grey water collection for toilet flushing/ irrigation	Manufacturer data.	Analysis on rain water availability in Netherlands, possible solutions in design.
Waste Management	Household waste	BREEAM-NL Wst 3: Storage of (non-)recyclable household waste	Availability and size of convenient place for storing recyclable waste	BREEAM-NL Wst3 demands: size and availability	Drawings	design spaces and solutions for good waste recycling in household
		BREEAM-NL Wst5: Compost	Availability of Composting facilities and user guide	facility for organic composting and user manual	Manufacturer data	Design composting facility in the garden place.

Affordability	Total investment costs & selling price	Socrates 2006 prognosis: allowed selling prices	Building costs, ground costs and additional costs	Selling price under 215,000 euro	Building cost information IGG	Study will be done on general expenses in Dutch housing and overview of investment costs for several sustainability measures.
	Return of Investment	IGG: within mortgage lifetime of house	Payback time based on annuity mortgage and operational cost reduction	Within 30 years	Mortgage model: Excel	Analysis for return on investment of several measures in a house. By help of the Net Present Value. If not available, than use of literature sources
Locally Applicable	Use of Local know-how, proven technologies and compatibility with regulations	Consultation of experts, case studies and standards	Already available systems in the Netherlands, use of Dutch figures, regulations	n/a	n/a	Integrated in assessment method by use of BREEAM-NL as framework

3.1.1 Thermal comfort

3.1.1.1 General aim

Finding the characteristics of the Dutch climate and compare them to the demanded indoor climate. The difference will define the need and choice of methods to design a comfortable thermal comfort.

3.1.1.2 Assessment method

BREEAM-NL credit *HEA 10: Thermal Comfort* aims to insure good thermal comfort by application of dynamic thermal building simulation in design phase. It specifies the demands as well as the assessment method for a good indoor climate. The demands are set higher than specified in the Dutch Building Decree. The assessment method is based on the widely used Predicted Mean Vote and a building simulation program for dynamic simulation is advised.

Climate reference year
Since in BREEAM-NL HEA 10 the reference climate year from NEN 5060 is prescribed, this data is used for analysis of the thermal comfort. For simulation of the several concepts, the DOE climate file for Amsterdam is applied, since the data from NEN 5060 could not be included in eQUEST. Although the specific data might differ a bit, the general influence of the climate will be represented by use of this climate file.

Demands for indoor temperatures
Using HEA 10, the demands for indoor temperatures can be deducted from GIW-ISSO publication 2008, which gives design and installation advices for new built single family homes and apartments. This publication mentions minimum temperature points for heating. More specifications are given in the publication, but these are of too much detail in this level of analysis. These values should be achievable in the house design, but lower temperatures are mainly used (e.g. 18 degrees for bedrooms and kitchen).

Table 8: Temperature demands for different rooms, according to GIW/ISSO 2008.

Room	Minimum heating temperature (°C)
Bathroom	22
Staying areas: Living room, bedrooms, kitchen etc	20
Travel spaces: Attics, Toilets, Internal storage spaces	15
Temperature setback in bath- and staying areas during night (23.00 – 07.00 hrs) is assumed.	

BREEAM-NL adds to this a maximum amount of hours per year in which a certain comfort level may be exceeded. This is done by hand of Prof. P.O. Fanger's model (published in NEN-ISO 7730) for thermal comfort of the predicted mean vote (PMV). This parameter combines different comfort parameters to one figure, including the surrounding (air temperature, mean radiant temperature, relative humidity, air velocity (maximum of 0.2 m/s)) and parameters considering a person (activity rate and clothing level).

The demand for overheating is given in HEA 10 by two categories of strictness:

- *Normal: the PMV value of 0.5 may be exceeded for maximum 300 hours per year.*
- Strict: the PMV value of 0.3 may be exceeded for maximum 250 hours per year.

For this study, the normal value will be taken as the minimum standard. Improvements in terms of PMV values closer to zero or less exceeding hours are preferable. Appendix 6 describes this PMV method in further detail, including the sensitivity of several influencing parameters.

Table 9: Design values for overheating temperatures (PMV+0.5) in common situations, source: ISSO 19

Room	Activity	Metabolism [met]	Winter situation (0.9 clo; RV=50%; v=0.1 m/s) [°C]	Summer situation (0.7 clo; RV=50%; v=0.1 m/s) [°C]
Living room, office room	Sitting work, some standing up	1.2	24.5	25.5
Kitchen	Standing, walking activity	1.7	21.5	22.5
Bedrooms*	Lying down	0.8	27.5	27.5
Traffic spaces	Walking	1.7	21.5	22.5

* deducted from the values for hospitals, patient rooms

Discussion of assessment method

Calculation of local discomfort is part of Fanger's method to predict thermal comfort as shown before. This is an important aspect, but is hard to estimate in the residential environment by a dynamic building simulation program as eQUEST. The program only calculates average hourly temperatures per room, and not per part of the room. Nor does it calculate the radiant temperatures of walls and other room partitions. Therefore, calculation of the PMV and especially calculation of the PPD will not be possible. Instead, assessment will be done based on the temperature levels as are given in Table 9, for the maximum temperatures in winter and summer.

Improvement of local comfort will be taken into account when deciding the terminal systems for heating and choice of window types and placement of them.

3.1.1.3 Methodology of analysis

Climate analysis

For the analysis of a house in the region of the Netherlands, the indoor temperature demands will be compared to the climate reference year conform NEN 5060**.** The Dutch institute for normalization has published a new reference data set for energy and capacity calculation for buildings. Every five years, the data from the previous 20 years is combined in a reference climate data set. The latest one combines the data from the years 1986 till 2005.

Different datasets are given:

- A data set for **energy performance** calculation
- A set for exceeding risks of temperatures (over- and under exceeding chances 1-2-5%, so the most extreme values occur in the 1%-dataset)
- Extreme dates for **cooling capacity design**
- Extreme dates for **heating capacity design**

- **Number of degree days (heating days),** to compare energy uses of different years

In this analysis only the data sets for energy performance and exceeding risk temperatures will be used. The extreme dates for heating and cooling are only necessary for designing the systems and the building details.

By use of this climate data, the difference between demand and supply of temperatures will be presented, and by that the demand for heating and/or cooling for the situation if there was no house involved. The demand temperatures will be deducted for the lower limit by use of the GIW/ISSO values; the upper limits are based on the average overheating temperature of 25 degrees Celsius.

Measures to achieve demands
Some design strategies were searched in literature which could be implemented in the residential sector, in the climate of the Netherlands. These include mainly measures in the building structure. Also, the influence that each comfort parameter has on the PMV will be discussed.

As an addition to this, an analysis in the different types of heating generation and terminal systems is presented to show which are most feasible to achieve the given demands.

3.1.1.4 Results

Climate analysis
Figure 10 shows in the blue line the outdoor temperatures as they are used for a general reference year for energy demand calculation.

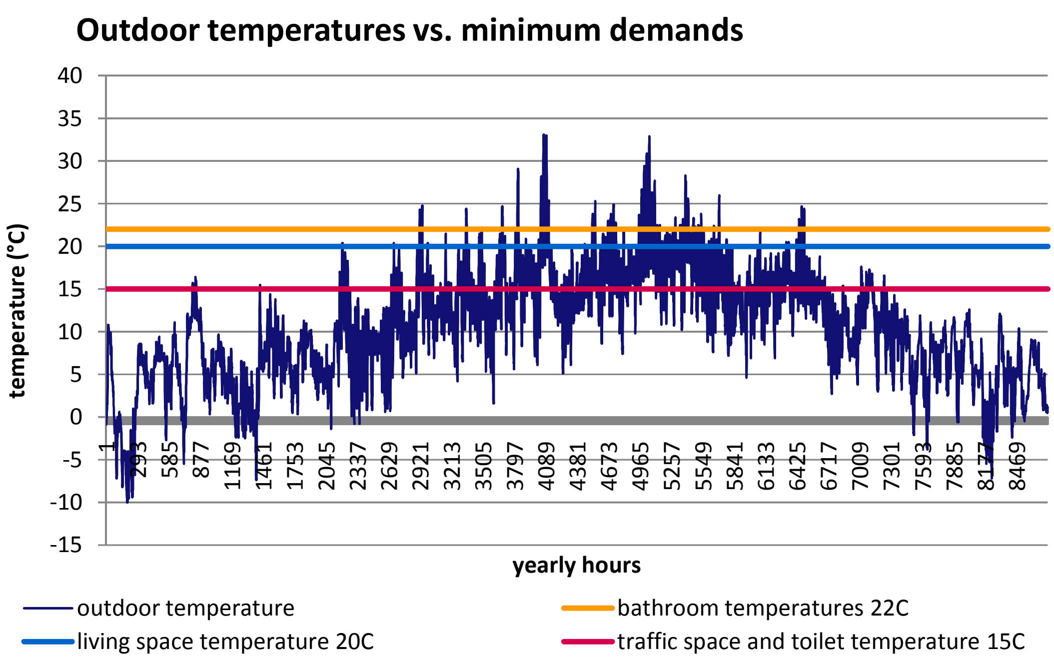


Figure 10: Hourly temperatures versus indoor demands following GIW/ISSO 2008. Source: NEN 5060

The heating time per year can be calculated from this graph, this is summarized in Table 10.

Table 10: Overview of heating hours during a year, for different rooms and temperature demands.

		traffic space, toilet	living space, home office, kitchen	bedroom,bathroom
minimum temperature	°C	15	20	22
heating hours	-	6546	8179	8456
heating time % (of yearly hours)	%	75%	93%	96%
average temperature difference	K	11.96	10.22	6.08

Overheating is defined as exceeding the PMV>+0.5 value. This value can only be calculated when a building is involved. To present the amount of overheating for the climate without building, temperatures for PMV <+0.5 are given in Table 11. This table shows that the use of overheating above 25 degrees is a proper level, it can be applied for most rooms.

Table 11: Overheating hours and temperature difference per room type, for climate NEN 5060 (PMV>+0.5)

		living room	living/office room: active	kitchen	traffic spaces
max. outdoor temperature winter	°C	25.5	24.5	21.5	21.5
max. outdoor temperature summer	°C	26.5	25.5	22.5	22.5
overheating hours	-	208	286	661	661
overheating time % (of yearly hours)	%	2%	3%	8%	8%
average temperature difference	K	473	724	2098	2098

Measures to achieve demands

Achievement of thermal comfort levels within the house (main heating demand) can be done in ways of passive and active measures. These are the main strategies within this research. In terms of sustainable design, the demand for higher indoor temperatures than outside can be solved in several ways (following the steps of Trias Energetica):

- By preventing heat from escaping the building (thermal insulation, air tightness)
- By storing excessive heat during periods of high outdoor temperatures for moments of lower outdoor temperatures (thermal storage: long term/short term)
- By passively using external heat sources (heat from sun, earth, waste, etc.).
- By actively adding heat to the house (by use of renewable sources or conventional gas-heaters)

Since this topic focuses on the achievement of good indoor climate, the GGD report for healthy homes has been consulted in order to show the best measures. They mainly focus on low temperature differences and reduction of overheating. The set of measures which is advised by the GGD is presented in appendix 6.2.

Terminal Systems Analysis

In this part, systems to ensure thermal comfort in the house will be discussed and comparison will be made between the systems in terms of their possible performances.

Literature study will be the basis for the comparison and evaluation of the systems. These systems only include the distribution of heat/cold in the house, so generation systems are not discussed here.

Distribution systems may be distinguished by the transport medium as water or air, and the temperature to supply heat/cold, i.e. high temperature or low temperature. If the transport medium is water, heat/cold is distributed by closed loop systems in combination with radiant surfaces. In practice several types of surfaces are utilized for the distribution of heat/cold including radiators, convectors, panels, floor, walls and ceiling. The heating/cooling energy can also be distributed through air, mostly ventilation air, and these can be heated up by air or water sources depending on the type of the generation system. Since water has about four times higher heat capacity and 1000x higher density than air, it is preferable for energy distribution. However, installation costs are higher since separate piping is necessary for water based systems while ventilation ducts can be used for air based systems.

The space heating plays a more important role than cooling demand in the Netherlands for the residential energy consumption, and the advantages and disadvantages of low or high temperature systems are similar for both heating and cooling purposes. So, in this section, terminal systems for space heating are investigated.

In the literature, design temperature ranges are defined as given in Table 12.

Table 12: Temperature ranges for different systems, source: (Dijk,H. et al., 1998)

System	Supply flow	Return flow
High Temperature	90 ^{o}C	70 ^{o}C
Medium Temperature	55 ^{o}C	35-40 ^{o}C
Low Temperature	45 ^{o}C	25-35 ^{o}C
Very Low Temperature	35 ^{o}C	25 ^{o}C

In the Netherlands, the most common type of heat distribution in residential buildings is high temperature radiators with a water supply temperature of 90^{o}C and return temperature of 70^{o}C (Eijdems and Boerstra,1999). However, there are several types of terminal systems which are applied in residential buildings. In order to comprehend the heating and cooling capabilities and characteristics of different terminal systems, results from a research conducted by IEA are listed in Appendix 7, the results are listed in Table 13. These systems are selected on the basis of possibility to apply in residential buildings as given in the guidebook.

The capacities of these systems are given in Watt per square-meter of user area. Maximum heating capacities are calculated for each system by taking the user floor area as 125 m^2 as in the SenterNovem reference house. Calculations show that the low temperature heating systems can deliver lower capacities compared to the high temperature radiators, except for air heating/cooling. This also explains the slow response of the water based low temperature heating systems and therefore operation of these systems require adequate control strategies. On the other hand, low temperature heating systems should be installed in well-insulated buildings. The comparison of the these systems in terms of their performance is made in the following part.

Table 13: Comparison of different terminal systems, source: Annex 37 IEA, 2003

	Systems	Heating Performance: Max. Capacity	
		per 125 m^2 house	per m^2
Water based systems	HT Radiators	18.75 kW	150W
	Floor Heating/ Cooling	8.75 kW	70W
	Wall Heating/ Cooling	12.50 kW	100W
	LT Radiators/Convectors	12.50 kW	100W
	Radiative Panels	8.75 kW	70W
	Ceiling Integrated System	6.00 kW	48W
Water/Air Based Systems	Fan coils	8.75 kW	70W
	Supply air conditioning	-	
Air Based Systems	Air/air heat exchangers	-	

There are several advantages of low temperature heating over high temperature heating in terms of energy consumption, indoor air quality and thermal comfort. A study for these advantages concluded these advantages (and disadvantages) as listed in Table 14.

In this table, '+' refers to better performance and '-' refers to worse performance compared to the reference system in the corresponding item and '0' means there are no differences between the performances of both systems.

Table 14: Low temperature heating and high temperature heating comparison, source: (Eijdems and Boerstra,1999).

	systems which are compared				
LT Heat Distribution	Floor Heating	Wall Heating	LT Radiators	LT Convectors	LT Air Heating
HT Reference	**90/70 Radiators**	**90/70 Radiators**	**90/70 Radiators**	**HT Convectors**	**HT Air Heating**
	results of comparison per topic				
Thermal Comfort					
Radiant heat	+++	++	+	0	0
Temperature gradient	+++	++	++	++	++
Radiant heat asymmetry	0	0	0	0	0
Floor Temperature	+++	0	0	0	0
Temperature fluctuations	++	+	+	+/0	+/0
Heating up period	-	-	-	-	0
Cooling options	+++	++	0	0	+
Air velocities and draught	+	+	+	+	0
Indoor Air Quality					
Particles	+++	++	+	+	0
Mites	+++	+	0	0	0
Enthalpy	+++	++	+	0	+
Annoyance and dust	++	++	+	+	+
Energy Consumption					
Transmission losses	-	-	0	0	0

Venting losses	++	++	+	0	0
Transport energy	-	-	-	0	0
Utilization of gains	+	+	0	0	0

As can be interpreted from the table, for thermal comfort low temperature heating performs better except for the heating up period which is one of the main disadvantages of low temperature systems. The most advantageous type seems to be the floor heating option, which has a lower energy consumption due to higher efficient heat distribution, high thermal comfort and indoor air quality. Another problem of low temperature systems is that they require larger surface areas compared to high temperature heating systems. If the heating surface area and temperature difference is directly correlated, the surface area requirement would be 3-4 times higher than high temperature heating to deliver the same amount of energy. This comparison is not relevant for air based systems. However, the amount of air to be transported should be increased in the case of low temperature air heating.
Using air or water as the transport medium for the design have both advantages and disadvantages, which are:

- Air has a lower specific heat capacity than water, so high amount of air should be transported to transfer the same amount of energy.
- Air based systems can deliver heating/cooling more rapidly than the water based systems.
- Water is circulated in pipes and breaking of the piping system can cause serious damages in the building, though this happens seldom.
- Air based systems can cause acoustical problems especially in the residential buildings.
- Water is more frequently used in the practice in the Netherlands, especially for the residential applications.

In the preliminary study, several examples have been studied and the following solutions have been obtained.

- *Woonhuis 2.0*
  Heating is based on the production of heat by vacuum solar collector tubes on the roof. The heat is transported by water to the floor heating system in the house.
- *Greenhouse homes (kaswoningen)*
  Heating for the house is provided by a high efficiency solar-gas combination heater, which gives the heat to a low-temperature floor heating system.
- *Powerhouse Leusden*
  Heating for the house is mainly produced by two large solar collectors which are installed on the façade of the garage (vertical) and two are placed on top of the garage (4 in total). The heat transported through the heating tubes in floor climate system.

These examples show that low temperature floor heating is one of the most common examples of heat distribution systems in low energy houses in the Netherlands.

Discussion

Thermal properties of the Netherlands are specified here for a specific location as matches with the used climate year (de Bilt). It should be acknowledged that there can be differences found for these temperatures in different parts of the Netherlands and in different residential areas. The city temperatures are generally higher (known as heat islands) than in open land or villages. In this study, higher temperatures for cities are not incorporated since the aimed location for the house will be in a village area.

Also, the comparison has been made between outdoor temperatures and minimum indoor temperatures. The aspect of building the building skin and systems is not taken into account. The comparison shows which demand for heating or cooling has to be met in each time of the year.

3.1.1.5 Conclusions

On methodology

- For assessment the minimum temperatures as given by GIW/ISSO combined with the demands for overheating hours over a certain PMV value will be used.
- The suggested PMV method is mainly used in offices and should be calculated per part of the room. The dynamic simulation program as suggested does not provide enough information to calculate these PMV values, therefore the temperatures for overheating as presented earlier in Table 9 will be used for assessment.

On demands

- Most of the year, heating is needed to comply with the minimum demanded temperatures. This could be read from Table 10, by the percentage of yearly hours in which heating is needed (75-96% for different room functions).
- The temperature difference for heating lies for the most rooms in the house around 10 degrees; it is 2 degrees higher for the traffic spaces and 4 degrees lower for the bathroom.
- Though the most hours per year demand heating, overheating can be a risk in the Dutch climate. In the worst case situation, overheating hours count up to 661 for kitchen and traffic spaces, which is much more than the allowed 300. Living- and office rooms could stay below the 300 hours, unless gains from sun, people and equipment are well considered.
- Based on comparison between indoor and outdoor temperatures, it can be concluded that there is a general demand for heating and a small demand for cooling. The building skin is not taken into account and can have a highly accumulating effect. Due to the difference in demand, there will not be an energy balance between heating and cooling. The cooling demand may not be neglected. This conclusion affects choices on energy balanced based solutions, like thermal storage systems (e.g. aquifers). The risk of imbalance is present.

Solutions

- Thermal discomfort could occur from design. In order to prevent this, an equal distribution of heat is favourable. This can be found for low temperature heating systems with large surfaces and careful design of window types and placement.
- Considering the evaluations and examples given above, and the fact that designed concepts will be well-insulated buildings, in all the concepts low temperature floor heating (and cooling if necessary) will be applied.

3.1.1.6 Strategies for design

Passive concept
In order to achieve thermal comfort in the passive concept, the focus will be on building skin improvements in order to minimize the influences from outside. This implies increasing the thermal capacity of the construction (higher weight materials), increasing the thermal insulation (higher Rc-values, thicker insulation) and increasing the air tightness (reducing infiltration losses). These measures comply with the first step of Trias Energetica: reducing the demand. The active system which is recommended complies with this passive design and will therefore be low temperature floor heating based on water distribution.

Active concept
In order to achieve thermal comfort in the active concept, a low temperature terminal heating system will be applied, based on water distribution. This type of system fits with several low energy heating generation systems and is therefore favourable for a sustainable house design. The thermal quality of the building structure will not be improved, since the current skin complies with building regulation and the approach is to do additional investments in active measures.

3.1.2 Indoor air quality

3.1.2.1 General aim

Aim is to improve the healthy indoor environment by providing enough fresh air by supply of clean outdoor air and exhaust of used indoor air. The indoor air should be kept free from pollution inside and outside the building. For persons, the CO_2 concentration should be kept below 800 ppm (for normal people density and outdoor CO_2 concentration of 350 ppm, which is common in the Netherlands).

3.1.2.2 Assessment method

For this parameter, BREEAM-NL *HEA 8: internal air quality* is taken as a lead for design and assessment. This credit takes the demand from the Building Decree as a lead and gives extra attention to the inlets and outlets of ventilation openings.
The inlets of mechanical ventilation systems should be 10 meter away from exhaust openings of mechanical ventilation. They should also be 20 meters away from any external sources of air pollution. All ventilation grills for purge ventilation and open able windows should be 10 meter away from any external sources of air pollution. Within mechanical ventilation systems, there may not be any recirculation nor internal insulation of air ducts and no air humidification (unless it is steam humidification). Filters in mechanical ventilation systems should comply with minimum demands of NEN-EN 13779. Spaces with internal sources of air pollution (e.g. kitchens) should have an exhaust which prevents the air to mix with other rooms in the building.
In order to achieve the level of CO_2 below 800 ppm, to prevent moisture problems and to prevent any high concentrations of other pollutants, the Building Decree specifies the demands for minimum ventilation flows in houses, see Table 15.

Table 15: minimum demands for ventilation in houses, Building Decree 2003

Room	Minimum demand		Quality	Air speed in living zone*
	$dm^3/s/m^2$	dm^3/s		m/s
Occupied zone (verblijfsgebied)	0.9	7	≥ 50% of total inlet directly from outside	
Occupied space (verblijfsruimte)	0.7	7		
Occupied zone with cooking facility (< 15kW)	0.9	21	≥ 50% of total inlet directly from outside, exhaust directly to outside	
Toilet		7	exhaust directly to outside	0.2
Bathroom		14	exhaust directly to outside	
Traffic area	0.7			
Metering cupboard	2 (per m^3)	2		
Waste storage area		100		
Dryer/laundry space <2.5 m^2		7		
Dryer/laundry space <14 m^2		14		
Storage room (not under stairs)		7		

**Living zone is the part of the used area, which is: 1.0 m from the external walls; 0.2 m from the internal walls; up to 1.8m from the floor.*

An **occupied zone** (verblijfsgebied in Dutch) is a part of the occupied function (e.g. a house) which includes at least one *occupied space*, which consists of one or more attached spaces on the same building level, not being a toilet, a bathroom, a technical room or a traffic space.

An **occupied space** (verblijfsruimte in Dutch) is a room for the stay of people, or a room in which the characteristic activities of the occupied function take place (e.g. sleeping room, living room, kitchen, hobby room).

In order to prevent unwanted and uncontrollable extra flow through infiltration, the Building Decree also gives limits for the air tightness of houses. This is maximum 200 dm^3/s per $500m^3$ of building volume, and ground floors with a maximum air flow of 0.002 $dm^3/s/m^2$.

Low air tightness affects the performance of a ventilation system, the energy use for heating and the acoustic performance of the façade in a negative way.

3.1.2.3 Methodology of analysis

This analysis chapter will not discuss the supply of polluting sources in the outdoor air, the air and wind pressures which could influence the quality of the ventilation system. These parameters are highly fluctuating, so no concrete strategies could be deducted from it for a conceptual house at an unspecified location. Therefore the analysis will be based on the current ventilation methods and in the Dutch housing stock. This indicates the quality of ventilation and the commonly used, advisable and proven methods. Topics of discussion are:

- Air quality in the existing stock
- Infiltration
- Ventilation principles
- Control systems

3.1.2.4 Results: comparison of demands and supply

Air quality in the existing stock
By the Dutch governmental Research Institute for Man and Environment (RIVM in Dutch), a research has been conducted on the air quality in the Dutch housing stock (Jongeneel et. al 2009). Several components in the air can be indicated as polluting. They range from moisture to CO_2 and to gases like radon. Details on the type of polluting components and the problems in the Dutch housing stock are presented in Appendix 8.

The report by RIVM on the indoor environment (recent scientific developments summarized) from 2009, combines the conclusions of several studies on the indoor environment in Dutch houses. One of the conclusions is that the intense focus on energy reduction leads to a lack of attention for ventilation and with that for the indoor air quality. The way to reduce the amount of pollutant is to ventilate the house.

Ventilation provides fresh air into a house and exhausts the used air from the house. It increases dilution of internal polluting sources and reduces the effect of outdoor particles which will be brought into the house. The amount of ventilation is depending on weather aspects, orientation, air tightness of the skin and user behaviour. Peaks in ventilation amounts will be resulting from user behaviour (opening windows) and peaks in pollution will be too (use of products or appliances).
Continuous pollution results from the building materials which are used in a house. If the ventilation rate drops, the concentration of pollutants can increase rapidly, since it behaves with a hyperbolic equation. A minimum of 0.5 air changes per hour in a room is set to prevent high concentrations of for example radon.

The increasing air tightness of homes (to achieve energy reduction) leads to risks of lower ventilation flows. Other measures have to be used (besides infiltration) to insure a certain ventilation level.

The sources of moisture in a house are leakages, rising moisture, local heating, people, cooking and use of the bathroom. Ventilation ensures the exhaust of moisture which is produced inside a home. A high level of moist can give health and building technical problems. Moisture problems have been reduced (as calculated for 1971, 1995, 2000 and 2020). The quality of the building has been improved, and with that the amount of moisture problems. Awareness is necessary in the future, when building skin is tightened to prevent moisture problems (van Veen 2001).

Infiltration
In order to achieve lower values for infiltration and therefore lower uncontrolled heat losses through air movement, the building skin needs to be tightened. This can be done by giving more attention to details, including air tight tape between the several connections. Also the cracks between open able parts like windows and doors need to be given an extra rubber band to ensure closing.

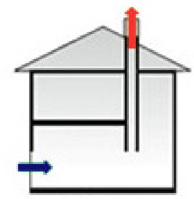
The achievable values for air tightness depend for some part on the type of building structure. The reference house is built with an infiltration value per user area ($q_{v,10,kar}$) of 0.625 $dm^3/s/m^2$. The Dutch Building Decree demands a value of 200 dm^3/s for a 500 m^3 volume house. This complies with 1.0 $dm^3/s/m^2$ when assuming 2.6m floor room height. According to Toolkitconcepten Passiefhuis values of 0.3 $dm^3/s/m^2$ should be well achievable for poured concrete structures. Additional measures are necessary to achieve the values which are demanded for the Passive house concept < 0.15 $dm^3/s/m^2$.

For wood frame building structures this value can also be achieved by using the vapour barrier as air tight layer or sheeting with tightened seems as air tight layer.

Ventilation principles
Design aspects of ventilation systems are mainly the energy use for preheating of ventilation air or driving fans and the thermal comfort of the people inside. The conflicting demands of optimizing both parameters make the ventilation in houses a difficult and to solve subject. Complaints about draught, the amount of fresh air, the quality of air and noise due to the system or ventilation openings are common.

In general, four ventilation principles are distinguished, which all have their advantages and disadvantages. Recommendations are given which show the possibilities of using the particular system in the most optimum way.

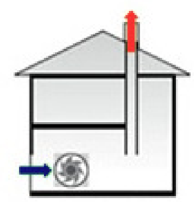
Natural ventilation (passive)



The principle is based on a combination of wind pressure and the stack effect in vertical direction. Openings in the façade provide fresh air and a chimney on top will lead the used air away. This system is noiseless and does not demand energy for fans. But the flow is highly depended on wind speed and user pattern. The minimum amount is not guaranteed. Draught can be prevented by self regulating grills and noise can be prevented by use of baffle chambers. Awareness is needed for fitting exhaust ducts into the design (to provide good stack effect). Heat recovery from ventilation air is not an option.

An option to prevent draught is to place inlets behind radiators in the façade. This will cause preheating of the air, though being on low positioned.

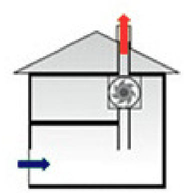
Mechanical inlet, natural exhaust



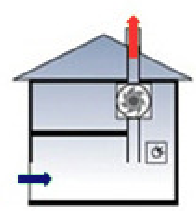
Only applied in combination with air heating, but not very feasible since preheating of air is necessary to prevent comfort problems and heat recovery in return air is not an option. Therefore it is not further explained here.

Natural inlet, mechanical exhaust (could be active or hybrid)

By use of mechanical exhaust, the ventilation flow will always be insured. Exhaust is mostly placed in kitchen, toilet and bathroom. Attention should be given to operation of the system, users should not be able to turn it off, but flow size must be controllable in kitchen and bathroom.



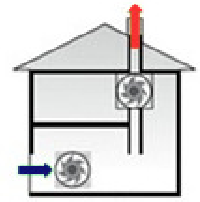
The systems gives more secure flows than natural ventilation, while duct sizes are kept small and user control is easy. Problems could be too low ventilation flows due to user behavior and draught near facades. This can again be prevented by using self regulating grills. Noise problems could occur because of the fan, which also needs auxiliary energy. Sound baffles can be needed if the external sound load is high.

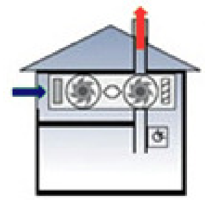


The hybrid version of this system will only apply mechanical exhaust if users demand extra ventilation or if natural forces are not sufficient to provide enough ventilation flow. The control systems which is needed for this is complex and expensive.

Mechanical inlet and exhaust (with heat recovery) = balanced ventilation

Air is mechanically provided, and mechanically exhausted from the rooms, and it is possible to recover most of the heat from the exhaust air, without mixing the air streams. To insure good quality, the system should always be on, and air tightness of the façade should be high enough to prevent cross ventilation. This will affect the performance of the system. The ventilation flow will be good controllable, and draught as well as noise problems (from outside) can be easily prevented.





Points of high attention will be the auxiliary electrical energy for fans (but this will be compensated by energy saved through heat recovery), sizing and spacing of ducts, careful design and placement of air inlets, air tightness of the house and control system (complicated). The maintenance of the systems is more sensitive than other systems. Filter replacement and cleaning of ducts asks for good attention.
(Valk 2005)

Control systems

The ventilation balance for a house can be set up for the whole house (per floor level) or per specific room. The first method accounts for equal use of the whole house on a moment in time, while the second method is based on the occupancy and use of certain separate rooms. The first method incorporates air transfer (and multiple use of the air) between rooms, which results in smaller ventilation grills. The second method based on the room balance leads to smaller fan power (since it is based on the biggest room and not on the combination of rooms) for mechanical ventilation.

General system types for control of a ventilation system are:

- Pressure control (mechanically or electrically controlling ensuring a constant flow through ventilation grills by changing the opening size as result of pressure differences)
- User control (by manually opening windows, changing ventilation flows in grills or changing the fan power of mechanical ventilation)
- Demand control (by programming the user behaviour and by that electrically controlling the opening of grills to provide only the ventilation flow needed)
- CO_2 controlled (automatic control of ventilation flow, based on actual detection of CO_2 concentrations in the house)

"Demand controlled ventilation can be relevant if the building occupancy varies substantially and when it is not evident to predict the occupancy. CO_2 controlled ventilation, which is currently more expensive than e.g. ventilation based on presence detection, becomes more interesting if the building is leakier (which is not recommended) and if windows can be opened. Therefore, the benefits strongly depend on these boundary conditions." (Wouters 2004, p. 8)

3.1.2.5 Conclusions: gap size between demand and supply

- The ventilation standards are set in the building decree in fixed numbers. Goal is to prevent large concentrations of several harmful components (from dust, particles and

CO_2 but also moisture). This could also be achieved to by reacting on the concentrations in the air, like CO_2 controlled ventilation systems.

- The use of mechanical ventilation in housing is increasing, due to higher air tightness values in the building skin. It is also necessary in order to assure the minimum amounts of ventilation.
- The quality of air by mechanical or balanced ventilation is mainly depending on the quality of installation, maintenance and control (RIVM).
- Current stock: in quite some houses, the amount of ventilation is too low to prevent certain levels of pollutants to occur. For the reference house this was assumed to be acceptable, due to the placement of balanced ventilation.
- The available types of ventilation systems all demand a certain amount of air tightness to decrease the uncontrollable influence of infiltration.
- Higher air tightness values could be achieved in building structure by tightening details and connections of open able parts.
- All ventilation systems have certain advantages and disadvantages and are depended on the energy or comfort considerations.

3.1.2.6 Recommendation: strategies for design

Passive concept
Passive design is based on the principle that the building regulates the climate by mainly structural measures. Auxiliary energy for driving forces are still necessary to make it perform to demand level. The natural ventilation with mechanical exhaust principle fits to this concept.

The thermal comfort can be assured by careful design of openings, acoustic comfort will be achieved by using sound baffles on locations with high external noise loads. In order to reduce additional energy loss by infiltration flows, investments will be done in building details in order to enhance air tightness of the house.

Active concept
Since active design is based on the careful demand control per user, balanced ventilation complies with these design principles. Heat recovery can be included in this to take advantage of the air flows through ducts. Active control per room is possible and is efficient to decrease the energy use. Advantage by this principle is the smaller size of fans necessary.
Since CO_2 demanded control is not profitable on a small scale, the control will be regulated based on user preferences. With this system, air tightness values can be kept on the reference house level.

3.1.3 Visual comfort

3.1.3.1 General aim

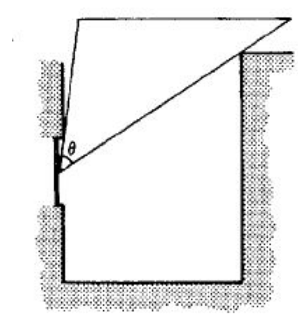
In order to ensure a safe and healthy living environment, visual comfort is a point of attention. The design can be influenced by daylight design and artificial lighting, of which the first one is preferred due to its broad spectrum of colors, the changes in intensity and changes in color temperature. From energy efficiency considerations, again daylight is preferred over artificial lighting.

Besides the type of light, the amount of illumination is a criterion for visual comfort in the house. For house design, glare performance is not part of the assessment.

3.1.3.2 Assessment method

In order to assess the visual comfort of the building combined with energy efficiency, BREEAM-NL *HEA1: Daylight availability* is assigned to this criterion. Further, some values for (energy efficient) artificial lighting will be presented to complete the lighting demand at all times.
BREEAM-NL HEA1 sets a demand for the minimum daylight factor. This should be at least 2% for 35% of the total used floor surface in homes. For office facilities (if they are part of the house) extra demands account for the view on the sky and the room depth.
The daylight factor is calculated (simplified) by the Average Daylight Factor (ADF) formula, as defined by the British Research Establishment (BRE). It gives an indication of the amount of skylight that enters a certain room in the house and is given in formula 1:

$$DF_{AV} = \frac{S_{window} \cdot T_{window} \cdot \gamma}{S_{skin} \cdot (1 - R_{AV}{}^2)} \qquad (1)$$



DF_{AV} average daylight factor in %
S_{window} window surface of the room in m^2
S_{skin} skin surface of the room (floor, ceiling, walls incl. windows) in m^2
T_{window} transmission factor of the window (LTA in Dutch) in %
γ vertical sky angle (with incorporated shadings and interferences) in degrees, see figure (°)
R_{AV} average reflection factor of the skin (excl. windows)

Demands from the Building Decree consist for a minimum equivalent daylight surface in staying areas of 10% and a minimum of 0.5 m^2 equivalent daylight area in user areas. The equivalent daylight area must be calculated following the standard NEN 2057. The amount of window surface complies in most cases with the 2% demand from BREEAM-NL. The average daylight factor will therefore be taken as a design parameter.

3.1.3.3 Methodology of analysis

Quantity analysis

In order to give design direction for the daylight openings in the house, the parameters of the Average Daylight Factor will be discussed in terms of average quantities and available solutions to increase the ADF. Topics of analysis will be:

- Daylight factors in houses, example of ADF in SenterNovem reference house.
- General transmission factors of widely used window types
- Influence and assumptions of obstructions on ADF.
- Influence and assumptions of reflection factor on ADF.

The demand of additional lighting levels will be predicted, based on sky illumination predictions of De Bilt.

Artificial lighting energy

The amount of energy necessary for artificial lighting will be presented as the result of a short literature study, showing the general use of electricity in houses and the type of lighting products used.

3.1.3.4 Results

Quantity analysis: daylight factor in houses

The daylight factor as recommended in HEA 1 of BREEAM-NL should give the house a daylit appearance and a low amount of supplementary electric lighting needed. This is deducted from the recommendations for Average Daylight Factors as presented by BRE and BE8206 Part 2, which is summarized in Appendix 9.

Table 16: Average Daylight Factors and share of total staying areas in SenterNovem reference house

Average Daylight Factor in SenterNovem Reference house

Assumptions: T_{window}=0.767, R_{wall}=0.7, R_{floor}=0.3, $R_{ceiling}$=0.8, obstruction distance = 15m.

floor	room	area (m^2)	ADF (%)
ground floor	living room	39.4	4.95
first floor	bedroom 1	18.2	4.75
	bedroom 2	10.2	3.67
	bedroom 3	6.8	4.94
second floor	attic	30.8	0.67

Results	m^2
total floor area	105.4
demanded area (80% with 2% ADF)	84.3
achieved area with 2% ADF	74.64
achieved % of area > 2% ADF	70.80%

For comparison, the SenterNovem reference house is calculated on Average Daylight Factors. The outcomes per room are presented in Table 16. Most of the important rooms in the house are well daylit (living room incl. kitchen, bedrooms). But the demand of 80%

surface with 2% daylight factors could not be met, since the large surface of the attic does not receive enough daylight. Extra daylight facilities are needed in the roof to make the room useable without or small amount of electric lighting. The rooms which do receive enough daylight are well above the demand.

Transmission

Table 17 shows a sample of a list of commonly used window systems in the built environment. The insulation value and the light transmission are cohering in an inverse way: increasing thermal resistance results in decreasing light transmittance. The relation between Average Daylight Factor and light transmission is linear, as can be deducted from formula 1. The light reduction by change in glazing will give an equal change in terms of percentages for the ADF.

Triple glazing with low heat emission (T=0.6; used in passive houses) reduces the light transmission by 14.3% compared to standard double glazing (T=0.7). If an ADF of 3.0% was realized in the double glazed situation, it will be reduced by 14.3% to 2.6%. This could influence the daylight experience of the room significantly.

Table 17: Multiple glazing performance data (indicative), source: BS 8205, part 2.

Glazing system (all glasses 6 mm, all cavities 12 mm)	U-value (W/m^2K)	Total transmission	Light T
Single glazing clear float	5.45	0.86	0.82
Double glazing clear float	2.80	0.76	0.70
Double glazing clear float + low E glass	1.90	0.72	0.69
Double glazing low E glass + low E glass	1.75	0.66	0.65
Double glazing clear float + low E glass − argon	1.60	0.72	0.69
Double glazing low E glass + low E glass + argon	1.40	0.66	0.65
Triple glazing clear float	1.85	0.67	0.66
Triple glazing low E glass + F + low E glass	1.15	0.59	0.60
Triple glazing low E glass + F + low E glass + argon	0.95	0.59	0.60

As can be deducted from Table 17 the change in transmission values for visible radiation also influences the transmission value for heat radiation and the insulation value of the (layered) glass.

Compromises need to be made in order to find the best combination of light transmission, heat transmission and reduction of heat loss to achieve a comfortable indoor temperature (without overheating) and enough daylight availability for a healthy environment. From the costs perspective it would be favourable to reduce the window surface and to use glazing with average insulating performance.

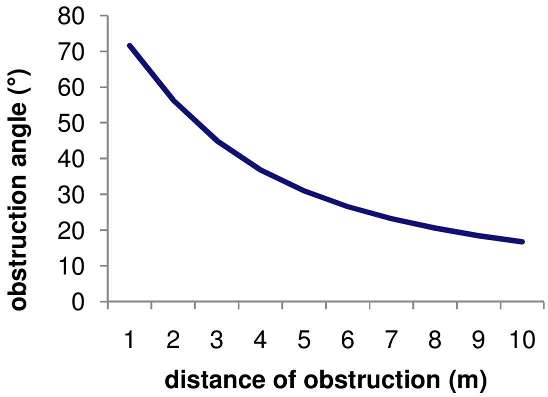
Persson et. al. (Persson et.al. 2005) discusses the passive house glazing configuration (triple glazing in insulated frames) in Passive Houses in Sweden. They conclude that instead of the traditional way of building Passive Houses (large windows on south, small on north) it is possible to enlarge the window area facing north and get better lighting conditions. To decrease the risk of excessive temperatures or energy for cooling, there is an optimal window size facing south that is (up to 50%) smaller than the 16% which was starting point of their research.

Independent study from a Dutch consultancy firm Except (Bosschaert 2009), discusses the effect of triple glazed window panes in the moderate climate of the Netherlands. The comparison is made for a house on energy, costs and material impact. Main conclusions are that triple glazing is not always better for energy performance. Combinations of double glazing with high insulation values could perform better. Wall insulation will have higher effects on energy reductions than replacing (HR) double glazing with (HR) triple. Solar gain is highly reduced by use of triple glazing and therefore gas reduction is lower than might be expected based on transmission values only. The cost analysis results in return of investments for triple glazing longer than 30 years (lifetime) if energy prices increase 3-6% per year and 26 years for energy price increasing of 8% (assuming interest rate of 4%). Material analysis results in a payback time of 3 years for embodied energy and only months for CO_2 emissions due to production and transport.

Placement of triple glazed products therefore appears to be not the most feasible measure to enhance energy performance in a house. Using double glazing with higher performance (including insulating gas) and increasing the thermal insulation value of the skin are more advisable.

Obstructions

The vertical sky angle depends on the distance to other obstructions outside the house (and height of these) and the size of overhangs on the house façade. Increasing the daylight factor implies decreasing the size of overhangs (while considering the effect of solar gain for thermal properties) and design of high located windows. This will reduce the influence of outdoor obstructions (their height compared to the window centre will be lower). An extra advantage of high placed windows is availability of sky parts with higher illuminance (illuminance of the sky is 3 times higher in vertical direction than parallel to the horizon). Careful design of obstructions is efficient, as can be seen in Figure 11. The obstruction angle increases rapidly when the obstruction distance is decreasing.



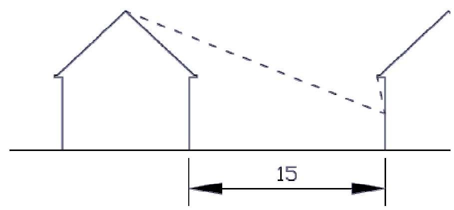


Figure 11 (left): Obstruction angle as function of obstruction distance (or height)
Figure 12 (right): Assumption on distance of obstructions in daylight calculations

A general street width of 15 meters is used in the daylight calculations. The same profile as the tested house is used to calculate the obstruction angle, see Figure 12. Other obstructions like trees are not taken into account for these calculations. The 15 m distance represents the average street profile in the Netherlands.

Reflection factors

Formula 1 shows an exponential connection between the average reflection coefficient and the average daylight factor. An increase in the higher levels of reflection can result in a significant difference of the daylight factor. Reflection factors of 0.6 or higher are therefore recommended and can be achieved by materials like e.g. white plaster (0.7-0.8), aluminium (0.65-0.75) or light wood (0.55-0.65). For the calculations, standard reflection factors are used: Wall = 0.7, Ceiling = 0.8 and Floor = 0.3.

Daylight factor and illuminance

The calculated Average Daylight Factors shows the possibility of daylight availability in a certain room. It gives insight in the amount of outdoor illuminance which enters a room:

$$Daylight\ Factor\ (DF) = \frac{Illuminance\ indoors}{Horizontal\ illuminance\ from\ unobstructed\ sky} \times 100\%$$

By using this parameter, different designs will be comparable, independent of the actual available amount of daylight. The actual horizontal illuminance of the sky depends on the time of year, time of day, cloudiness, orientation etc. For the worst case scenario (CIE Overcast Sky) the sky luminance is independent of the orientation. The sky illuminance can be estimated by use of the sun elevation for each time of the day and year. For De Bilt, these illuminance levels are presented in Appendix 9.

For the Reference house, if one would take the CIE overcast sky with an illuminance of 10,000 lux as a standard, ADF's of 2% would result in room illuminances of 200 lux.
When taking into account that weather conditions will change the sky illuminance between 8,000 and 25,000 lux, the room illuminance will lie between 160 and 500 lux. Additional electric lighting will be necessary for moments that the indoor illuminance falls under the recommended values for different rooms, as deducted from SenterNovem Cijfers and

Tabellen 2007 (p. 53). An example of lighting demands is given in Figure 13, showing the daylight illuminance for Daylight Factor 2% in May, and illuminance demands for electric lighting in different room types. The user patterns are deducted from GIW/ISSO 2008 (specifications for overheating 5.1). See appendix 9 for details.

Daylight availability and lighting demand in may

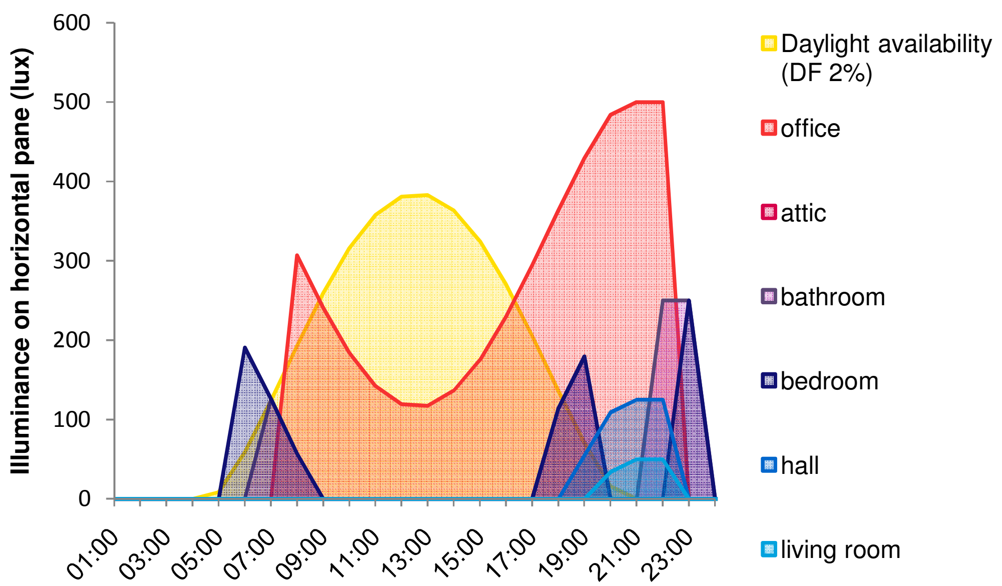


Figure 13: Daylight availability (DF 2%) in May and the resulting demand for artificial lighting in several residential functions (incl. user patterns)

Artificial lighting

The amount of energy used for artificial lighting strongly depends on the designed daylight factor. Besides the daylight factor, it depends on the energy efficiency of light bulbs and user behavior. According to EPN, the lighting use in a house is 6 kWh/yr/m2, resulting in 745.8 kWh/yr for the reference house. A research on electricity use by households (BEK2000, EnergieNed 2002) presents a lower value of 559 kWh/yr, which is (also according to ECN, as discussed in a study comparing EPN and PHPP) more realistic. This value will be assumed for the reference house. The effect of user behaviour or luminaire type cannot be distinguished in this value, but halogen lighting with efficiency of 25 lm/W will be assumed for the reference house.

Differences in lighting efficiency lay between 6-19 lm/W for incandescent light bulbs, 25-80 lm/W for fluorescent lamps and 55-90 lm/W for LED's. Reduction on electric energy demand for artificial lighting can lay between 30-50% by changing the lamp type.

3.1.3.5 Conclusions

Daylight factor

- The recommended daylight factors comply with the demands for well day lit houses. They will result in acceptable lighting levels throughout the day lit periods of the day.
- The SenterNovem reference house does not comply with the demands in BREEAM-NL HEA1. When designing other concepts similar to this house, an effective improvement

measure can be the increase of daylight in the attic.

- By increasing the light transmission of windows, the daylight factor can be increased
- Obstructions influence the daylight factor highly, when they are close to the objected building. Careful design for creating larger sky angles implicates small overhangs and obstructions on large distance with low height. High placed windows are favourable.
- Reflection factors of the room are of importance for achieving high daylight factors. Especially factors above 0.6 give good results. The use of light coloured and reflecting materials are recommended (while taking into account glare risks).
- Daylight factors of 2% could give enough illuminance for the major room functions in the house, without additional artificial lighting. This accounts for the period of day in which the sun is up. User patterns lie also outside these hours, so artificial lighting will be necessary. An office function with 2% daylight factor will require additional artificial lighting throughout the day. Use of locally higher lighting levels (only on the desk) could reduce the lighting demand.

Artificial lighting

- Most artificial lighting is demanded in periods without or with a low amount of daylight. So increasing the daylight factor will not decrease the electric lighting demand intensively. Instead, decreasing the demand by intelligent switches, presence registration or energy efficient lighting solutions will help to decrease the energy demand.
- In most households, energy efficient lighting is generally not installed. The use of artificial lighting with higher efficiency can decrease the total demand in electricity for lighting. Higher daylight factors can reduce the demand for additional artificial lighting, especially in periods with lower sky illuminance (winter, begin/end of day) and in rooms with higher lighting demand (offices).

3.1.3.6 Recommendation: strategies for design

For both concepts the sizes of windows will be reconsidered in order to achieve average daylight factors over 2%, but to prevent daylight amount much higher than that in order to save investment costs on window glazing and frames.

Both concepts will not be given separate strategies, since it is of importance for both to achieve acceptable daylight levels and to reduce electricity use for artificial lighting. It is advised for both to invest in energy efficient lighting systems and to control this based on the available amount of daylight. Window types will be chosen based on their high transmission values and overhangs will be designed to just achieve the demanded daylight levels and on the other hand provide enough shading to prevent overheating. The exact sizes and characteristics will follow from the design process.

3.1.4 Acoustic Comfort

3.1.4.1 General aim

Aim is to insure good sound insulation and noise barriers to bring noise nuisance and noise pollution to an acceptable level so high acoustic comfort will be achieved inside the building.

3.1.4.2 Assessment method

BREEAM-NL credit HEA 13: Acoustic Comfort will be used for the assessment criteria for this parameter. The demands as are a bit higher than written in the Dutch Building Decree, and are given in Table 18. Since the demand for characteristic sound insulation is given as a 5 dB increase of the Building Decree value, this one had to be calculated in advance. The method and reasoning of defining the characteristic sound insulation is given in the results paragraph.

Table 18: Demands for acoustic performance of the house, from BREEAM-NL HEA 13: Acoustic Comfort. Compared to values from Building Decree 2003.

	Characteristic sound insulation ($G_{A,k}$)	Characteristic air sound level difference ($D_{nT,A,k}$)	Weighted contact sound level (L_{nT},A)	Characteristic services sound level ($L_{I, A,k}$)
BREEAM-NL	5 dB higher than Building Decree (dB(A)): Road: 50-35+5 = **20** Rail: 57-35+5 = **27** Industrial: 50-35+5 = **20** Air traffic: **n/**a	>32 dB between all residence areas inside a house Complies with: $I_{lu;k}$ = -20 dB	< 59 dB between all residence areas inside a house Complies with: I_{co} = 0 dB	< 30 dB(A)
Building Decree	Minimum: 20 dB(A) Road: 50-35 = 15 -> **20** Rail: 57-35 = **22** Industrial: 50-35 = 15 -> **20** Air traffic: **n/a**	Inside a house: $I_{lu;k}$ = -20 dB Between houses: $I_{lu;k}$ = 0 dB	Inside a house: I_{co} = -20 dB Between houses: I_{co} = +5 dB	< 30 dB(A)

Calculation of the quantities in Table 18 is based on methods as described in the standards:

- NEN-EN 12354: noise proofing in buildings – calculation of acoustic qualities of buildings with properties of building elements
- NEN 5077: noise proofing in buildings – method for quantities of sound insulation of external structures, air sound insulation, contact sound insulation, sound levels by services and reverberation time.

The levels of sound insulation for road, rail and industrial are based on the preferable values as given in the Law on Noise Nuisance, reduced by the maximum internal load as result of this value and raised with the BREEAM-NL demand of 5 dB increase. Since air traffic only gives loads in small parts of the country, which does not make it representative for all, this load is not applicable for the conceptual house design. The resulting demand for characteristic sound insulation for external partitions is 27 dB(A).

3.1.4.3 Methodology of analysis

Principles of noise insulation
Noise insulation is aiming to reduce the noise load as a result of external sources in a certain room function of a house. In order to characterize the amount or nuisance as result of noise, levels of insulation are set for air noise, contact noise, outdoor noise and noise from building services. The factors which influence these insulation levels are discussed, based on acoustic theory and with examples from the practice guides and building decree.

Current practice
In the current housing stock, the performance of acoustic insulation is indicated. Also building advice for noise insulation on a basic and a comfort level are given. Since the calculation methods for noise insulation are very complex, this is the most effective method to describe different concepts.

3.1.4.4 Results

Principles of noise insulation
Noise production is the result of sound waves in the air. They can bring movement in structures, which can pass it through to other rooms with air. This is defined as air sound. Contact sound is a result of direct movement of a structure by a machine, walking or hammering. The structure passes the sound to another room with air.

Air sound insulation measures are based on the addition of mass (doubling of weight gives insulation increase of +5 dB), the addition of extra layers with air between them and the increase of cavities within a structure. These measures reduce the efficiency of sound energy passing through the structure. Also the actual sound load on the external wall structure can be reduced by the building shape. Balconies or highly structured facades can reduce the impact of the load. Openings in a structure, like cracks, ventilation grills or ductwork decrease the sound insulation of a certain structure in a high amount.

Measures to reduce contact sound are the uncoupling of installations from the building structure, use of unconnected cavity walls, use of floating deck floors and lowered ceilings.

Sound loads and insulation are measured in decibel (dB), a quantity which gives the smallest hear able sound level difference in 1 dB per frequency range. The value dB(A) gives the sound load or insulation converted to the frequency sensitivity of the human ear.

The characteristic sound insulation of the façade depends on the room size which lays behind it. This differs for all situations. For the sound insulation between internal partitions, values are given for standard and commonly used types of structures. These are divided in structures on level of Building Decree and level of Comfort. The sound insulation as result of building services has to be deducted from the supplier information of these services.

Current practice

The most built houses in the Netherlands are based on a stacked stone or concrete structure. This could work in advantage for the internal sound insulation between room functions and between adjacent houses. Problems do occur with low sound insulating windows, cracks and ventilation openings.

Several building methods can be distinguished, which can guarantee for a certain level of acoustic insulation. Here the methods for concrete, stacked sand-lime bricks and wood skeleton typologies are mentioned. The major wall and floor structures are described, but detailing is important as well. In order to find the good details to achieve the indoor sound insulation levels, the Dutch Practice Standards (NPR) 5070 and 5086 may be used during design. Dessing (2005) gives the sizes and weights of three different house structures which comply with a level of comfort and one which complies with the Building Decree (wood structure). In those descriptions, she refers to details in NPR and gives design advice for connections between building parts. Types of floors, external and internal walls and roofs are given. A copy of these tables is presented in Appendix 10.

Most current building structures have sound insulation values above the demanded 27 dB(A). Double glazed windows give values between 31 and 43 dB(A). Stony wall structures exceed this with values between 38 dB(A) for single slab walls to 54 dB(A) for double walls of 600 kg/m^2. Even for wood skeleton structures with wooden external layers with total wall mass of 40-55 kg/m^2 the sound insulation value R_A lies between 33 and 37 dB(A). This could be increased by adding gypsum board finishing with higher weight or more insulation material (best is mineral wool).

To achieve a minimum sound reduction of 20 dB(A) on a façade, ventilation grills should have a sound insulation value $R_{q,A}$ at least -2.0 dB(A). This is depending on the share of the grill as part of the whole façade. It is advised to use sound baffles on grills for sound insulation values up from 23 to 25 dB(A) with $R_{q,A}$-values of minimum 6 dB(A) for the baffles.

Product suppliers for all types of façade elements can be used to find the design values for the sound insulation.In order to reduce the impact of contact sound in houses, mostly floating deck floors are used. They are placed on an elastic layer on top of the load carrying under floor. Mostly used for top floors is strengthened gypsum board or anhydrite cement. This could increase the contact sound insulation by + 5 dB.

3.1.4.5 Conclusions

- The demanded sound insulation levels lie slightly above the ones presented in the Building Decree. But the height of them is such that they can be achieved with many common methods of design.
- Noise reducing measures which may be applied are an amount of weight, multiple layer structure with cavity and insulation material and fractioned façade surfaces. To reduce contact sound between rooms and functions, separating (insulation) materials between high weight structures are necessary.
- In current building practice, acceptable insulation levels can be achieved with commonly supplied materials. Attention has to be given to ventilation openings (grills) and cracks or

openings in the façade.

3.1.4.6 Recommendation: strategies for design

For all concept typologies, the same minimum level of sound insulation could be achieved. The value should be calculated at the end, but problems will hardly come up. Points of attention for the active concept are the noise produced by several active systems. In order to prevent disturbance, the system should be placed on floating floor elements or should be covered with some sound insulating structure (e.g. in a separate room). The inlets and outlets of ducts should be placed carefully in order to prevent nuisance from fan noise and crosstalk.

Appendix 10 presents a list of measures to take into account for good acoustic comfort.

3.1.5 Spatial comfort

3.1.5.1 General aim

One of the primary factors of choice for house buyer's is the amount and type of spaces available. Important for extending the lifetime of the house is the flexibility of space. To be apt for different users, the size and accessibility of rooms is crucial and safety needs to be improved. In this analysis, the spatial impact of these factors is discussed, in order to advise certain space plans which comply with the basic demands.

3.1.5.2 Assessment method

For quality of outdoor space, accessibility, safety and flexibility the demands from BREEAM-NL HEA 14 (private outdoor space), 15 (flexibility) and 16 (accessibility) will be used as a guide for design. These topics give some requirements for size and building method. They are summarized in Table 19.

Table 19: demands for spatial comfort from BREEAM-NL

Topic	Demands
Outdoor space	Min. 7% of user area Min. 5 m^2 Min width 1.5 m Not: French balcony or conservatory
Accessibility	Entrance path ≥ 1.20 m Height difference in floors ≤ 0.02 m Door width ≥ 0.85 m Space in front and behind entrance door ≥ 1.5*1.5 m Equal floor or elevator for user functions Hallways with doors on long wall ≥ 1.2 m wide Hallways without doors on long wall ≥ 0.9 m wide Toilet width * length ≥ 0.9*1.2 m Bathroom width * length ≥ 2.15*2.15 m or 2.5*0.9 m Kitchen: radius of turning circle ≥ 1.50 m Kitchen: distance counter-wall ≥ 1.5 m
Flexibility	25% expandable floor surface Disconnection of building structure and building services

The demands for accessibility are given in BREEAM-NL for disabled visitors or users. The demands given in this table combine both user types. For these demands it accounts that if one is not achieved, the design does not pass. As the terraced house can be assumed including a garden space (even terrace area achieves the demands), the first topic (private outdoor space) will be achieved and will not be given any further study.

3.1.5.3 Methodology of analysis

Accessibility

Accessibility of the general houses in the Netherlands does not comply with the demands as set before. Mainly the difference in floor height makes the houses not to achieve these demands. A short analysis is done on possibilities of implementing accessibility options without influencing the common space plan too much.

Flexibility
Flexibility will be part of the accessibility study, since changing in space plans will make the house accessible for future users. Possible space plans will be presented for different user types. The demand for disconnection of building structure and building services will not be discussed in terms of placement of systems. Also possibilities for change in systems will be discussed.

3.1.5.4 Results

Accessibility
For insight in the spatial design of accessible homes examples from case studies during preliminary study, the mentioned excursion and a Belgium design guide for 'meegroeiwoningen' (grow along with the user) are used. One case study was found on the BRE innovation park in Watford, the Renewable house (see short description in appendix 3.2.4 and small ground floor space plan in Figure 14). This house is designed for life time adaptability by the following measures:

- Large toilet on ground floor. Shower can be added to this later on.
- Space in living room free for including elevator to bedroom on first floor in the future
- No doorsteps in the house
- Living room on ground floor can be split to include a bedroom in the future
- Hallway is wide and spacious to make ground floor accessible
- Wide space plan (7.1 m wide, 8.3 m long)

The Belgium design guide also includes an example of a house which can be made apt for elderly in the future. This house includes a large entrance which gives access to the ground floor and to the top floor. This access can be split, to make the top floor useable as separate studio house and the ground floor for elderly. Figure 14 shows the floor plans of two adjacent homes. The blue area is the toilet on the ground floor and can be expanded to a bathroom by including the storage room next to it. The green square in the back indicates the space for a bedroom on the ground floor. Also this house has a wider space plan of 9.8 m wide and 11.3 m long.

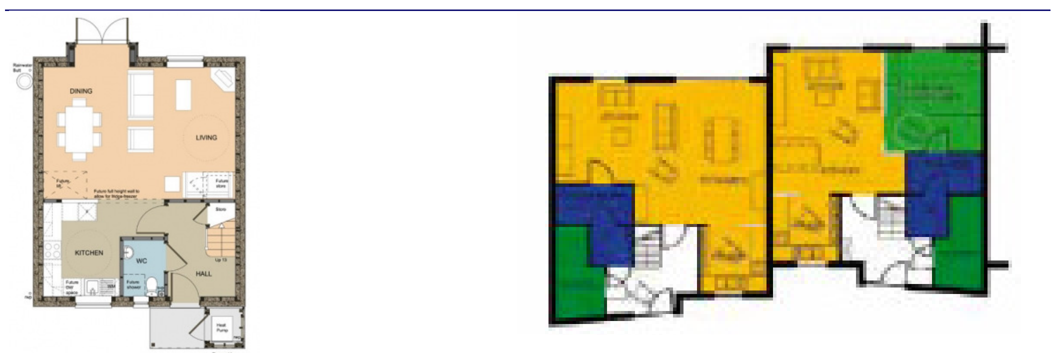


Figure 14: Left: ground floor plan of Renewable House as built on BRE innovation park, Watford, UK.

Right: VMSW (Vlaamse Maatschappij voor Sociaal Wonen), Bouwheer Vivendo, ontwerper Peter Lanszweert

The general advice in this design guide is to make the houses accessible for disabled visitors and easy to adapt to future use by disabled people. Expanding toilets on the ground floor to bathrooms and splitting living rooms to include bedrooms are the main aspects in this, besides the general size of hallways and door openings.

Accessibility of the top floor(s) can only be achieved by stair lifts or vertical elevators. Since the most feasible space plan for a terraced house is about 5*10 m for the Netherlands, the option of one floor level for a user surface of 125 m^2 is not possible. A good compromise is given in the examples: accessibility of the ground floor and sharing the house with more able user on the top floor. For the SenterNovem terraced house space plan, this results in space plans as suggested in Figure 15.

Change in space plan for accessibility

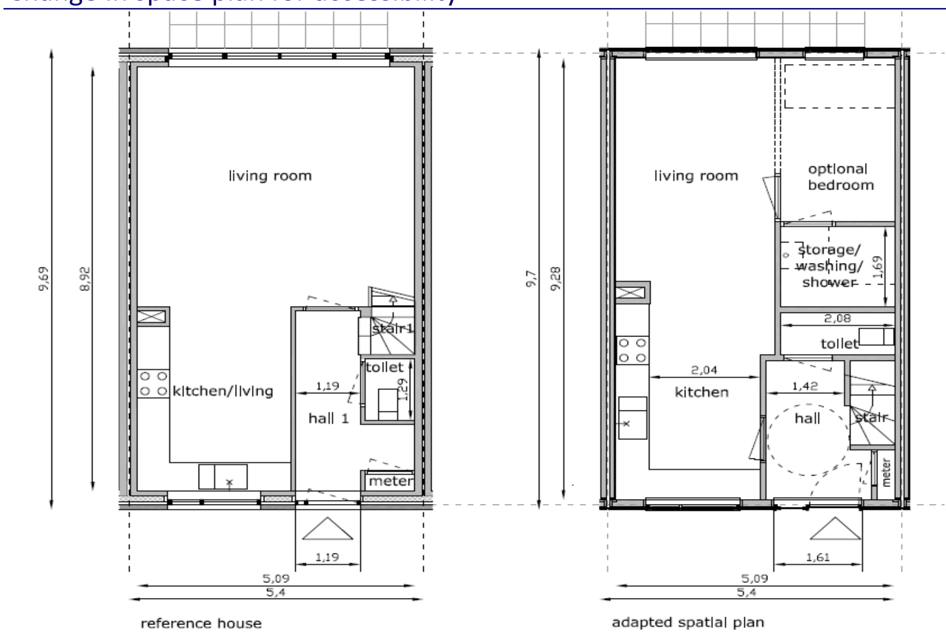


Figure 15: Ground floor of SenterNovem reference house (left) and adapted space plan for accessibility (right)

This change of space plan on the ground floor is based on the possibility of expanding the toilet to shower (by removing the wall between storage- and toilet space) and on the accessibility at the entrance. As result of this, the staircase was moved to the front of the house. A slight change in façade occurred: on the south side a closed partition is introduced between the sliding doors to the garden, in order to facilitate the wall between living and optional bedroom. The size of the living room decreased due to these changes, but the room for storage increased on the ground floor.

Flexibility

Industrial, flexible and demountable building methods should be found in order to give the possibilities for flexibility. These methods are based on steel or wooden structures (assembled) with wall, roof or window elements between. The common building practice is based on concrete walls and floors or stacked building methods for walls. These cannot be de-assembled. The demand for decoupling of building structure and services should be taken into account in detailed design phase and will not be discussed here. The spatial design for placement of these services is considered in the attic, a separate (and closed) room of 5.8 m^2 is spared for different types of services and gives room for maintenance.

An expansion in user area of 25% will result for in an increase of 31.1 m^2 (from 124.3 m^2 to 155.4 m^2) for the average terraced house. If this would be done on top of the house (each floor has a surface of about 50 m^2), the initial wall structure should be able to carry this load. It is assumed that expansion of the attic by changing the roof shape to flat roof is possible within the current structure. The removal of sloped roof parts results in the demanded additional user area for expansion.

An extruded space plan in length (extra 6 m) would not be favourable, since the daylight availability in the core would reduce and the outdoor space would be limited.

3.1.5.5 Conclusions

- Demands for private outdoor space can be achieved within the current SenterNovem reference house design.
- Accessibility for disabled demands a change in floor planning, especially if the ground floor should be made accessible for disabled. This is possible by including an accessible toilet for visitors and taking into account options for change to ground floor bed- and bathrooms.
- Flexibility in design can be achieved by use of light weight and demountable structures, especially for internal partitions. Services which are placed in a separate and oversized space will have options for good maintenance and replacement if necessary.

3.1.5.6 Recommendation: strategies for design

For all new designs, an improved spatial planning, safe entrance of the house and a flexible design are favourable in order to extend the lifetime of the house. Safe ventilation openings are useful for both the active, the passive and the hybrid concept since they can help in achieving summer night ventilation and therefore cooling.

All of these measures will influence the costs of the house. By accessibility planning the amount of useful area will change, the amount of internal walls increases and for safe ventilation openings extra materials will be necessary in or around the window frame.

3.1.6 CO_2 Emissions

3.1.6.1 General aim

In order to comprehend the possibilities of applying the sustainable energy technologies, the corresponding conditions in the building site should be studied. These conditions include solar irradiation data, wind speed and availability, precipitation and some geographical properties of the Netherlands. These conditions will imply some strategies and if it is technically viable to utilize certain technologies in the house.

An analysis of the sustainable energy technologies is done in order to compare different options to generate energy from renewable sources or use the energy in an efficient way. The results of the analysis will reveal the advantages and disadvantages of different options.

3.1.6.2 Assessment method

For this specific parameter, BREEAM-NL *Ene1: CO_2 emissions* will be used for the performance check of the design. This criterion aims to stimulate building design with the lowest possible CO_2 emission of building related primary energy use during the occupation phase. It is calculated by the improvement of primary energy use compared to the regulated allowable primary energy use. The following equation reveals the improvement:

$$\mathrm{EP}_{\mathrm{improvement}} = \left(1 - \left({}^{\mathrm{Qpres;\,tot}}/_{\mathrm{Qpres;\,per}}\right)\right) \times\ 100\ [\%]$$

$EP_{improvement}$ = improvement of energy performance compared to requirements by the regulations [%]
$Q_{pres;tot}$ = total primary energy use [MJ]
$Q_{pres;toel}$ = total permissible primary energy use [MJ]; this is defined in EPC calculation of the reference house as 45893 MJ.
Attached to the primary energy calculations, CO_2 emissions due to the primary energy consumption will be investigated although BREEAM-NL does not ask for CO_2 emission calculations.

Since this method is based on the performance of the building, in this part of the study, 'CO_2 emissions' parameter will be studied in the context of the possibilities for sustainable energy technologies to be applied in the building and so available sources will be evaluated in this analysis. However, primary energy savings will be calculated for different sources so that results can imply some advantages of using these systems in terms of energy performance.

3.1.6.3 Methodology of analysis

First of all, energy use in an average house in the Netherlands is investigated to be able to comprehend in which items savings should/can be achieved.

After having explained the important energy consuming activities in the house, the potential of sustainable energy sources in the Netherlands is studied. In this manner, climatic conditions of the Netherlands have been analyzed. For the climatic data in the Netherlands, as BREEAM-NL points out, NEN 5060 norm is used as the basis of the analysis. In addition to that literature study is performed to find relevant information.

As mentioned previously, site conditions are analyzed for the following items:

- Solar
  - Irradiation data
  - Solar path
- Wind
  - Wind velocity
  - Wind directions
- Geographical properties
  - Type of soil
  - Temperature in the ground
- Biomass
  - Availability of biomass based applications in the Netherlands

3.1.6.4 Results

As explained previously, average household energy consumption is first presented according to the values obtained from literature including SenterNovem and Milieucentraal.

Breakdown of the energy use of the Dutch households reflects the main energy consumers per sources of the energy, which are electricity and natural gas in this case. The following table shows the corresponding values for average household in 2006.

Table 20: Energy use breakdown in average Dutch household, source (Groot et al, 2008)

Natural Gas		1.73 $kgCO_2/m^3$*
Activity	**m^3 (% of total)**	**CO_2 Emission [kg]**
Space Heating	1204 (73%)	2082.92
Hot Water	385 (23%)	666.05
Cooking	63 (4%)	108.99
Total	**1652**	**2857.96**
Electricity		0.6 $kgCO_2/kWh$*
Activity	**kWh (% of total)**	**CO_2 Emission [kg]**
Washing/drying	708 (21%)	424.8
Cooling	590 (17%)	354
Lighting	543 (16%)	325.8
Heating/hot water	500 (15%)	300
Appliances	1061 (31%)	636.6
Total	**3402**	**2041.2**

*source: http://www.milieucentraal.nl

According to the table, energy use for space heating and hot water has the highest share in the total consumption. Based on these values, the space heating requirement of the house for one household is estimated approximately 10 MWh (the boiler efficiency of 0.95), which means for the SenterNovem reference house (125 m^2 user space) the space heating requirement would be 84 kWh/m^2. However, if this value is decreased to around 20 kWh/m^2, the energy requirement for space heating would be lower than that of hot water generation. On the other hand, energy used by the appliances is the most important item for electricity consumption in Dutch households. Therefore, efficient appliances will reduce the electricity demand the most significantly.

The CO_2 emissions related to the use of natural gas and electricity is given in the same table. This indicates which fuel causes more CO_2 emissions and the effect of the energy consumption items in the greenhouse gas emissions. As can be seen from the values, using natural gas causes 3 times more CO_2 emissions than using electricity. As a result of the average use of natural gas in the house, nearly 3 tones CO_2 is emitted while this value is 2 tones CO_2 for electricity use, i.e. 1.5 times higher. This figure illustrates that saving natural gas consumption is more important than saving electricity consumption in terms of greenhouse gas emissions. However, the energy content of 1 m^3 natural gas is 10 kWh, so using electricity directly for heating can cause more CO_2 emissions than natural gas to deliver the same amount of heating energy.

Solar Energy Analysis

Solar irradiation is a critical parameter for the design of the house. Both the passive solar design of the house and the solar energy related technologies are affected by the solar properties of the location. The direction, availability and the potential of the solar irradiation are critical issues to make decisions.

In order to have a general solar energy potential overview of the Netherlands, the yearly sum of global irradiation received by an optimally oriented PV module is presented in Figure 16. According to the results of a research by Photovoltaic Geographical Information System, shown, yearly sum of global irradiation received by an optimally oriented (for the Netherlands it is 36^o to the south) PV module is around 1100 kWh/m^2 in average. This figure also shows that in the north-west part, this value reaches 1200 kWh/m^2. These values can also be used for calculation of heat generation by solar collectors.

Global irradiation on optimally inclined PV panels

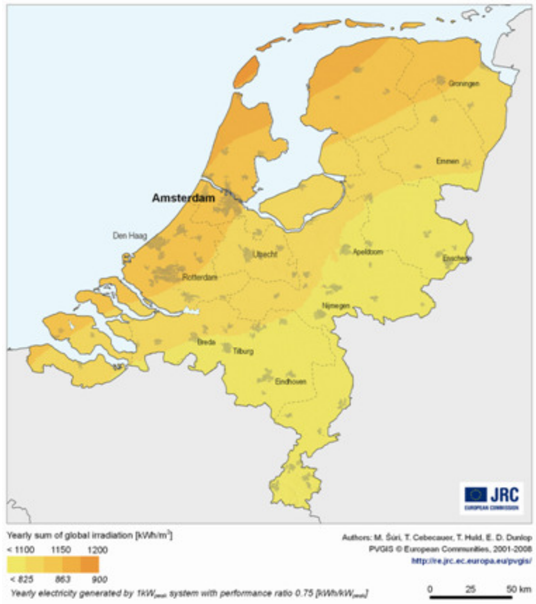


Figure 16: Yearly sum of global irradiation received by optimally-inclined PV modules in the Netherlands measured in period 2001-2007, source: Šúri, 2007

It is important to observe the seasonal differences in solar energy availability, therefore the global solar irradiation on a horizontal surface throughout the whole year is investigated in Appendix 11. As can be seen from the figures, solar irradiation is below 20 kWh/m^2/month in winter period and around 160 kWh/m^2/month in summer period (3 months). Although this figure does not illustrate the irradiation in optimum azimuth angle, it gives an idea how the characteristics of solar irradiation vary in different periods of the year. As can be seen from the figure, in summer solar irradiation levels are nearly 10 times higher than the levels in winter. If this figure is translated to the energy production in a year then nearly 50% of the energy production in a year would be generated in summer period. If the energy is generated through solar energy is not directly consumed in the house in the summer period then energy storage/transfer would be necessary.

In addition to the solar irradiation data, solar path diagrams are useful to determine the orientation of the building and passive solar design of the building. The corresponding figure generated by IES VE is attached in Appendix 11. As the figure implies, sun follows a low altitude from the south during the winter time with a maximum of approximately 20^o whereas it is at high altitudes in the summer with a maximum of approximately 65^o. . Angle of the roof with the horizontal should be 35-36° which is determined as the optimum azimuth angle for solar power systems, either PV or solar thermal system. (European Commission Joint Research Center Photovoltaic Geographical Information System).

Wind Energy Analysis

As being one of the most promising renewable energy sources, the possibility of applying wind energy is studied. For that purpose, average wind velocities recorded in the Netherlands are investigated together with the wind directions. This research can also help to determine the position of the ventilation openings in the house to make use of the outdoor air for natural ventilation.

The monthly average wind speeds measured at 10 meters height as published in the NEN 5060 is given in Appendix 11. It shows that the average wind speeds are mostly between 2-4 m/s throughout the year, and relatively stable throughout the year compared to the solar power. This set of data is consistent with the Figure 17 which shows the average wind speed in the Netherlands which were recorded in 1971-2000 years. This shows that in the inner parts of the Netherlands, the average wind speed at 10 meters height is around 3.5 to 4.5 m/s. However, in the coastal part it is as high as 7 m/s which can be related to the temperature difference between the land and the sea.

Average wind speed

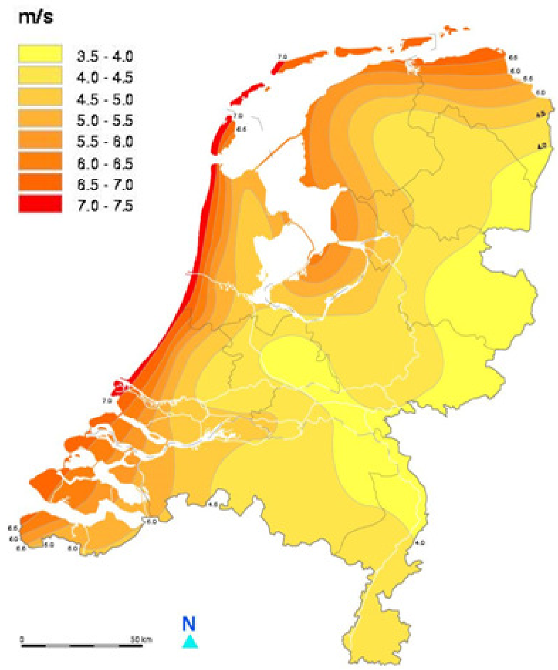


Figure 17: Average wind speed in the Netherlands at 10 meters height, recorded in 1971-2000, source: KNMI

In addition to the wind speed, the direction of the wind is an important factor for passive design of the house, especially for the ventilation openings and natural ventilation. In Appendix 11 the wind direction distribution is presented according to the data given by NEN5060. The southwest and west are the predominant directions for the wind throughout the year. The maximum speed of the wind is recorded as 9.3 m/s from the west and the wind speeds above 7.0 m/s are recorded from the west and southwest directions in general.

Geographical Analysis

The soil properties of the Netherlands are obtained from the research of Soil Survey Institute in Wageningen and are included in Appendix 11. The data represents the general soil constitution in the Netherlands in 1 meter depth.

According to the data, the country is covered with mostly sandy soil and clay based soil either sea or river clay. Some parts are covered with peat and especially the southern part is fertile lands with loam type of soil. Clay and sandy soils can be excavated and processed relatively easier compared to stony grounds.

In addition to the suitability of the ground to be excavated, type of the soil affects the capacity to extract the heat from the ground, which also determines the size of the systems. Table 21 shows the heating capacities of different soil types. Since the most common type of soil is sandy in the top layer of the ground, average heating capacity can be accepted as 15 W/m^2. For deeper parts of the soil (deeper than 1 meter), the average value from the table below is used for the calculations, i.e. 50 W/m. These values are used for sizing the ground source heat exchangers, which are taken from a report by a supplier in the Netherlands.

Table 21: Heating capacities of different soil types, source: Warmtepompen, Viessman

	Heating Capacity for depth <1 m		Heating Capacity for depth >1m	
Soil Type	Min W/m^2	Max W/m^2	Soil Type	W/m
Dry-sand	10	15	Dry sediment	20
Wet-sand	15	20	Normal bedrock	50
Dry-loam	20	25	Normal bedrock with high thermal conductivity	70
Wet-loam	25	30		
Ground aquifers	30	35		

On the other hand, the temperature distribution in the ground should also be taken into account while designing ground coupled systems. The average underground temperature distribution for a year period is given in Figure 18 which presents the measurement results made in the Netherlands in a well located in De Bilt, This shows that the temperature of the soil near the earth surface is varying between 9^{o}C and 14^{o}C throughout the whole year. However, the temperature stabilizes as the depth increases and at around 50 meters the temperature is predicted at around 11^{o}C. This figure also illustrates the temperatures in the deeper parts of the soil and changes in years. Since the typical energy storage systems and ground heat exchangers are installed in the range of 20-150 meters (NVOE), this figure can be used for temperature assumptions if necessary.

Nederlandse Vereninging Ondergrondse Energieopslagsystemen (NVOE) suggests that vertical ground heat exchangers can be installed for 1 house and 30-50% of the heating and cooling requirement can be supplied. On the other hand, deep geothermal applications are suggested for at least 2500 houses, heat/cold storage is suggested for at least 50 houses. So, vertical and horizontal ground heat exchangers are the options for this study.

In order to prove the applicability of vertical ground heat exchanger technology in the Netherlands, the data provided by a research by TNO is attached in Appendix 11. It shows that the ground properties in most parts of the Netherlands, is suitable for heat extraction.

Ground temperatures

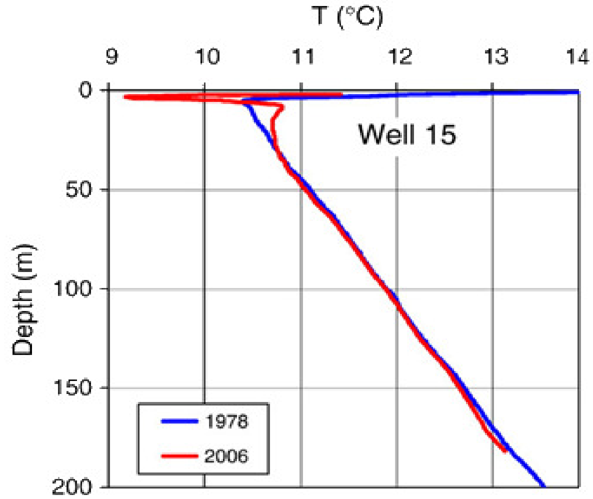


Figure 18: Ground temperature measurements in the Netherlands, de Bilt (Kooi, 2008)

Biomass Analysis

Biomass has been one of the main producers of electricity in the Netherlands, mostly by co-firing of biomass (main), waste incineration and bio-fuels as shown in (SenterNovem, 2009). In residential sector, domestic wood burning stoves still contributes to the energy production in the Netherlands, although it declined slightly over the years. The co-firing mainly consists of wood pellets. Other sources are agro residues, and animal manure. This is shown in Figure 19. Since the energy production from waste is possible in large scale for now and the bio-fuels are used in transport and industry mostly, the only possibility for producing energy from biomass in small scale is through the use of wood pellets.

Biomass contribution to energy generation in the Netherlands

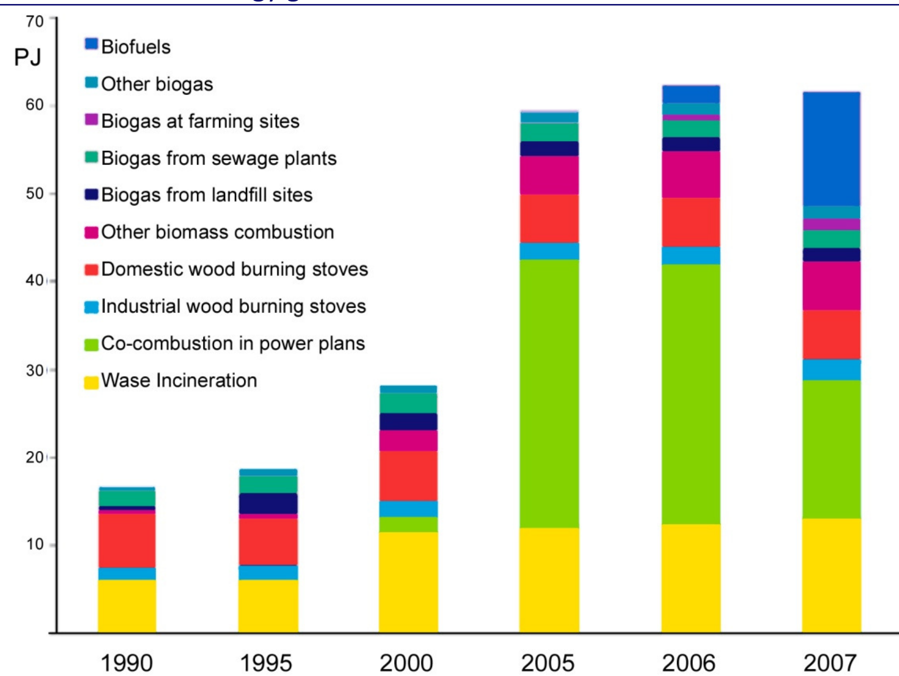


Figure 19: Biomass contribution to sustainable resources in the Netherlands, source:

Pellets@las country report, 2009

The Intelligent Energy for Europe project PELLETS@LAS study shows that in the Netherlands there are three wood pellet producers which have a total capacity of 130.000 tons/year. There are also several wood pellet suppliers importing from other countries. However, in the same study it is noted that use of wood pellets for domestic heating in small-scale boilers is rather uncommon in the Netherlands, most likely due to the lack of specific support schemes, the presence of a natural gas grid throughout the entire country and high-efficiency natural gas boilers, and perhaps also limited storage space for wood pellets. The most important feature of the wood pellets for heating is that the CO_2 emissions due to the use of it as a fuel can be compensated by the growth of forestry. Therefore it is generally addressed as a CO_2 neutral fuel.

Analysis in System Level

The renewable energy technologies should be installed in the house to mitigate the CO_2 emissions while the house is inhabited. However, the application of renewable energy technologies is limited by the site conditions as presented above. The analysis in the following section presents the estimated performances of several technologies as they are applied in the Netherlands.

Photovoltaic Solar Panels

PV solar panels are widely used and one of the most promising technologies to supply electricity in the buildings. PVs can be installed in stand-alone or grid connected configurations. In this study, it is assumed that the system is placed on top of the roof and is connected to the grid.

In the Netherlands, application of solar panels has been increasing recently, as presented in PV status report by SenterNovem. This means these systems will be manufactured in larger volumes every year, so both economic and technical feasibility of these systems are expected to enhance.

The silicon based PV panels are dominating the market, with 90% of the total production in the Netherlands (PV Status Report in 2008, SenterNovem); especially multi-crystalline and mono-crystalline types. Being the most widely used type of PV panels (SenterNovem website), multi-crystalline type solar cells are assumed to be installed in the houses (if any).

Using the values as presented in Appendix 11, the performance values are estimated such that the PV panels will meet the total demand of the house. Accordingly, for 1 m^2 PV panels installed on the roof of the house (assuming optimum orientation and inclination), 103 kWh of electrical energy is possibly produced by solar cells. This means, for an average house in the Netherlands with a electricity consumption of 3400 kWh/year, 33 m^2 of PV panels would be required in order to generate all the energy consumption in a year. The table summarizes the expected performance of PV panels.

Sizes for ready to use systems in the market are presented in Appendix 11, these values are obtained from a specific supplier and they are assumed to be reflecting the current practice levels in the market. As the data implies, the required size for an average household in the Netherlands will deliver around 4.5 kW at maximum.

Table 22: Estimated performance of PV panels for SenterNovem reference house

Type: Mono-crystalline PV panels	
Size of the system	32.3 m^2
Total System Efficiency (incl. Inverter)	9.4%
Yearly yield	3325 kWh/year
Peak power output	4510 Watt

Urban Wind Turbines

Generating electricity using wind is a proven technology and is applied all over the world. The large scale turbines are built both on-land and off-shore but the small scale applications with generation capacity in the range of 1-20 kW are not as common as the large scale ones.

This is due to several reasons as specified in a report from Intelligent Energy Europe project (Urban Wind Turbines, 2007) which are still valid:

- The electricity yield shows large variation depending on location and turbine model.
- The investment costs are too high, especially compared to the benefits.
- Obtaining permits for UWTs is complex, takes too long and is different in each municipality or local authority.

On top of this, the field tests performed by the utility energy company DELTA together with the province of Zeeland between April 2008 and August 2010 imply that with a yearly average wind speed of 3.7 m/s approximately 2700 kWh/year can be generated by installing the most efficient small wind turbine tested, which is about 77% of the total electricity consumption of a household. However, the test results for different models exhibits generation levels as low as 65 kWh/year. The test results are shown in Appendix 11.

According to the same report by Intelligent Energy Europe project, urban wind turbines start operating generally at 2.5 m/s, which means operating hours of a urban wind turbine would be 64% of the year according to the data presented in Appendix 11 (without any maintenance). The nominal wind speed around 10 m/s for full power, so according to the data the turbines given in the research will never give their nominal power.
Because of the reasons specified above, the urban wind turbines are not regarded as an alternative to generate electricity for the house concepts.

Fuel Cells

Although fuel cell is a promising technology for electricity generation, the technology is not yet developed as a commercial product for small scale applications. Due to the applicability and availability reasons, fuel cells are not yet an option for the residential market, therefore is not considered in the design process.

Residential Heat Supply Systems

Heating energy in the house can be generated through utilization of following sources and carriers:

- Natural Gas

- Electricity
- Solar energy
- Biomass
- Ground sources

Biomass, solar power and ground sources are regarded as the sustainable energy sources while natural gas is a fossil fuel which emits CO_2 for heat generation. On the other hand, electricity can be sustainable depending on the source of the electricity but currently in the Netherlands using the grid electricity causes CO_2 emissions as presented previously. Natural gas has higher CO_2 emissions per m^3 than electricity per kWh of energy, however the grid electricity causes higher emissions if it is used to supply heat directly. For example, using 1 m^3 of natural gas means 1.73 $kgCO_2$ emissions while to generate the same amount of heating energy by using electricity causes around 6 $kgCO_2$ emissions. However, the policies of the government to improve electricity generation efficiency and the possibility of using sustainable energy sources to generate electricity make the use of electricity for heating an attractive solution.

For the comparison of the systems a reference situation should be modelled so that the advantages of the systems can be visible. In this study SenterNovem reference house is used as the baseline for the comparison of the concepts. Table 22 shows the reference values for space heating and domestic hot water (DHW) energy demands and energy use.

Table 23: Reference performance values from Senter Novem reference house, source: eQUEST

Energy Demands	
Space heating energy demand (GJ/year)	22.35
Space heating peak power demand (kW)	7.5
Domestic Hot Water (DHW) energy demand(GJ/year)	12.4
Primary Fuel and Energy Use*	
Space heating primary energy (GJ/year)	23.5
Space heating natural gas consumption (m^3/year)	670
Primary energy for DHW (GJ/year)	18.4
DHW natural gas Consumption (m^3/year)	523
Total Natural Gas Consumption (m^3/year)	1193
Total Primary Energy (GJ/year)	41.9
Total CO_2 emissions (kg/year)	2064

* These values are calculated by assuming boiler efficiency of 95% for space heating and 67.5% for DHW

It should be noted that the values presented for the fuel use and primary energy calculations are not results of dynamical simulation. This is calculated based on average efficiencies in order to achieve an objective comparison of the systems. Therefore, partial load characteristics are not taken into account for this comparison, which means actual consumption figures are expected to be higher.

In the following section of the report, several technologies will be evaluated in terms of their capabilities and in terms of their applicability in the Netherlands.

Gas Fired Boiler

The high efficiency, natural gas fired, condensing boilers are the most widely used type of heat generation system for the residential sector in the Netherlands (Eijdems and Boerstra,1999). As given in the specifications of the Senter Novem reference house, high efficieny boiler in 107 class can be used to generate heat in the house. The average efficiency of this type of boilers is around 90-97.5% (Senter Novem). Classes and corresponding efficiency ranges are shown in Table 24.

Table 24: Efficiencies of high efficiency condensing boilers of several classes, source: NEN-5128, table 18.

Type	Efficiency	
	T_{return}<55	T_{return}>55
Conventional	0.75	0.75
HR-100	0.925	0.9
HR-104	0.95	0.925
HR-107	0.975	0.95

An analysis in eQUEST simulation program showed that high efficiency boilers can save up to 100 m^3 of natural gas (around 3.5 GJ) in a year compared to conventional boilers. However, they use natural gas as fuel which cannot be regarded as a renewable energy source and cannot be generated on site.

Heat Pumps

A heat pump extracts heat from a source and transfers it to a sink at a higher temperature, as defined by ASHRAE. Heat pumps are an efficient way of generating heat by using electricity or natural gas for the compressor operation. Depending on the design, natural gas fed heat pumps are called absorption heat pumps. The details of the heat pumps, definitions and efficiencies are given in the Appendix 11. Since heat transport medium is chosen to be water in the previous chapters, water-to-water or air-to-water heat pumps will be evaluated in this study.

The most widely used sources for the heat pumps are outdoor air, exhaust ventilation air, surface water and ground sources. Since the conceptual design does not have an exact location defined, surface water is not considered as an option for the design.

Using outdoor air as the heat source can lead to varying COPs throughout a year because the average temperature of the outdoor air will be different in different seasons. The temperature difference between the source and the sink influences the performance of the heat pump so the variations in source or sink temperatures are not desirable as high temperature difference causes a drop in COP of the heat pump. In order to avoid this problem, ground coupled heat pumps are used so that the source temperature is more stable throughout the year.

Since the generation efficiencies presented in the Appendix 11 include the efficiency of the electricity grid, electric heat pumps exhibit a lower efficiency in total. According to the data, the efficiency of using exhaust ventilation air for heating domestic hot water is the highest and this is because the temperature of the exhaust air is the highest among others, which is around 20^{o}C. However, heat pumps running on exhaust air cannot generate enough heat for space heating and generally used for domestic hot water supply (SenterNovem).

On the other hand, using ground water for one house is not economically feasible, which becomes feasible if it is applied for more than 50 houses (NVOE). Considering the COP stability regardless of the season of the year, ground coupled heat pumps are interesting to be investigated further for the concepts. The decision whether to use horizontal or vertical ground source arrangement is investigated in the following paragraphs.

Considering the data obtained by the literature study, the calculation for the heat generation for the reference house of Senter Novem which has a heating demand of around 22 GJ/year needs following amount of fuel and primary energy to meet the heat demand with the specified type of heat pumps and sources.

Table 25: Performance estimations for different types of heat pumps in case of SenterNovem reference house

	Ground Source (brine) Heat Pump for space heating	(Outside) Air to water heat pump	Exhaust Air Heat Pump for DHW	Outdoor Air or Ground Source (brine) Heat Pump for DHW
COP	4.4	3.8 (average)	2.2	1.4
Primary Energy [GJ/year]	12.7	19.3	14.4	17.5
Fuel per year [kWh/ year]	1373	2089	1085.9	1103 (+208 m^3 natural gas)
CO_2 Emissions [kg/year]	824	1253	651.5	1022.5

On the other hand, the performance of an exhaust air heat pump is estimated for heating the domestic hot water which requires around 12 GJ of thermal energy in a year. This means the system will consume around 1000 kWh of electricity in a year, assuming a COP of 2.2 and sufficient capacity to supply all the hot water demand. These heat pumps are regarded as replacements for heat recovery systems coupled with balanced ventilation which utilizes the exhaust air to heat the fresh outdoor air. The evaluation of a ventilation heat recovery system is presented in the following sections.

If the outdoor air-to-water or ground source water-to-water heat pumps are used for hot tap water supply then the COP of the system drastically drops from 4.4 to 1.4 and the systems is assumed to supply up to 8kW and the peak boiler will supply the rest of the demand up to 19 kW as being the peak for hot water supply. The primary energy use and CO_2 emissions are higher than that of the exhaust air heat pump.

The configuration of the ground source heat exchangers for ground coupling of the heat pumps is an important parameter for the design of the system. As explained previously, two configurations are possible, i.e. vertical and horizontal. For the horizontal configuration, 15

W/m^2 can be collected from the ground and for the vertical boreholes it can be as high as 50 W/m. Considering the COPs given above and the heating demands of the reference house, the horizontal configuration will require a surface area of around 400 m^2 if the spacing between the horizontal pipes are kept at 1 meter. For the vertical configuration, the boreholes should be as deep as 125 meters. Although 125 meters is in the range that is advised by the supplier, the contacted installer advised to use at least 200 meters deep boreholes, therefore this value is used for the cost calculations.

Micro Cogeneration of Heat and Power (CHP) Systems

Micro-CHP systems are considered as one of the most efficient ways to convert energy in a primary fuel into electricity and moreover useful energy as heat for space heating and domestic hot tap water.

Micro-CHP units can be classified according to the operation principle into four main categories which are units run by internal combustion engines, Stirling engines, steam engines or fuel cells. To start with, internal combustion engines are very well developed but their emission rates and maintenance costs are high compared to other options. Although their electrical efficiency is high, around 25 %, their heat based efficiency is under 90 %. Steam engines have low emission rates and maintenance costs as well as a long operation period. However, their electrical efficiency is around 10 % which makes their use less favourable when compared to Stirling engines. Units with Stirling engines also have low emission rates and maintenance costs and also silent operation, which is preferable in household applications (Konstantinidou, 2008). On the other hand, fuel cell based micro CHP units are under development and they are expected to be on the market in 2015 (Wit, J. and Näslund, M., 2007). Therefore, stirling engine based micro CHP units which utilizes natural gas as fuel are investigated for the design of concepts.

Since NEN 5128 is not valid for CHP installations with a power output lower than 5 kW, manufacturer data is used for the estimations.

A small scale product (Remeha HRe) available in the market which can supply 1 kW of electricity and in a range from 5.4 to 26.3 kW of thermal energy (nominal 7 kW) can be used as an example for estimations. The overall efficiency of these systems are considered to be around 90% and they are assumed to be supplying space heating demand. If this system is used in the Senter Novem reference house, the following performance would be possible for space heating and domestic hot water generation.

Table 26: Estimated performance of a Stirling engine micro CHP system for space heating of the reference house

Micro CHP performance	Space Heating	Domestic Hot Water	
Electric Output	1	1	kW
Electric Efficiency	16*	6**	%
Overall Efficiency	90	90	%
Total NG use	821	412	m³
Total Electricity Production	1306	246	kWh

Net Primary Energy Use	17	12.5	GJ/year
Net CO_2 emission	637	566	kg

* Estimated according to the field test results of the Remeha micro CHP unit

** Estimated according to the DHW generation capacity of 19 kW and 1 kW electricity generation

As can be seen from the table, total natural gas use in a year increases approximately 20% compared to the reference case which is 670 m^3 in a year with a high efficiency boiler. However, 1300 kWh electricity can be produced in a year. As a result, estimated CO_2 emission in a year is quite at reasonable levels compared to electric heat pumps.

Another problem with micro CHP installations in the current practice is that this type of micro CHP system uses natural gas. But biogas can also be used instead of natural gas. However, producing around 1200 m^3 of biogas in a year on site is not reasonable and the natural gas distribution system should supply the required amount which can be realized in the future.

Wood Pellet Boilers

As already concluded in the biomass analysis above, currently wood pellets are the only source of biomass for small scale applications. Wood pellets can be combusted by wood pellet boiler to supply heat for the house. Although there are no manufacturers in the Netherlands for small scale applications, there are suppliers of the products which have been manufactured in Germany, Sweden, France and Austria markets (Oekoenergie-Cluster, 2008). Therefore, it is interesting to evaluate the wood pellet boilers among the options to supply heating demand of the house.

The wood pellets have heating values of approximately 18 MJ/kg and wood pellet boilers are claimed to reach about 80% (Haller M.,2008). Following table shows the performance of the wood pellet boiler if it is used to supply space heating demand and the domestic hot water demand for the reference house.

The domestic hot water demand is supplied with wood pellet boiler in combination with a peak boiler which will provide supplementary heat whenever the capacity of the boiler is not sufficient. The peak boiler efficiency is assumed to be the same as the reference case.

Table 27: Estimated performance of a wood pellet boiler for space heating of the reference house

Wood Pellet Boiler	Space Heating	Domestic Hot Water	
Thermal Output	2-8	8 -19	kW
Thermal Efficiency	80	80	%
Total wood pellet use	1510	386*	kg/year
Primary Energy Use	27.2	14.2	GJ/year
CO_2 emissions (excluding transportation)	0	0	kg/year

*208 m^3 natural gas required as supplementary

The storage and/or transportation of the wood pellets is an important issue because a small scale wood pellet boiler has an internal storage, for example 25 kg, then wood pellets should be transported to the house at least for 90 times a year, which is around once in 4 days. If the delivery is arranged for two times a year, then approximately 2 m^3 of storage space will be required, which means around 1 m^2 of surface requirement in the house.

Space requirement of a typical wood pellet boiler is normally a boiler room of 2m x 2m if the boiler has internal storage space (Oekoenergie-Cluster, 2008). Additional 1 m^2 for storage means the space requirement for the total system is around 5 m^2. Since the reference house does not have a basement, the boiler should be installed in the attic.

Direct Electrical Heating

Electric heating can be used directly in the rooms to supply the required amount of heat or the heaters can be used to heat the water supplied to the zones. The efficiency of this kind of a system can be accepted as 100% because all the energy will be converted to useful heat. Based on this assumption, the following performance in the reference house can be estimated.

Table 28: Estimated performance of electrical heating for space heating of the Senter Novem reference house

Electric Heating for	Reference house	
Heater Capacity	7.5	kW
Electricity consumption	6041	kWh/year
Primary Energy Use	55.8	GJ/year
CO_2 emissions	3625	kg/year

As can be seen from the table, using electricity directly for heating causes around 2.5 times higher primary energy use for space heating than the reference case. Moreover, CO_2 emission in a year is also excessive because of the high electricity consumption and the inefficiency of the electricity generation in the Netherlands. Even if this electricity demand is claimed to be compensated by PV panels, then required area of panel would be around 60 m^2 which is beyond the physical limits of the roof.

The expectation of an increase in the electricity generation efficiency in the future with the introduction of sustainable energy sources should be considered for this case. But on the other hand, imposing such high peak power demands to the grid and using electricity ineffectively compared to heat pumps makes this option less favorable in terms of environmental performance.

In addition, electrical boilers can be used to supply the hot tap water demand. The thermal efficiency of these systems is given by NEN 5128. Accordingly, following performance results can be calculated. It can be seen that the electricity consumption is considerably high, nearly equal to the average household energy consumption, which is the drawback of the system.

Table 29: Electric boiler performance for DHW in the Senter Novem reference house, source: NEN 5128

Electric boiler for domestic hot water		
Electric boiler thermal efficiency	75	%
Electricity consumption	4593	kWh/year
Primary Energy Use	42.4	GJ/year
CO_2 emissions	2756	kg/year

Solar Thermal Collectors

Solar thermal collectors are the systems that are used to convert solar power to thermal energy, mostly for the purpose of supplying domestic hot water. There are two types of solar collectors which are used commonly in today's practice. These are flat plate collectors and vacuum (evacuated) tube collectors. The principles of operation of these systems are given in the Appendix 11.

Evacuated tube type solar collectors are more efficient than flat plate collectors if the temperature difference between the inlet and outlet streams is required to be higher. Moreover, in days with lower direct solar irradiation, e.g. cloudy days, evacuated tube collectors exhibit a superior performance due to the capability of absorbing diffuse solar irradiation (E. Zambolin,2010).

Overall thermal efficiency of these systems should be determined in order to calculate the yearly energy yield from these systems. The overall efficiency is defined by NEN 5128 depending on the ratio of the heating demand and the solar irradiation falling on the solar collector (Table 32). However, using overall efficiencies may be insufficient in order to see the seasonal performance of the collectors. Therefore, it is decided to develop a model for the purpose of this study. This model allows the estimation of the solar thermal collector performance based on their optical efficiencies and seasonal characteristics of the location as explained in Appendix 15. So, a more accurate estimation of the performance can be made.

As a result, the performance of the solar thermal collectors can be concluded as follows for the Senter Novem reference house. The assumption is that the optimum collector area is determined as 6 m^2 and 200 liters of storage in PZE study by ECN (Koune et al., 2001).The following table shows the estimated performance of the solar thermal collectors according to the model developed and described in Appendix 15.

Table 30: The performance of solar thermal collectors in Senter Novem reference house, rough estimations

	Collector Specifications		
Collector area	6		m^2
Storage Capacity	200		liters
	Flat Plate Collector	Evacuated Tubes	
Total yield (share of the total)	6.5 (52)	9.5 (76)	GJ/year (%)
Natural Gas Consumption	343	294	m^3/year
Total Primary Energy Use	12.3	10.5	GJ/year

CO_2 Emissions	593	509	kg/year

As can be seen from the table the evacuated solar collectors can generate around 75 % of the total energy required by domestic hot water use while with the same collector area flat plate solar collector can generate 50 % of the total. Most of the heat is generated in the summer period for the flat plate collectors, but evacuated solar collectors are expected to have a more even distribution of the energy generation profile throughout a year.

Although the generated amount of heat by the collectors is high, the reduction of natural gas consumption is not as high since the most of the solar power is available during the summer period. However, the use of 200 liters of storage volume enhances the performance of the solar thermal systems.

Ventilation Air Heat Recovery

Although heat recovery is not a primary heating source for space heating, since it helps to reduce the energy consumption for space heating, and so CO_2 emissions, it is evaluated under this topic. Ventilation air heat recovery is used to recover heat from exhaust air stream to the fresh outdoor air stream so that the heat losses due to ventilation can be minimized. Recently heat recovery systems have been commonly used in houses in combination with the balanced ventilation systems. 'Air Infiltration and Ventilation Centre' (AIVC) explains the only condition for applying heat recovery in houses as the house being airtight, specifically lower than 10-20% of the flow rate trough the heat recovery unit.

The calculation procedure for the effectiveness of the heat recovery unit is given in the Appendix 11. An analysis of the SenterNovem reference house by eQUEST showed following results for the performance of the heat recovery unit.

Table 31: Heat Recovery Unit Performance in the SenterNovem reference house

Heat Recovery efficiency average	56	%
Recovered heat in a year	12	GJ/year
Natural gas savings	340	m^3/year
Additional energy consumption due to heat recovery	126	kWh/year
Total ventilation electricity consumption	643	kWh/year
Net Primary Energy Savings (Savings-Consumption)	11	GJ/year
CO_2 emission	386	kg/year

3.1.6.5 Conclusions

Solar analysis conclusions

- As shown in the solar analysis part, 1100 kWh/m^2/year is received by optimally oriented solar panels, so an average household would need approximately 33 m^2 solar panels.
- The yearly output of a 1 m^2 solar panel will be 103 kWh/year which would save 950 MJ primary energy in a year, which is 2% of the allowable primary energy use of a terraced house.
- If the solar energy is converted to thermal energy for hot tap water, then 6 m^2 solar thermal collector area would be required to meet 50% of the demand requirement of an

average household with flat plate collectors.

- Solar path diagram implies that the solar systems, namely PV cells or solar thermal collectors, should be oriented to the south and the optimum angle to receive the direct sunlight throughout the year is between 30-40^o.
- As different solar irradiation values in different times of the year imply, the size of the systems which utilizes solar power should be determined based on the load profiles and corresponding solar irradiation values. The worst case scenario, which would give the biggest area requirement, will be to calculate the size according to the solar irradiation values in the winter period.
- If solar power should be used in the house in order to generate heat for domestic hot water and electricity, the optimally inclined roof area for solar collectors and PV panels should be around 40 m^2. Therefore, the size of the roof should be increased in the reference house design for solar power applications.

Wind analysis conclusions

- Wind blows from the west and southwest directions dominantly, and the average wind velocity is around 3.5 m/s and maximum is around 9 m/s throughout a year.
- Yearly average wind speed of 3.5 m/s implies that approximately 2700 kWh/year can be generated at most by installing the most efficient small wind turbine tested, which is about 75% of the total electricity consumption of a household.
- The urban wind turbines start operating generally at 2.5 m/s, operating hours of a urban wind turbine would be 64% of the year (without any maintenance). The nominal wind speed around 10 m/s for full power, so according to the data the turbines given in the research will never yield their nominal power.
- If natural ventilation will be utilized for the ventilation concept of the house then the ventilation openings should be placed on the west or south-west orientation. On the other hand, mechanical exhaust of the ventilation system (if any) should not be directed towards west since it will increase the required fan size.

Ground Source Analysis Conclusions

- Ground source heat pumps are quite commonly used in the Netherlands, for heating and cooling purposes.
- If the space heating of the house is supplied by using a horizontal ground source heat pump, the required area of 400 m^2 is unacceptable for a terraced house in the town centre. Therefore, the vertical boreholes will be preferred for ground source which should drilled to 200 meters.
- It is possible to install vertical ground heat exchangers in most part of the Netherlands, costs due to the excavation till the depth of around 200 meters should be considered.
- Literature study showed that there are geothermal sources in the Netherlands which would be used to provide heating for neighbourhoods, so the house design should be flexible to fit to different sources like geothermal heat.

Biomass Analysis Conclusions

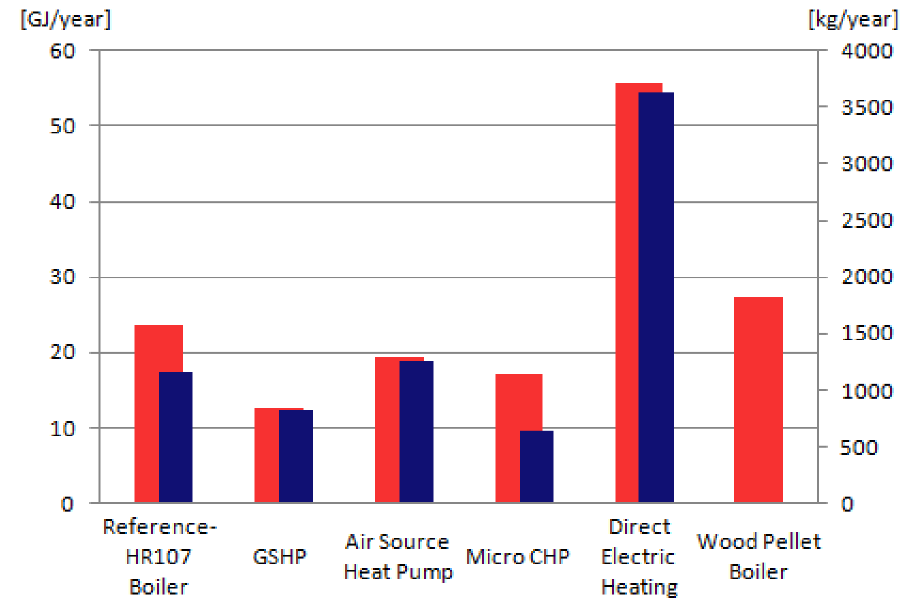
- As explained in the analysis part, domestic wood burning comes out to be the only option for small scale applications in the house to use biomass as the energy source.
- Wood pellets are easy to transport and have high heating values of 18 MJ/kg, so it is the most promising fuel to be used as biomass in the house.

- Considering the reference house with approximately 21.75 GJ total heating energy in a year and the wood pellet boiler average efficiency as 80%, yearly at least 1500 kg of wood pellets would be required to cover the whole heating demand.
- A small scale wood pellet boiler typically has 25 kg of wood pellet storing capacity, so in a year more than 60 times wood pellet delivery is required. In order to talk about the environmental benefits of using wood pellets, this issue should also be considered. Otherwise, storage space in the house for wood pellets should be spared, around 1 m^3.

System Analysis Conclusions

Results of the analysis for space heating options are summarized in the following figure:

Space heating options



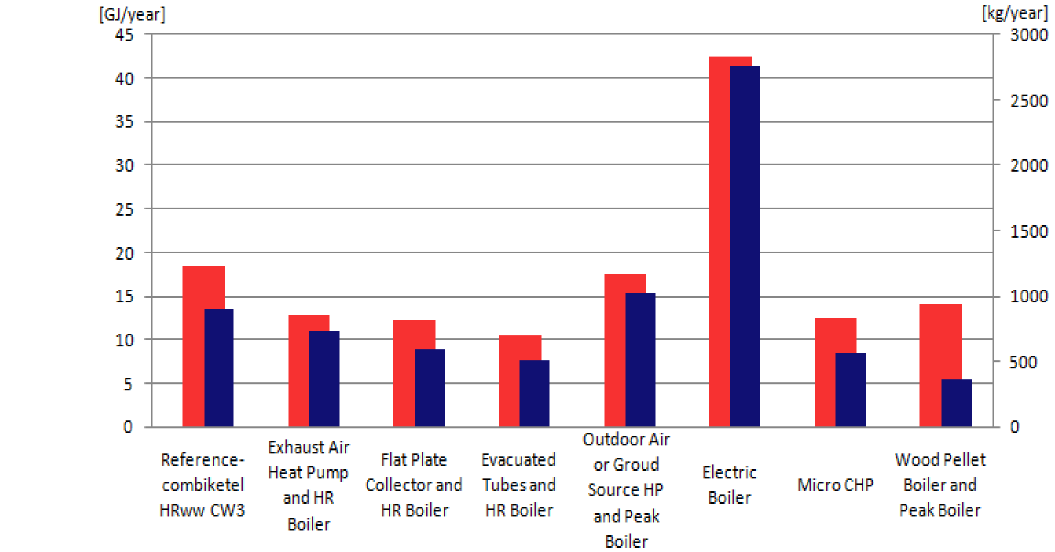
	Reference-HR107 Boiler	GSHP	Air Source Heat Pump	Micro CHP	Direct Electric Heating	Wood Pellet Boiler
Primary Energy Use	23.5	12.7	19.3	17	55.8	27.2
CO2 Emissions	1159	824	1253	637	3625	0

Figure 20: Primary energy use and CO_2 emission comparison of different systems for space heating

These results reveal that for space heating ground source heat pumps, outdoor air-to-water heat pump and micro CHP units are superior to the reference case in terms of primary energy use and CO_2 emissions. Comparison of these systems for the economic feasibility is discussed in the following parts of the report. The direct electric heating results in high primary energy consumption and CO_2 emissions compared to the reference case therefore this option is not taken into account for economical feasibility analysis.

Wood pellet boilers are claimed to emit no CO_2 because of the wood being CO_2 neutral in its lifecycle. However, this value does not include the processing and the transportation of the wood pellets. The space requirement for storage of wood pellets and the system itself is around 5 m^2 which is nearly as big as the smallest bedroom of the reference house. According to the study conducted by ECN in 2007 compared to solar thermal collectors, the public acceptance of wood pellet boilers among the target group of the study is 6% while it is

around 30% for solar thermal collectors. Most of the people in the research group, 35%, did not prefer the wood pellet boilers even if it is 10% cheaper than the conventional systems while it is 7% for solar thermal collectors (van der Drift et al., 2007). Therefore, wood pellet boilers are not included in the economic value analysis.
Results of the analysis for hot water supply options are summarized in the following figure.



	Reference-combiketel HRww CW3	Exhaust Air Heat Pump and HR Boiler	Flat Plate Collector and HR Boiler	Evacuated Tubes and HR Boiler	Outdoor Air or Groud Source HP and Peak Boiler	Electric Boiler	Micro CHP	Wood Pellet Boiler and Peak Boiler
Primary Energy Use	18.4	12.9	12.3	10.5	17.5	42.4	12.5	14.2
CO2 Emissions	904.8	738	593.0	509	1022.5	2755	566	360

Figure 21: Primary energy use and CO_2 emission comparison of different systems for DHW supply

Figure 21 shows the benefits of solar thermal collectors over other solutions to generate domestic hot water. If it is combined with a boiler as in the reference case, the flat plate collectors save around 33% of the primary energy and evacuated tubes around 43%. Among the other options, electric boiler causes the highest primary energy consumption and CO_2 emissions as expected. Since the COP of the ground source or outdoor air heat pump drastically drops to supply high temperatures, the primary energy saving is lower than the other options while exhaust air heat pump performs comparable to the flat plate collectors in terms of primary energy consumption. Micro CHP systems, due to their high thermal efficiency, also cause reduction in both primary energy CO_2 emissions.

The comparison of exhaust air heat pumps and the ventilation heat recovery units is presented in the following table. Both systems save primary energy but net primary energy savings of ventilation air heat recovery is nearly two times higher than the exhaust air heat pump. Therefore, as stated in the literature (Koune et al., 2001) exhaust air heat pumps are not recommended to be used instead of heat recovery units.

Table 32: Comparison of ventilation air heat recovery system and exhaust air heat pump

	Exhaust Air Heat Pump	Ventilation Air Heat Recovery
Primary Energy Use (GJ/year)	12.9	1.65
Primary Energy Saving (GJ/year)	18.4	12.2
Net Primary Energy Saving (GJ/year)	5.5	10.5

Strategies and Solutions for concepts

In each concept following strategies should be taken into account:

- In order to use the solar potential of the site more efficiently, the roof of the house should be designed such that enough area for the systems is oriented toward south. Angle of the roof with the horizontal should be 35-36° which is determined as the optimum azimuth angle for solar power systems, either PV or solar thermal system. This will also decrease the energy and cost for the installation of the system.
- The required area for PV system is greater than the roof area even if the roof is optimally oriented and size of the system is calculated by annual sum of irradiation values. Therefore if PV system is to be used and all the electrical energy of the house is to be supplied by PV, south oriented roof area should be increased or the demand should be decreased.
- Considering the varieties in solar irradiation, thermal and electrical energy storage should be considered for a house because both electrical and thermal energy demand decreases in the summer while the potential of the solar irradiation increases.
- Although wind velocity averages seem to be stable throughout the year, the uncertainties in the instant wind velocity and the surrounding conditions in the urban area makes the performance of small wind turbines unpredictable. Despite the possible benefits of energy generation on site, application of small scale wind turbines involve a lot of uncertainties and therefore it is not recommended.
- If the natural ventilation will be used as the ventilation principle of the house, then in order to ease the flow through the openings into the house openings can be placed in the west orientation.
- If the mechanical ventilation will be used in the house and the airtight envelope will be required then the south-west and west oriented walls and openings require extra attention during the design process.
- Horizontal ground heat exchangers require an extensive ground area for a terraced house in the Netherlands. Therefore, the vertical ground heat exchangers are preferable in terms of applicability.
- Although ground sources offer a lot of possibilities for heat storage/supply, the related costs for the installations should be considered especially for the vertical heat exchangers.

Recommendations for the active concept

The most efficient energy generation system, in terms of primary energy savings, is the ground source water-to-water heat pump for space heating and the micro CHP unit for space heating and domestic hot water combination. However, currently available micro CHP units run on natural gas which is a fossil fuel based source. Unlike electricity, natural gas cannot be generated on site through renewable energy sources. Although biogas is an option for the future applications, considering the current practice the ground source water-to0water heat pumps are the most suitable option for space heating. Relatively high primary energy consumption can be compensated by installing solar thermal collectors on the roof of the house. The type of the solar collector will be decided based on the costs of the systems since the primary energy savings of the both type are comparable.

Since the active concept will incorporate installations to compensate for the relatively higher thermal energy demand, horizontal ground sources with a limited ground area (considering the town centre position of the concept) can be insufficient which will urge the use of the vertical ground heat exchangers for ground source heat pumps. As mentioned previously, the use of PV and solar thermal collectors is effective to reduce the primary energy consumption.

Recommendations for the passive concept

Since the thermal energy demand will be lowered in the passive concept, then ground source heat pumps can be used to supply the remaining small heat demand. However, the costs of these systems should be discussed in order to make a decision for the passive concept because the main criterion for this selection is the feasibility of these systems. This is discussed in the following sections.

3.1.7 User Behaviour

3.1.7.1 General aim

All the strategies, solutions and the efforts to build a sustainable built environment are more effective as soon as the users contribute positively to the environmental performance. Especially for the systems in the house to operate more efficiently, user behaviour should be well analyzed and the means to increase the awareness of the users should be defined in order to reduce the environmental impact of their activities.

3.1.7.2 Assessment method

In BREEAM-NL, the way to change/affect the user behaviour is not pointed out in BREEAM NL for residential buildings, while it is suggested to .
So, for the assessment of this parameter, availability and effectiveness (which can only be based on assumptions and literature) of the metering devices are evaluated.

3.1.7.3 Methodology of analysis

In order to perform the analysis, different measuring equipments are investigated at the first place and then the effect of using these on the user behaviour is analyzed through a literature research. So there are three major focus points; the user profiles, the solutions to improve the user behaviour and their affectivity.

In the study by TNO and ECN for the ‘Building Future’ program of the Netherlands, the four main drivers for the users’ energy consuming/saving behaviours were identified and different users with different drivers were investigated. The resulting figure is shown in Table 33. Although users may have different drivers, costs seem to be the main driver for most of the user groups to save energy.

Table 33: Different drivers for different Dutch households, source: Paauw et al, 2009

Household type	Convenience	Conscious	Costs	Climate
Single	●○○○○	●●●○○	●●●●●	●○○○○
Two adults below the age of 60	●●●○○	●●●○○	●●○○○	●●○○○
Single parent family	●○○○○	●●●●○	●●●●○	●○○○○
Family (two parents)	●○○○○	●●●○○	●●●●○	●●○○○
Seniors above the age of 60	●●●○○	●○○○○	●●●●○	●●○○○

In the same study by TNO and ECN, the characteristics of every driver have been presented. Since the most common driver is the ‘ Costs’ according to the literature, the user profile related to that is presented in Table 34 and the corresponding behaviour is the basics for determining the user patterns during simulations.

Table 34: User preferences (Paauw et al, 2009) and corresponding conclusions for this study

Heating	Cooling	Hot Water
• Heating not unnecessary on • Conscious with temperature at home • During the night/ in the morning, heating hardly on • Extra blankets or clothes So for this study: • Heating schedules only in active occupancy times, i.e. in the evenings • Relatively lower set temperatures for heating, 18 or 19^{o}C	• Conscious use of cooling possibilities So for this study: • Cooling by window opening • Installation only if required • Relatively higher set temperatures for cooling around 25^{o}C (thermal comfort limit)	• Hot water as requested So for this study: • The pattern as defined by NEN norm
Ventilation	**Lighting and electronic equipment**	**Cooking**
• Windows open if necessary, closed on time. • Mechanical ventilation if necessary, not unnecessary use So for this study: • Window operation is ideal • Mechanical ventilation is kept at the minimum levels as required by building decree	• Lighting/appliances never unnecessarily on • Strategic use of energy saving bulbs and energy efficient appliances So for this study: • Artificial lighting is only on when daylight is lower than minimum requirement • Efficient lighting (LED) and appliances	• Cooking for more meals once • One-pan meals So for this study: • Nothing special can be estimated.

Although in this table, the possibility of lower set temperatures for heating is mentioned, for simulating the concepts minimum thermal comfort requirements are taken into account. Lower set temperatures are the subject of a sensitivity study to observe the changes in energy demand for different behaviours of users.
Having the user type defined measures to change the user behaviour and their effects can be discussed in the following section.

3.1.7.4 Results

It is clear that user behaviour in a house affects the environmental performance of the house. In a study conducted by ECN in the Netherlands (Jongeneel et al., 2001), it was concluded that an energy intensive lifestyle in a very energy efficient residence can lead to a higher energy use, than an energy extensive lifestyle in a less energy efficient residence. Therefore, it is necessary to change the user behaviour towards more energy efficient life styles. Three basic steps are described to change the user behaviour (de Groot et al, 2008):

- Awareness: Change the valuation of how the environment already plays a role in household tasks and change the perception of the energy friendliness of behaviour.
- Feedback: Increase knowledge about behaviours that reduce energy consumption.
- Easy accessible: Reduce time constraints and complexity within households by coaching on routines and easy-choice options for investments.

Within the scope of this study only the feedback steps are taken into consideration, which is achieved through advanced energy management systems. So, the measures to increase the awareness of the users for the consequences of their behaviour are investigated. By improving the feedback provided by the measurement and control equipments (domotica in Dutch), in theory, energy intensive behaviours can be reduced.

These systems are characterized in three different types in a research by TNO and ECN (Opstellen et al, 2007) as: environment-adaptive, user-adaptive and user-educational control. Environment-adaptive control changes the system settings according to environmental conditions while user-adaptive control does according to the behaviour and the preferences of the user. User-educational control aims to influence the behaviour and the preferences of the user, for example by providing feedback on the consequences of the current behaviour. The study estimates the potential savings by incorporating this control and monitoring systems, which is presented in the table. Although higher values are estimated for houses built in 1960-1970's, they are representative for the savings potential of average households. In the last column, the percentage of the households which can apply this saving measure is presented.

Table 35: Primary energy saving potential of different types of control strategies, source: achter de meter, ECN, 2006

Measure	Potential saving for studied houses	Potential savings for average household*	Application depending on	Applicable Households
Environment-adaptive	**$GJ_{Primary}$/year**	**$GJ_{Primary}$/year**		**%**
Irradiation control with solar shading	2.3	0.05	Mechanical cooling	2
User-adaptive	**$GJ_{Primary}$/year**	**$GJ_{Primary}$/year**		%
Presence based ventilation control	3.0	1.7	Mechanical exhaust	55
Window closure based control of space heating	0.3	0.3	-	100
Disconnection of appliances in standby-mode	7.2	2.0	Various appliances	28
Presence based control of space heating	4.6	3.9	-	85
User-educational	**$GJ_{Primary}$/year**	**$GJ_{Primary}$/year**		**%**
Feedback on ventilation	1.9	1.9	-	100

behaviour				
General feedback on measured energy use	2.6	2.6	-	100
Influencing hot water use to match available solar heat	0.4	0.005	Solar heater	1.2

* Average is calculated by dividing the whole potential savings to total household number

These measures and their potential savings are evaluated also in terms of their technical applicability. It shows that user-adaptive and user-educational control systems have the highest potential to save energy. If the households are supplied with feedback on the general energy use periodically, it was observed that approximately 3% reduction in total energy use can be achieved.

In order to achieve this saving, the costs of installing smart meters to provide feedback are investigated. Energy companies offer replacement of old monitoring systems and installing smart meters for a monthly rent. The total cost of rental agreements is around 30 €/year while the estimated energy savings can achieve around 45 €/year reductions on electricity and gas according to the savings potential presented above. It should also be noted that the saving is not certain and these systems can be unobservant after a certain period of use. Considering the uncertainty of savings, this measure is not taken into account for the concepts but it is considered for the sensitivity analysis.

In addition feedback on ventilation behaviour, especially closing the windows while heating is on, has a high potential for energy savings.

The relation between user behaviour and energy consumption should also be taken into account if potential savings are to be estimated. The study carried out by ECN in 2001, which was mentioned previously, concluded some important behaviours:

- The bandwidth in heating demand is mainly determined by set point heating temperature.
- When the participant keeps a record of their energy use, the set point heating temperature turns out to be lower.
- Preferred set points are not influenced by type of thermostat (programmable or analogue).
- Participants with an analogue thermostat tend to more often adjust the temperature set point to a lower temperature, in case of a longer period of absence, than participants with a programmable thermostat.
- The hot water demand is influenced significantly by shower and bath frequency.
- Participants with one or more children under five have the highest bath use.
- As children grow older, bath use decreases and shower use increases.
- As the family size increases the possession of appliances increases.
- All families of two or more people posses a washing machine and the frequency of use is increasing as the number of people increases.
- All families of five or more people posses a tumble dryer.
- Participants who use energy consciously are willing to adjust their heating behaviour, but not their shower and bath behaviour.

The selection of the energy efficient appliances is considered as a preference of the users, so the effect of this preference is discussed in this section of the report. The energy label A is assumed to be preferred for the appliances such as fridge, washing machine, television etc. The website initiated by 'Stichting Natuur en Milieu' (TOP10) lists several products for energy efficient appliances and savings in electricity consumption. The following savings in percentage is estimated compared to the conventional counterparts:

- 'A' labelled refrigerator with a freezer part can save up to 50%
- 'A' labelled TV can save around 35%.
- 'A' labelled washing machine (without 'hotfill' function) can save around 20%.
- 'A' labelled dishwasher can save around 20%.

Considering the share of these equipment in the total equipment consumption which is estimated around 1700 kWh/year, the expected reduction in overall would be around 30%.

This value is incorporated for the designed concepts but not for the reference house to exhibit the benefits of choosing the energy efficient appliances. Additionally, tools to disconnect the appliances while use in stand-by mode can be used in the concepts, which are called standby-killers. According to the study by ECN called 'Demand Side Management (Achter de meter)', it is specified that the energy saving potential of the standby killers is around 200 kWh out of 400 kWh yearly consumption by standby appliances. This is due to some appliances which cannot be shut down, such as fridge, telephones etc. Accordingly, this value is reflected to the energy simulations in eQUEST. It is simulated by halving the equipment electricity consumption value which is defined per room whenever the value is at its lowest level.

3.1.7.5 Conclusions and strategies for design

As a result of the analysis, for the concepts following strategies should be followed:

- Each concept will be equipped with the traditional monitoring device
- Analogue thermostat will be installed.
- The set temperature will be assumed to be 20^{o}C.
- Windows will be assumed to be closed while heating.
- Heating and cooling schedules will be assumed to be optimal; lower/higher set temperatures during unoccupied periods.
- Electrical equipment will be assumed to be unplugged while they are not used, which is estimated to save around 200-250 kWh_e per year.
- Energy efficient appliances will be used in the house, including TVs, refrigerator, washing machine and dishwashers with A label.
- Hot water use schedules will not be influenced.

3.1.8 Building materials

3.1.8.1 General aim

Building materials influence some major topics in terms of sustainability: embodied energy, environmental impact and health effects. This assessment will aim to give an overview of mainly used materials (or combinations) and their general effect on the environment. These effects can be specified in a high level of details, but the scope of this analysis is to present some general lines of impact.

3.1.8.2 Assessment method

The quantity to assess low material impact in BREEAM-NL is a 'shadow price' (or: hidden environmental costs) in euro per meter squared. This price is calculated from the impact of nine environmental aspects of the building materials (greenhouse effect, damage to ozone layer, humane-, aquatic-, and terrestrial toxicity, photochemical oxidants, acidification and eutrophication) . The amount of reduction on the shadow price of 0.8 €/m^2 gross floor area is valued in an amount of credit points (1 per 10% reduction). All materials which concern the construction period of the house are included in this price. Lighting, communication, finishing and taps e.g. are excluded from the calculation.

This shadow price can be calculated by use of the tool GreenCalc+ (V2.20). The building materials can be specified in this and it will calculate the environmental impact. For each concept this shadow price will be calculated to compare them in terms of environmental impact of materials.

3.1.8.3 Methodology of analysis

The analysis is based on the starting points of the SenterNovem reference terraced house with balanced ventilation as given in the publication of reference buildings. The building materials for this house are mainly standard brickwork with concrete floors and wooden layered roofing. In order to compare this building system with other options, the materials for the main structures are varied. Also a comparison is made between different types of building services and the influence of energy generation systems.

3.1.8.4 Results: comparison of demands and supply

Literature
The share of embodied energy in building materials as part of the total amount of energy used during the life time of a house increases when the amount of needed operational energy per year decreases. This topic was discussed by Thormark (Thormark 2006). He concludes that by material substitution a decrease of 17% or increase of 6% can result from different choices in material use. Studies of Dutch residential construction revealed that an increase in wood use could reduce CO_2 emissions by almost 50%, compared with traditional Dutch construction (Goverse et. al., 2001)

Share of building parts in reference house

The share of the shadow prices per building part cannot be given, since it is determined by adding the equivalences on environmental impact of the total building. A slight indication of impact is given in Figure 22 in terms of 'environmental costs', but this is not translatable to shadow prices since weighting factors are different. In this parameter the floors result in the highest impact, followed by facades, internal walls and foundation. These are all stone materials in the house with heavy weight. To compare: the roof with has 1/3rd of the impact than the façade while it is twice the size of the façade.

Environmental costs per building part

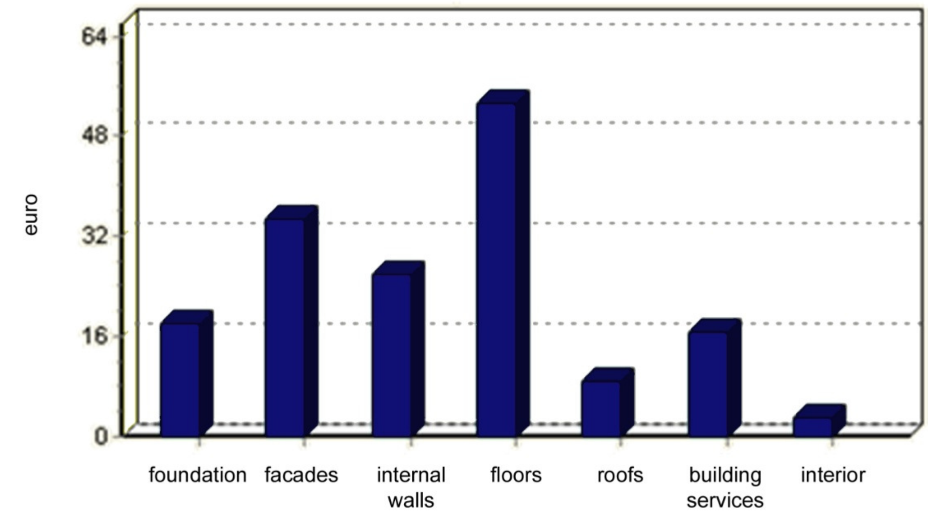


Figure 22: GreenCalc+ V2.20 result on reference house: environmental costs (is not shadow price)

Influence of building types and services

For this short analysis three types of building structures are compared and three different types of building services. Also the influence of changing the window size is indicated. PV- or wind systems are not included in the options of Greencalc+ V2.20 calculations and therefore not included in this comparison. The variations and results are presented in Table 36 below.

Table 36: Variations in building materials and influence on shadow price

GFA: 157 m^2	Shadow price (€/GFA)
Standard reference house: traditional brickwork, concrete floors, wood roof structure	0.69
Wood frame walls and floors, wood roof structure	0.52
Concrete structure: concrete walls, concrete floors, concrete roof structure	0.70
Based on reference house structure: *Balanced ventilation replaced by mechanical exhaust*	0.68
Based on reference house structure: *High efficiency boiler for hot water and space heating (> 55°C) replaced by Combined heat pump with solar collector*	0.70
Based on reference house structure: *High efficiency boiler for hot water and space heating (>*	0.76

55°C) replaced by Combined heat pump with ground source	
Addition of 5m^2 glass in facades	0.69

The reference house already complies with the BREEAM-NL demand of 0.80 €/m^2. It achieves already 1 credit by this. As can be expected, a structure based on wood frames scores better (is lower) on the shadow price than stone or concrete. Although a concrete structure does not influence the price much. Bigger changes are found when the traditional gas fired boiler is replaced for a system heat pump and a ground source. The results show that the influence of the heat pump itself is low, since the combination with a solar thermal collector gives an increase of only 1 cent. The replacement of the balanced ventilation system with heat recovery for a simple system with mechanical exhaust gives a reduction of 1 cent.

The influence of glass size in the façade is so low that it is not reflected in the shadow price. Since the active and passive solutions both affect the shadow price, combination will be sought in order to decrease the shadow price in the concepts or keep it equal by compensating negative solutions. As example: a wood frame structure could compensate the negative effect of a ground source heat pump.

3.1.8.5 Conclusions

Share of building materials in house

- The main part of the environmental impact by building materials in the house can be found in the foundation, facades, internal walls and floors. Roof partitions have a remarkably low share in the environmental impact.

Influence of different materials

- Choosing a light weight structure like wood frame over the traditional brickwork or over the heavy weight concrete gives a significant reduction on the environmental impact.
- A different ventilation system will only slightly reduce the impact, but the application of a heat pump has higher effect.

3.1.9 Water use

3.1.9.1 General aim

The aim of this part of the study is to improve the environmental performance of the house by decreasing the drinking water consumption through certain measures. In 2007 (which is similar to previous 30 years levels), 14.531 million m^3 of water was extracted totally in the Netherlands. The households and companies (other than industrial companies, power plants and refineries) used 3 times higher than their winnings (website: 'Compendium voor de leefomgeving'). Therefore, water management efficiency in the houses should be improved. This will also save the energy required for processing of clean water before and after use at residential sector. Moreover, the scarcity of the water resources is predicted to be a problem in the world in the long term.

3.1.9.2 Assessment method

BREEAM-NL evaluates the water efficiency measures in 3 criteria under Water section (abbreviated as Wat4, Wat5 and Wat7) and rewards credits based on the availability of certain solutions as it points out:

- Installing toilets with water saving function (maximum 6 or 4 litres),
- Use of water saving taps (with sensors based on presence or time),
- Water saving shower heads,
- Water use monitoring devices,
- Water recycling systems

In order to assess the resulting (predicted) water consumption values based on the performance, total yearly water consumption per capita in the house has been investigated. This value is compared to average consumption of water in the Netherlands, so the improvement in the water consumption can be evaluated.

3.1.9.3 Methodology of analysis

As described above, the average water use per capita in the Netherlands is investigated. Solutions to decrease this demand are researched other than the ones that were suggested by BREEAM-NL.

As a potential source of water for the use in the house, precipitation values are deducted from the dataset of NEN 5060 based on the climatic year (reference climate details table A.2).

Also breakdown of the water consumption will be investigated to look at the hot water consumption and the main activities of water consumption so that measures will be relevant.

3.1.9.4 Results

The average household water consumption in the Netherlands is given in Appendix 12 with a breakdown, which shows the total consumption value 127.5 litres/person/day recorded in 2007. The trend in the water consumption figures compared to population growth is shown in Figure 23.

Water consumption in the Netherlands

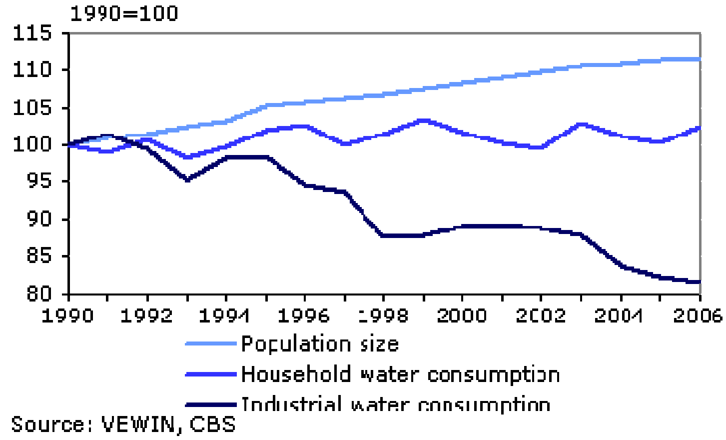


Figure 23: Average household water consumption change in the Netherlands source: [*http://www.cbs.nl/en-GB/menu/themas/natuur-milieu/publicaties/artikelen/archief/2008/2008-2527-wm.htm*]

The data shows that the total water consumption per household has declined slightly (app. 7%) but due to the increase in the population the national total tends to increase in households while the industrial water consumption has declined drastically since 1990. So, the measures to decrease the household water consumption should be taken immediately.

Based on the values given in Appendix 12, the breakdown of the consumption for different items is visualized in the following pie chart. It shows that the main water consumption items are shower (39%), toilet flushing (29%) and washing machine (12%). And according to the values over the years, water consumption due to showering increased while washing machine and toilet flushing consumptions decreased, most probably due to the more water-efficient system developments.

Household water consumption

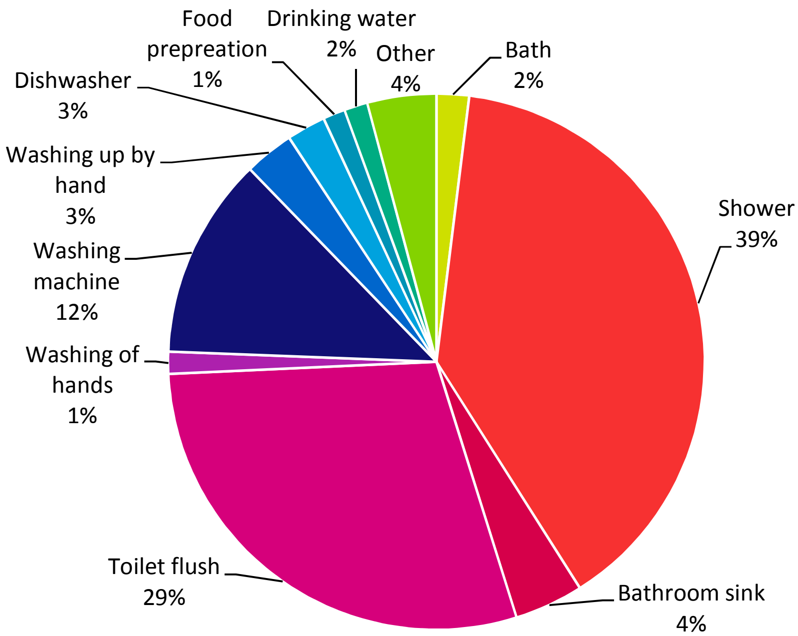


Figure 24: Average household water consumption breakdown

The total water use in an average house, assuming the average of 2 people per house, is therefore 255 l/day according to 2007 values. So in a year, this value adds up to 93 m^3 of water consumption per house. This will be the basis value for the further study. However, values for different seasons are not indicated by these figures.

As a potential source for the water, precipitation values are studied. These values are obtained from NEN 5060. Data from the NEN norm is used and monthly total precipitation is calculated as presented in Appendix 12. In a year 817 mm of total precipitation is recorded, which means nearly 40 m^3 of water is falling onto the roof of a standard terraced house in the Netherlands within a year. The quality of the water allows the use in the house for washing machines which requires around 31 m^3 of water in a year.

The storage capacity of the vessel to be installed for rain water recycling should be decided according to the maximum precipitation amount in a day. According to the data given by NEN, the storage capacity should be 1.6 m^3 for storing two days of rain water at maximum levels. So, for the simplicity reasons the volume is assumed to be 2 m^3.

For the calculation of the required energy for domestic hot water, the use pattern is determined. This is based on average values by NEN 5128 in different classes and gives details of hot water use in a day, with total volumes, flow rates, required temperatures and available temperatures. These details are given in Appendix 12.
According to these values, hot tap water flow rate is 5.5 l/min and supply temperature is given as 40^oC. On the other hand, the total hot water demand is 227 l/day as Class 3 (CW3) is selected as the hot water use pattern in the reference house which includes regular showering rates but includes 2 times per day as can be seen in Figure 25. Seasonal and daily variations in hot water use are not reflected in NEN 5128, so these average values will be

used for the design and will be regarded as the maximum values. Two peaks represent the shower times during the day.

Daily domestic hot water use pattern

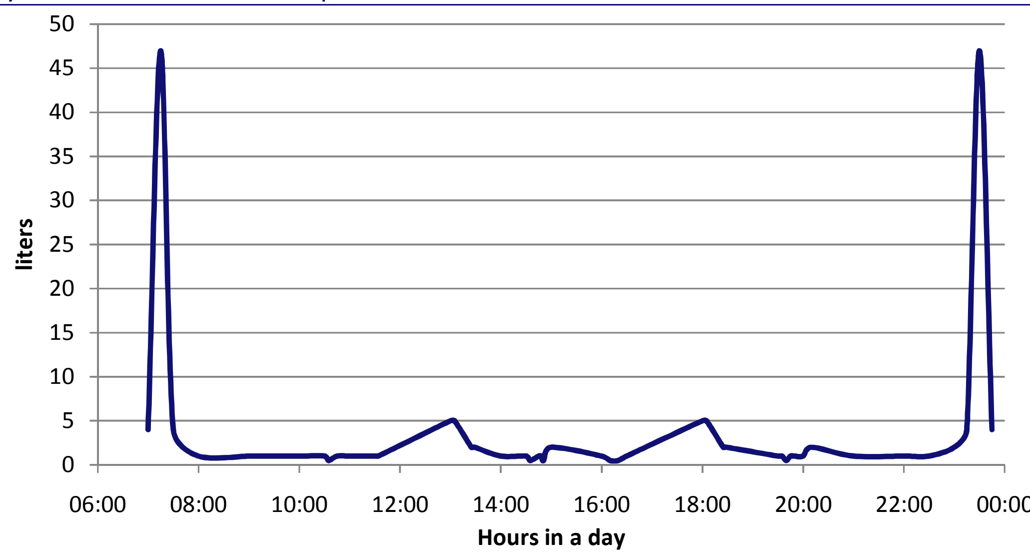


Figure 25: Daily hot water use pattern according to the class CW3, source: NEN5128

Analysis in solutions level

In terms of water saving measures, some systems are investigated as they are suggested by BREEAM-NL.

- *Water saving shower heads*

Being the main item for water (hot water) consumption in the house, water savings by using low flow shower heads can decrease the energy consumption as well. Conventional showerheads have a flow rate of 10 l/min and with a low-flow showerheads can supply 5.5 l/min (Milieucentraal). The average water consumption for showering with conventional system is 85 litres, while with saving measure it is estimated as 47 litres (bespaardaar.nl). This amount is perfectly matching with the water consumption value obtained from NEN 5128 class 2, although the flow rate is given lower in the standard. Using these consumption values, yearly 8 m^3 of water is estimated to be saved.

- *Installing toilets with water saving function (maximum 6 or 4 litres)*

Since toilet flushing is one of the main water consumption items in the house with 29% of the total, using toilets with lower water saving function is helpful to reduce the total consumption. Water savings by different measures are estimated as:

Table 37: Water savings by low flush toilets, source: http://www.milieucentraal.nl/pagina.aspx?onderwerp=Bespaartips%20water

Measure	Costs [€]	Saving per flush [litres]	Saving per year [m^3/year] (Percentage of the total flush water use)
6-liter toilet	450**	3 to 6	13.5 (50%)
Flush reducing on existing toilets	7	1.3	7 (26%)
4-liter toilet	-	5 to 6.5	17 (63%)
Vacuum toilet*	550**	8**	24 (88%)

** supplier data

These values are normalized according to the average values as given previously. Conventional toilets are assumed to use 9 litres per flush and based on the average water consumption of 37 litres per day for toilet flushing, in an average house with two people, savings per year are calculated. The total average consumption per year is estimated at 27 m^3 of consumption.

It should also be noted that 4-liter toilets require flow increasers and underground barrel of 14-18 litres to be installed in order to avoid clogging risks. Moreover, vacuum toilets require vacuum stations and energy consumption for each flush. Although the black water generated from vacuum toilets can be used for energy generation in anaerobic digesters, this technology is not yet developed for small scale applications.

- *Use of water saving taps*

In the market, new taps are available which have flow limiters at the maximum flow rate of 6,8,10 or 12 litres per minute. If the flow limiter with 6 litres/minute maximum is installed in kitchen and sinks, estimated savings for a house with two inhabitants will be approximately 2.5 m^3 per year for each tap (Milieucentraal).

- *Water recycling systems*

In order to recycle water, two possibilities are available; grey water and rain water recycling. Grey water recycling is to recycle the used water in sinks, showers to flush the toilets. On the other hand, rain water collection systems store the rain water for use toilet flushing or washing activities. The possible savings for each measure and the installations for it are shown in the table.

Table 38: Water recycling measures

Recycling Method	Installation Requirement	Possible Savings
Grey water recycling (bathroom sinks, shower, washing machine) to supply toilet flushing	Storage vessel of around 140 litres volume and pumping system	140 litres/day available for recycling, efficiency should be around 50% to supply daily toilet flushing
Rain water recycling to supply washing machines	Storage vessel and pumping systems	40 m^3 of rain water available per year, 30% recycling efficiency required

Grey water recycling systems are considered to be without purification systems due to the complexity it brings about, so maximum 24 hours of storage is possible and after 24 hours storage vessel should be evacuated automatically.

3.1.9.5 Recommendation: strategies for design: passive, active and combinations

Based on the explanations above, following strategies and solutions are proposed for the concepts. These will be applied in each concept since the line of thoughts for different concepts are not differentiated by water consumption parameter.

- Since it does not require additional systems and energy, toilets with 6 litres/flush will be installed in the house.
- Grey and rain water collection systems will not be applied in the concepts considering their savings versus high costs.
- Low-flow showerheads will be installed and the water consumption will be assumed to be the same as given in NEN 5128 class 2, i.e. 47 litres per shower and two times per day. And the flow rate will be kept to 3.5 litres per minute.
- Flow limiters with 6 litres/minute (as suggested by BREEAM-NL) for each tap will be installed which has no significant costs and reasonable water consumption, i.e. 2.5 m^3/year/tap.

  Therefore following table summarizes the measures, savings and corresponding costs.

Table 39: Cost and estimated savings of several water saving measures, source: http://www.milieucentraal.nl/pagina.aspx?onderwerp=Bespaartips%20water

Measure	Costs [€]	Saving per year [m^3/year]
6-liter toilet	100 additional	13.5
Grey water recycling	2000* (tank and pump)	27 (all toilet flushing)
Rain water recycling	3000* (tank and pump)	31 (all washing machine)
Low flow shower heads	9-45	8
Flow limiters for taps 6 litres/minute	4.5 per tap, 13.5 in total	10 (assuming 4 taps)
Total		77

* these prices are estimated by contacting system supplier

Grey water recycling and rain water recycling measures are expensive measures compared to the other measures. Since the water is cheap in Netherlands, i.e. 1.73 €/m^3, the savings are limited to approximately 50 €/year which means simply payback times of investments are 40 years for grey water and 60 years for rain water recycling systems. Moreover, both systems require pumping installations which are estimated to consume around 100 kWh/year and will cancel out all the savings financially. Therefore, these systems are not implemented in the concepts.

3.1.10 Waste

3.1.10.1 General aim

The aim for this section is to analyze the waste management strategy in the houses, and to look for possibilities to improve it. The improvement in this case means:

- Distinguishing the recyclable and non-recyclable waste
- Waste management on site

3.1.10.2 Assessment method

The assessment method will be based on BREEAM-NL suggestions. In 'Waste' section, several criteria are assigned and checked. Since the scope of the study is limited to conceptual design, criteria regarding the construction site are not considered in this analysis. The remaining criteria are:

- *Wst 3: Storage of non-recyclable and recyclable household waste*
  Aim is to make facilities for storage of recyclable waste during building use, to make waste segregation efficient for recyclable materials. Availability of waste collection area near the building is checked. It should be located in an area which is well accessible, and good to clean, by water and power connection. Minimum size requirement is 2 m^2 per 1000 m^2 building surface while for dwellings the storage space should be 40x60 cm.
- *Wst5: Composting facility*
  Aim is to stimulate recycling of waste on the building terrain in order to decrease the amount of transportation for waste disposal.

Based on these two criteria, possibility of applying these measures will be investigated and in addition to these, energy generation possibility will be analyzed.

3.1.10.3 Methodology of analysis

First of all, household waste in the Netherlands and important waste items for this study, i.e. compostable and recyclable waste, are investigated. Based on the findings, the measures and their contribution to the environmental performance of the house are investigated.

3.1.10.4 Results

Data for the household waste in the Netherlands is collected through municipalities and it is based on the collected waste. Some of the waste comes from the shops so a small amount (uncertain) does not belong to the households. However, for the scope of this study this uncertainty is neglected and the annual totals are presented in Figure 26. As can be seen, the amount of waste is not changing drastically over years, which is measured as 561 kg/year/inhabitant. This means each day around 1.5 kg of waste is generated by each household. If the house is thought to have two inhabitants then 3 kg of household waste is generated everyday in the house. This calculation also assumes the same amount of waste throughout a year.

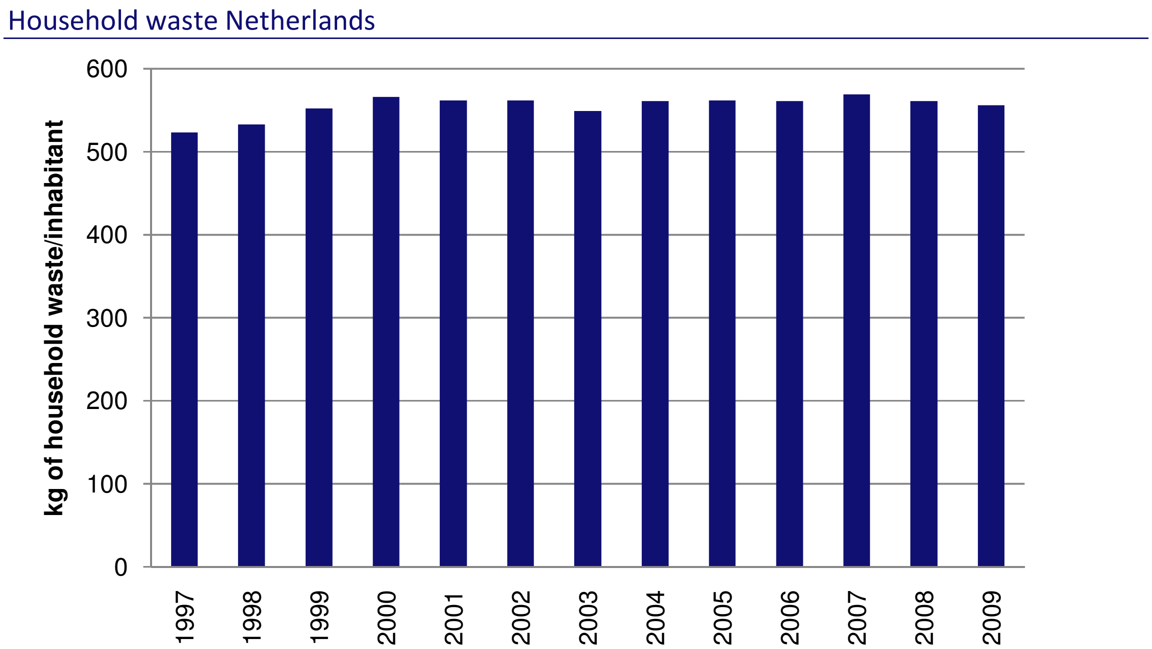


Figure 26: Total household waste per inhabitant in the Netherlands, source: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLnl&PA=7467&LA=nl

Glass, paper, metal and plastics are considered as the recyclable waste streams and the required space for the storage facilities can be calculated based on the data provided by CBS. As can be seen from Table 40, plastics and metal waste amounts are considerably smaller than paper and glass. However, for each item, there should be enough space for the storage of these items.

Table 40: Recyclable waste amounts per inhabitant, source: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLnl&PA=7467&LA=nl

Recyclable Waste	kg/year/inhabitant
Paper and paperboard	68
Glass (bottles)	21
Plastics	0.8
Metal (tin)	0.1

In 2004, around 70% of paper, 75% of glass, over 80% of metal and 35-40% of plastics waste was recycled (VROM, 2006). However, these values have not been improved drastically in the last years. So, in order to improve this, waste segregation is necessary at house level, which will not take big storage spaces. For example, in order to store the paper waste for two weeks 40 litres of a container bin would be enough (nearly 5 kg of waste paper in two weeks).

The main advantage of composting for the environment is that the process emits less greenhouse gases than landfill process. On the other hand, composting in house will save environmental load due to transporting of the waste to the landfill or centralized composting areas. For composting the organic and green waste amounts are critical to learn, which are given in Table 41. According to these values, in a year total 210 kg of organic waste will be collected from an average house.

Table 41: Compostable waste amounts per inhabitant, source: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLnl&PA=7467&LA=nl

Recyclable Waste	kg/year/inhabitant
Organic waste	79
Green waste	26

For the composting of the organic waste composting bin would be required to be placed in the garden of the house. Assuming 250 kg/m^3 bulk density of organic waste (SenterNovem, 2008), and cleaning the bin of the composted waste each two months, the required size for the composting bin would be 140 litres.

3.1.10.5 Conclusions and recommendations for the concepts

The conclusions and recommendations for the waste management analysis are presented in this part. These can be applied to all the concepts. Accordingly, the following items are interpreted:

- For paper based waste, 40 litres of waste bin would be enough for two weeks of storage.
- For plastics, no special storage space requirement can be determined because the average plastics waste generation is low.
- Therefore, the space requirement of 40x60 cm specified by BREEAM-NL is reasonable to store the recyclable waste.
- A compost bin of 140 litres size can be replaced in the garden for green and organic waste generated for two months.
- Since these measures don't require additional space, they will be applied in all the concepts.

3.1.11 Economic value

3.1.11.1 General aim

This parameter considers the economic value of the various concepts. The aim is to provide the highest possible quality in terms of basic and ecological value with the smallest amount of costs. This goal is set to make this type of housing most feasible for the largest amount of people, to increase the impact of taken measures.
Aim of this analysis is to find the possibilities for cost reductions during design.

3.1.11.2 Assessment method

The overall assessment method BREEAM-NL does not include any guides or demands for cost boundaries. There are several possibilities to compare costs performances of houses.

- **Life cycle cost analysis (LCCA):** a method which includes initial, operational and demolishing costs to one indicative number, while excluding any inflation influence. This method is very complex, since the life time of the building has to be defined. Also it is complicated to translate the ecologic burden into costs. The level of detail required for assessment by this method goes beyond the scope of this study.
- **Initial costs**: it could be an interesting starting point to design three concepts within a certain amount of investment costs. The starting position would be equal and the results achieved or the operational period would give additional financial advantages. Also, house buyers are mainly focused on these initial costs and do not take the operational costs into account. But since the costs for sustainable measures are expected to be higher than those for the reference house, the concepts with higher quality (sustainability) would not be positive awarded for their low energy (and maintenance) use.
- **Annuity mortgage model**: to reduce the complexity of LCCA and to increase the effectiveness of comparison based on initial cost, a simple model is set up to compare the result of investment over a fixed period of time (30 years). This model shows the annual expenditures for each concept and the comparison of total cumulative expenditure over the calculation period can be shown. The annual expenditures are based on:
  - Mortgage payments. These are based on the result that the investment (ground costs, building costs and additional costs) will be paid off at the end of the viewed mortgage period. The annuity mortgage is based on a fixed annual payment for pay-off plus interest. Equation 1 gives the annuity, which is the annual amount to be paid on the sum of payback and interest.

$$annuity = S_0 \cdot r \cdot \left[1 + \frac{1}{(1+r)^n - 1}\right] \quad (1)$$

Equation 1: formula for annuity, used in the mortgage model. Source: Rust e.a. 1997

With:
S_0 the initial investment
R yearly interest rate (%)

N number of years

During the viewed period, the remaining investment will reduce, and therefore the annual interest payment decreases. The annual payback of investment increases each year, until all investment is paid back.

- Energy payments. The height of energy bills is based on the annual payments for connection to the grid (gas and electricity) and the use of energy sources (euro/m^3 gas or euro/kWh electricity). It is predicted that energy prices will increase in future years, which is a trend for some time now.

Maintenance costs and subsidies are not taken into account due to the broad variety in assumptions which should be made for that. Subsidies are highly depended on governmental policy and could change each year.

Figure 27 shows a fictive example which compares the total cumulative expenditure on mortgage and energy for a standard and a energy efficient (12,000 euro additional investment) for a period of 30 years. The growth rate for gas and electricity is assumed on average 8%. The mortgage interest is assumed on 5%.The negative values show a lower expenditure for the reference house, the positive values indicate total lower expenditure for the passive house. The break-even point for the passive house compared to the reference house lies for this situation on 14 years.

Difference in cumulative total expenditure: reference and 'passive house'

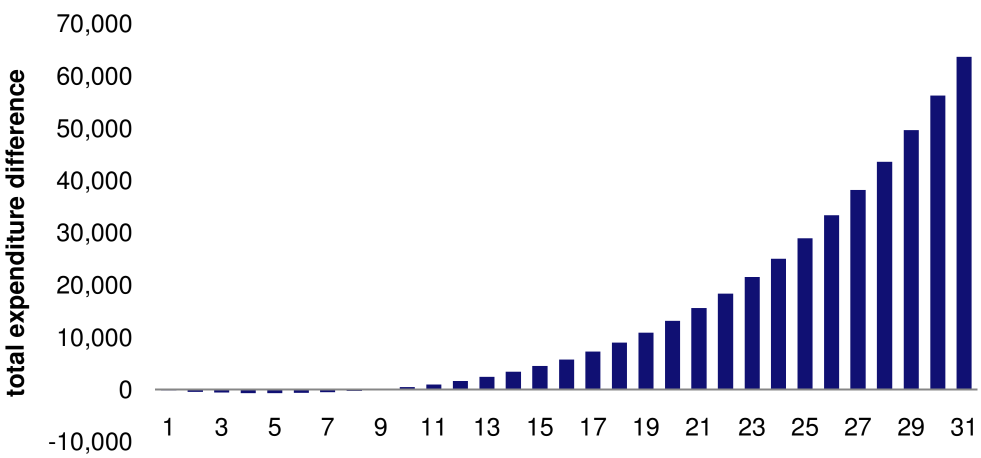


Figure 27: Example of difference in cumulative total expenditure: reference and passive house

Textbox 2: Example of annuity mortgage model

3.1.11.3 Methodology of analysis

As indicated in the previous paragraph, the used model includes a list of assumptions. The main assumptions in the method will be explained. This explanation includes the definitions of the various cost terms in order to clarify the used figures.

From this explanation, a list of influencing parameters is given. In order to indicate the field of possibilities for optimization, the main parameters will be explained in their size and changeability. This accounts e.g. for the building costs which are highly influenced by design decisions. The share of building parts in total and the ratio of passive and active measures will be elaborated. Some common values for building, additional and ground costs as well as energy prices will be given for comparison.

3.1.11.4 Results

Assumptions in models

- Investment costs: the costs which have to be made for the total build-up of the house. The explanation and definition of all parts included in these investment costs are given in NEN 2631 for formal communication. Table 42 shows the division of these terms. In this project, the investment and exploitation costs will be considered.

Table 42: Definition of building costs, as presented in NEN 2634. Building costs are marked in grey.

INVESTERINGSKOSTEN (4)																			EXPLOITATIEKOSTEN (6)						SLOOP-KOSTEN
GRONDKOSTEN			BOUWKOSTEN (5)							INRICHTING			BIJKOMENDE KOSTEN o.a.												
Verwervingskosten	Infrastructurele voorzieningen	Bouwrijp maken	Bouwkundig	Werktuigbouwk. installaties	Elektrotechnische installaties	Lift & Transport	Terrein	Vaste inrichtingen	Algemene uitvoeringskosten	Bedrijfsinstallaties	Losse inrichting	Bouwkundige voorzieningen	Voorbereiding	Heffingen	Aanloopkosten	Financiering	Onvoorzien en terrein	BTW	Vaste kosten	Energie	Toestandsafhankelijk onderhoud	Storingsafhankelijk onderhoud	Administratie	Bedrijfskosten	(7)

Ground costs are taken into account, but will be an equal value for all projects. Based on a study (RIGO 2009) on ground prices and house production in recession, an indication of ground prices in different parts of the Netherlands could be found. These were translated to an average for a lot of about 100 m^2 (50 m^2 building lot + equal size garden). These results in a ground price per house of 30,000 euro excl. VAT. This price was assumed in this study for all concepts. Because of different selling prices of the concepts, the ground price percentage changes from 18% of selling price (excl. VAT) for the reference house or lower for the other (higher priced) concepts.

- Building costs are calculated by help of the cost experts from 'IGG Bouwkosten Advies' (see Appendix 13 for description). These include the costs for material and labour. It also includes indirect costs for the contractors work and includes tax over the used materials and work. Some estimations are very rough and can be doubted in exactness, this is due to building method depended costs or sizings of e.g. windows. For instance the costs for improving connections in the building skin to achieve higher air tightness values.
- Additional costs are also calculated by means of assumptions from IGG. These assumptions are presented in Appendix 13. These costs include salary of architects and advisors, grid connections, insurances and finance costs. The additional costs are partly depended on the building costs and the amount of houses to be built. An amount of 8 houses in a project is assumed.

  - Costs for demolishing are not accounted in the calculation, though attention to this will be given in design phase for flexibility and material choice.
  - Exploitation costs are based on costs for energy, water and replacement of active systems after their lifetime.
- **Mortgage interest rate:** the interest rate for mortgages differs by influence of the economy, market processes between banks and on duration of the mortgage period. Since the variable mortgage is not predictable, a reference value for mortgage duration of 30 years is taken as 5%. The sensitivity of this assumption is high. Difference of 1% interest rate results in about 45,000 euro differences in the total expenditure of the reference house. When comparing the reference and passive concept, this is 4,000 euro per 1% rate change. Since interest rates influence both concepts in a feasibility comparison, the actual influence is relatively small. For the case of the passive concept, this will only be feasible at 1% interest rates, which is not likely to occur. In Appendix 13, a graphical representation of this sensitivity is presented for the example of reference and passive concept. Also the historical interest rates in the Netherlands are presented (DNB). Since rates generally lie around an order of magnitude of 5% (in range between 3 and 6%) and the concepts are far from feasible at this rate, the interest rate at 5% was taken as a fixed parameter since it will not affect the payback time within 30 years.
  The duration of the mortgage is estimated on 30 years, which is the maximum amount of years in which a person could get refund on their mortgage taxes and therefore is a common period to assume in the Netherlands.
- **Energy price rate:**
  Household expenditure for energy is split up in fixed costs for network and delivery and costs per amount of use. The fixed costs are assumed to be equal for the total mortgage period, including the taxes which belong to that. These are 222.57 euro for electricity and 176.03 euro for gas (split-up of these costs is given in Appendix 13)

For the variable costs, the Dutch research institute on energy (ECN) publishes periodical predictions of electricity and gas prices. This prediction is taking many factors into account, including the oil prices in the world market, the position of the Netherlands in the European energy market, predicted generation of energy in the coming years, governmental policy etc. The estimation is given for 2010-2020, only price values for the start and end year of this period are given.

Since only 1/3rd of the mortgage period can be reasonably predicted by the figures from ECN, the predictions till 2040 are taken from the CPB long term scenario study on four types of markets. The bandwidth between these markets is taken as a reference for the further years. In these predictions a large increase in prices can be found around 2020, since gas fields are expected to be depleted in the Netherlands and UK.

The relative increases rate changes in the CPB predictions are added to the ECN predictions in graph X below. It shows the total variable prices for electricity (in eurocent/kWh) and gas (in eurocent/m3) including distribution and taxes.

As can be read from the graphs below, the changes in rates are relatively small and vary for gas between -0.2% to +0.5% per year, for electricity between +0.4% and 0.6% per year. The large step change in electricity price in 2013 results from the predicted new tax, which is planned to stimulate the use of renewable energy sources (SDE-tax).

Gas and electricity price predictions by ECN/CPB

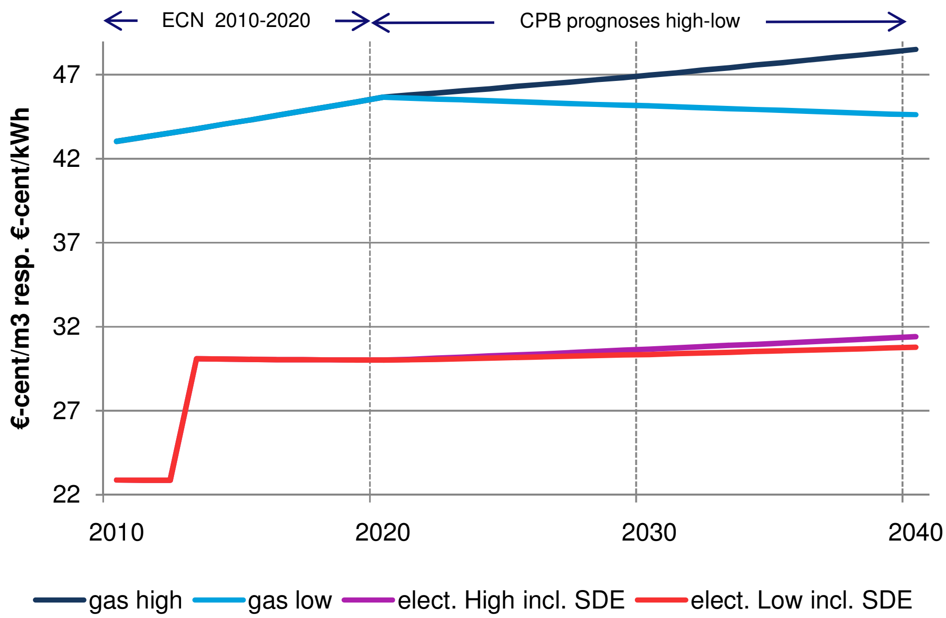


Figure 28: Energy price predictions from ECN (2010-2020) and CPB (2020-2040)

- **Water costs:** the price for water is low, €1,68 per m^3 according to Milieucentraal (2010). Any major changes in price are not assumed within the cost calculation of 30 years.
- **Feed-in tariffs:** these are found for electricity delivery to the grid on the Senternovem SDE website (for 2010): 0.225 €/kWh. These costs are refunded by the electricity supplier and are therefore not based on policy changes or depletion of funding budgets of the government.

Current situation, reference house

Since the project goal is to make the house design financially accessible to a high amount of people, a certain house typology is deducted from Socrates 2006. This house typology complies with demands for new houses and comes with a certain selling price (below €215,000 for 125 m^2 user area; €1688/m^2).

To indicate the price point of the SenterNovem reference house in this project, building cost experts from IGG indicated the building costs of this house. The given assumptions on ground costs and additional costs lead to the final selling price of 210,870 euro (This is within the range as given in the Socrates study. Feasibility of the other concepts will be determined based on the payback time compared to the reference house (within the mortgage period of 30 years) and the boundary of €1688/m^2 selling price.

Table 43: Breakdown of selling price for SenterNovem reference house, estimation by IGG

	Costs name	Details	€/house	€/GFO
1	ground costs	fixed price	30,000	191
2	building costs	excl. VAT	103,240	658
3	additional costs	based on 8 houses	32,370	206
4	net investment costs	total of [1+2+3]	165,609	1,055
5	project development	7% of net investment	11,593	74
6	VAT	19% over [4+5]	33,668	214
7	**total selling price**	Incl. VAT	**210,870**	1,343

GFA = gross floor area (in Dutch: BVO = Bruto Vloer Oppervlak)
VAT = value added tax (in Dutch: BTW = Belasting over Toegevoegde Waarde)
Total selling price (in Dutch: Vrij op Naam prijs (V.O.N.-prijs)

Willingness to pay
Although it could be assumed that a sustainable house with higher quality in comfort will lead to a higher willingness to pay, this factor is not taken into account. In the graduation study by van Eck (2008) this topic is discussed and leads to the conclusion that people are only willing to pay more if they are forced to choose a sustainable house. Since this study is focussing on to expel the choice for sustainability by showing the feasibility, the additional willingness to pay is not included.

Budget of additional investments
Some scenarios are given here which show the limits of the budget in which we are working. Some estimations as described below show how much additional investment is allowed in building costs (excl VAT) to stay within the budget of €1688/m^2 user area and have a payback time just within 30 years.

When taking into the effect of additional investments on the selling price, the boundary of €1688/m^2 results in a maximum allowed investment in building costs (excl. VAT) of 5000 euro. In order to make this investment just feasible, one would need zero gas and 372 kWh less on electricity, or just 2234 kWh reduction of electricity.

Conclusion is that the budget for investments is very small but the necessary reductions in energy need to be very large if one would be able to pay it back within the mortgage period.

Breakdown of building costs
In order to show the options for improvement, and possibilities for cost reductions the building costs of the reference house are split in several parts.
The main shares are shown in the graphs of Figure 29. It shows that the majority of costs is in building skin and structure (65%), 16% for building services. The building skin and structure are divided in the middle graph, which shows the main costs for structural work and façade finishing. For building services, the costs are mainly for climate control, but the plumbing and electrical installations also take a big share.

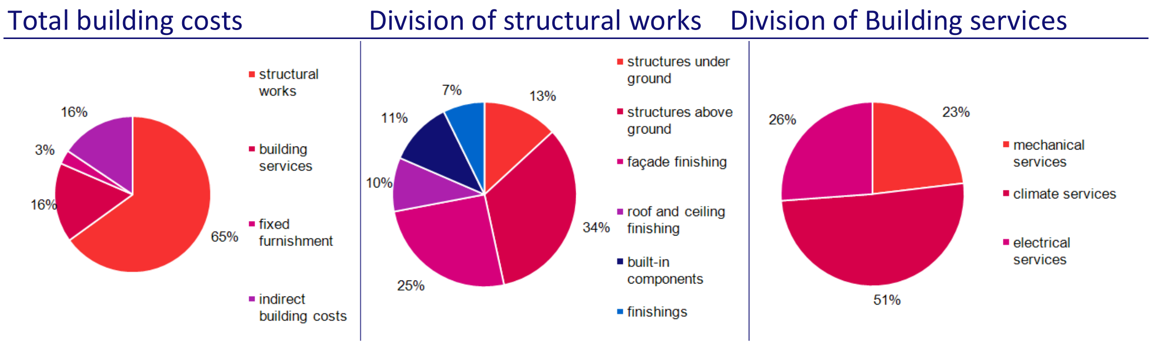


Figure 29: Results of cost calculation SenterNovem reference house (source: IGG).

In the scope of this study, design decisions for cost reductions will be made for building costs. The careful design building structure, skin and services should lead to a sustainable and feasible solution. Since the main part of building costs is in the structure, this topic is part of discussion. The structure and façade are the most expensive components, while the roof is relatively low priced. Reducing the façade area and increasing the roof area might therefore be a solution for cost reduction, though higher costs for windows have to be accounted.

Also the layout of the façade could be adapted to save building costs which than could be invested in measures for sustainability. The type of window frames could result in large reductions, as well as the choice of façade finishing material. Insulation on the contrary only results in a small share. Increasing this part will only result in a small increase of total façade costs.

Energy and costs for building skin and structure
In order to gain insight in the performance of several passive components in the SenterNovem reference house, a list of variants has been set up which are all tested on their influence on overheating, heating energy and financial impact. Overheating and heating energy were simulated by use of the building simulation program eQUEST, the financial impact of the measures was estimated by the building cost consultants of IGG. Although other studies have been done on comparison of building measures to reduce energy consumption, this study is reflected on the reference house typology.

Other studies on total concepts (Audenaert et.al, 2007):

- Passive house design is based on high investment in insulation and air tightness and window insulation and tries to decrease budget for active system (removal of condensing boiler)
- From Belgium study: low-energy house is more feasible than passive house, if one takes energy payments and investment into account.

Per measure:

- EPC and costs comparison (www.bureoepn.nl) results in high feasibility of CO2 controlled ventilation, insulation, shower heat recovery, insulated windows and balanced ventilation (all below 200 euro/EPC reduction of 0.01 (which is about 574MJ primary energy difference for the reference house). If expressed in m3 gas, this results in 16 m3 (if 0.45 euro/m3) than annual saving of 7.4 euro. The payback time would be 200/7.4 = 27 years.

- In studies on retrofitting (Nemry et. al.) the conclusions lead to an advice for insulation measures and increasing air tightness of the skin. In insulation, a distinction is made in roof- and façade insulation, of which the latter one is said to be less feasible.

Energy and costs within this study

For this parametric study, some parameters remained fixed, for reasons as presented in Appendix 14. In the first phase, each possible measure is changed individually and the results are compared to find the best performing measures. Reasonable combinations of measures are deducted from these results and tested on their combined performance.

The types of variables is summarized in Table 44, the detailed and extended list is given in Appendix 14. For each variable the situation for the reference house is given, and up to three different options for the value are presented. These are most given by realistic and possible values. Some are deducted from the building decree or from the concept known as the Passive House.

Table 44: Summary of parametric options to be assessed on heating energy, overheating and costs

Category	Summary of options
Window size	Increasing or decreasing in window size on the north- or south façade; on the north or south roof.
Window type	Changes in thermal insulation of windows by choice of different types in DOE library. With the change in U-value (m^2K/W) come changes in solar heat gain coefficient and visible transmission. A second set is tested with fixed solar heat gain coefficient according to reference house value.
Category	Summary of options
Building mass	Change in building mass from traditional to low- or high weight.
Shading	Additions in terms of moveable exterior shading or overhangs with different length. Tested on south- or north façade.
Insulation	Increasing of thermal insulation in separate building parts (wall/roof/ground floor) or total packages.
Infiltration	Change in air tightness to extends of Building Decree and Passive House standard.
Roof size	Differences in roof shape and size, including a flat version, one optimized for efficient solar power and a version which increases the roof size and decreases the façade area

In the second phase of this comparison, some measures were combined to find out the best performance of total. As could be expected, the ones which scored highest on energy and the ones which scored highest on overheating resulted in the best performing total (see Figure 30).

Overheating and heating demand for combined options

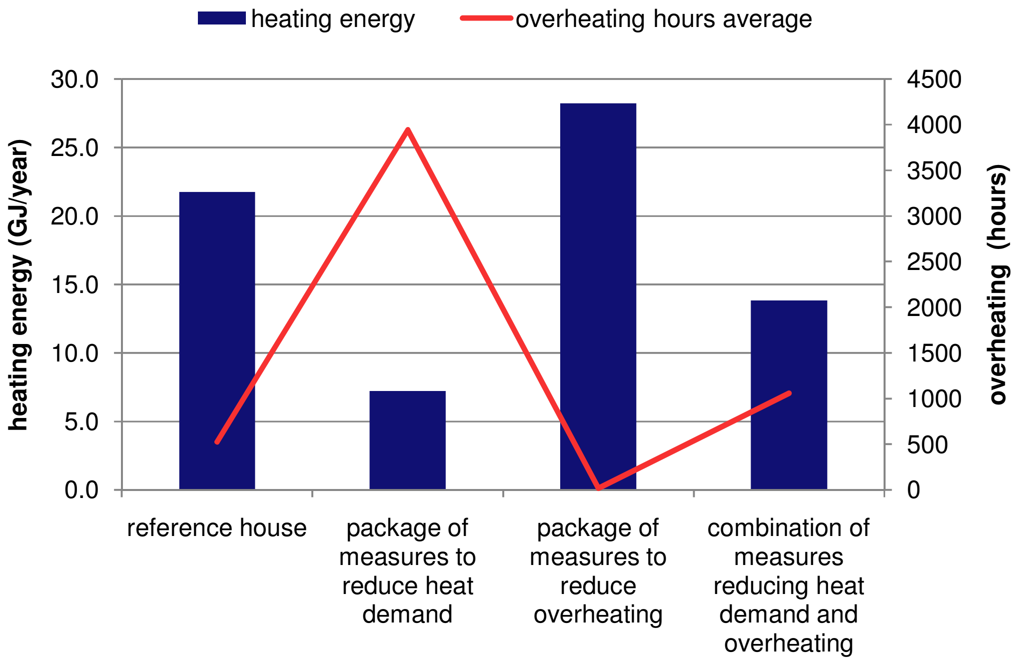


Figure 30: Overheating and heating demand for combined options

In reality, only a check for energy reduction will be necessary, since the possibility to open windows if temperatures increased was not included in the current model. The option with largest decrease in energy is therefore chosen for the concept with improves building skin.
If one would also include the financial aspects, of these energy reducing measures, insulation will be the best.

Cost comparison
Based on cost indications by IGG, a comparison of the costs per measure has been made and is included in the total selling price of the houses as total. The costs are compared to those of the reference situation. Some measures show a reduction of this selling price (like smaller windows, different roof size), but most of the majors give an increase in selling price.

The additional investment per saved GJ on heating energy is compared for all options. If the heating energy did not increase (equal or higher than the reference house), the option was not presented in Figure 31. Positive values are given to measures which reduce costs AND energy, negative values are given to measures which increase costs, but reduce energy.

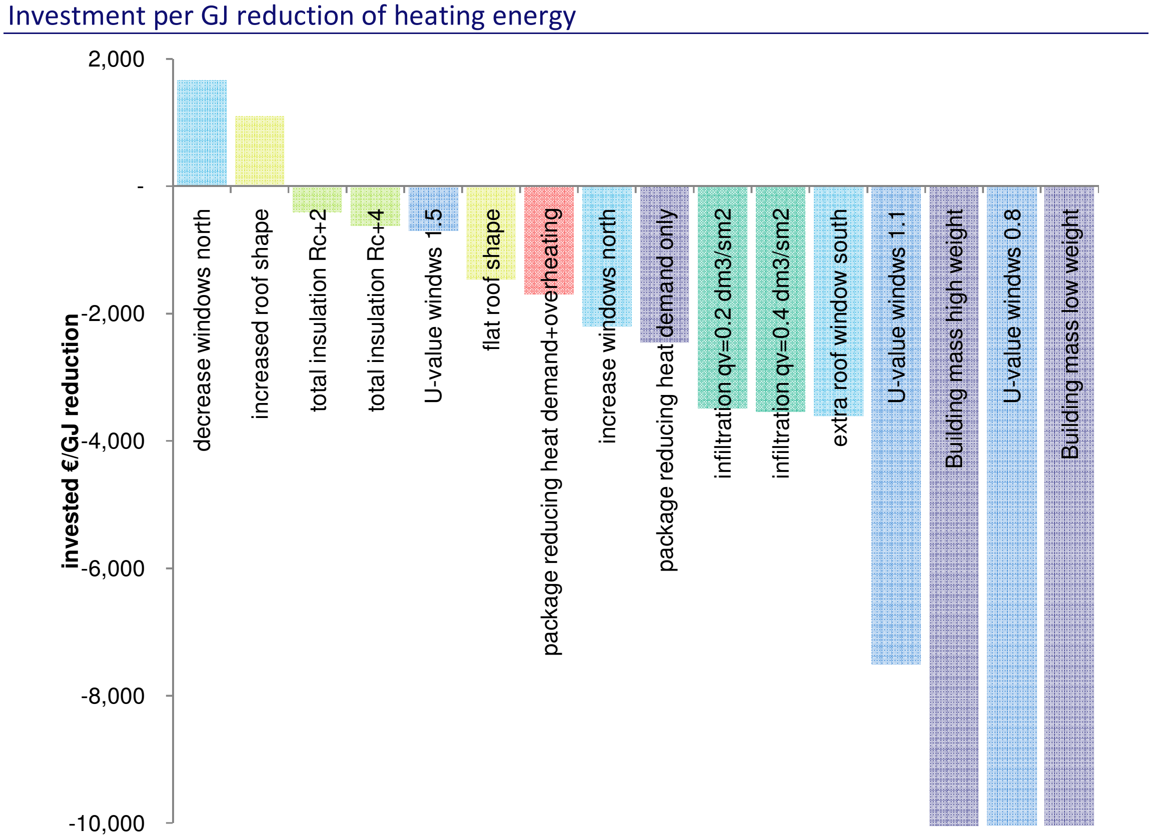


Figure 31: Investment per saved GJ (positive = cost reduction/saved GJ; negative = additional costs/saved GJ)

From this graph, it is clear that insulation measures of closed partitions are the most feasible in terms of energy reduction. Also the change of window transmission to a lower level is feasible up to a small increase, especially if the solar heat gain coefficient is kept equal to the reference house value. Though this is not a realistic solution. Increase of infiltration values might still be feasible, but the price per GJ is 7 times the value of the average insulation value. Change of the building mass to higher or lower weight is basically very expensive, so the energy reduction which it results in does not justify this. Although, the improvement on environmental impact when using more natural materials like wood could improve the level of sustainability but unfortunately this will not be expressed in financial advantage for the house buyer/user.

Although some measures seem feasible, the real profit can only be shown by calculating the net present value (explained in next paragraph). This was done for two examples on the negative side of this graph.

Table 45: Payback time of sustainable passive measure, based on gas and electricity price predictions by ECN/CPB

	Window transmission U-value 1.5, standard SHGC		Total insulation of ref house Rc +2	
	Low energy prices	High energy prices	Low energy prices	High energy prices
Payback	> 75 years	> 75 years	> 75 years	> 75 years

time				
NPV (75 yrs)	- 572.43	- 572.78	- 1,433.28	- 1,432.64

None of the most affordable solutions will be feasible within their lifetime of 75 years (considering energy price increasing as discussed under Economic Value). The outcome in the mortgage model is a bit more positive (which also includes a slight change in electricity use) and results in a NPV after 30 years of -1,383 (low energy) and -1,336 (high energy).

So this negative profit will also account for all other measures which are worse in euro/GJ reduction. A possibility to design a feasible and more sustainable house is to combine measures that reduce costs with those that ask for additional investment.

Cost Analysis in Solutions Level

This analysis is intended to show the economical value of the solutions individually and to compare their economical benefits or disadvantages. In order to evaluate the solutions, 'Net Present Value' (NPV) method is used since these solutions can be considered as investments. NPV accounts for the cash flows within the years including the initial investments, future maintenance, operational costs and savings per year and their present values. It is calculated by the following formula:

$$NPV = C_0 + \frac{C_1}{(1+r)} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_n}{(1+r)^n}$$

In this equation, C_0 stands for the initial investment for the solution, which includes unit and installation costs. C_1, C_2 and C_n stand for the yearly cash flows which include maintenance and operational costs, energy savings. In order to calculate the present value of the future costs and savings, interest rate, indicated by r, is introduced. This is defined by the current financial market of the Netherlands and it is assumed to be 5% for this study.

In these calculations, energy prices play a vital role in calculations and evaluations of the financial advantages of the solutions. As mentioned previously, energy prices are expected to increase and the same assumption holds for the NPV calculations. The energy prices are assumed to be the same as estimated previously.

The payback period of the components are calculated when the NPV becomes zero and the comparison is made in terms of payback periods of specific solutions. In the following part of the report, several solutions with their net present values are presented.

Photovoltaic Solar Panels

For the evaluation of the costs related to the PV panels, information from a supplier is investigated. The data includes the prices for the PV systems as a package including cells, inverters, cables and mounting system. It is assumed that the information gathered will reflect the market situation in the Netherlands.

As an example, sufficient amount of PV panels are assumed to be placed on the roof of the reference house such that it will be energy neutral over the year. As explained previously, this means a panel area of 33 m^2.

It should be noted that for PV panels there is a subsidy program for the year 2010. Two categories are defined; small systems such that peak capacity between 1kWp and 15kWp, and big systems such that peak capacity between 15kWp and 100kWp.

In this study, the PV system will be assumed to be in the small system category, i.e. ≥1kWp and <15kWp. The subsidy claims that for each kWh of electricity generated on site €0.249 will be paid by the government and € 0.225 will be paid by the energy supplier for each kWh of electricity that is fed to the grid. This subsidy is valid for 15 years. Since the subsidy policies are vulnerable to change in time, only the feed-in-tariff by the energy company is taken into account for the feasibility analysis.

In the following table, some values for the NPV calculations are presented, which include the performance of PV panels. In these calculations electricity fed to the grid and directly used in the house is estimated by using eQUEST so that the feed-in tariffs can be incorporated in the NPV calculations.

Table 46: Feasibility analysis of PV panels, source: Price List Photovoltaic Equipment, Version 4, 2010, Oskomera, based on gas and electricity price predictions by ECN/CPB

PV Panels -33 m^2		
Investment Costs	16579	€
Energy Savings		
Total Electricity Generation	3535	kWh/year
Direct Use	1032	kWh/year
Electricity to grid	2503	kWh/year
Feed-in Tariff Energy Company	0,225	€/kWh
Maintenance Cost	Neglected	€/year
NPV in 25 years based on high energy prices	-5212	€
Payback Period	>25	years
Primary Energy Savings/Investment	2.23	MJ/€

As can be seen, PV system does not pay itself based on the assumption that the feed-in tariffs will remain the same for 15 years and estimated energy price increase. Also the lifetime of the PV panels is expected to be 25 years, so PV systems do not pay back in their life time according to this energy price increase predictions.

On the other hand, as the system size gets smaller, the price of the system also decreases but the system still does not payback in 25 years.

Reference Situation for space heating options

For the comparison of the residential heating systems, a reference situation has already been defined in the previous sections. Accordingly, in this part, HR-107 boiler will be evaluated in terms of costs. The table shows the corresponding parameters for feasibility study. Following table presents the reference values for the calculations. The maintenance costs are calculated based on the maintenance contracts as the common practice in the Netherlands.

Table 47: Financial evaluation of HR 107 gas fired boiler, source: http://www.milieucentraal.nl/pagina.aspx?onderwerp=Nieuwe%20CV-ketel#Wat_kost_dat?

HR-107 combi-boiler		
Investment Costs	3430	€
Energy Use		
Total Electricity	Neglected	kWh/year
Natural Gas (DHW + Space Heating)	1193	m^3/year
Maintenance Cost	145*	€/year

* http://www.kemkenscvinstallatieonderhoud.nl/page/42/cv-onderhoud-cv-ketel-verwarming-service.html

Heat Pumps

The feasibility of the investments for heat pumps depends highly on the source of the heat pump. As mentioned previously, outside air-to-water heat pumps and ground coupled heat pumps with vertical closed loops are analyzed. Both systems are compared to the reference situation as defined above. The data for the heat pumps is collected from the supplier and the installation costs are determined by consulting an installer.

Table 48: Feasibility analysis of heat pumps, source: www.tb-ferwert.nl, www.warmtebelang.nl and NIBE, based on gas and electricity price predictions by ECN/CPB

	Water-to-water Ground Source Heat Pump	Outdoor Air Source Heat Pump	Exhaust Air Heat Pump for DHW	
Additional Investment Costs	14620	8470	4370	€
Energy Use & Savings				
Total Electricity	2476	3192	1086	kWh/year
Natural Gas Saving	985	985	523	m3/year
Maintenance cost difference with the reference case	-145*	0	0	€/year
Savings per year	3**	-306**	-23.3	€/year
Payback Period	>15	-	>15	
Primary Energy Saving	11.7	5.1	5.5	GJ/year
Primary Energy Saving/Investment	0.80	0.60	1.25	MJ/€

* (-) sign means lower maintenance costs than the reference case ** (-) sign means no savings but higher costs than reference case

As can be seen, both systems cause higher investment costs than the reference case and the yearly costs due to fuel consumption are higher than the reference case for both types of heat pumps. Although the ground source heat pumps are estimated to have zero maintenance costs per year, the savings per year are not satisfactory to pay the investment back within the lifetime of the equipment. In this case, it is not necessary to calculate the payback period of the air source heat pump, because the yearly costs increase compared to the reference case. The comparison can be made in terms of 'Primary Energy Saving/ Investment' ratio. It shows that the vertical ground source heat pump is a more sound investment for a better environmental performance than the air source heat pumps.

Micro CHP

As discussed above, natural gas fed Stirling engine based micro CHP units are about to be commercialized in the Netherlands. The performance of the units are estimated according to the field tests performed by Remeha, which is one of the developers in the Netherlands. The table below presents the predictions for the prices of the micro CHP units. On the other hand, the micro CHP units are subsidized by Dutch government but since the subsidies are not taken into account in this study, it is not considered for the feasibility analysis.

Table 49: Feasibility analysis of micro CHP systems, source: Remeha, based on gas and electricity price predictions by ECN/CPB

Micro CHP		
Additional Investment Costs	10441	€
Energy Use		
Total Natural Gas	1233 (40 extra)	m^3/year
Electricity Saving	1552	kWh/year
Maintenance Cost (2%)	250	€/year
Savings per year	443	€/year
Primary Energy Saving	12.4	GJ/year
Primary Energy Saving/Investment	1.1	MJ/€
Payback Time	>15	Years

These estimations reveal that the micro CHP units do not payback if they are utilized for space heating and domestic hot water supply. However, the yearly financial savings are much higher than that of the heat pumps, and the primary energy reduction per investment cost figure is higher than the heat pumps.

Solar Thermal Collectors

In CO_2 emissions section, it is explained that these systems can save up to 60% of the total natural gas consumption for domestic hot water generation. As calculated previously, if the evacuated tube solar thermal collectors are installed on the roof of the house, around 300 m^3 of natural gas is required for domestic hot water heating, which means a reduction of 220 m^3 of natural gas consumption. The saving is around 180 m^3 of natural gas for flat plate collectors.

The costs of the solar collector are calculated for the total system with 200 litres of thermal storage and installation costs of the system which is kept constant for both type of systems. The maintenance cost of the solar thermal collector system is assumed to be zero.

According to the figures estimated and the prices supplied by the manufacturer and the contractors, the following table is constructed.

Table 50: Financial analysis of solar thermal systems, source: Viessmann and http://www.tb-ferwert.nl, based on gas and electricity price predictions by ECN/CPB

	Flat Plate Collectors	Evacuated Tube Collectors	
Additional Investment Costs	4801	8695	€
Energy Savings			
Natural Gas	180	229	m^3/year
Financial Savings			
Natural Gas Bill Reduction	73	94	€/year
Maintenance Cost	0	0	€/year
Primary Energy Saving/Investment	1.32	0.93	MJ/€
Payback Time	>25	>25	years

The figures presented in the table shows that, although yearly costs of generating hot tap water decreases the investment costs for both types of the solar thermal systems, i.e. evacuated tube collectors and flat plate collectors, do not payback the investments within the equipment lifetime which is estimated to be 25 years. Therefore, the application of these systems is not financially feasible. However, the primary energy saving per investment figure of flat plate collectors is better than the value of the other domestic hot water supply options.

Although solar thermal systems are not paid back with this energy price predictions, the flat plate collectors are the most feasible domestic hot water supply systems in terms of energy efficiency and the primary energy savings per investment figures, therefore they will be applied in both active and passive concepts.

3.1.11.5 Conclusions

Cost model

- The assumptions as explained in the cost model have been made with high accuracy and partially based on the experience of Dutch building cost experts from building practice. Therefore it is assumed that the outcomes will lie within reasonable boundaries.

Analysis of current building costs

- Facades are expensive building parts of the house; windows in facades are even more expensive. Roofs are relatively cheap, so a strategy could be to increase the roof size with façade decrease. This gives more financial space for extra windows.

Analysis of feasible changes in building structure

- From the parametric study can be concluded that improvements in the building structure generally request additional investments in order to result in lower energy demand for heating.
- Some measures are feasible, being the change in roof shape (more roof, less façade) and the reduction of window area on the north side. Most demand additional investments and also will not pay back within their life time.
- They can be divided in more or less feasible measures. It can be concluded that

insulation is a more feasible solution than e.g. increasing air tightness levels or window U-values. Changes in building structure are costly, but have only little effect on energy reductions so are not very feasible.

Although some measures may not seem feasible in terms of energy compared to others, they will not be directly excluded for use in the concepts, since they might improve performance in other fields of sustainability. Unfortunately, only reduction in energy will be clearly expressed in costs.

Analysis of feasibility of generation systems

- The heat and electricity generation systems do not pay the extra investments back within their estimated life-time, with the energy price predictions in this study.
- The primary energy saving per investment figure is the highest for micro CHP systems but the performance of these systems is still questionable since they are just commercialized as this study is conducted. Therefore, they will not be applied due to the applicability reasons.
- The ground source heat pumps have relatively high primary energy savings per investment compared to the air source heat pumps. Since these systems are not financially feasible, they will not be applied in the passive concept but only in the active concept due to the primary energy savings.
- Solar thermal collectors and photovoltaic panels have high investment costs but low maintenance costs and no fuel consumption make them attractive options to generate energy on site.
- Flat plate collectors have 50% lower investment cost than the evacuated tube type collectors and the primary energy savings per investment figure is the highest for the flat plate collectors.

3.1.11.6 Recommendation: strategies for design: passive, active and combinations

Advice for the passive concept is to adapt the shape to save costs (less façade, more roof), to increase the insulation values, to reduce the window sizes (if daylight allows it) and to slightly increase the window insulation factor. Addition of building mass by choosing concrete is slightly sustainable in terms of energy reduction but not feasible in terms of environmental and financial impact. For the passive concept, the space heating will be supplied by the high efficiency boiler since the heating energy generation systems are not financially feasible. For domestic hot water energy reduction, solar thermal collectors will be installed in the passive concept due to the primary energy savings potential, the simplicity and the relatively low investment costs.

For the active concept no specific building structural measures will be included to improve the energy performance. The use of wood frame structure will be taken into consideration to reduce the environmental impact by building materials. Additional investments will be done for ground source heat pumps and the flat plate solar collectors considering the primary energy savings per investment figures.

3.2 Conclusions from analysis per topic

From all topics of study, results, conclusions and advice are compiled and can be translated into the three concepts for design. The preliminary study resulted in some topics of interest, experts gave a broad perspective on sustainable building, case studies learned about the applicability of technologies and the parameter analysis gave the actual demands in the design.

Table 51: Summary of conclusions and influence on the concepts

From	Conclusions	Influence on concepts
Preliminary study	Low attention for transport, materials, water and waste. Lack of attention for land use, ecology and pollution	Choice of main research topics: energy, economics and health and comfort. Not location bounded.
	More attention should be given to: acoustics, spatial comfort, air quality, feasibility, embodied energy, land use, flora/fauna, changeability, simplicity, user control, local know-how and experience	Implemented in the design parameters, which are analyzed and which will be the points of assessment in the final design (given below). Not taken into account: land use and flora/fauna due to not location bounded.
Case studies	Mainly experimental projects are found. Some large scale projects, but main focus on energy in that. Best to use proven technologies and include the user in design process or make it simple.	Use of proven technologies in the design, take user control into account, reduce the amount of systems and design according to common spatial planning of housing (applicability).
Expert: Renz Peijnenborgh	Build ecological: use wood and reduce concrete and bricks. Use floor and wall heating and use solar gain from conservatory. Natural ventilation with supplementary mechanical exhaust.	Reduction of radon exhaust by material choice, use of low temperature heating systems, consider of wood use.
Expert: Jan-Willem van de Groep	Integral design in building process with all parties working together will reduce the amount of errors and failure and therefore lead to more affordable solutions in sustainable design.	This conclusion is not applicable in the designs within this project, but the advice is a good recommendation for building practice.
Expert: Stefan van Uffelen	BREEAM-NL as assessment tool is favourable for applicability and market value of conceptual house. An industrial building method can reduce building costs (element-based)	Definition of location parameters of conceptual house interesting for comparison of several concepts. In design, there will be attempt to decrease the amount of elements.

Thermal comfort analysis	Higher heating than cooling demand during the year. Low temperature heating is best for thermal comfort due to its reduced temperature asymmetry. Water based terminal systems are preferred due to local applicability.	Improvement of building skin in insulation and air tightness; temperature based placement of room types. The low temperature heating system is preferred in all concepts. Choice of high thermal mass and shading to prevent overheating.
Indoor air quality analysis	Current stock generally fails in air quality. In new design ensuring flow is most important. Control can give efficient use of energy	Mechanical exhaust or balanced ventilation systems can be used. Use of a control system will be considered for each concept, based on feasibility.
Visual comfort analysis	The daylight availability in general households can be improved by adding more openings in the roof. In other rooms the current ADF is higher than demanded. Addition of larger openings in the façade only slightly reduce energy for artificial lighting, since the main demand is found outside day lit periods. Control and type of artificial lighting reduce the electric demand.	Additional daylight openings in attic and design of other daylight openings to just achieve the demanded ADF. Thereby reducing heat loss and costs.
Acoustic comfort analysis	Noise reduction can be achieved in building details, which are achievable by following standards.	Follow building details in design and careful place openings for ventilation in external skin or in the rooms.
Spatial comfort analysis	Safe, accessible, flexible and including outdoor space design can be achieved but leads to a different space plan and therefore usability.	The concepts will be designed with an adapted space plan on ground floor and safety measures for open able windows. Flexibility could be achieved by modular light weight internal walls.
CO_2 emissions analysis	Solar power should be used in order to reduce heat and electricity energy from fossil fuels. Electricity generation for wind on small scale is not applicable, but ground sources could be used for heating. Best options for heating systems are heat pumps or gas fired boilers.	Roof slopes to be designed according to solar power optimum of 36°. Choice of heating systems as vertical ground source water-water heat pump and gas fired boiler.
Building materials analysis	The main share of building materials impact is in the main structure of the house. Changing the traditional brickwork to wood	Use of wood is applied in one of the concepts, which can balance the negative influence of the ground source heat pump. The passive

	frames will reduce the environmental impact, but changing simple boilers to ground coupled heat pumps give an increase	concept will be made of heavy materials in low impact environmental classes
User behavior analysis	Users are mainly focused on costs of their behaviour, hot water use is not influenced by feedback. Simple control and feedback are most effective measures	Setback of temperatures to lower values, closing windows when heating is on, analogue thermostats and install feedback monitors on use. To reduce hot water demand only water saving taps could be used. For all concepts applicable.
Water use analysis	Water use can be reduced by installing several measures on the end use. Also water collection is an option for rain water and reuse as toilet flushing	Water saving taps and shower heads and water saving toilets will be installed to reduce water demand. Water collection will be considered for placement underground.
Waste analysis	For improving user behaviour in waste separation, space in the house for general waste and green waste should be considered.	A place of 40*60 cm for paper/glass/rest waste in the house should be available and a compost bin of 140 litres in the garden.
Costs analysis	Most expensive parts in the current house are walls and wall openings. Additional systems for reduction of energy use and energy generation systems will add up to investment costs. Payback of these systems if crucial for feasibility	For different concepts, the investment will be done in different parts but should be about equal for all in total. Systems/measures will be chosen on their effects in terms of cost reductions.
Reference house analysis	Quite cheap and affordable. Too little daylight. High energy use. Too high environmental impact. Too high water use. Too many overheating hours, No waste location. Spatial design not good for future use. Simple design is good for users, but no feedback. It is locally applicable.	Improve the energy efficiency but keep as much as possible to the given spatial planning. The investment costs could increase till certain extend, especially if the payback would be within an acceptable range.
Passive definition	To spend most investment on passive measures: not using or providing energy.	Increase the quality of building skin, use investment for improving windows etc
Active definition	Use systems to solve the problems, invest in the systems keep the skin Rc 3	Pick the systems on their cost effectiveness
Hybrid definition	The hybrid design is a concept of concession between active and passive measures	The best systems and passive solutions will be combined.

4 Discussion: Concepts and comparison

As the first parts of this report described the methodology and an analysis per topic of interest, this chapter focuses on the design of the concepts to be assessed and their comparison. The reference house is one of the assessed concepts and is used for comparison as the current situation in the Netherlands.

4.1 Concepts

The concepts are described in words, and the reasons for certain specific choices in the designs will be explained as they result from the analysis per topic. They are presented in schematic figures in Table 52. Specifications of the building structure, exact sizes and characteristics and types of systems are presented in Appendix 15. That part also includes detailed drawings of these concepts.

4.1.1 Reference house

As was described in the beginning of the report, the reference concept is based on traditional building practice which complies with the Building Decree. The space plan is deducted from the ‘Monitor Nieuwe Woningen’ as was described in Referentiewoningen 2006 by SenterNovem. The building skin properties follow the minimum demands of the Building Decree and the indoor climate is controlled by a condensing gas boiler with high efficiency (for both space heating and hot water) and the house is ventilated with balanced ventilation including heat recovery.

4.1.2 Passive concept

The passive concept is based on outcomes from the preliminary study, the partial analysis and its shape and plan are initially based on the SenterNovem reference house. The design decisions were based on the additional investment in structural measures and minor investments in building services.

- Change of **spatial planning** of (initially) the ground floor, which resulted in a shift of the staircase to the north side of the house and therefore also a changed spatial plan of the first and second floor. The ground floor is now accessible for different users and changeable to a space for living and sleeping. The included storage space gives room for waste collection facilities.
- The change of **roof shape**, which is feasible in terms of energy and costs (resulting from the parametric study) and which reduces the environmental impact of building materials. It gives the possibility to install solar thermal panels to gain heat for domestic hot water. The attic under the roof has been made more useable, creating an attic space and an extra bedroom and still having enough area for building services.
- The thermal quality of the **building skin** is improved by additional insulation, higher insulating glazing and increased air tightness to prevent uncontrolled ventilation flows. From the cost study it was concluded that insulation measures were most affordable and a slight increase of glazing insulation can be beneficial as well.
- Ventilation based on **natural inlet** through façade grills and mechanical exhaust in bathroom, toilet and kitchen is applied in the passive house concept; it is based on the

smallest possible total flow through the house in order to save heating energy but still comply with the demands from Building Decree.

- Daylight has been analyzed and resulted in a reduction of windows area where **daylight** was exceeding demands and increased if demands were not met. This resulted in repositioning but in total a reduction of window area, so benefits in terms of costs and heat loss reduction.
- Building materials were chosen based on their **mass** and environmental impact, resulting in a slow responding house type, but with some negative influence in the costs.
- The main building shape and layout was kept as the main line in order to achieve applicability to comply with the demanded house type in the Netherlands. This consideration was also applied to the types of systems: proven technologies were chosen over experimental systems in order to assure good performance.
- **Water saving**s are achieved by flow limiting taps and low-flush toilets. The rest of the measures are not installed due to their high investment costs and relatively small savings.
- The space heating demand is met by a high efficient **condensing boiler** as in the reference house, since other options are either costly or inefficient and the main investment items are 'passive' measures.
- The domestic hot water demand is reduced by installing **solar thermal collectors** of 6 m^2 size. The thermal storage tank is decided to be 300 liters following the advices of the manufacturer. Additionally, **heat recovery from shower** waste water is incorporated to reduce the demand.
- Electricity is reduced by use of energy **efficient lighting, A++ labeled equipment** and **standby killers.** The demanded electricity is used from the grid, since local electricity generation systems were proven to be unfeasible.

4.1.3 Active concept

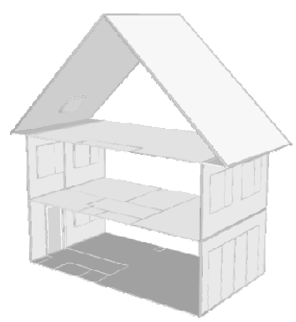
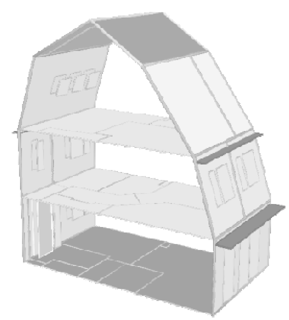
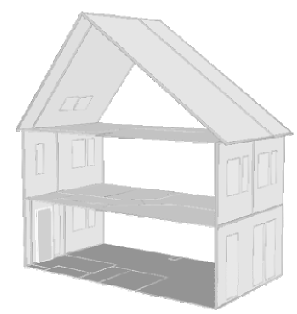
The active concept is based on the idea of CO_2 emission reduction by means of building services, and thereby investment of building costs in that part of the total. The thermal quality of the building skin was not improved compared to the reference house. These design decisions resulted in the active concept:

- Change of **spatial planning** of (initially) the ground floor, which resulted in a shift of the staircase to the north side of the house and therefore also a changed spatial plan of the first and second floor. The ground floor is now acceptable for different users and changeable to a space for living and sleeping. The included storage space gives room for waste collection facilities.
- The thermal property of the building skin is kept at reference house levels, as well as air tightness and the window type.
- The ventilation principle is **the balanced mechanical ventilation with heat recovery**; this is the same as in the reference house. The heat recovery system is equipped with a by-pass for the exhaust air flow to prevent overheating in the summer period.
- The demand for heat generation with lowest CO_2 emissions leads to the decision to install a **vertical ground source water-water heat pump**. This system is placed in the created storage space on the ground floor in order to reduce duct length to the ground source. The floor plan has thereby reduced slightly in usability.
- The heat pump is also used for domestic hot water generation since the COP of the

chosen unit is higher than the value proposed by NEN5128, which is proven by TNO (Gelijkwaardigheidsverklaring, 2010).

- Domestic hot water demand is met by the ground source heat pump in combination with **solar thermal collectors** on the optimally designed **36 degrees roof with large size**. The pipe type heat recovery from the shower waste water is also installed to reduce the demand. The optimally inclined roof also makes the installation of photovoltaic panels possible if demanded.
- **Low mass construction materials** were chosen in order to reduce environmental impact by building materials. This was mainly done to compensate the negative impact of the ground source heat pump (the ground work results in higher impact).
- **Water saving**s are achieved by flow limiting taps and low-flush toilets. The rest of the measures are not installed due to their high investment costs and relatively small savings.
- Electricity is reduced by use of **efficient lighting, A++ labeled equipment** and **standby killers**. The demanded electricity is used from the grid, since local electricity generation systems were proven to be unfeasible.

Table 52: The shapes of the reference (left), passive (middle) and active (left) concept

Reference house	Passive concept	Active concept
		
Rc values skin: 3-4 m^2K/W	**Rc values skin: 7-8 m^2K/W**	Rc values skin: 3-4 m^2K/W
Uwindow: 1.8 W/m^2K	**Uwindow: 1.3 W/m^2K**	Uwindow: 1.8 W/m^2K
Air tightness: 0.62 $dm^3/s/m^2$	**Air tightness: 0.15 $dm^3/s/m^2$**	Air tightness: 0.62 $dm^3/s/m^2$
Balanced ventilation	Mechanical exhaust vent.	Balanced vent. + heat recov.
Heat recovery on vent. air	**Solar thermal collector 6 m^2**	**Solar thermal collector 6 m^2**
Gas fired boiler, combi	Gas fired boiler, combi	**Vert. ground src. Heat pump**
High temp. radiators	**Low temp. floor heating**	**Low temp. floor heating**
No water saving options	**Low flow tap, toilet, shower**	**Low flow tap, toilet, shower**
Artificial lighting 50 lm/W	**Artificial lighting 25 lm/W**	**Artificial lighting 25 lm/W**

4.2 Assessment

Deducted from the BREEAM-NL framework for integral assessment, per topic the assessment methods are described under the 'analysis and design' chapter. The models which are used in order to compare the concepts are listed below. The main assumptions which were used for input values are presented in Appendix 15. For each program or tool also a short description is given. Several tools are used for the assessment of the concepts, which are listed below.

- eQUEST: thermal comfort and energy use
- Domestic hot water and solar thermal collector hourly calculations, excel spreadsheet
- Building costs (IGG) and mortgage model excel spreadsheet.
- BRE average daylight excel spreadsheet
- Ventilation flow schemes, excel spreadsheet
- Greencalc+ V2.20 program for environmental impact of building materials, combined with translation worksheet to shadow prices provided by BREEAM-NL.

The final assessment for all topics of interest was done by means of the BREEAM-NL criteria and by assigning credits for achieved performances. The comparison of these scores was extended with the selling price per amount of achieved weighted percentage of all achievable.

4.2.1 Assessment method and tools

eQUEST

The search for a dynamic building simulation program which could combine the effects of passive and active measures resulted in the choice for eQUEST which is developed by U.S. Department of Energy (DOE). Although it is claimed that the convenience of default assumptions and configurations for several systems could enhance quick design and analysis, this does not apply for this study because of the differences of Dutch and U.S. practice. For example, in U.S. practice, the systems are mainly air based and central air heating is common while the practice for heating in the Netherlands is based on the hot water distribution systems with a boiler and radiators in the rooms.

Therefore, some adaptations had to be processed in order to make the models reveal reasonable results. The changes were mainly made to model space heating systems and the ventilation strategies. The details of the modelling procedures and the major changes are presented in Appendix 15.Although there are some variations in the concept simulations, the main procedure is outlined as:

1. As the first step, the building shape and the floor plans are defined in the wizard mode.
2. Then the details of the building materials are finalized in the detailed design mode.
3. The next step is to define the corresponding schedules, internal loads per room as defined in the Appendix 15.
4. After having defined the building shell, the next step is to assign generation systems in 'Water-Side HVAC' and the distribution systems 'Air-Side HVAC' parts of the eQUEST
5. The ventilation strategy is defined per room and per system depending on the ventilation principle.
6. In the last phase, the results are investigated if the model yields reasonable results.
7. If required, using the hourly reports provided by eQUEST some post-processing is performed.
8. If the outputs are not realistic or satisfactory, for the additional calculations, the necessary data is exported to Excel or related tools to obtain the final results.

The variations between the concept simulations are presented in Appendix 15, especially after the fourth step.

Model validation

The reference house was used for model validation. It is partly based on performance figures for energy uses and is compared to the figures as found in the literature.

As discussed by de Groot et. al., the electricity use for equipment and lighting was 1744 kWh and 570 kWh respectively. These values were given without a certain house typology. The values for electricity use for lighting and equipment were modelled in order to achieve these same values in the reference house. This also resulted in the amount of internal loads.

Energy for building operation is calculated by means of eQUEST and compared to reference values as given in literature or in NEN 5128, which is the basis for energy performance calculations for houses (EPW).

- The 694 kWh for fans is in the same order of magnitude as the 517 kWh calculated by EPW, though a bit higher. The difference results from the calculation by fixed assumptions in EPW and dynamic simulation in eQUEST.
- Auxiliary energy of 321kWh complies with the EPW 312 kWh value.
- The energy use for domestic hot water is deducted from the same pattern of water use as given by EPW, being class CW2 for the reference house. The 17.8 GJ as calculated by EPW complies with the eQUEST result of 18.5 GJ.
- Heating demand and energy use for space heating differ from values as found in EPW. Differences in assumptions and the use of dynamic simulation influence the these values significantly. EPW gives 22 kWh/m^2 for a 0.74 EPC terraced house, while calculation by the Passive House Planning Package (PHPP) gives 63 kWh/m^2. Our value of 52 kWh/m^2 lies between these values. Considerations as given in an ECN study (de Boer et.al., 2009) on comparison of EPW and PHPP methods discuss these differences which in general also account for the 52 kWh/m^2 value as found in eQUEST:
  - high internal gains load in EPW calculation: 6.0 W/m^2 in EPW, 2.1 W/m^2 for PHPP and 2.26 W/m^2 for eQUEST model
  - indoor temperature setpoint 18°C for EPW, 20°C for PHPP and 15/20/22°C (with 5°C setback during nights) for eQUEST.
  - Average external temperatures differ slightly: 8.5°C for eQUEST and 9.5°C for EPW climate data. EPW climatic data are given monthly and eQUEST data is given on hourly basis.

Since these assumptions apparently highly influence the heat demand, the outcomes in terms of energy use is also compared to an ECN study (Menkveld, 2009) which combines findings and measurements from actual performances of houses in the Netherlands. Specific for terraced houses they find a total gas use of 1500 m^3 per year (including tap water and space heating). For (not typology specific) houses built after they assume a reduction of 20% due to higher insulation, resulting in 1200 m^3 gas per year. This value complies in order of magnitude with the found value of 1225 m^3 gas per year in eQUEST.

Although the presented values are comparable in order of magnitude to the given reference values, they differ a bit. That is one of the reasons why the reference was modelled in eQUEST in order to compare the designed concepts to this house typology.

Domestic hot water and solar thermal collector calculations

Since eQUEST is not capable of simulating the solar thermal collectors, it is necessary to use another tool for estimating the performance of the collectors. This tool is also used for the initial performance estimation which was necessary for making the design decisions.

For this purpose, the hourly data of the global irradiation on the roof surface is exported from eQUEST together with the hourly outdoor temperature data. These are used to estimate the efficiency of the solar thermal collector in different periods of the year. The detailed explanation of this calculation is given in Appendix 15.

In this model, short term thermal storage is also incorporated together with the immerse heaters, gas fired boiler or the ground source heat pump input. So, the model is expected to reveal more accurate results than the estimations made by an efficiency factor for a year.

The model is validated by checking the results with the RETScreen excel tool, which is developed by the Canadian research centre Natural Resources Canada and which is a validated tool. The result for a flat plate collector and a boiler system, i.e. natural gas consumption over a year, is around 360 m^3 while with the proposed excel tool the result is 343 m^3 per year.

The energy savings is compared to the literature results as well. In PZE study by ECN (Koune et al., 2001), the energy delivered by a flat plate collector of 6 m^2 is estimated 6 GJ/year by using TRNSYS software, and by using the model presented in Appendix 15, the estimation is that 6.8 GJ/year is delivered by the flat plate collector.

Building costs

As was discussed under the analysis of economic value, the estimations of energy prices, ground prices, building costs and additional costs are always depending on the economic situation. By using the experience of cost experts the best possible assumptions were brought together for this project. The sensitivity of e.g. the energy price will be part of the robustness study in the comparison paragraph in order to show the feasibility if boundary conditions change. Differences in building costs for measures, ground prices and changes in the building process that result in higher or lower additional costs could highly influence the outcomes of design. Though changes will always affect all concepts (if built in the same period of time), therefore these differences were neglected.

ADF, Ventilation and Greencalc+

The formulas and models used to assess topics of lower interest were applied as presented in the topic analysis or as they were given by the supplier. Assumptions are presented in the Appendix 15.

BREEAM-NL

The residential version of BREEAM-NL does not always fit to the characteristics of a house. Some parts are too much deducted from the office version. This might be partly due to the fact that the residential version from February 2010 is still the Beta version and not final. Besides this, the economic part is not addressed in the tool and should be, since it is an important quality of a building and is highly influenced by the choices to achieve sustainability. Showing the profitability helps to achieve the goals that BREEAM-NL aims for.

Assigning credits in the concepts is partly depending on the assessors' choices (especially in conceptual design phase). For example assigning credits to flexibility which are achieved when building services can be disconnect from the building structure. This highly depends on detailing of the structure.

Due to the small amount of criteria used in this study (and therefore adapted weighting) the influence of small changes (like including or excluding compost bin) is large: reduction of 1 credit reduces 6.25% of total weighted percentage and for example passive concept increases the selling price per weighted percentage with about 400 euro.

In general
The integration of various methods which all influence the performance of the building design is a complex work. Changes made based on the outcomes of one model need to be adapted by hand in all other models to show the result. This is a time intensive and error sensitive process which is not favourable in conceptual design stages. The need for an integrated design tool in order to find a satisfying result in the integral assessment tool is significant.

4.3 Comparison

4.3.1 Reflection on designs

The resulting designs of the active and passive concepts differ a bit from the standard (and widely accepted) reference house. Especially the changes in ground- and first floor spatial planning might affect the likeability of the design. The bedroom area is split in more and smaller rooms, and the bathroom size decreased. But an extra separate toilet was created on the first floor and the attic floor is organized in separate and more useable spaces.

The material choice of the active house differs from the common (brickwork) practice in the Netherlands. Acceptance of this material type might be lower than normal, though this topic was not part of the analysis.

Passive concept vs. Passive House
The passive concept as suggested is not equal to the more known Passive House concept as introduced by Feist. The demands as are given with the latter concept are not set for the passive concept in this research. The passive concept in this research does seem similar, but differs in its ventilation method, in the position and thermal properties of windows and the thermal properties of the skin. The choices in this research are based on the integral approach on sustainability including applicable spatial planning for the Netherlands. A short description of the Passive House as introduced by Feist can be read in Textbox 3.

A passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems (Adamson 1987 and Feist 1988). The house heats and cools itself, hence "passive".
For European passive construction, prerequisite to this capability is an annual heating requirement that is less than 15 kWh/(m²a) (4755 Btu/ft²/yr), not to be attained at the cost of an increase in use of energy for other purposes (e.g., electricity). Furthermore, the combined primary energy consumption of living area of a European passive house may not

exceed 120 kWh/(m²a) (38039 Btu/ft²/yr) for heat, hot water and household electricity.
With this as a starting point, additional energy requirements may be completely covered using renewable energy sources.

Textbox 3: Passive House description. Source: www.passiv.de, visited 28/09/2010

4.3.2 Results per topic of interest

The results per topic were assessed according to the methods as presented. Besides the actual values according to all assumptions, some values on robustness are presented as well.

Table 53: Performance results for reference house, active and passive concepts

			Reference house	Passive concept	Active concept
Thermal comfort: overheating hours	Living + kitchen	hrs	80	-	125
	Living (separate)	hrs	-	224	-
	Kitchen (separate)	hrs	-	53	-
	Bedroom 1	hrs	57	10	94
	Bedroom 2	hrs	77	10	96
	Bedroom 3	hrs	95	0	59
	North room	hrs	-	0	46
	South room	hrs	-	0	45
	Total attic	hrs	60	-	-
Air quality	Type	-	Balanced	Mechanical	balanced
Annual energy use	Space heating	kWh; GJ-prim	- -	- -	1327 12.2
	DHW	kWh; GJ-prim	- -	- -	694 6.4
	Aux. (pumps&boiler)	kWh; GJ-prim	321 3.0	356 3.2	648 6.0
	Fans	kWh; GJ-prim	694 6.0	240 2.2	598 5.5
	Equipment	kWh; GJ-prim	1744 16.1	1144 10.6	1164 10.7
	Lighting	kWh; GJ-prim	570 5.3	248 2.3	283 2.6
	Space heating	m^3 gas; GJ-prim	708 24.9	577 20.3	- -
	DHW	m^3 gas; GJ-prim	517 18.5	245 8.6	- -
	Heating load	kWh/m^2	51.5	48.2	52.7
	Primary energy	GJ	74.9	47.2 (44.5)[1]	43.5 (33.0)[2]
	CO_2 emissions	kg	4131	2613 (2524)[1]	2829 (2028)[2]
Daylight	% area with ADF 2%	%	70.8	82.6	88.8
Acoustics	Building details	source	SBR	SBR	SBR
	Noise by systems	dB(A)	< 30 dB(A)	< 30 dB(A)	< 30 dB(A)
Spatial	Accessibility	yes/no	no	yes	yes
Materials	Shadow price	€/m^2	0.68	0.68	0.59
Water use	Amount of use	m^3/year	93	62	62
Waste	Area for storage	m^2	0	3.5	3.5
Economic value	Selling price (Δ with the boundary)	€ (Δ€ to 215,000)	210,870 (-4,130)	235,084 (+20,084)	254,594 (+39,594)
	Payback time	years	n/a	> 30	> 30
	Total expenditures over 30 years	Δ€ to reference	0	+35,579	+123,797
BREEAM-NL	Credits (weighted %)	- (%)	15 (34%)	24 (63%)	26 (67%)
	Selling price/ weighted %	€/%	6203	3733	3713

[1] with exhaust air heat pump to DHW
[2] with 38 m^2 of photovoltaic panels on roof

Since both the passive and active concept exceed the selling price of the reference house but do reduce energy demand, these (+ variants with heat recovery and PV) are presented in Figure 32. It gives the difference in cumulative expenditure (including mortgage, energy, water and reinvestments) based on energy prices as predicted by ECN/CPB. Since for all concepts the results are negative, this implies that they do not pay back within the 30 years mortgage period.

Cumulative expenditure compared to reference house

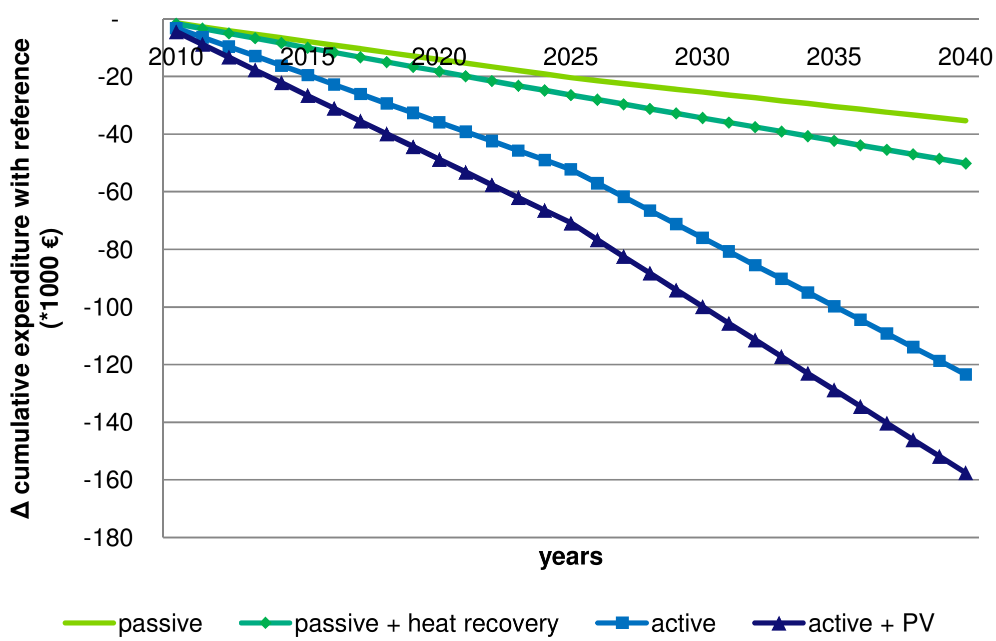


Figure 32: Cumulative expenditures of the concepts in 30 years compared to the reference house. Comparison is made based on energy prices according to ECN/CPB predictions.

4.3.3 Interpretation of results

Per topic the results as presented in Table 53 are discussed below.

1. **Thermal comfort:** The amount of overheating hours (based on the maximum temperatures deducted from PMV +0.5) is in the acceptable range in the reference house. Additional measures like cooling are not necessary to reduce these. However, the energy saving measures applied in the concepts affect the indoor temperatures which results in different overheating hours. The split-up of living room and kitchen (in order to reduce the ventilation demand) results in more overheating in the living room for the passive concept. This may be related to the fact that the insulation values are higher in the passive concept and the living room facing south has a decreased volume compared to the active concept and the reference house. Nevertheless the average value of overheating hours in living room and kitchen (if the space is considered to be combined as in the other concepts) is in the same order of magnitude as the active concept. The mechanical ventilation (passive) concept results on the other hand in lower overheating

hours in the bedrooms and attic rooms, compared to the active one. In general, all values are satisfying the PMV+0.5 for maximum 300 hours criterion.

2. **Ventilation method:** The choice for natural inlet and mechanical exhaust in the passive concept results in a lower decrease in heating demand than the possible reduction achieved by use of balanced ventilation with heat recovery. Although, it has a positive influence on the electric use since fan power decreases drastically.
3. **Annual energy use**
   - The heating loads of the active and passive concept are close to the reference house values. Although this is expected for the active house since the thermal quality of the building skin was not improved, the expected reductions in the passive concept are not achieved due to the natural ventilation strategy. However, the lowest heating demand is still achieved by the passive concept.
   - The effect of the ground source heat pump in the active house on primary energy use for space heating is significant (24.9 GJ in reference; 12.2 GJ in active). But the rebound effect of this can be found in the difference in selling price as presented under the economic value comparison.
   - The reductions of primary energy use for domestic hot water generation can be observed for both of the concepts compared to the reference house, being 9.9 GJ/year for the passive concept and 12.1 GJ/year for the active concept. This is as expected related to the utilization of solar thermal collectors in both concepts and the use of heat pump in active concept.
4. **Daylight:** According to the ADF, both designed concepts perform better on daylight availability than the reference. The large difference in electricity used for lighting results partially from this increase in daylight availability and partially from the use of energy efficient lighting (50 lm/W instead of 25 lm/W).
5. **Acoustic performance:** The houses are designed according to SBR reference details, which comply with the details for low nuisance from structural noise. Both active and reference concepts include balanced ventilation. If well installed, these systems should comply with the boundaries for noise by building services.
6. **Accessibility:** This is assured on the ground floor for both the passive and the active concept. The ground floor plan changed in order to be accessible for visitors and flexible for future use by elderly.
7. **Building materials:** the reduction of environmental impact by building materials is relatively small. In both of the concepts the amount of structure increases due to more internal walls, but the environmental load of the materials changes (more roof and less façade resp. wood instead of stony materials).
8. **Water use:** the water use is reduced in both concepts by simple and feasible measures.
9. **Waste:** little attention was given to the waste area, being placed in the storage room on the ground floor, resulting in better BREEAM scores for the both concepts.
10. **Economic value:** besides the reference house, none of the concepts falls below the st boundary limit of 215,000 euro selling price. It is exceeded by the passive concept with 20,000 and by the active with about 40,000 euro. The selling price of the passive concept is 12% above the reference house, the active concept is 21% higher. Therefore, affordability is not achieved by both concepts and as given in Figure 32 the additional investments could not pay back within the mortgage period.

    The roof shape change results in €1,994 reduction of building costs (excl. VAT) in the passive concept. The extra building costs result from insulation (€1,979), air tightness

(€2,448), change in spatial planning (€5,427), active systems for energy reduction (€2,814) and improvement of daylight (€2,073). Addition of building costs result in higher influence on the selling price due to indirect building costs, additional costs and VAT percentages. For the active concept, extra building costs mainly result from the wood frame structure and the choice for a ground source heat pump (€15,170 incl. ground works).
Since the ratio between selling price and building costs is about a factor 2, reductions in building costs of about €10,000 euro for the passive concept have to be made in order to achieve a selling price within the boundary of affordability.

11. **BREEAM-NL**: the assessment in BREEAM-NL only results in a small difference between the active and passive concept, resulting from differences in building materials and CO_2 emissions. The main difference between reference house and the both concepts lies in energy and health and comfort (daylight, accessibility and flexibility).

4.3.3.1 Robustness for change

The performance estimation of the concepts and the reference house are based on several assumptions. The user behaviour and the energy price predictions are the most influential ones. In order to see the effect of changing the parameters to the concepts' performance, i.e. the robustness of the designs for different assumptions, the models are analyzed in the following sections. On the other hand, the future use of the concepts is discussed as well in the end of this part.

Energy prices
The energy price predictions as taken from the literature by ECN/CPB depend on several factors and assumptions, therefore the calculations based on these assumptions should be checked to see the effect on the conclusions. The effect on total expenditures with changing energy price increase is presented in Figure 33.

It can be read from this graph that the additional investment of the passive concept over the reference house selling price will only pay back at an energy price increase of 7.8% per year. (ECN/CPB predictions lie around 0.5%). For the active concept the annual energy price needs to exceed 15% in order to achieve feasibility. Below, also the influence of addition of PV in the active, and heat recovery on ventilation air in the passive concept are discussed.

Sensitivity of concepts on energy price changes

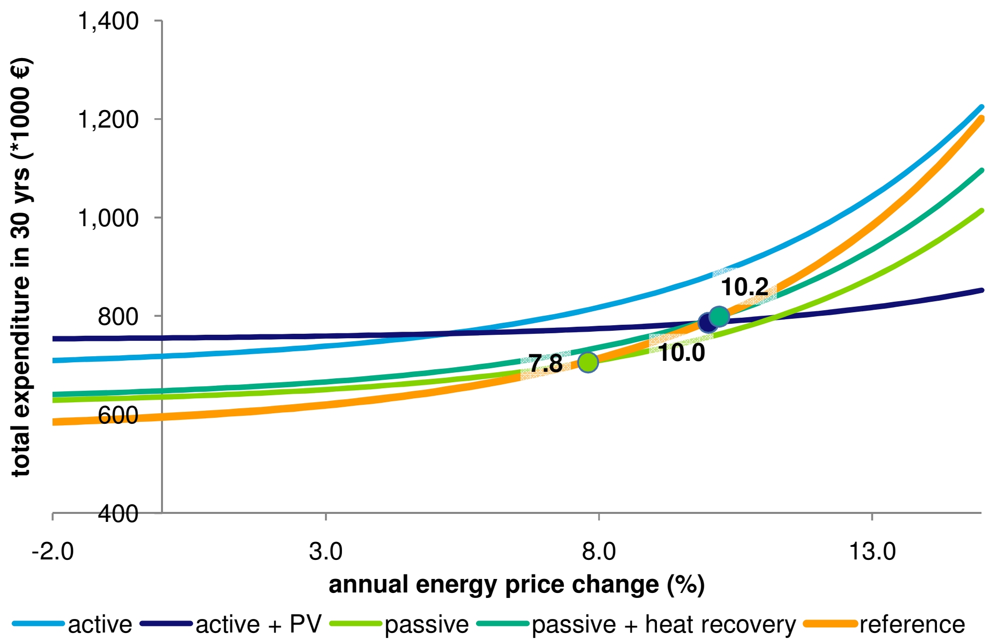


Figure 33: Sensitivity of concepts on energy price change, Data points indicate feasibility of passive resp. active concept at certain energy price increase

Following conclusions may be drawn;

- Influence of PV: addition of PV panels results in a relative small increase in initial investment compared to active concept (see difference between light- and dark blue line on Y-axis). The difference in robustness on the other hand is much bigger. The active concept including PV is very robust, even for energy price increases over 10%.
- Influence of heat recovery on ventilation air in passive concept: the annual saving on gas for DHW does not pay back, since this system needs additional electric energy (annually, 84 euro can be saved on gas, but 98 euro has to be spent on electricity). It will only be feasible at annual energy price increases over 10.2%.
- Comparison of active+PV and passive concept: the level of robustness is about equal till about 11% energy price increasing. Though the initial investment for the active+PV concept is much higher than the passive concept. So the passive design achieves a comparable robustness as the active+PV with two third of the investment costs.
- Though invested in sustainable energy technology as ground source heat pump, the robustness of the active concept is not improved compared to the reference house; the initial investment is more than twice as high.

User behaviour

In all concepts, the user behaviour (which influences energy for space heating, artificial lighting and equipment) accounts for about half of the total energy demand, as shown in Figure 34. This indicates that the influence of changes in user behaviour will be significant.

Share of user influence in energy use

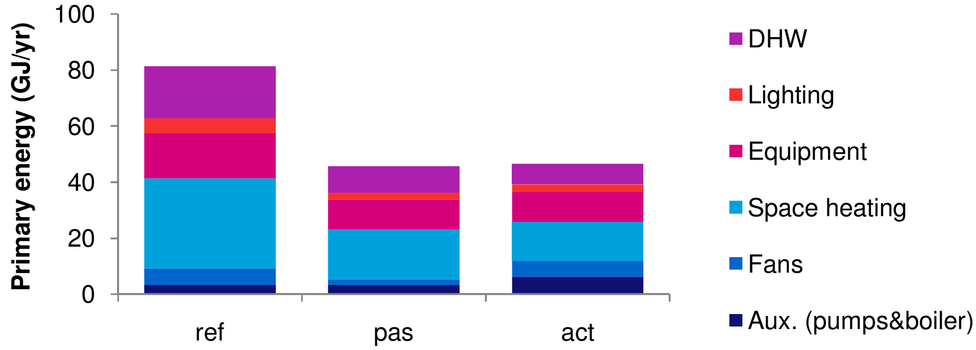


Figure 34: Share of energy use by users: red/purple coloured categories are highly influenced by users

The user behaviour assumptions for the concepts directly bounded to the user preferences include:

- Set temperatures are kept at the design levels, i.e. 20°C for living room and bedrooms, 22°C for bathroom.
- A++ labelled equipment is installed in the passive and active concept which are determined by the user
- Efficient light bulbs are used in the active and passive concept

Since these behaviours are based on certain assumptions and subject to change, the situation where these assumptions are not valid is analyzed through simulations. The changes in the models and corresponding changes are presented in the following table.

Table 54: User behaviour changes and the corresponding results

Changes in the models		Reference house	Passive concept	Active concept
Lower set temperature (18°C)	GJ-prim(Δ%)	68.6 (-8.3)	40.7 (-13.75)	41 (-5.9)
Higher set temperature (22°C)	GJ-prim(Δ%)	82.9 (+10.7)	55.7 (+18)	46.5 (+6.75)
Different equipment & lighting	GJ-prim(Δ%)	70.2 (-6.3)	53.1 (+12.5)	50.3 (+15.7)

Figure 35 shows the change in primary energy consumption if the room temperatures are set to higher and lower values. The reference case for three concepts is 20 °C.

As can be seen from the graph and the information shown in the table, the primary energy consumption for space heating is the most sensitive to the thermostatic settings in the passive concept whereas in the reference house and the active concept this is less sensitive. This can be related to the natural ventilation principle in the passive concept. The relatively low primary energy change in the active concept is due to the fact that the ground source heat pump uses the electricity efficiently to supply space heating, which means the influence of the user behaviour is minimized by utilizing efficient technologies.

Sensitivity of the concepts to different set temperatures

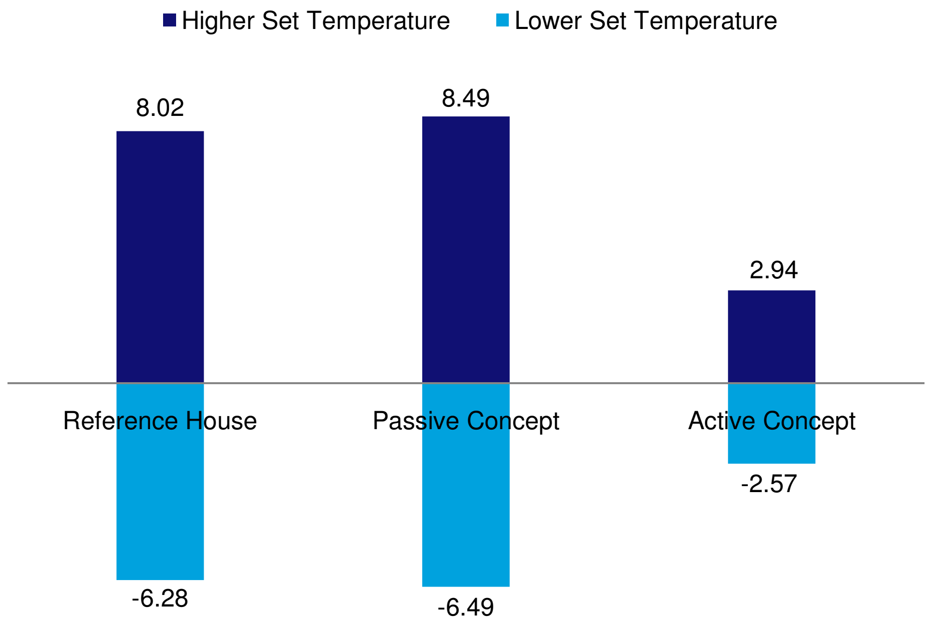
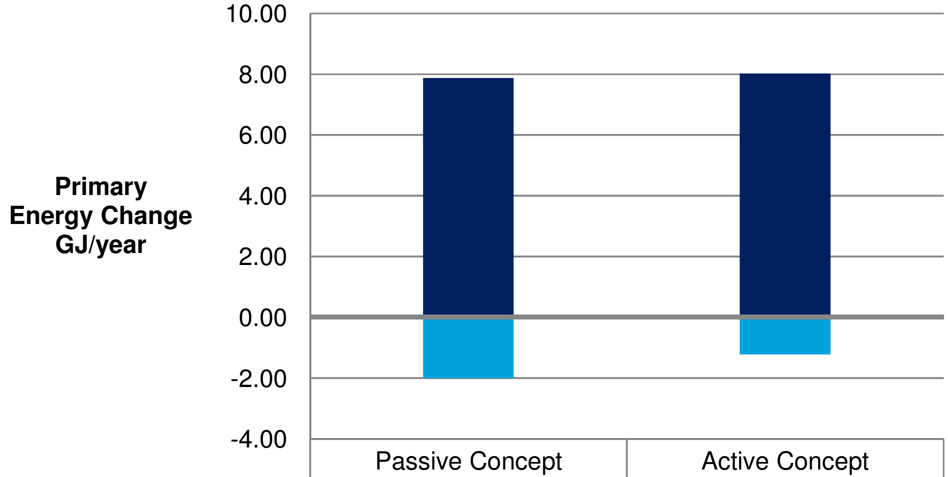


Figure 35: The change of primary energy use for different room temperatures

The influence of different electrical energy consumption including appliances and the lighting, which is changed to higher figures in both active and passive concepts, is a complex issue to explain since it is related to the internal gains as well. In order to clarify this for the two models, Figure 36 presents the changes in electricity and heating primary energy consumption changes.

The figure shows that the heat generated by the internal loads is better captured in the passive concept so that the primary energy decrease is higher compared to the active concept. On the other hand, it might be concluded that the primary energy change for heating does not compensate for the change of the electric energy consumption.

Sensitivity of the concepts to different electricity consumption



	Passive Concept	Active Concept
Heating	-2.00	-1.22
Equipment & Lighting	7.88	8.03

Figure 36: Primary energy change for higher electrical energy consumption (lower for the reference house)

Future use

As mentioned in the design of the concepts, the floor plan in the active and the passive concept is changed to improve the accessibility of the house. It is improved such that it is possible to adapt the house for future users (elderly people for example), which is an improvement for the functionality and flexibility of the concepts.

The changes in the function of the rooms and the user types in the future will result in the user preferences and so the change of the loads. The effect of the changing preferences is presented in previous section. However, the change in the function of the spaces will affect many parameters which make the calculations for the performance of the future typology beyond the scope of this project. The following can be estimated:

- The heating demand will increase as elderly people will live in the house, which is similar to the condition of higher temperature setting as presented in the previous section. Therefore, the heating demand can be met with the current design of the houses.
- Domestic hot water demand will increase as the number of people living in the house increases. The systems will be able to meet the demand by the advantage of thermal storage tank, which reduces the power demand.
- Amount of ventilation flow will increase due to using the storage room as bathroom.

4.4 Hybrid concept

Based on the findings in comparison of the passive and active concepts, the recommendations are implemented in a third concept which will be a hybrid of both.
As an example, the ‘lighthouse’ concept by Kingspan incorporates renewable sources for both heat and electricity generation in the house in addition to the passive measures. The technologies include; biomass boiler, PV panels, solar thermal collector, mechanical ventilation with heat recovery, water recycling systems and energy efficient appliances. On

the other hand, thermal quality of the building skin is also improved so that the house will have a reduction of energy demand. However, in ‘lighthouse’ concept, cost was not a criterion as the concept is developed to be an example to achieve the highest levels in both active and passive measures.

In this case, considering the costs, the measures will be selected based on their relative effect on the environmental and basic performance. In this perspective, the passive concept scored the best (low investment per BREEAM-NL percentage, selling price with lowest exceeding over the boundary, smallest difference in total expenditure after 30 years and highest robustness for energy price changes). Therefore this concept will be taken as leading in the design of hybrid concept.

- For daylight, water and waste the achieved performance is acceptable and will therefore not be improved further.
- In terms of thermal comfort, an optimization should be found for the general high overheating hours in the living room. The excluded moveable external shading is reconsidered but appears not to be necessary for overheating hours.
- In terms of operational energy, further improvements are made in heating demand if balanced ventilation with heat recovery is applied. The ventilation flow scheme will therefore change so the gain will be lower than expected.
- The building skin and shape are designed according to highest quality as achievable in practice, except for the insulation value of glazing. Still this will not be improved, since the gain/cost impact is not profitable enough.
- The heat generation system which currently is a high condensing boiler could be replaced if district heating can be provided. This could have a large effect on CO_2 emissions. The initial costs of a condensing boiler are low, and connection costs for district heating are currently still quite high. Therefore the initial costs will reduce slightly, while the payback will be worse due to higher payments for heating energy.
- The environmental impact of the passive house was not improved compared to the reference situation. By changing the façade finishing from brickwork to wooden cladding, improvements could be made. This also has a positive effect on the selling price. It is possible since the thermal mass of brickwork on the outside layer does not enhance the thermal capacity of the house due to the insulation layer between.
- Although the selling price of the passive concept exceeds the boundary of affordability, big changes were not made in order to improve this. The current combination of measures as applied in the passive concept is optimal in terms of their cost effectiveness to achieve a high level of sustainability as resulted from the economic analysis.

4.4.1 Results per topic of interest

Table 55: Performance results for the hybrid concept compared to the reference house and passive concept

			Reference house		Passive concept		Hybrid concept	
Thermal comfort: overheating hours	Living + kitchen	hrs	80		-		-	
	Living (separate)	hrs	-		224		278	
	Kitchen (separate)	hrs	-		53		57	
	Bedroom 1	hrs	57		10		19	
	Bedroom 2	hrs	77		10		27	
	Bedroom 3	hrs	95		0		0	
	North room	hrs	-		0		0	
	South room	hrs	-		0		0	
	Total attic	hrs	60		-		-	
Air quality	Type	-	Balanced		Mechanical		balanced	
Annual energy use	Space heating	kWh; GJ-prim	-	-	-	-	-	-
	DHW	kWh; GJ-prim	-	-	-	-	-	-
	Aux. (pumps&boiler)	kWh; GJ-prim	321	3.0	356	3.2	332	3.1
	Fans	kWh; GJ-prim	694	6.0	240	2.2	608	5.6
	Equipment	kWh; GJ-prim	1744	16.1	1144	10.6	1144	10.6
	Lighting	kWh; GJ-prim	570	5.3	248	2.3	248	2.3
	Space heating	m^3 gas; GJ-prim	708	24.9	577	20.3	368	13
	DHW	m^3 gas; GJ-prim	517	18.5	245	8.6	245	8.6
	Heating load	kWh/m^2	51.5		48.2		29.2	
	Primary energy	GJ	74.9		47.2		43.5	
	CO_2 emissions	kg	4131		2613		2460	
Daylight	% area with ADF 2%	%	70.8		82.6		82.6	
Acoustic	Building details	source	SBR		SBR		SBR	
	Noise by systems	dB(A)	< 30 dB(A)		< 30 dB(A)		< 30 dB(A)	
Spatial	Accessibility	yes/no	no		yes		yes	
Materials	Shadow price	€/m^2	0.68		0.68		0.68	
Water use	Amount of use	m^3/year	93		62		62	
Waste	Area for storage	m^2	0		3.5		3.5	
Economic value	Selling price (Δ with the boundary)	€ (Δ€)	210,870 (-4,130)		235,084 (+20,084)		238,735 (+23,735)	
	Payback time	years	n/a		> 30		> 30	
	Total expenditures over 30 years	ΔRef. in €	0		+35,579		+49,481	
BREEAM-NL	Credits (weighted %)	- (%)	15 (34%)		24 (63%)		26 (70%)	
	Selling price/ weighted %	€/%	6203		3733		3482	

4.4.2 Interpretation of results

1. **Thermal comfort:** The amount of overheating hours (based on the maximum temperatures deducted from PMV +0.5) was already higher in the passive concept than the reference house as explained previously. On top of these reasons, the implementation of balanced ventilation causes higher amount of hours in most of the rooms in the hybrid concept. However, the attic and the smallest bedroom do not get higher temperatures than desired.
2. **Ventilation method:** As expected, using the balanced ventilation with heat recovery caused a reduction in the heating load compared to the passive concept. However, the electricity consumption due to the fan use increased compared to the passive concept. The effect of this on the energy bills is discussed in the economical value part.
3. **Annual energy use**
   - As specified previously, the heating load is reduced to 60% of the passive house as expected and the electricity is increased by 150% compared to the passive house.
   - The total primary energy use in the hybrid concept is lower than that of the passive concept. The same primary energy level of the active concept could be achieved by only reducing the demand for space heating.
   - Since no additional measures are taken for the domestic hot water generation, the primary energy use stays at the same level.
4. **Daylight:** Since the passive design of the passive concept did not change for the hybrid concept, the daylight availability is still satisfactory being 88.8%.
5. **Acoustic performance:** The houses are designed according to SBR reference details, which comply with the details for low nuisance from structural noise. Both reference and hybrid concepts include balanced ventilation. If well installed, these systems should comply with the boundaries for noise by building services.
6. **Accessibility:** This is assured on the ground floor for the hybrid concept as well since the floor plan is not changed.
7. **Building materials:** The impact of building materials remains the same as the passive concept although the balanced ventilation is introduced in the hybrid concept.
8. **Water use:** the water use remained the same.
9. **Waste:** small attention was given to the waste area, being placed in the storage room on the ground floor.
10. **Economic value:** The selling price of the hybrid concept is even higher than the passive concept due to the implementation of the balanced ventilation with heat recovery. But the increase is small due to the change in façade cladding. On top of that, the yearly energy bill increased because the natural gas savings due to the heat recovery system is ruled out by the additional electricity consumption. It is calculated that the energy bill increases yearly around 90€, compared to the passive house, assuming the current energy price levels.

    Equal to the passive concept, the hybrid concept exceeds the boundary for affordability and does not pay back the additional investments over the reference house level, which is around 13% increase.
11. **BREEAM-NL**: The assessment in BREEAM-NL only results in a small difference between the passive and hybrid concept. The difference is in reduced the primary energy consumption reduction and reduction of environmental impact by building materials in the hybrid concept. The cost of achieving credits for the hybrid concept is slightly lower

than the passive concept, which means the hybrid concept (and lower than the active concept) is the most feasible to achieve BREEAM-NL credits.

4.4.2.1 Further optimization

The hybrid concept is the optimum concept for the boundary conditions specified in this study. This is proven by the results as presented above, having the lowest energy demand and CO_2 emissions. However, the design still includes a gas fired boiler which is not the cleanest way of supplying heat and the design is still fossil fuel dependent. The alternative options for sustainable energy generation in small scale were proven to be financially unfeasible considering the current costs and the energy price increase predictions in this study.

Therefore, the requirement for avoiding fossil fuel use in the residential sector can be met by introducing large scale solutions, such as district heating systems based on geothermal energy, gas motor based CHP. These solutions will increase the efficiency of the units in current technological development level and spread the technical and financial risks to more households rather than individual households.

For heat generation in large scale, the district heating can actively be supplied by the following options (stadsverwarming, www.eneco.nl):

- Industrial waste heat: The waste heat of the electricity generation plants is used for supplying heat to the districts. In the Netherlands, the cogeneration factor is accepted as 0.30, which means for each GJ of heat 0.3 GJ of natural gas should be co-fired to generate the same amount of electricity (Menkveld, 2001). This results in 16.8 kg CO_2 emissions per GJ of heat.
- Gas-motor CHP: Cogeneration of heat and power in large scale plants which utilizes gas fed motors. These systems are assumed to deliver 1 GJ heat with 26 kg CO_2 based on a study comparing district heating options (CE Delft, 2009). The same study estimates 60% primary energy reduction compared to the high efficiency boilers.
- Geothermal heating: The heat of the deep geothermal sources in the depths larger than 500 meters, typically around 1.5-3 km. The CO_2 emissions for the geothermal heat are estimated as 10 kg/GJ as explained in the following paragraph.

The energy use of the pumps to deliver geothermal energy to the households is estimated to be approximately 18 kWh per GJ of thermal energy, which is based on an article about the potentials of the geothermal energy in the Netherlands (Verwarming & Ventilatie, July 2008). This means around that 10 kg CO_2 per GJ of thermal energy is emitted if the total amount of houses is assumed to be 1200 so that a peak boiler is not necessary.

The most important advantage of these systems over the gas fired boilers is the primary energy savings and CO_2 emission reductions. The performance of the district heating options would be as presented in the following table assuming that they generate heating energy to meet the space heating and domestic hot water demand of the hybrid concept.

Table 56: CO_2 emissions by different large scale heat generation options

Option	Primary energy use GJ/year (%of gas fired boiler)	CO_2 emissions kg/year (% of gas fired boiler)
Industrial waste heat	6.5 (30%)	327 (31 %)
CHP- gas motor	8.6 (40%)	500 (47%)
Geothermal	3.5 (16%)	190 (18%)

- As the comparison in Table 56 and Figure 37 show that the geothermal heating is the most suitable option for primary energy and CO_2 emissions reductions. In the Netherlands, geothermal sources are available throughout the country to apply these solutions in the near future.

Environmental benefits of large scale heating energy generation

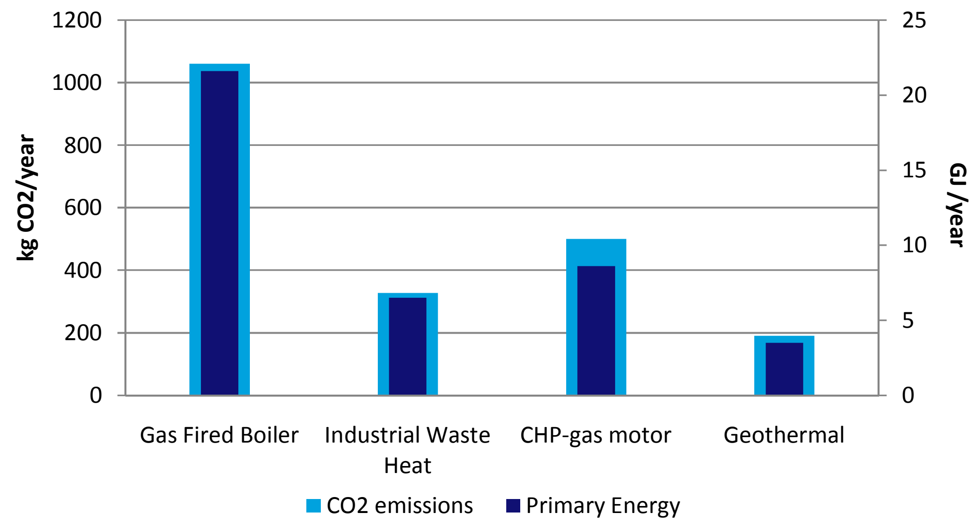


Figure 37: Primary energy consumptions and CO_2 emissions for different large scale heating energy supply options compared to the gas fired boiler in the hybrid concept

On the other hand, the costs related to the use of district heating are compared to the reference gas fired boiler in an article published in 2008 (Verwarming & Ventilatie, July 2008). From the figure it seems that the total costs of district heating and geothermal heating are comparable to that of the gas fired boiler. In the Netherlands, the prices for district heating are correlated to the costs of using gas fire boilers.

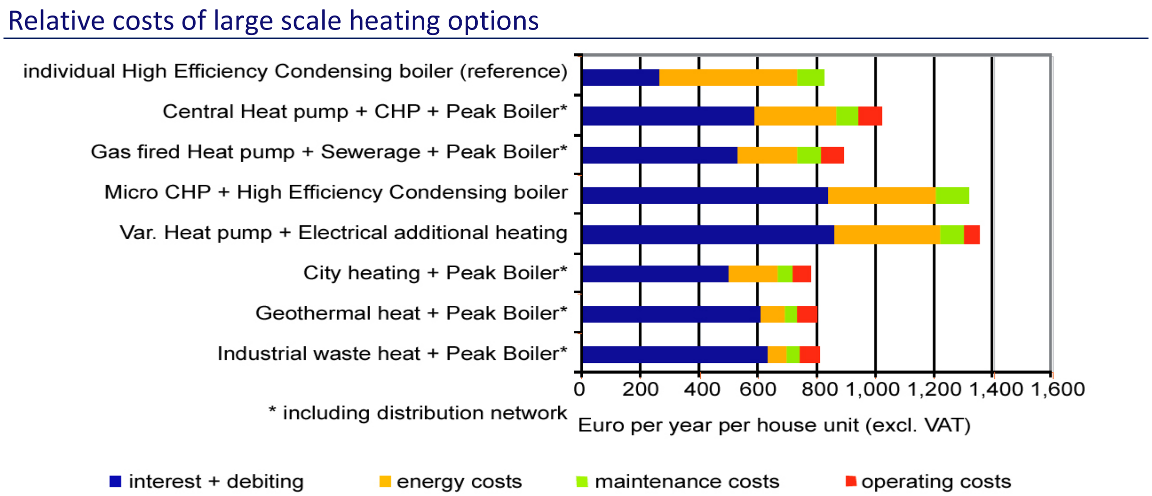


Figure 38: Costs of using district and geothermic heating compared to several options, source: Verwarming & Ventilatie, July 2008.

As a result, it can be concluded that with the same amount of yearly costs, primary energy and CO_2 emission reductions up to 80% can be achieved by applying geothermal heating. Although the investment costs for geothermic systems are high, the low energy and maintenance costs compared to the high efficiency boilers result in a comparable expenditure for households in a year.

The pricing of the district heating in the Netherlands has been discussed for years and the conclusion was that the principle of users not paying more than they would otherwise does not apply to residents of new dwellings and the energy prices are not reasonably determined for all consumers (Price Audit by Algemene Rekenkamer, 2007).

4.4.2.2 Robustness for change

As done for other concepts, the sensitivity of the hybrid design to changing assumptions is checked in this section. In this manner, the improvements can be observed compared to the reference house and the passive concept which is the baseline of the hybrid concept.

The assumptions for the energy price increase and the user behaviour is checked in the following parts. The future use of the hybrid concept is not discussed since the conclusions mentioned in the previous section holds for the hybrid concept as well.

Energy prices
Similar to the previous discussion for the comparison of the concepts, the total expenditure of the hybrid concept is compared to the reference house and passive concept with changing energy price increase assumptions. For the hybrid concept, two options are modelled with a gas-fired boiler and district heating connection. Figure 39 presents the results for different concepts and options.

Following conclusion may be drawn from Figure 39:

- The hybrid concept with gas fired boiler and the passive concept have similar sensitivity to energy price changes, although the break-even point for the hybrid concept is higher due to the investment for mechanical ventilation with heat recovery.

- As the energy prices increase with higher percentages, the hybrid concept gets closer to the passive concept, which means the extra investment for the ventilation system is compensated if the energy prices increase.
- Although district heating option is claimed to be priced in correlation with gas-fired boilers, the pricing proves to be more costly in longer term such that this option requires higher energy price increase to pay the investments back.

Sensitivity of concepts on energy price changes

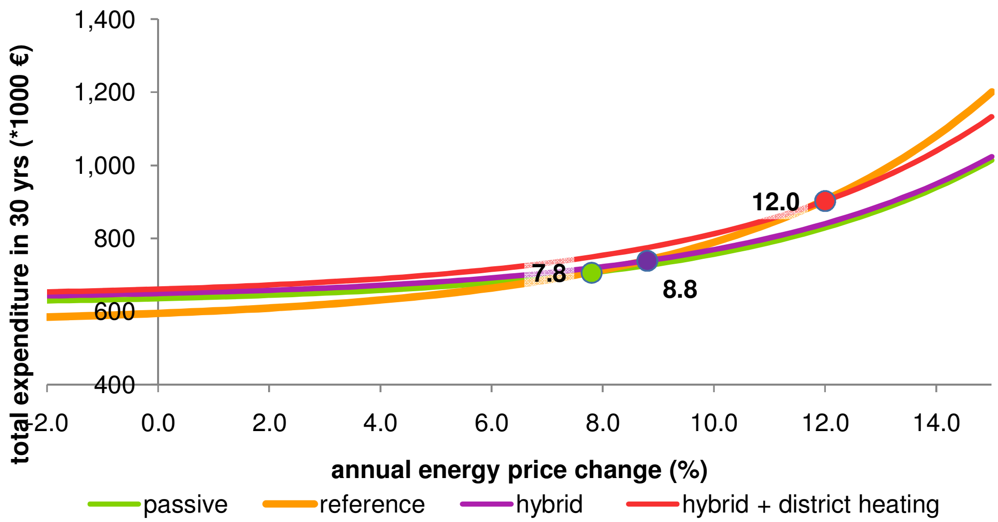


Figure 39: Sensitivity of concepts on energy price change, Data points indicate feasibility of passive resp. active concepts at certain energy price increase

User behaviour

The same assumptions as in the previous comparison section is taken into account to compare the sensitivity of the hybrid model to changing user behaviour.

The changes in the models and the corresponding results are presented in Table 57 and in Figure 40.

Table 57: User behaviour changes and the corresponding results

Change in the models		Reference house	Passive concept	Hybrid Concept
Lower set temperature (18°C)	GJ-prim(Δ%)	68.6 (-8.3)	40.7(-13.75)	40.9(-5.9)
Higher set temperature (22°C)	GJ-prim(Δ%)	82.9(+10.7)	55.7 (+18)	47.6 (+9.4)
Different equipment & lighting	GJ-prim(Δ%)	70.2 (-6.3)	53.1 (+12.5)	49 (+12.7)

As can be seen from the figures and the results, implementation of the mechanical ventilation with heat recovery resulted in a relatively less sensitive, therefore improved, concept to the changing heating preferences.

Sensitivity of the concepts to different set temperatures

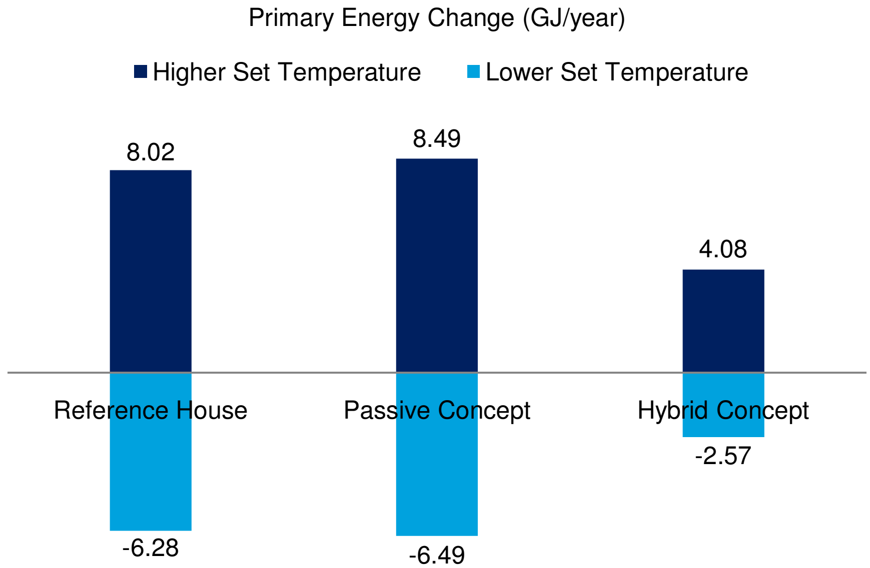
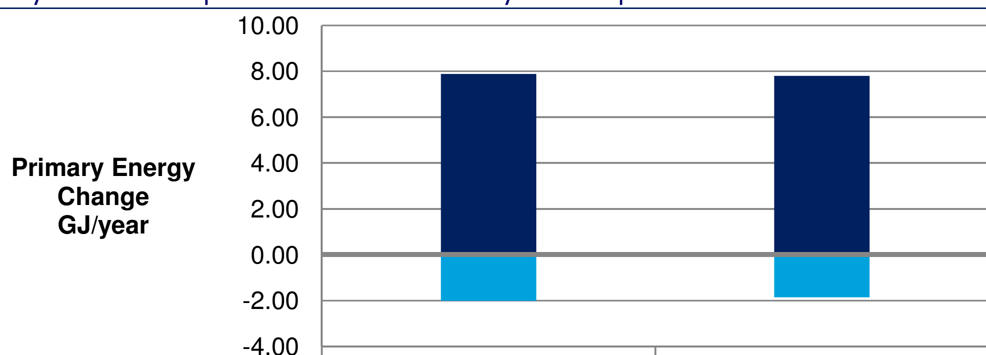


Figure 40: The change of primary energy use for different room temperatures

On the other hand, the change in the equipment and lighting loads result in changes in the heating loads and primary energy consumption. In the hybrid concept, the changes due to the internal loads are slightly lower than the passive concept which might be related to the change of the ventilation principle. Results are presented in the following figure to give an impression of the sensitivity of the concepts.

Sensitivity of the concepts to different electricity consumption



	Passive Concept	Hybrid Concept
Heating	-2.00	-1.86
Equipment & Lighting	7.88	7.79

Figure 41: Primary energy change for higher electrical energy consumption (lower for the reference house)

5 Conclusions

The conclusions are presented in a structured way to answer the research question as defined previously. First of all, conclusions regarding the main research question and thereafter the conclusions about the detailed analysis and the concept designs are presented. Lastly, the scope of the project and the limitations are concluded.

5.1 Conclusions: main research question

The main research question of the study was defined in the first phase of the project as:
What is the optimum combination of the design strategies and measures to achieve high basic, environmental and economic value in the design of a 'sustainable' and 'affordable' single family house in the Netherlands?
Although 'integral design' is a complex process and difficult to prescribe in a stepwise approach, in order to answer the main research question an approach which starts with a detailed analysis of both demand and supply aspects of the focus areas was implemented. The outcomes of the analysis are evaluated to take design decisions, in terms of both 'passive' and 'active' measures as defined previously. The design decisions were made to propose two concepts namely the 'active' and 'passive' concept to find the optimum combination of measures.

The choice of the topics of interest and the assessment criteria in the BREEAM-NL method are in line with the approach of the detailed analysis and resulted in a workable set of information to take design decisions. The resulting concepts are assessed in terms of their environmental performance and financial consequences.

From the two concepts (passive and active), the best performing in terms of basic, environmental and economic values was chosen to be the baseline for the hybrid design which is aimed to be the optimum concept. The detailed calculations and dynamic simulations showed that the passive concept performed the best in terms of energy consumption and the financial measures. Although the calculated selling price of the passive concept exceeds the predetermined affordability limit, it is both financially and environmentally more favourable than the active concept.

The results of the design decisions were taken into account and showed that the optimum solution can be achieved with the 'passive' measures but the natural ventilation principle causes significant increase in the heating energy demand. So, the hybrid concept is designed based on the passive concept with the addition of the balanced ventilation with heat recovery.

The resulting hybrid design exceeds the selling price boundary, but a much lower heating power demand and therefore lower primary energy use and CO_2 emissions. Due to a different mixture of gas- and electricity use, the annual expenditure on energy appeared to be higher than the passive concept. It should be noted that the use of electricity instead of natural gas is more favourable in the sense that the electricity could be generated both on-site and in large scales in a sustainable way while the natural gas is one of fossil fuels which have limited availability.

Although the selling price exceeds the affordability boundary by 11% and the selling price of the passive concept by 1.5%, the hybrid concept is advised as result of this concept since the benefits in primary energy use are significant. It has more options for sustainable performance in the future when considering the possibility of 'green' electricity generation. Also the selling price per weighted BREEAM-NL percentage is lower than the other concepts, although the difference is not significant.

The financially unfeasible position of the 'active' solutions in small scale, based on the energy price predictions in this study, demonstrate the requirement for large scale solutions for both financial and environmental benefits. Depending on the type of generation, the heating energy generation in large scale promises high primary energy and CO_2 emissions savings up to 80%. Therefore, energy can be supplied to the households in a more sustainable way while keeping the financial situation at comparable levels to the conventional systems.

However, the financial feasibility of large scale systems for end-users is highly dependent on the yearly costs reflected on their yearly bills and investment costs. Considering the current price levels these systems are more costly than gas fired heating systems per house (taken into account both investment and operational costs).

As a result of all analysis, it became evident that the measures to achieve a higher level of sustainability are more costly than the current practice. This results either from the larger amount of materials, the complexity of the systems or the higher attention for details which asks more labour during built. Therefore, end-users can achieve considerable amount of reductions in the energy demand but the government and the local authorities should take measures to meet the remainder in a more sustainable and financially feasible way.

5.2 Conclusions: detailed analysis

On preliminary work

The preliminary work clearly showed the limited focus of the sustainable building design; the solutions are mainly focused on energy efficiency. On the other hand, the projects which are assessed in the preliminary study are all experimental projects instead of reasonable concepts which are applicable at a larger scale. The designs lacked attention in each of the six value domains, but specifically in certain aspects of the basic, ecological and economic values. So the focus in sustainability lacked attention in the applicability and feasibility of the projects in order to be accessible to a large share of the population.

Boundary conditions

The boundary of Netherlands as location resulted in application of the Dutch codes and standards for design. But the non specific location of the town environment within this country resulted in a general design for climatic data as was found in the regulations or software. Also the ground costs were assumed to be fixed. Differences in exact location could mainly influence the selling price due to ground costs.

The typology terraced house resulted from demand prognoses and thereby assured the applicability of the designed concepts, when staying within the boundaries of selling price.

Analysis per topic

- **Thermal comfort:** Looking at outdoor temperatures, about 93% of the year heating would be necessary and 3% of hours would be overheating. The demands could be achieved by passive or active means. The passive means to achieve the heating demands include enhancement of building skin properties in terms of insulation and air tightness values, but also could be found in position of thermal zones. Prevention of overheating could be achieved by changing window types and solar shading. The choices to be made in this are numerous and are partly made based on the economic analysis of several measures under 'economic value', under 'spatial comfort' and by the definition of the passive and active concept.
  Active systems which could assist in achieving these demands were studied. The most advantageous type is the floor heating option, which has a lower energy consumption, high thermal comfort and indoor air quality. The disadvantage of slow response could be solved by higher insulation values of the building skin.
- **Indoor air quality:** The ventilation standards are set in the building decree in fixed numbers. Goal is to prevent large concentrations of several harmful components (from dust, particles and CO_2 but also moisture). The use of mechanical ventilation in housing is increasing, due to higher air tightness values in the building skin. It is also necessary in order to assure the minimum amounts of ventilation. In the current stock of houses, the amount of ventilation is too low to prevent certain levels of pollutants to occur. For the reference house this was assumed to be acceptable, due to the placement of balanced ventilation. The available types of ventilation systems all demand a certain amount of air tightness to decrease the uncontrollable influence of infiltration. The limits for infiltration are prescribed in the Building Decree and will be applied for the active concept. For the passive concept air tightness is improved in order to control the flow. To comply with the regulations and the description of passive design, natural inlet and mechanical outlet is applied for the passive concept and a balanced ventilation system with heat recovery is applied in the active concept.
- **Visual comfort:** Daylight availability as assessed for the reference house does not comply with the strict demands as set by BREEAM-NL. The average daylight factor demands for a larger day lit area than currently achieved by common terraced houses. For both of the concepts, the window sizes were adapted in order to achieve the demand in a large area of the floor area. Transmission and obstructions by overhangs highly influence the average daylight factor and were therefore carefully taken into account during design. Fixed assumptions were taken for distance of obstructions and reflection factors. In order to improve the house energy performance, improvements were assumed in artificial lighting types for both the active and passive concepts.
- **Acoustic comfort:** acoustic comfort can be characterized by either sound insulation values of structures or noise production levels by active systems. Ventilation methods are affecting this performance since they include façade openings and mechanical systems with moving parts. By use of reference details and by placing ventilation systems in a closed room, main steps were taken in achieving thermal comfort. This topic was addressed in a low level, therefore exact calculations on the performance were not executed.
- **Spatial comfort:** The topic of spatial comfort addresses the availability of outdoor space, the accessibility of the house for different users and flexibility of spaces. The current

practice is acceptable for outdoor space, not accessible for different users. By making changes on the ground floor an option is presented to make future use of the house possible for elderly or disabled users. Flexibility is increased by this concept as well as the separate design of services space close to a central duct.

- **CO_2 emissions:** The assessment of CO_2 emissions is based on the primary energy use during the operation of the house. As a result of the analysis, it is advised to use solar energy for both heat and electricity generation (with roof inclination between 30-40°). Wind application is not recommended due to the low performance of small scale wind turbines which results from large variations of wind available. Ground source technologies are advised, since the ground typology in most parts of the Netherlands has a reasonable thermal capacity. Wood pellets are the only source for small scale applications. However, the wood pellet boiler is not recommended due to the limited applicability and acceptance since the supply, distribution and storage of wood pellets is problematic.
  Conclusions from the system analysis are to use a high efficiency boiler (comparable to the reference house) for the passive concept based on the feasibility analysis and a ground source (water-water) heat pump for the active concept based on the environmental performance analysis. Solar thermal panels are advised for supply domestic hot water (DHW) and are combined with the boiler for the passive concept and the heat pump for the active concept.
- **User behaviour:** Based on literature research form it could be concluded that feedback can have a positive effect on reduction of energy consumption. Referring to the preferences of the end-users in the Netherlands, it is advised to use analogue thermostats, to assume set temperatures of 20°C, to assume windows closed while heating, to use stand-by killers on electric equipment and energy efficient appliances. Domestic hot water schedules are not changed since users are found to adapt this.
- **Building materials:** The effect of building materials on the environment is by use of the shadow price. This price is calculated from the impact of nine environmental aspects of the building materials (greenhouse effect, damage to ozone layer, humane-, aquatic-, and terrestrial toxicity, photochemical oxidants, acidification and eutrophication). The tool GreenCalc+ (V2.2) was used to calculate the impact of these environmental aspects. Analysis of the reference house showed a large impact by floors, facades and internal walls. Changes in design could reduce this price (by wood use or mechanical instead of balanced ventilation) but also could increase it (concrete structure or use of ground source heat pump). The passive design is be based on a heavy weight structure, and the active house on wood frame structure to compensate the negative effect of the ground source heat pump that was recommended for CO_2 emission reduction.
- **Water use:** Toilet, shower and use of the washing machine count up to the biggest share of all household water use. The total use is about 93 m^3 per year as deducted from yearly averages per household. Several systems were assessed which either reduce the water or recycle the rain water. Based on possible savings and the costs, in the new concepts only water saving taps, 6 liter toilets and low flow shower heads were applied. For reduction of heat demand, shower heat recovery systems were applied.
- **Waste:** The separation of waste and the facilities to allow this is incorporated in the designs. The household waste is produced in 79 kg/yr/inhabitant in organic types and for 26 kg/yr/inhabitant in green waste. The required size of space in a house would be 40 litres for paper, 0.4*0.6 metres for recyclable waste and 140 litres for compost in the

garden. These measures are applied in all concepts.

- **Economic value:** The economic value of a house is highly depended on a list of assumptions. The ground prices, energy prices, additional costs or selling prices depend on time and market situations. The economic value of a design is not assessed in any topic of BREEAM-NL. Therefore a method based on an annuity mortgage over 30 years is applied for comparison of the concepts. Assessment occurs on basis of payback time compared to the reference house, the selling price (with boundary of 215,000 euro), and the selling price per achieved BREEAM-NL credit. The building costs of the reference house lie mainly in structural works (63%) of which more than half in building structure and facades. Therefore possible reductions were found in reducing the façade area and decreasing window sizes. In the calculations energy prices as interpreted from ECN and CPB predictions were used (in range of 0.5% increase per year) but sensitivity was also presented on different energy price increasing.
  The parametric study on options in building structure resulted in a recommendation for insulation measures and an increased roof size, resulting in lower façade costs and lower heating demand. Triple glazing options were found not to be feasible due to the small amount of energy reduction per invested euro. By hand of Net Present Value analysis some active systems were assessed and all found to be not feasible in the predicted energy prices. They do not pay back the investments within the technical life time. Therefore the most feasible one in terms of CO_2 emissions and primary energy is applied for the active concept.

Concepts

The concepts were defined in passive and active terms and were designed according to the principle in main additional investment in the one or other type of measures. But some topics of sustainability were addressed (and improved compared to reference) by both: spatial design, water use, acoustics and daylight. Therefore the compared concepts differed in thermal quality of the building skin, type of building services, shape and materials.
The number of concepts was kept to two, but in two distinctive directions.
Measures were chosen based on the analysis of all separate topics in order to improve the sustainability value, achieve applicability and minimum increase of initial costs.

Assessment method(s)

Assessment in this project is performed by means of several tools, which were finally integrated in one score, being the selling price per achieved weighted percentage of BREEAM-NL credits. This value showed the feasibility of several sustainability concepts, though a critical view on this score is necessary due to the possible differences in credit score and selling price that result from assessment.

The topics of highest attention (energy, thermal comfort and costs) were assessed by eQUEST and the annuity based mortgage model respectively. The attempt to increase reliability of these models is secured by use of reference values from regulation and research; for the cost model by use of experience of building cost consultants. Although the assumptions are well founded, the difference in performance due to the assumptions on user behaviour could not be avoided. The sensitivity on total expenditure from these behavioural changes decreases for concepts with lower primary energy demands.

The used simulation program for energy and thermal conditions being eQUEST was the most appropriate for the demanded tasks within this project. It could take into account the spatial and structural properties (passive) of the house and couple them with the active systems. A number of drawbacks could be found, being the IP-units system (instead of metric), the American system defaults and the range of assessment possibilities (no PMV's).

By use of the various models and integration in BREEAM-NL a score could be given per model, but due to the reduced amount of criteria included in this study the influence on the selling price per weighted percentage is large.

5.3 Conclusions: the scope and limitations

Broadness of the scope
The broadness of scope characterized this research and its outcomes. The amount of topics addressed was large and therefore the level of depth in which they were addressed was not identical for all topics. In general the research gives a clear overview of the needs, problems and possibilities in the Dutch sustainable building practice for the residential sector, specifically terraced houses. Topics as energy, thermal comfort and economic value were highly addressed, which resulted in lower attention for others such as waste management, building materials etc. It should also be noted that some of the topics which might be included in the definition of sustainability were not studied since this project is limited to the conceptual design phase.

Price for sustainability
As concluded before, the measures to achieve a higher level of sustainability are more costly than the current practice. These conclusions and the results of the analysis are highly dependent on the energy price predictions as mentioned several times in the report. As can be observed from the robustness analysis, the changes in energy price predictions could make the concepts financially feasible.

The subsidies for the sustainable energy technologies are not included for the financial analysis in order to show the actual costs and feasibility of the technologies. On the other hand, the subsidy policies are subject to change in years which would decrease the value of conclusions over time.

Sustainability is assessed for the period when the house is in use, but not for the construction and demolition phases. This is due to the fact that the designs are conceptual.

User behaviour
As found in the comparison results, the influence of users on the total energy use in operational period is large. The analysis was done on this topic based on literature search, but the actual effect of specific measures and their influence on the user was not investigated. In dynamic simulation models, ideal user behaviour is assumed. Although the effects of the assumptions are investigated, the depth of the analysis is kept at minimum considering the objectives of this study.

Scale of scope
This project focused on single family terraced house, discarding the other houses in the row, the street around it, the district or the city. As the main conclusion is that implementing sustainability is an expensive practice, the need to broaden the scale of implementation is clear. By that initial system and operational costs can be reduced since the efficiency is increased. Small scale technologies are less efficient and by that cost intensive. On the other hand, district heating is currently still costly in terms of use, higher operational costs are found than use of a gas fired boiler.

Models for simulation
Since the demands for sustainable solutions become more integrated in the current building practice, and following environmental policy plans, the need for integrally assessing simulation models will grow. Designers are forced to comply with these demands and will need models that give direct feedback on their decisions. The coupling of all topics that affect sustainability (basic, ecological, economical, strategic, functional and future value) is therefore necessary. Within this study such a tool was not found, the search for a tool which could practically integrate different passive and active measures in a certain level of detail ended up in a tool, namely eQUEST, which is based on USA practice. 'Work-around' procedures to avoid the conflicts may affect the reliability of the results, so the simulation results are carefully interpreted.

Financial Analysis
As was concluded in the choice of the integral assessment method and while comparing the concepts, the lack of economic assessment for the residential buildings in BREEAM-NL leads to the use of the mortgage model developed for this study. The effects of different parameters on the outcomes are avoided by comparing the concepts to the reference house. Moreover, the mortgage interest rates and the energy price predictions are investigated.

The financial analysis is performed in detail for the period when the building is in use and a life-cycle-costs analysis was not made due to the conceptual framework of the project. The indicators to compare the concepts are chosen to comply with the objectives of the study. However, it was not possible and in the scope of this project to show the value of some measures, such as the improved spatial plan for accessibility and future users.

6 Recommendations

This project has resulted in several conclusions for the main research question as presented in the previous section. These conclusions and the limitations of this study bring about recommendations for further analysis on some topics. These are listed as follows:

- Possible improvements in the designs could be found in the choice of building materials, including more recycled material and types with lower environmental impact (natural sources or small amount of process steps).
- The currently designed spatial plan which gives access on the ground floor for handicapped or elderly is one of the options to achieve accessibility. Although further and more detailed study could be done on this to both improve the accessibility, usability and likeability of the space plan.
- Since the influence of user behaviour is about 50% or higher (also influencing space heating), the focus in creating sustainable houses should include this topic as well as the technical developments, especially when the energy performance of the building increases.
- The building process was not addressed in this project but could give solutions in prefabrication of building elements and reduction of additional costs by integration in the design process. Which amounts of reductions could be made here should be estimated in further research in those fields.
- In terms of technical and financial feasibility, the large scale systems need to be addressed in further detail. They could give a solution for changing energy sources in the future without replacing all heating systems per house. This also accounts for sustainable electricity generation, which is currently already more feasible in large scale than small scale (wind/solar).
- The process of finding an optimum for multiple values of sustainability could be improved if a tool (in terms of software) would be made available that could combine both ‘active’ and ‘passive’ measures. Assessment is currently integrated within the framework of BREEAM-NL, but integrated design is not facilitated yet.
- As was concluded in the choice of the integral assessment method and while comparing the concepts, the lack of attention for the economic value within BREEAM-NL is a point of improvement in order to stimulate the design of sustainable housing for a large share of the residential sector. Awarding designers for sustainable solutions which are also affordable for the user or feasible within their life time is also a topic of sustainable design.
- A detailed research could be done in order to find the best applicable indicator to assess the affordability of sustainable measures.

7 Bibliography

Audenaert, A.; De Clein, S.H.; Vankerckhove, Economic analysis of passive houses and low-energy houses compared with standard houses, (2008), Energy Policy 36 (2008) p. 47-55

Anink, D.; van Ewijk, H.; Haas, M., Handleiding milieuprestaties gebouwen, Final version 1.1, dd. 7.11.2007, (2007)

Algemene Rekenkamer, The price of district heating Part I: Conclusions and Recommendations, (2007), Den Haag, the Netherlands

Clocquet, R.; Boonstra, C.; Joosten, L.; Instrumenten Beoordeling en Promotie Duurzame Kantoren, (2008), DHV B.V., published under authority of SenterNovem

de Boer, B.G., Kondratenko, I., Jansen, D.,Joosten, L., Boonstra, C., Passiefhuis en EPN: Onderzoek naar de waardering van passiefhuizen volgens EPN en PHPP, (2009), ECN, Pettern, the Netherlands

Bollen, J., Manders, T., Mulder, M., Four futures for energy markets and climate change, (2004), CPB Netherlands Bureau for Economic Policy Analysis, The Hague, the Netherlands

Bone, A.H.L.G., Bouwkunde Tabellenboek, (2003), tenHagen&Stam bv, Den Haag

BREEAM Communities, Technical Guidance Manual, Development Planning Application Stage, (August 2009), BRE, United Kingdom

BREEAM-NL v1.0, Keurmerk voor duurzame vastgoedobjecten, Beoordelingsrichtlijn Nieuwbouw, (October 2009), Dutch Green Building Council, Rotterdam, Versie 1.0

BREEAM-NL v1.2 bèta, Keurmerk voor duurzame vastgoedobjecten, Beoordelingsrichtlijk Nieuwbouw, (February 2010), Dutch Green Building Council, Rotterdam, Version 1.2 bèta

Buitenhuis, J.J., Diepe geoterhmie, een onontgonnen warmtebron, (2008), Ventilatie & Verwarming, pp. 494-499

CE Delft, Configuraties en optimalisaties van het warmtenet in Amsterdam, (2008), Delft, the Netherlands

Dessing, J., Praktijkgids bouwbesluit Geluid, (2005), Nederlands Normalisatie Instituut, Delft

Dobbelsteen, van den, A.A.J.F, Modelvergelijking voor de Nederlandse Green Building Tool, (2008), TU Delft, faculty of Architecture, Climate Design & Sustainability, Delft, final report version 2.4 July 1st 2008

Eck, A. van, De 'willingness' to pay' voor een energiezuinige nieuwbouwwoning, (2008), Delft University of Technology, faculty of Architecture, unit Real Estate and Housing, Delft, master thesis

EnergieNed, Basisonderzoek Electriciteitsverbruik Kleinverbruikers BEK2000, (2002), EnergieNed, Arnhem

de Groot, E., Spiekman, M., Opstelten, I., Dutch Research into User Behaviour in Relation to Energy Use of Residences, (2008), ECN, Petten

Haas, M., NIBE's Basiswerk: Milieuclassificaties Bouwproducten, part 1-4, (2008), NIBE Research BV, Bussum

Intelligent Energy Europe Project, Urban wind turbines: guidelines for small wind turbines in the built environment, (2007)

Jansen, D.; Joosten, L.; Clocquet, R.; Raijmakers, T., Uitwerkingsinstructie Toolkitconcepten Passiefhuis, Eengezinsrijwoning Ri7 en Twee-onder-een-kapwoning, (2009), SBR, Rotterdam

Jeeninga, H., Uyterlinde, M., Uitzinger, J., Energy use of energy efficient residences (in Dutch: Energieverbruik van energiezuinige woningen), (2001), ECN, Petten, report ECN-C-01-072

Jong, de, M.; Boer, G.; Bonte, P.; Houwaard, C., Bouwkostenwijzer 2008, (2008), Archidat Bouwkosten bv, Oegstgeest

Jongeneel, W.P. et.al., Binnenmilieu, Recente wetenschappelijke ontwikkelingen en beleid op een rij, (2009), RIVM, Bilthoven, under authority of VROM, RIVM brief report 630789003/2009

Kester, J.C.P.; Zondag, H.A.; Demand Side Management achter de meter, Raming verduurzamingspotentielen, (November 2006), ECN, Petten, the Netherlands

Knudstrup, M.A.; Hansen, H.T.R.; Brunsgaard, C., Approaches to the design of sustainable housing with low CO_2 emission in Denmark, (2009), Renewable Energy 34: 2007-2015

Konstantinidou, E., Micro Combined Heat and Power Systems with combustion engines for single family and multi-family houses-State of the art, (2007), R&D, PEP-Net Project, 6th Framework Program

Koune, F.G.H.; Jong, M.J.M.; Kaan, H.F.; Verwarmingsconcepten PZE-Woning, (2001), ECN, Petten, the Netherlands.

Krutwagen, J.; Kortman, B;Monné, T., Gekwantificeerde milieudoelstellingen voor bouwmaterialen, (2004), IVAM, Amsterdam, research conducted under authority of VROM

Mallory-Hill, S.M., Supporting strategic design of workplace environments with case-based reasoning, (2004), Eindhoven University of Technology, Eindhoven, dissertation

Menkveld, M., Kentallen warmtevraag woningen, (2009), ECN, Petten, the Netherlands

Menkveld, M., Verificatie CO2-meter voor de stichting face, (2001), ECN, Petten, the Netherlands

Nijenmanting, F.C.; Senel, M.S., Assessment of sustainable housing projects, (2010), unit Physics of the Built Environment of faculty Architecture, Building and Planning, unit Sustainable Energy Technology of faculty Mechanical Engineering, Eindhoven University of Technology, Eindhoven, master projects

Novem, Strategisch Kader CO_2-reductie in de Gebouwde Omgeving, (2002), Novem

Rutten P.G.S., Strategisch bouwen, (1996), Eindhoven University of Technology, Eindhoven, inaugural speech.

Ochoa, C.E.; Capeluto, I.G., Strategic decision-making for intelligent buildings: Comparitive impact of passive design strategies and active features in a hot climate, (2007), Building and Environment 43, 1829-1839

Oekoenergie-Cluster, Key Issues for Wood Pellet Market Development, Austria, 2008

Ontwerpgids Meegroeiwoningen, (2009), Vlaams Expertisecentrum Toegankelijkheid-Enter VZW

Opstellen, I.; Bakker, E.; Kester, J.; Borsboom, W.; Elkhuizen, B., Bringing an energy neutral built environment in the Netherlands under control, ECN, 2007

Otter, H.J. den; Heida, H.R., Primos Prognose 2007, De toekomstige ontwikkeling van bevolking, huishoudens en woningbehoefte, (2007), ABF Research, Delft

Paauw, J.; Roossien,B. , Energy pattern generator- understanding the effect of user behaviour on energy systems, (2009), ECN, Petten, Netherlands

Person, M.L.; Roos, A.; Wall, M.; Influence of window size on the energy balance of low energy houses, (2006), Energy and Buildings 38 (2006) 181-188

Poulus, C; Heida, H.R., Woningmarktverkenningen, Socrates 2006, (2006), ABF Research, Delft

RIGO, Gemeentelijk grondprijsbeleid en woningproductie in recessietijd, (2009), RIGO Research en Advies BV, Amsterdam, report no. 12560, under authorisation of Vereniging

Eigen Huis
Rust W.N.J.; Seyffert F.; den Heijer, A.C; Soeter, J.P., Vastgoed financieel, (1997), DUP 1997,Management Studiecentrum, Vlaardingen
SenterNovem, Referentiewoningen nieuwbouw, (2006), SenterNovem, Sittard
SenterNovem, Cijfers en Tabellen, (2007) under authorisation of VROM
SenterNovem, LCA Studie Landelijk Afvalbeheerplan 2, Uitvoering Afvalbeleid, (2008)
Šúri M.; Huld T.A.; Dunlop E.D.; Ossenbrink H.A., Potential of solar electricity generation in the European Union member states and candidate countries, (2007), Solar Energy, 81, 1295–1305
Taskforce verlichting, Groen licht voor energiebesparing, (2008), Eindrapport van de taskforce verlichting
Thormark, C., The effect of material choice on the total energy need and recycling potential of a building, (2006), Building and Environment 41 (2006) 1019-1026
TU/e, Daglicht en scheidingsconstructies, Tijdelijk dictaat voor 'licht' – bouwfysisch ontwerpen 2, Eindhoven University of Technology, Eindhoven
TU/e, Building Physics Lecture notes
US Department of Energy, Annual Energy Review 2008, (2008)
Van der Drift, A.; van Doom, J.; Derickje, E.; Uitzinger, J.; Warmte uit biomassa- Vergelijking van de opties bioWK, kachel en SNG, ECN, January 2007
Valk, H., Praktijkgids bouwbesluit Ventilatie, (2005), Nederlands Normalisatie Instituut, Delft
Veen, van, M.P.; Crommentuijn, L.E.M.; Janssen, M.P.M.; Hollander, de, A.E.M., Binenmilieu-kwaliteit: ventilatie en vochtigheid, (April 2001), RIVM, Bilthoven, RIVM report 630920 001
VROM (Dutch Ministry of Housing, Spatial Planning and the Environment), Nationaal Milieubeleidsplan 4 (NMP4) 'Een wereld en een wil: werken aan duurzaamheid', (June 2001), VROM, The Hague, nota, article code 1076
VROM, Verpakkingen Afval in Nederland, (February 2006)
Weterings, M, GGD Richtlijn Gezonde Woningbouw, (2005), Landelijk Centrum Milieukunde
Wit, J.; Näslund, M, Micro-CHP implementation, (2007), PowerGen Europe, Denmark, Danish Gas Technology Centre
World Commission on Environment and Development, Our Common Future, (1987), Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment August 2, 1987. Retrieved, 2007.11.14
Wouters, P.; Heijmans, N., Considerations concerning costs and benefits with application to ventilation, (February 2004), Belgian Building Research Institute, Division of Building Physics and Indoor Climate, Belgium
Zambolin, E.; Del Col, D., Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions, (2010), Solar Energy, Volume 84, Issue 8, August 2010, Pages 1382-1396

Regulation, standards and guidelines

BRE information paper 15/88: Average daylight factor: a simple basis for daylight design, Building Research Establishment, Watford, UK
BREEAM-NL 2010, KEURMERK VOOR DUURZAME VASTGOEDOBJECTEN, Beoordelingsrichtlijn Nieuwbouw, Versie 1.1, january 2010
BREEAM-NL 2010, Keurmerk voor duurzame vastgoedobjecten, Beoordelingsrichtlijn Nieuwbouw, versie 1.2 beta, (februari 2010), Dutch Green Building Council, Rotterdam.

BS 8206-2: 1992, Lighting for buildings - Part 2: Code of practice for daylighting, British Standard
Dutch Building Decree 2003, January 20th, 2010
GIW/ISSO 2008: Ontwerp- en montageadviezen nieuwbouw eengezinswoningen en appartementen, ISSO.
ISSO 19: Thermisch binnenklimaat, aanbevelingen
ISSO 74: Thermische behaaglijkheid – Eisen voor de binnentemperatuur in gebouwen
NEN 2057 (nl): Daglichtopeningen van gebouwen
NEN 2634 (nl): Terms, definitions and rules to transfer data of costs and aspects of quality for building projects
NEN 5060 (nl): Hygrothermal performance of buildings – Climatic reference data
NEN 5128+A1 (nl): Energy performance of residential functions and residential buildings – Determination method
NPR 5070 (nl): Noise control in dwellings – Examples of stony partition walls and floors, February 2005
NPR 5086 (nl): Noise control in dwellings – Noise control of lightweight partition walls between dwellings, June 2006
NPR 5129 (nl): Energy performance of residential functions and residential buildings – Calculation program (EPW) with handbook
NEN-EN-ISSO 7730 (en): Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.
SBR Referentiedetails woningbouw, (mei 2002), SBR, Rotterdam

Websites

Bespaardaar website:
http://www.bespaardaar.nl/html/maatregel_11.php, visited 01/09/2010
Energieprijzen website:
http://www.energieprijzen.nl/rekentool/stroomgasproduct.php?pid=1985&aid=EGPZ&pc=3500AA&tarief=ET&m3v=1800&hv=3500&lv=0&vgid=CM&aansluiting=A1X025,visited 06/09/2010
CBS: Average household water consumption change in the Netherlands,
http://www.cbs.nl/en-GB/menu/themas/natuur-milieu/publicaties/artikelen/archief/2008/2008-2527-wm.htm, visited 06/09/2010
Compendium voor de leefomgeving:
http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0037-Waterverbruik-per-inwoner.html?i=26-113, visited 06/09/2010
Milieucentraal website:
http://www.milieucentraal.nl/, visited 21/09/2010
Monitweb, Energy information website by ECN:
http://www.energie.nl/index4.html, visited 03/09/2010
Whole Building Design Guide (WBDG) by National institute of Building Sciences: http://www.wbdg.org/resources/lcca.php, visited 12/03/2010
Senternovem SDE website:
https://www.senternovem.nl/sde/zonnepanelen/index.asp, visited 08/09/2010
Stadsverwarming, Eneco
http://zakelijk.eneco.nl/Productenendiensten/Warmtekoude/Pages/Stadsverwarming.as

px
visited: 10/09/2010
Stichting Natuur en Milieu, TOP10:
http://www.top10.hier.nu/, visited on 10/09/2010

Appendices

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15 Details and Modelling of Concepts

1 Division of tasks

Within this project, both students contributed in an equal workload, but both focusing on the topics of their own specialty. The main setup of the project was constructed by both. Also all the meetings which were part of this project were attended by both. In order to give the reader insight in the different parts where the main work was done by the one or the other, Table 58 shows an overview of the main tasks within the scope of this project.
Where a task is mentioned in combination with a specific person, this implies the major work is done by this person. He or she wrote down the major text in that part or built up the specific model. This work is in general reviewed by the other and discussed by both in order to make improvements when necessary.

Table 58: division of tasks

Graduation proposal: methodology of project		
	Decisions on methods, planning and process	Both
Workshop/excursion		
	Compiling information booklet	Sinan
	General setup/contact; summary	Both
Report (and analysis)		
	Preface	Filique
	Summary	Both
1	Introduction	Filique
1.1	Preliminary study and results	Sinan
1.2	Research setup	Filique
2.1	Topics of interest	Sinan
2.2	Boundary conditions	Filique
2.3	Assessment method	Filique
2.4	The performance assessment tool	Sinan
3	Results: Analysis and Design, introduction	Both
3.1.1	Thermal comfort	Filique
3.1.1.4	Terminal systems analysis	Sinan
3.1.2	Indoor air quality	Filique
3.1.3	Visual comfort	Filique
3.1.4	Acoustic comfort	Filique
3.1.5	Spatial comfort	Filique
3.1.6	CO_2 emissions	Sinan
3.1.7	User behaviour	Sinan
3.1.8	Building materials	Filique
3.1.9	Water use	Sinan
3.1.10	Waste	Sinan
3.1.11	Economic value	Filique
3.1.11.4	NPV analysis of systems	Sinan
3.2	Conclusions from analysis per topic	Both

4	Discussion: Concepts and comparison	Both
5	Conclusions	Both
6	Recommendations	Both
7	Bibliography	Both

Modelling work

Autocad drawings	Filique
eQUEST – Building structure	Filique
eQUEST – HVAC systems	Sinan
Costs: mortgage model (Excel)	Filique
Costs: building costs model (Excel)	Filique
Daylight: ADF model (Excel)	Filique
Domestic hot water systems (Excel)	Sinan
Building materials: Greencalc+ V2.20	Filique
Spatial comfort assessment (Excel)	Filique
BREEAM-NL criteria assessment	Filique

Appendices

1	Division of tasks	Both
2	Definitions	Both
3	Excursion summary	Both
4	Reference house description	Filique
5	BREEAM-NL categories	Filique
6	Background: thermal comfort	Filique
7	Comparison of terminal systems	Sinan
8	Background: indoor air quality	Filique
9	Background: visual comfort	Filique
10	Background: acoustic comfort	Filique
11	Background: CO_2 emissions	Sinan
12	Background: water use	Sinan
13	Background: economic value	Filique
14	Details of parametric study	Filique
15	Details of modelling concepts: 15.1 and 15.4	Sinan
15	Details of modelling concepts: 15.2, 15.3, 15.6, 15.7, 15.8	Filique

2 Definitions

Definitions of terms and abbreviations	
ADF	Average Daylight Factor
BREEAM-NL	Beta version of BREEAM-NL residential buildings which is published in March 2010
EPC	Energy Performance Coefficient
GFA (in Dutch: BVO)	Gross Floor Area (in Dutch: Bruto Vloer Oppervlak)
HVAC	Heating Ventilation Air Conditioning
NEPP (in Dutch: NMP)	National Environmental Policy Plan (in Dutch: Nationaal Milieubeleids Plan)
Passive House	German standard on passive houses with assessment method PHPP, including demands for space heating and total energy use in kWh/m^2
Passive concept	The passive concept is developed for this study to illustrate the effectiveness of the passive design strategies (solutions/systems) to achieve the predetermined goals
VAT (in Dutch: BTW)	value added tax (in Dutch: BTW = Belasting over Toegevoegde Waarde)
V.O.N.-price	Total selling price (in Dutch: Vrij op Naam prijs)
VT (in Ducth: LTA)	Visible Transmittance (in Dutch: Licht Toetreding Absoluut)
SHGC (in Dutch: ZTA)	Solar Heat Gain Coefficient (in Dutch: Zon Toetreding Absoluut)

3 Excursion summary

Summary: excursion on affordable and sustainable housing, London: 11-12th of February 2010. By Filique Nijenmanting and Sinan Senel, February 17th, 2010

This document summarizes the presentations and discussions which were held during this excursion. Purpose is to share the total experience of the two-day excursion with all participants. Per topic, some background documents can be found in the appended folder. The references to these are given on top of each subject.

Participants of both days: ir. Bart Kramer (Sustainability consultant at Arup Amsterdam), Léon van Maurik (Marketing manager Benelux at Kingspan Sustainable Building systems), Filique Nijenmanting (graduating student Building Physics TU/e and intern at Arup Amsterdam), Sinan Senel (graduating student Sustainable Energy Technology TU/e and intern at Arup Amsterdam). All partly participants are introduced below, per topic.

3.1 Day 1, Arup office, 8th Fitzroy Street

3.1.1 Speech by graduating students: Filique Nijenmanting and Sinan Senel

In a short introduction, the purpose of the excursion was explained, being the search for design methods, design criteria and aimed strategies in the process to affordable sustainable housing concepts for the Netherlands.

Figure 42: Presentation sheet 5: topics of attention as found in preliminary study

Assessment of sustainable housing projects

A finished project by theses students considers a description of trends in sustainability in houses and a method to assess sustainability strategies in finished housing projects. The main trend which has been found is a main focus on energy reduction by use of the energy performance certificate (deducted from EPBD). The assessment method to find strategies in 6 case studies is compiled from assessment and design methods 'BREEAM-NL' and the 'Model of Integrated Building Design' (Rutten). The BREEAM-NL criteria were simplified to qualitative values, being yes/no for most criteria. The search focused on the topics which were addressed in the design, and it concluded in the topics which lacked attention. Main conclusions of this study can be found in different categories of BREEAM-NL. These are shown Figure 42.

Design of an affordable and sustainable home for the Netherlands

The topics which lack attention have lead to a list of attention fields for the current graduation project, in which the students will work on the design of an affordable and sustainable home for the Dutch region. This design project will consider a broad view on sustainability, and the integral aspects of the design process are a central part of the methodology.

3.1.2 Speech by Chris Twinn: Sustainability in policy and trends

Chris Twinn is the leader of the Building London Sustainability Group at Arup. He discusses learning points from early phase sustainable building projects and reflects these points on the current practice. The view on carbon trends leads his thoughts to the solutions for the future, being a robust design, since this will possibly decrease energy from user behavior (e.g. currently hot water gives the major energy demand for a home).

Figure 43: Chris Twinn

Learning from practice:
BEDZed
As requested, he shortly indicates the advantages and drawbacks of the BEDZed project. In this project the whole building team was enthusiastic, which is special since many times one or more parties are critical and less willing to join in the strategies to sustainability. Maybe due to this enthusiasm, the amount of innovation (new technologies) which was integrated in the design was too much. The difference with other houses was by that too large. For example, the combined heat and power boiler only worked for 6 months. When new parts had to be ordered, it was found that the supplier busted.

Due to practical problems, less insulation was used than prescribed in the design stage. Also some 'weird' corners evolved from the turning capacities of some building machines on site. These aspects show that there is more to a good integral design than choosing materials and making design. Building practice is an important factor to take into account in order to come to the planned result.

General
New technologies like phase change materials are presented as replacing measures for thermal mass, though the time lapse in which they function is completely different, which also affects the total house performance (example Barratt Green House vs. Lighthouse).

Smart metering systems will be mandatory in some yeas in the UK. It is assumed that they will reduce the energy use for some time, but when occupants get used to it, the normal behavior might return.
Sizing of renewables in housing can be a topic of discussion, since efficiency is mostly higher when they are applied on a larger scale than single-house.

The danger of energy efficient measures are found in the final use of them: if a measure is very efficient, one might think it can be used more. By that energy demand will rise after all.

Costs
He sees a trend in the sustainability topic that materials and systems are on the market in a broader level. This will bring down the prices and increases quality. So applicability of sustainable building projects has been improved in the last decade. It takes some time for innovations to be implemented in the building industry, since regulation has to be driving factor in that. The funding of innovations is critical, since investors have to be assured that technologies will give profit at the end.

An example of the cost reductions for sustainable design is the Kingspan Lighthouse project. He estimates a 30% extra investment above normal building costs (for sustainable measures) at the moment it was designed (about ten years ago). When it would have been built in current time, this percentage could be lower, about 10% extra costs.

Carbon
The amount of available carbon is influencing the sustainable building sector in two ways: the contribution it has to global warming and the depletion of fossil fuels. The reduction of carbon in the built environment is many times defined in carbon per capita. This will not hold, since the global K policy is stricter than the European goals on carbon reduction: 80% reduction in 2050. Mr. Twinn points out the importance on changing the trends in up going carbon use for this moment. He predicts an increase of costs per amount of carbon reduction in the future.

The right type of energy should also be used in the right place. In that perspective, buildings should make use of lower quality energy than they do now. Renewable energy sources are available, but the carbon reduction which follows from them can only be claimed by one party! This is a result of the greenwashing strategy of companies: the use of sustainable measures in their promotion, when these measures are less effective than claimed.

The carbon discussion and attention for it is positive, though he notices that regulation is only based on reduction of carbon and does not (or in a minimal way) take other factors into account. But he has to acknowledge that when focusing on all aspects at once, nothing will be done at the end.

Performance assessment
Since the European Performance for Buildings Directive (EPBD) is introduced, many countries have translated it to a energy certificate which assesses the design of the building. The UK introduces two energy labels, one for designed performance and one for actual performance when in use. A building could have level C for design, but F (worse) for actual performance).

3.1.3 Speech by Bob Giles: Affordable Eco Residences

Bob Giles is the Product Design and Product Development Manager of the University Partnership Program (UPP). The UPP facilitates residential facilities on student campuses by building and managing them during the operational phase on university ground, and selling the property back to university at end of lifetime.

Figure 44: Bob Giles

He discussed sustainability from a commercial point of view with a focus on costs. The discussion was driven by the project that UPP carried out with Lancaster University. The project was awarded with BREEAM Excellent and cost effectiveness was important issue because the rents should be affordable for students.

He mentioned additional costs of reaching passive house levels (around 20-25%) are not only due to material and system costs but also due to the labor costs. For example, air tightness was mentioned to be practically hard to achieve so corresponding labor costs are higher compared to conventional building processes. So, for the cost analysis and decisions practical difficulties should be taken into account.

Figure 45: Affordable Eco Residences

Mr. Giles also mentioned that water saving measures have a payback time around 20 years, so it's not interesting in terms of cost effectiveness from investor's point of view. So, payback time is an important factor to take into account and different parties have unique interpretations. This illustrates the fact that cost analysis should be performed from a certain perspective that we would like to focus. He concludes that 'simple' measures are most effective and feasible: solar thermal energy gain, high insulation and a good airtight box. And measurement/monitoring of energy use is one of the most expensive parts of low energy house design.

Reduction by competition

Although monitoring is a costly measure depending on the level of implementation, they installed monitoring facilities in the dormitories for students to decrease their energy consumptions. UPP organized a competition between students such that the students with the least energy consumption were rewarded. This incentive improved their behaviors. However, their point was not to decrease the consumption for environmental reasons but for economical reasons because the company had to pay the utility bills. This means that different parties have different benefits and interests and a successful project should satisfy these demands.

3.2 Day 2: BRE Innovation Park

3.2.1 Visit of the Housing Projects:

Figure 46: Graham Hardcastle

In the innovation park sustainable housing projects were visited. Prior to the visits, Graham Hardcastle who is Innovation Park Liaison Officer gave a presentation about the innovation park and the projects. One of the most important points he mentioned was that the projects in the innovation park is part of the learning process and the mistakes in the application constitute an important part of this. Projects in this park were built for a fair which was held in 2007.

Figure 47: The Hanson Eco House

3.2.2 Hanson EcoHouse - CSH 4

This house was designed to reach Level 4 of the Code for Sustainable Homes. It was designed such that the heat is generated in the bottom part of the house and excessive heat is extracted from the roof opening by making use of the 'kiln' like shape. (The small model of a kiln which can be seen in front of the house represents this similarity). Materials are chosen for their thermal mass, in order to flatten the peaks in heating and cooling demands. The facade is constructed from a steel structure which holds brick panels. A roof opening is both useful to release the heat and increase the daylight level, which was quite satisfactory. The first floor of the house is spacious due to the kiln shape. Its open plan makes the house more suitable to young couples than for families.

A ground source heat pump is used in the house for energy needs but the operation of the pump was problematic. The roof cladding is made of zinc which was worn out in time. Water recycling pumps were also noisy in operation.

3.2.3 Barratt Green House - CSH 6

Figure 48: Barratt Green House

Barratt Green House is designed to achieve Level 6 of the Code for Sustainable Homes. Retractable sun shading devices can be controlled by the control system, which enhances daylight levels and decreases solar gains when necessary. Indoor environments of all the rooms are independently controlled by touch screen panels and the house is equipped with an expensive IT system. All the utilities in the house are placed in the attic which decreases the maintainability of the house. Although some small details are quite smart from an architectural point of view, some details in the house were unsatisfactory (such as an air inlet next to the bedside). Space efficiency is created with a drying space above the central staircase. The existence of LCD screens in each room, which is costly, can be questioned in a sustainable house. Attention for waste separation and cycle storage are given by a cabin op recycled glass material in the appending carport.

3.2.4 Renewable House - CSH 4

The Renewable House is designed for Level 4 of the Code for Sustainable Homes. The most differentiated feature is that hemp is used together with lime in the timber frame walls. The house is designed to be an affordable house and build cost is given as £ 75.000. The 'strange' smell, which is claimed to be due to soya based paint, is an unexpected problem of using

Figure 49: Renewable House

organic materials. The simple design of the house makes it suitable for social housing.

Foundation of the house is specially designed and insulation materials are used together with concrete, which reduces the use of concrete and insulates the house from the ground. However, extensive use of steel and complexity of the foundation can be questioned for its sustainability.

Changing needs for occupants during their life is taken into account in the space-plan: large door openings, no bumps and space for elevator installation are designed.
An air/water heat pump is installed next to the front door, which transports its heat to room radiators (which is not most efficient due to different design temperatures).

3.2.5 Kingspan Lighthouse - CSH 6

Figure 50: Kingspan Lighthouse

The Kingspan Lighthouse has achieved level 6 of the Code for Sustainable Homes as the first home in UK. The walls are timber frame with TEK panels and cladding is made of sweet chest nut wood. The interior planning of the house is spacious and daylight level is quite satisfactory. Although the curved façade enhances the surface area of the roof, it is claimed to pose some practical problems during construction phase. Automatically controllable ventilation openings are quite functional for natural ventilation. The solution to improve the natural ventilation, namely 'Wind catcher', on the roof is quite expensive for the little extra stack effects it creates.

Sweet chest cladding caused contamination in the rain water recycling system because the cladding was dissolved by the rain water.

Manually controlled retractable shutters are heavy and hard to operate, though shutting them is critical in summer. A boiler is installed on ground floor, which cannot be reached for replacement or maintenance, since it is built in during construction and opening is too small.

3.2.6 Speech by Paul Newman: Lighthouse and Other Stories

Paul Newman is the technical director of Kingspan offsite.
Brian Bengry works for Kingspan Insulation.

Throughout his presentation he talked about the Code for Sustainable Homes, Kingspan Lighthouse, Hanhan Hall and Brodsworth projects.

Code for Sustainable Homes

As a material supplier, Kingspan is involved in the developments and changing demands in the UK regulation. Adaptability is important, since different regions set their own demands. Some difficulty in reaching these levels are hat energy should be produced on site to be awarded by the code, though larger scale generation is more efficient in general. Another inconsistency can be found in the ecological topic, in which some credits excluded if others are gained. The total building costs are affected for about 80% by the investment in energy reduction measures.

Figure 51: Paul Newman at Kingspan Lighthouse

Like Chris Twinn has mentioned in his presentation on Day 1, Paul Newman also points out the struggle with a low attention for quality which is lead by a main search for cost reduction by the UK housing developers.

Hanham Hall and Brodsworth projects

These projects include both applications in the building level and in the district level. He mentioned different strategies to achieve levels in the code for sustainable homes. As one of the strategies, the design of the building can be focused on the building fabric and increasing the thermal performance of the building or thermal performance of the fabric can be compromised and instead some renewable technologies can be applied to meet the higher demand due to relatively poor thermal performance of the building fabric. Another strategy they put forward was to improve the air-tightness of the building and include a mechanical ventilation system since the natural ventilation would not be enough to supply fresh air into the building. Costs of these strategies should be questioned for the design decision. Paul Newman and Brian Bengry define the affordable house as social housing.

3.2.7 Speech by Justin Wimbush: 'Sustainability & Affordability' in housing

Justin Wimbush is a senior mechanical engineer at Arup London office.

Figure 52: Justin Wimbush

Throughout his presentation, he tried to show the feasibilities of different strategies to achieve sustainability. The importance of the location for renewable energy technologies is mentioned. The de-carbonizing of the electrical grid in the future should be also taken into account while designing homes considering the lifetime. It was also noted that extra costs related to the application of low carbon technologies are reduced by increasing the size of the development or number of units.

Bottlenecks to renewable energy technologies are explained and as a result he pointed out that in small scale these technologies are either not feasible or not advantageous. Therefore, the application of renewables in community scale seems to be the most feasible option for now in terms of costs and efficiency.

Introduction of feed-in-tariffs is an important factor to install these technologies and to achieve sustainable solutions in a cost effective way. So, local conditions including the government policies and technology developments should be considered carefully to decide which solutions to use in the design.

3.3 Discussions and learning points

Throughout the excursion, some moments of thought took place in the meeting rooms during or after the presentations. Also the travelling group of Dutch participants took their time for discussion on the road. Some of the main discussion topics are summarized here and the main learning points and insights as we experienced them are summarized.

3.3.1 Learn by doing? Or learn before doing?

As could be seen in the BRE Innovation Park, the houses which were built have taken a shot in the good direction. They were built in a short notice, but the drawback of that is the result of some crucial problems in the designs. The question rises if this approach is the right one, or that research and design should have a larger share in the process to prevent mistakes. The outcome of the Innovation park method is a number of buildings which clearly show the advantages and drawbacks of sustainable design methods and gives clear learning points for the future. But could we have learned more if the design was more carefully made? As we take the BEDZed example, this was driven by enthusiasm, but it apparently resulted in the lack of practical insight. Some design decisions resulted in changes during the building process, the feature of the CHP resulted in a failure of the system.

3.3.2 Learning points

The learning points below are interpreted from all excursion program parts by the graduation students. One might have other learning point for themselves.

Figure 53: Sharing

1. **Conflicts in design and practice**

The intentions of an architect or engineer for a building design could be perfect, honest and well calculated. But when translating these intentions and solutions to building practice, many changes can occur which can influence the final outcome of the building performance tremendously. New solutions might not be proven and lack robustness, demands for air tightness are hard to be met by the builders on site and the wanted size of materials might not be supplied. And if all has come together to a final product, one can only hope that user behavior will comply with the designed loads.

2. **Policy or market driven innovation**

As indicated by several speakers during this excursion, it is still hard to find the balance between environmental and economical values in a project. Partly this difficulty could be dissolved by help from the government (in policy or funding), but the building process could be improved too if many contributing parties are brought together at the start of the design process. The sustainability levels of the Code for Sustainable Homes are set out by the national government in the UK, but local governments and developers are competing with each other to reach higher levels than demanded. This puts pressure on the designers and suppliers so that they are stimulated to innovate or utilize improved solutions.

4 Reference house description

In order to compare the designed concept to the reference situation, SenterNovem Reference house, type terraced house with balanced ventilation, was chosen for this project. The tables and figures below present the details as were collected from Referentiewoningen nieuwbouw 2006.

Table 59: Specifications of SenterNovem Reference house: terraced house

General	
Validity	Complying with building regulations of January 1st, 2006
Details	- Expanded method for calculation of linear cold bridges (psi-values by SBR). Additional 25% psi-value (1,25) for incorporating practice failures. - Standard details: comfort and basic detail types are both used (by SBR reference details for housing)
Design strategy	- Trias Energetica (as much as possible) - Compatible with current practice, realistic, affordable and general applicable
EPC	- No use of equivalency declarations - Use of quality declarations - EPC ≤ 0.8
Health and Comfort	Considered
Typology	Terraced house, 2 sided sloped roof (slope 43°)
Thermal capacity	High: massive structural walls, massive inner façade walls
Size	
Width (NL: beukmaat)	5.1 m
Depth	8.9 m
Room height	2.6 m
Useable surface A_g	124.3 m^2
Surface of loss $A_{verlies}$	156.9 m^2
Ratio $A_g/A_{verlies}$	0.8
Ground floor surface	46.2 m^2
Roof surface	60.8 m^2
Total of closed surfaces	37.2 m^2
Windows front façade surface	9.4 m^2
Windows back façade surface	14.8 m^2
Surface closed doors	2.4 m^2
Building technical	
$R_c$value façade	3.0 m^2K/W
$R_c$value roof	4.0 m^2K/W
$R_c$value ground floor	3.0 m^2K/W
U-value windows	1.8 W/m^2K
U-value front door	2.0 W/m^2K
External sun shading orientation	South, fixed
ZTA	0.6
Wall material	Brick slabs

Infiltration: q_v10; kar/m^2	0.625 dm^3/sm^2
Building services (based on balanced ventilation)	
Type of heating system	HR-107 heater, with high temperature radiators
Type of ventilation system	Mechanical inlet and exhaust
Efficiency of heat recovery	95% (by help of quality declaration)
Type of fans	Direct current
Type of hot water system	Combiketel HRww CW4
Efficiency of how water	62%

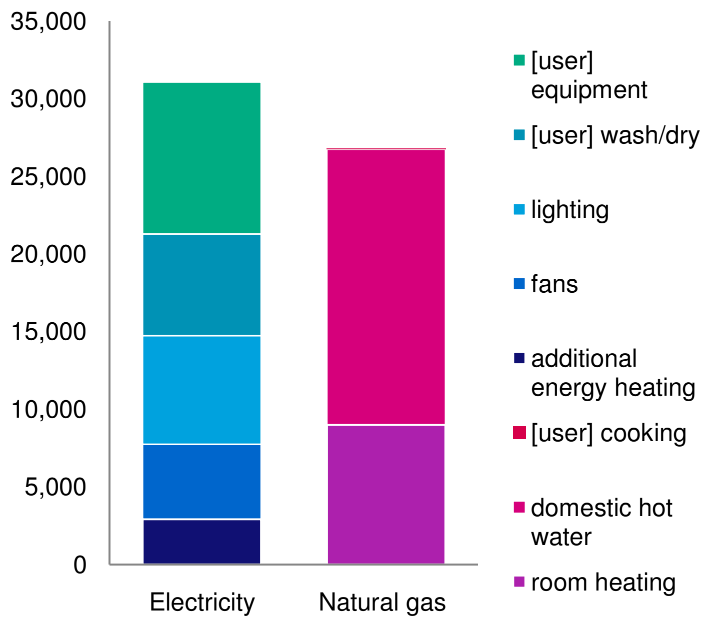
Energy performance	
EPC by NPR 5129, version 2.02	0.74
Yearly energy use per m^2 by NEN 5128	340 MJ/m^2
Yearly CO_2 emissions	2521 kg

Detailed energy use is given in the EPC calculation and presented in Table 60 below. This calculation is based on the method of January 1st, 2006.

Table 60: Detailed energy use by EPC, January 1st 2006; User energy from: de Groot 2008

Energy use according to EPC (2006) and de Groot 2008, all in MJ/year primary energy

Heating	8989
Additional energy	2917
Domestic Hot water	17756
Fans	4819
Lighting	7012
Summer comfort	722
User: cooking	63
User: equipment	6535
User: wash/dry	9793
Total	**42215**
Qpres;toel	**45893**



Drawings of the reference house are presented in Appendix 15.

Literature

Referentiewoningen nieuwbouw, 2006, SenterNovem, Sittard

de Groot, E., Spiekman, M., Opstelten, I., Dutch Research into User Behaviour in Relation to Energy Use of Residences, ECN, Petten, 2008.

5 BREEAM-NL categories

BREEAM-NL is based on the assessment per topic of sustainability. For each criteria topic a certain amount of points can be achieved according to the description of that criteria (e.g. for ENE1 CO2 emissions 1 credit can be achieved per 10% reduction of CO2 emission) .The awarded credits per criteria are weighted with the percentages as given in the second column of Table 61. The total weighted percentage of all available credits leads to a label for the design being pass (30%), good (45%), very good (55%), outstanding (70%) or excellent (85%).

Table 61: BREEAM-NL categories, v1.2 february 2010, residential sector

Category	Weight	Indicator	Criteria	Credits
Management	**12.0%**	MAN1	Performance insurance	2
		MAN2	Building site and surroundings	2
		MAN3	Environmental impact of building site	4
		MAN4	User manual	1
		MAN8	Safety (elective)	1
Health and Comfort	**15.0%**	HEA1	Daylight	1
		HEA8	Internal air quality	2
		HEA10	Thermal comfort	2
		HEA13	Acoustics	1
		HEA14	private outdoor space	1
		HEA15	Accessibility	2
		HEA 16	Flexibility	2
Energy	**19.0%**	ENE1	CO2 emission reduction	15
		ENE4	Energy efficient outdoor lighting	1
		ENE5	Use of renewable energy sources	3
		ENE 8	Energy efficient elevators	2
		ENE10	Thermal quality of building skin	2
		ENE 11	Insulation values	2
Transport	**8.0%**	TRA1	Availability of public transportation	2
		TRA2	Distance to local amenities	1
		TRA3	Bike shed	1
Water	**6.0%**	WAT1	Water use	1
		WAT5	Water recycling	2
		WAT6	Irrigation system	1
Materials	**12.5%**	MAT1	Building materials	6
		MAT3	reuse of building façade	1
		MAT4	reuse of building structure	1
		MAT5	Well-founded origin of materials	4
Waste	**7.5%**	WST1	Construction Site Waste management	3
		WST3	Storage space for recyclable waste (household)	1
		WST5	Compost (only for houses with garden)	1
Land use and ecology	**10.0%**	LE1	Reuse of land	5
		LE3	Existing flora and fauna on location	1
		LE4	Flora and fauna as joint users of the planned area.	2

		LE9	Efficient ground use	2
Pollution	**10.0%**	POL1	GWP van cooling resources for climate control	1
		POL4	Space heating related NOx emission	3
		POL5	Building protection against flooding	3
		POL6	Minimizing pollution of surface water run-off	1

Credits as they were used within this project are summarized in. The table gives for each criteria the name and choice to use or not use it in the project, including short argumentation. The amount of achievable credits in the original version of BREEAM-NL is given and the achievable credits in this study. Those result in the adapted achievable weighted percentages. These are deducted from the weighting in the second column, but converted in order to make 100% achievable in this study.

Table 62: Choice of used BREEAM-NL credits and the new weighting.

Topic	Weight	Indicator	Criteria name	Assessment method		Applicability			Available credit points		Weight
	BREEAM %			in BREEAM-NL	Y/N	if No reason	if Yes Specific point of interest	if Yes Value domain	in BREEAM-NL	in study	in study %
Management	12,0%	MAN1	Performance insurance	measurement after built	N	conceptual design			2		0,0%
		MAN2	Building site and surround	policy during built	N	conceptual design			2		
		MAN3	Environmental impact of b	policy during built	N	conceptual design			4		
		MAN4	User manual	checklist of content	N	conceptual design			1		
		MAN8	Safety (elective)	PKVW checklist	N	no PKVW check possible			1		
Health and Comfort	15,0%	HEA1	Daylight	BRE-formula	Y		visual comfort	basic	1	1	25,0%
		HEA8	Internal air quality	NEN calculation	Y		internal air quality	basic	2	2	
		HEA10	Thermal comfort	dynamic simulation program	Y		thermal comfort	basic	2	2	
		HEA13	Acoustics	NEN 12354; NEN 5077	Y		acoustic comfort	basic	1	1	
		HEA14	private outdoor space	check, size	Y		spatial comfort	basic	1	1	
		HEA15	Accessibility	check, size	Y		spatial comfort	basic	2	2	
		HEA 16	Flexibility	-	Y		spatial flexibility	strategical	2	2	
Energy	19,0%	ENE1	CO2 emission reduction	EPC calculation	Y		CO2 emission	ecological	15	15	31,7%
		ENE4	Energy efficient outdoor li	power, control, placement	N	prescriptive, in ENE1			1		
		ENE5	Use of renewable energy	sentemovem protocol	N	for this study: in ENE1			3		
		ENE 8	Energy efficient elevators	product information	N	no elevator expected			2		
		ENE10	Thermal quality of building	measurement after built	N	conceptual design			2		
		ENE 11	Insulation values	Rc-values	N	for this study: in ENE1			2		
Transport	8,0%	TRA1	Availability of public trans	distance	N	location not specified			2		0,0%
		TRA2	Distance to local amenities	distance	N	location not specified			1		
		TRA3	Bike shed	check; size	N		users: bicycle use	ecological	1		
Water	6,0%	WAT1	Water use	volume flows, product info	Y		users: water use	ecological	1	1	10,0%
		WAT5	Water recycling	check; size	Y		users: water use	ecological	2	2	
		WAT6	Irrigation system	check	N	location not specified			1		
Materials	12,5%	MAT1	Building materials	shadow price;Greencalc	Y		embodied energy	ecological	6	6	20,8%
		MAT3	reuse of building façade	based on current building	N	no renovation			1		
		MAT4	reuse of building structure	based on current building	N	no renovation			1		
		MAT5	Well-founded origin of ma	TIER level + calculation tool	N	out of scope			4		
Waste	7,5%	WST1	Construction Site Waste n	policy during built	N	conceptual design			3		12,5%
		WST3	Storage space for recycle	check; size	Y		waste recycling	ecological	1	1	
		WST5	Compost (only for houses	check	Y		composting facilities	ecological	1	1	
Land use and ecology	10,0%	LE1	Reuse of land	location lists; maps	N	location not specified			5		0,0%
		LE3	Existing flora and fauna o	ecologist	N	location not specified			1		
		LE4	Flora and fauna as joint u	check	N	only for community space			2		
		LE9	Efficient ground use	size; ratio	N	equal for all			2		
Pollution	10,0%	POL1	GWP van cooling resources for climate control	type of material	N	out of scope			1		0,0%
		POL4	Space heating related NOx emission	NOx calculation	N	out of scope			3		
		POL5	Building protection against flooding	location reports	N	location not specified			3		
		POL6	Minimizing pollution of surface water run-off	NEN demands	N	out of scope			1		
TOTAL			39		13				89	37	
Percentage	100,0%								100%	100%	100,0%

Literature

BREEAM-NL v1.2 bèta, Keurmerk voor duurzame vastgoedobjecten, Beoordelingsrichtlijk Nieuwbouw, February 2010, Dutch Green Building Council, Rotterdam, Version 1.2 bèta

6 Background: thermal comfort

Comfort in the human body will be achieved when the thermal energy balance between the body and surroundings is stable; the body is neither gaining nor losing heat. When this situation of thermal comfort occurs depends on several parameters. By means of climatic room research by Fanger in the 80's, comfort could be described by the Predicted Mean Vote (PMV). This value (if zero) indicates the point on which most people feel comfortable and little will be dissatisfired (Predicted Percentage of Dissatisfied, PPD).

Main research on this was done on offices, and some results of this are discussed. On the other hand, the health services in the Netherlands give advice on practical measures in houses to achieve thermal comfort.

6.1 PMV method

This parameter combines different comfort values to one figure, including parameters considering the surrounding (air temperature, mean radiant temperature, relative humidity, air velocity (maximum of 0.2 m/s)) and parameters considering a person (activity rate and clothing level). The values differ between -3 and +3 indicating very cold to very hot and zero being neutral. The relation between predicted mean vote and percentage of people dissatisfied is given in Figure 54 on the left. The percentage of people which is dissatisfied at a -0.5<PMV<+0.5 is about 10%. Figure 54 on the right shows the influence of local discomfort caused by radiant temperature asymmetry.

Description of thermal comfort by relation to PPD and local discomfort

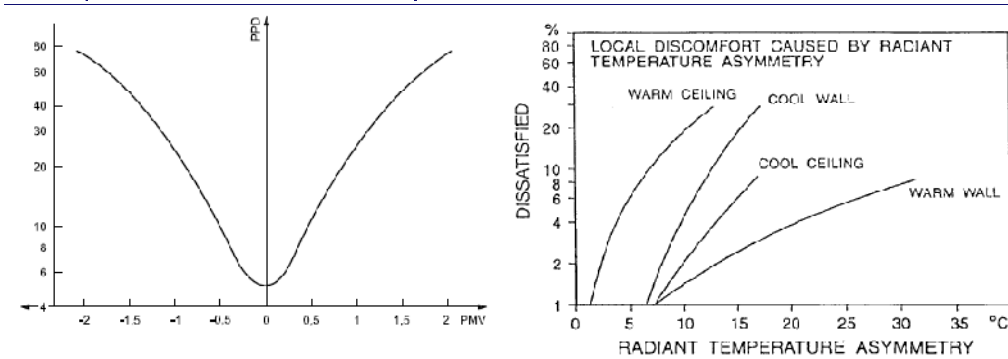


Figure 54: Relation between PMV and PPD (left) and percentage of people dissatisfied in relation to local discomfort caused by radiant temperature asymmetry (right).Source: NEN-EN-ISSO 7730

Recommendations for design in order to prevent local discomfort are:

- Air speed ≤ 0.15 m/s
- Vertical temperature difference between 0.1m and 1.1m above floor level ≤ 3K
- Floor temperature 19-26 °C (exception for bathroom 29 °C)
- Radiant asymmetry (vertical) of ceilings and floors, temperature difference ≤ 5K
- Radiant asymmetry (horizontal) of windows

Since the assessment method for thermal comfort works by the PMV, it is interesting to see which aspects influence this value the most. Some parameters can be influenced by the building design, but the activity rate and the clothing level cannot. For these, some standard values have to be taken into account. Prediction of these is not easy, since they depend on the time of day (and year), the room function and user behavior. The clothing level can vary between 0-2 clo and the activity level varies between 0.8-4 met.

ISSO 19 publication indicates the sensitivity of PMV parameters for office circumstances. The summary of these is presented in Table 63. It shows a high influence of clothing and metabolism (the parameters which cannot be influenced by the building) in relation to the building depended parameters. For the building related parameters, the air temperature and air velocity are of highest importance. Therefore the focus in study is mainly on air temperature.

Table 63: Sensitivity of PMV parameters, source: ISSO 19

Sensitivity	Parameter change	Influence
Clothing	+/- 0.1 clo	+/- 0.14 PMV
Metabolism	+/- 0.1 met	+/- 0.14 PMV
Air temperature	+/- 0.2 K	+/- 0.022 PMV
Mean radiant temperature	+/- 0.2 K	+/- 0.016 PMV
Air velocity	+/- 0.2+0.07 var m/s (var = mean velocity in relation to the body)	+/- 0.03 PMV
Relative Humidity	+/- 10%	+/- 0.05 PMV

6.2 Measures for thermal comfort

Achieving thermal comfort in the residential sector can be achieved by following measures that are proven in practice. A list of these is presented below in Table 64.

Table 64: measures to achieve thermal comfort

Measure
Prevention of overheating • Window areas and orientation (heat gain from the sun) • Seasonal shade (heat gain from the sun) • Insulation of the building envelope • Minimizing / avoiding thermal bridges (temperature differences) • Surface to floor area ratio of the building shape • Air tightness of the building envelope (control of the air flow) • Ventilation strategy (natural, mechanical, thermal mass activation) (Knudstrup 2009)
Orientation • Place the garden or balcony on the south (sunny) side *Space* • Do not compartmentalize the house • Place functions like entrance, kitchen and bathroom and 'cool' bedrooms on the north. • Do not design room functions under a sloped roof with just a roof window as ventilation measure, provide extra mechanical ventilation supply.

- Design a closed kitchen or a damp screen with a minimum height of 40 cm on the ceiling between kitchen and living room.

Shape

- Large roof overhangs or integrated sun/light reflection and high parapets of 50-60 cm.

Skin

- Windows included with sun shading (wind resistant)
- Built without a crawling space under the ground floor, or a very air tight ground floor, well sealed on the edges and openings.
- Give extra attention to the insulating quality of the building skin, achieve higher values than given in the Building Decree
- Use high insulating glazing (HR++ or better) with heat reflective coating on the outside (for sun exposed facades)
- For walls connected to indoor environment: use sand brick stones or wood skeleton structures (to prevent high concentrations of radon). Decrease the use of concrete and other heavy stone materials, but ensure a certain amount of active thermal mass on the inner side of the insulation and enough mass between house dividing structures.
- Design open able windows with several positions (well fixable, visible and light to handle), break in safe and with low risk of accidents
- For natural air supply:
    - Wind pressure related grills and outdoor noise reducing
    - Controllable opening positions from inside (reachable and light to handle)
    - Capacity division in horizontal lines
    - High position (max. 30 cm from ceiling)
    - Airflow directed to ceiling
    - Practical control from the floor (1.2-1.5 m. high)
    -

Systems

- Place heat pumps in a separate room opposed to staying areas or place a closing structure around them.
- Use radiant heating with low temperature values (floor and wall heating or oversized radiators), which can also be used for cooling. Do not use air heating and convectors.
- Pipes for floor heating should be placed in surface layers, so that response of the system will be faster than embedded coils. This solution also makes it possible to apply floor heating in low thermal mass buildings. In addition, removal of the surface layer is easier than the embedded coils, which makes the solution more flexible.
- Base the heating demand on low temperature heating. Set the supply temperature on 55°C. Set the thermostat for floor and wall heating on 35 °C.
- Design a heating regulation with week and day program and individual changeability per room. Do not base the control on outdoor temperatures.
- For balanced ventilation with heat recovery:
    - Large distances between inlet and exhaust
    - Bypass in heat recovery system to provide summer night cooling
    - Easy to change filter
    - Clean able ducts
    - Sound level in bedrooms at low position < 20 dB(A) and other rooms < 25 dB(A)

(Weterings, 2005)

Literature

Knudstrup, M.A.; Hansen, H.T.R.; Brunsgaard, C., Approaches to the design of sustainable housing with low CO_2 emission in Denmark, (2009), Renewable Energy 34: 2007-2015

Weterings, M, GGD Richtlijn Gezonde Woningbouw, (2005), Landelijk Centrum Milieukunde

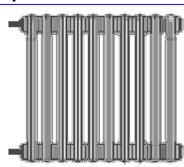
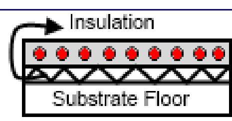
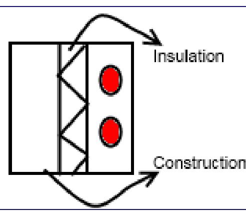
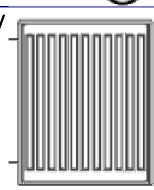
NEN-EN-ISSO 7730 (en): Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

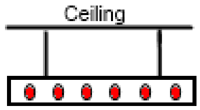
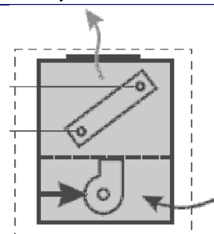
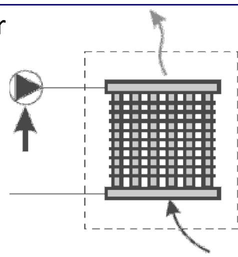
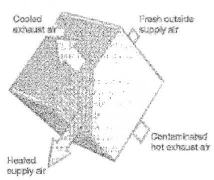
7 Comparison of terminal systems

In the Netherlands, the most common type of heat distribution in residential buildings is high temperature radiators with a water supply temperature of 90°C and return temperature of 70°C (Eijdems and Boerstra,1999). However, there are several types of terminal systems which are applied in residential buildings. In order to comprehend the heating and cooling capabilities and characteristics of different terminal systems, results from a research conducted by IEA are listed
Table 13. These systems are selected on the basis of possibility to apply in residential buildings as given in the guidebook.

The capacities of these systems are given in Watt per square-meter of user area. Maximum heating capacities are calculated for each system by taking the user floor area as 125 m^2 as in the SenterNovem reference house. Calculations show that the low temperature heating systems can deliver lower capacities compared to the high temperature radiators, except for air heating/cooling. This also explains the slow response of the water based low temperature heating systems and therefore operation of these systems require adequate control strategies. On the other hand, low temperature heating systems should be installed in well-insulated buildings.

Table 65: Comparison of different terminal systems, source: Annex 37 IEA, 2003

Systems	Illustration	Max. Heating Capacity (W/m^2)	Max. Cooling Capacity (W/m^2)	Heating Temperature Range	Cooling Temperature Range	Heating Performance Comparison
Water Based Systems						
HT Radiators		150	-	80-130 °C	-	Max. Capacity: 18.75 kW
Floor Heating/ Cooling		70	50	28-35 °C	15-20 °C	Max. Capacity: 8.75 kW
Wall Heating/ Cooling		100	40	25-50 °C	10-15 °C	Max. Capacity: 12.5 kW
LT Radiators/ Convectors		100	-	30-50 °C	-	Max. Capacity: 12.5 kW

Radiative Panels		70	80	25-50 °C	10-15 °C	Max. Capacity: 8.75 kW
Ceiling Integrated System		40	40	25-50 °C	10-15 °C	Max. Capacity: 6 kW
Water/Air Based Systems						
Fan coils		150	150	25-30 °C	10-15 °C	Max. Capacity: 18.75 kW
Supply air conditioning		-	-	40-90	10-15	Max. Capacity: -
Air Based Systems						
Air/air heat exchangers		-	-	40-90		Max. Capacity: -

8 Background: indoor air quality

Table 66 below shows the outcomes of RIVM research on the indoor air quality in the existing residential stock. The number of harmful gases or particles is significant, as well as the estimated percentages of Dutch houses in which these are a source of problems.

Care for ventilation flow design is therefore necessary, and will be more important when houses are built with higher values of air tightness.

Table 66: Air problems in Dutch housing stock and size of the problem. Source: RIVM brief report 630789003;

Particle/problem	Estimated percentage of Dutch houses
Moisture problems	6-16% of houses, depended on date of building
Visible moult	9% of houses, depended on date of building
Pet allergens	33% of houses
Presence of tobacco smoke	Approximately 40-49% of houses
Passive smoking by non-smokers in houses	18-40% of houses
Concentration of PM2,5 inside>outside	25% for non-smokers, 95% for smokers
Drainless water heaters at which combustion products are not directly drained off	12% of water heaters
Volatile Organic Compounds (VOC)	In 0-8 % of houses, the sum of VOC exceeds the advice value of the Health Council of 200 $\mu g/m^3$
Formaldehyde	In 60% of houses, the MAC* for long time exposure is exceeded (10 $\mu g/m^3$)
Radon	Present in 100% of houses, 0% above European recommendation of 200 Bq/m^3
CO_2 concentration > 1200 ppm	59% of occupied zones 47% van sleeping rooms
Overheating in summer	17% of houses

** MAC is het Maximum Acceptable Concentration*

Literature

Veen, van, M.P.; Crommentuijn, L.E.M.; Janssen, M.P.M.; Hollander, de, A.E.M., Binenmilieu-kwaliteit: ventilatie en vochtigheid, (April 2001), RIVM, Bilthoven, RIVM report 630920 001

Jongeneel, W.P. et.al., Binnenmilieu, Recente wetenschappelijke ontwikkelingen en beleid op een rij, (2009), RIVM, Bilthoven, under authority of VROM, RIVM brief report 630789003/2009

9 Background: Visual comfort

9.1 Average daylight factor

The achieved Average Daylight Factor in design indicates the appearance of the room and the predicted amount of artificial lighting which is needed for use. This is summarized in Table 67.

Table 67: Average Daylight Factor Recommendations

Average Daylight Factor (ADF)	
> 10%	Clarity reduction is probably needed
> 5%	The room has a bright daylit appearance. Daytime electric lighting is usually unnecessary
2-5 %	The room has a daylit appearance but electric lighting is usually necessary in working interiors
< 2 %	Electric lighting is necessary, and appears dominant. Windows may provide an exterior view but give only local lighting.
BS 8206 Part 2 – Average Daylight Factor Recommendations	
> 5%	**No electric lighting:** If electric lighting is not normally to be used during daytime, the Average Daylight Factor should not be less than 5 %
> 2%	**Supplementary electric lighting**: if electric lighting is to be used throughout daytime, the Average Daylight Factor should not be less than 2%
> 1%	Bedrooms
> 1.5%	Living rooms
> 2%	Kitchens

9.2 Illuminance

The calculated Average Daylight Factors shows the possibility of daylight availability in a certain room. It gives insight in the amount of outdoor illuminance which enters a room:

$$Daylight\ Factor\ (DF) = \frac{Illuminance\ indoors}{Horizontal\ illuminance\ from\ unobstructed\ sky} \times 100\%$$

By using this parameter, different designs will be comparable, independent of the actual available amount of daylight. The actual horizontal illuminance of the sky depends on the time of year, time of day, cloudiness, orientation etc. For the worst case scenario (CIE Overcast Sky) the sky luminance is independent of the orientation.

The sky illuminance can be estimated by use of the sun elevation for each time of the day and year. For De Bilt, these illuminance levels are presented in Figure 55.

Horizontal illuminance for De Bilt in several months

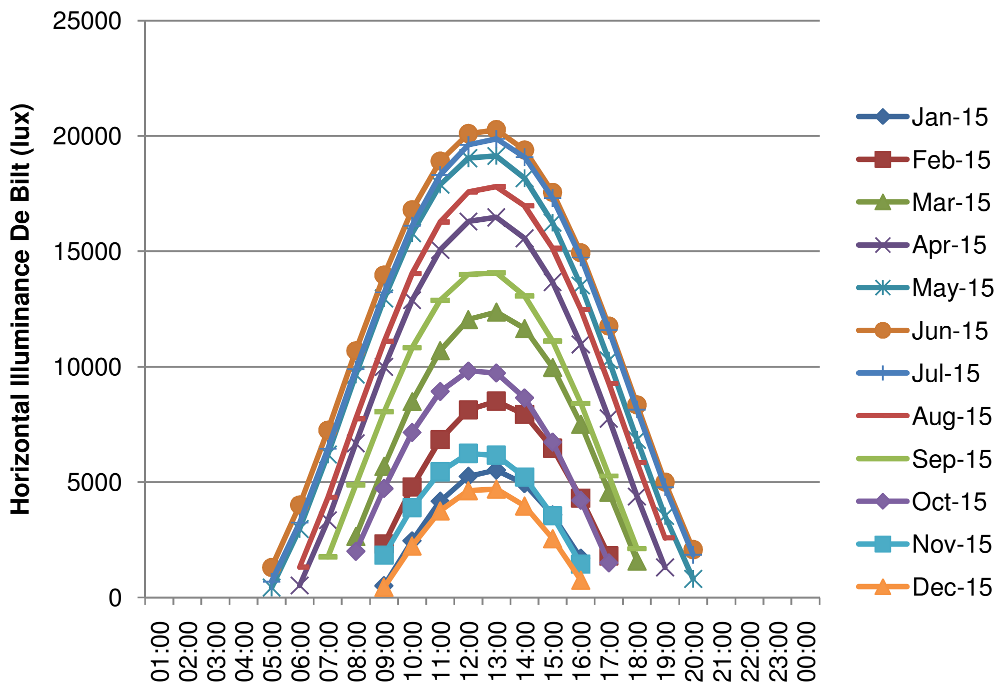


Figure 55: Horizontal illuminance for De Bilt, per hour per month (lux).

The needed amounts of illuminance in several rooms in a house are presented in . They are deducted from the values as are suggested in Cijfers en Tabellen 2007 by SenterNovem. The times of the day that these levels need to be achieved depend on the user presence, as is deducted from the schedules inGIW/ISSO 20068 (page 60). The values as presented here are also used during simulation of the concepts.

Table 68: Demands for illumaninance values in several room functions

Room		Cijfers en Tabellen 2007, lux	User presence (GIW/ISSO 2008)
Living rooms	workplace	500	08:00 – 22:00h
	general	50	
	ambiance	50	
Kitchen	workplace	250	08:00 – 22:00h
	general	125	
bedroom/bathroom/toilet		250	06:00 – 10:00h, 18:00 – 20:00h, 23:00 – 24:00h
hall/stair/attic/basement		125	11:00 – 14:00h (attic), 08:00 – 23:00h (halls)
storage/garage		250	

9.3 Measures

From lecture notes by TU/e, a list of measures is summarized which gives advice on building skin related, room and system levels.

Table 69: Measures to achieve high levels of daylight availability. Source: TU/e

Window orientation

- South orientated windows will give a varying illumination inside a room. But the difference will be larger for east- or west oriented windows. North oriented windows give the least variation in illumination levels.

Building shape

- Increase façade surface. More façade surface gives more possibilities for window openings. Drawback: large façade surface works negative on energetic aspects.
- Use profile of the building section for daylight increasing

Window systems

- Horizontal windows will show a small difference in illuminance distribution throughout the day. And they will give a panoramic view.
- Vertical windows will show depth in the view, and a varying illumination during the day. Light will enter deeper lying parts of the building, but the risk on glare is higher.
- Design 40% of the façade as lighting opening, to prevent extreme heat loss, heat gains or visual discomfort
- Place window systems high in the façade, to receive a higher lighting level and uniformity, but do consider a good view out.
- Place light openings on different walls of a room to increase uniformity and daylight levels.
- Design the framework of window openings carefully. By good slopes and high reflecting materials, daylight factors can be increased and discomfort by contrasts can be reduced.
- Roof lighting provides higher daylight levels than vertical windows.

Room characteristics

- Use highly reflecting materials.
- Use large glazed surfaces in internal parts of the building.
- Place highly daylight demanding functions closer to the façade than functions with lower demands.

Light directing elements

- Global position and climatic circumstances influence the performance of daylight systems. Many of them function by direct solar radiation. In the Netherlands, only 30-35% solar time, direct sunlight occurs.
- Some redirecting daylight systems reduce the visual contact with the surrounding. Sight parts are essential for these systems (e.g.: perforation of the lower part of venetian blind, to provide view).

Artificial lighting

- Energy efficient lights (LED, tungsten, fluorescent).
- Daylight depended control
- Hand control

Literature

Average daylight factor: a simple basis for daylight design, Information Paper 15/88, Building Research Establishment, Watford, UK.

Cijfers en Tabellen, 2007, SenterNovem, under authorisation of VROM

GIW/ISSO 2008: Ontwerp- en montageadviezen nieuwbouw eengezinswoningen en appartementen, ISSO.

TU/e, Daglicht en scheidingsconstructies, Tijdelijk dictaat voor 'licht' – bouwfysisch ontwerpen 2, Eindhoven University of Technology, Eindhoven

10 Background: Acoustic comfort

Element	Randvoorwaarden
woningscheidende wand[1]	15 mm gipsplaat houten stijlen 38 x 89 mm h.o.h. 400 mm, met 90 mm minerale wol ankerloze luchtspouw van 60 mm houten stijlen 38 x 89 mm h.o.h. 400 mm, met 90 mm minerale wol 15 mm gipsplaat
dragende wanden	als houtskeletbouw binnenspouwbladen gevels
woningscheidende vloer	18 mm vloerhout met droge verend opgelegde dekvloer balklaag 45 x 220 mm met 80 mm minerale wol 2 x 15 mm vezelversterkte gipsplaat aangebracht op veerregels zie detail vloer-bouwmuur woongebouwen (figuur 34)
begane grondvloer	massa ≥ 250 kg/m² inclusief dekvloer plaatsen onder ankerloze woning-scheidende wand
verdiepingsvloer/dakvloer[2]	18 mm vloerhout balklaag 45 x 220 mm met 80 mm minerale wol 15 mm plafondplaat aangebracht op veerregels
hellend dak	ontkoppeld aansluiten aan weerszijde van of op woningscheidende wand minerale wol strook toepassen op woningscheidende wand tussen dak-elementen[3] panlatten onderbreken t.p.v. woningscheidende wand

Element	Randvoorwaarden
binnenwanden	stijl- en regelwerk met minerale wol en beplating (dragend)
binnenspouwblad langs- en kopgevel	het houtskeletbouw binnenspouwblad is in de kop- en langsgevel dragend minerale wol strook toepassen t.p.v. woningscheidende vloerranden dilatatievoeg aanbrengen in buitenblad ter plaatse van woningscheidende wand
kozijnen	beplating tussen kozijnen direct aansluitend op woningscheidende wand ontkoppelen

1 Uitgangspunt is een woningscheidende wand bestaande uit open spouwbladen, waarbij in de spouw geen plaatmateriaal is aangebracht. Indien dit om constructieve redenen wel noodzakelijk is, moet het beperkt blijven tot maximaal 50% van het oppervlak aan beide zijden en niet tegenover elkaar aangebracht. In verband met de brandwerendheid moet de woningscheidende wand in woongebouwen voorzien worden van 2 x 15 mm gipsvezelversterkte gipsplaat.
2 De verdiepingsvloer maakt onderdeel uit van de hoofddraagconstructie en moet daarom 60 minuten brandwerend m.b.t. bezwijken zijn.
3 Deze maatregel is volgens veel attesten inmiddels achterhaald doordat de dakkappen veel dikker geïsoleerd worden.

Table 70: Design propositions for wood structures to achieve acoustic comfort on Builiding Decree Level

Element	Randvoorwaarden
woningscheidende wand[1]	massief 280 mm woongebouwen ankerloos 120-60-120 mm woningen[2] ankerloos 150-30-150 mm (alleen bij gebouwdilatatie woongebouwen)
kopgevel[1]	150 mm woongebouwen
dragende wanden[1]	150 mm woongebouwen
woningscheidende vloer	210 mm met natte verend opgelegde dekvloer
begane grondvloer	massa ≥ 250 kg/m² inclusief dekvloer flexibel aansluiten op massieve woning-scheidende wand massa ≥ 350 kg/m² inclusief dekvloer bij starre aansluiting op massieve woningscheidende wand massa ≥ 250 kg/m² inclusief dekvloer onder ankerloze woningscheidende wand met akoestisch oplegmateriaal
verdiepingsvloer/dakvloer	180 mm[3]
hellend dak	ontkoppeld aansluiten aan weerszijde van woningscheidende wand minerale wol strook toepassen op woningscheidende wand en onder pannen panlatten onderbreken t.p.v. woningscheidende wand
binnenwanden	70 mm Gibo zwaar (GZ 70) tussen verblijfsruimten[4] alle binnenwanden flexibel aansluiten op plafond alle binnenwanden op dekvloer plaatsen zie attest fabrikant
binnenspouwblad langsgevel	dubbele gipsbeplating 2 x 12,5 mm (totaal ≥ 20 kg/m²) flexibel aansluiten op plafond ontkoppeld aansluiten op woningscheidende wand minerale wol strook toepassen t.p.v. woningscheidende vloerranden en -wanden dilatatievoeg aanbrengen in buitenblad ter plaatse van woningscheidende wand akoestische onderbreking in spouw aanbrengen afstand tussen kozijnen grenzend aan woningscheidende wand aandachtspunt zie detail gevel-bouwmuur woningen (ook woongebouwen bij afwijkende wand) zie detail gevel-vloer woongebouwen (figuur 35)

1 In woongebouwen moet een dragende wand op zich voldoende massa hebben om flankerende overdracht verticaal te voorkomen.
2 De dikte 120 mm van de spouwbladen betreft een praktische maat. Uit akoestisch oogpunt kan met minder massa worden volstaan.
3 De massa van de verdiepingsvloer moet minimaal 350 kg/m2 bedragen. Een kleinere dikte is dus toe-gestaan, maar is constructief veelal onvoldoende.
4 Er zijn meer mogelijkheden voor de materialisering van de binnenwanden. Een alternatief kan zijn: 100 mm kalkzandsteen of cellenbeton (tussen verblijfsruimten).

Table 71: Design propositions for concrete structures to achieve acoustic comfort on comfort Level

Element	Randvoorwaarden
woningscheidende wand	ankerloos 150-60-150 mm woningen ankerloos 120-60-120 mm woningen bij extra aandacht in aansluitdetails
begane grondvloer	massa ≥ 250 kg/m² inclusief dekvloer onder ankerloze woningscheidende wand 150-60-150 met akoestisch oplegmateriaal – woningen massa ≥ 250 kg/m² inclusief dekvloer onder ankerloze woningscheidende wand 120-60-120 met akoestisch oplegmateriaal en verdiepte spouw of verend opgelegde dekvloer – woningen
verdiepingsvloer/ dakvloer	180 mm[1]
hellend dak	ontkoppeld aansluiten aan weerszijde van woningscheidende wand minerale wol strook toepassen op woningscheidende wand en onder pannen panlatten onderbreken t.p.v. woningscheidende wand
binnenwanden zie attest fabrikant	70 mm Gibo zwaar (GZ 70) tussen verblijfsruimten[2]
binnenspouwblad langsgevel	afstand tussen kozijnen grenzend aan woningscheidende wand aandachtspunt zie detail kozijn-bouwmuur (figuur 36)

1 De massa van de verdiepingsvloer moet minimaal 350 kg/m2 bedragen. Een kleinere dikte is dus toegestaan, maar is constructief veelal onvoldoende.
2 Er zijn meer mogelijkheden voor de materialisering van de binnenwanden. Een alternatief kan zijn: 100 mm kalkzandsteen of cellenbeton (tussen verblijfsruimten).

Table 72: Design propositions for sand-lime brick structures to achieve acoustic comfort on comfort level

10.1 Measures

Additional measures to assure acoustic comfort could be found in Building Physics (2) lecture notes (TU/e):

Protection against sound from outside
- Place sound sensitive rooms on the low sound side
- Use small glass surfaces
- Do not use open able parts in a high sound façade
- Use a mechanical ventilation system or baffles on grills

Protection of sound between rooms
- air and contact sound insulation will mostly be determined by the building skin
- a room under a sloped roof needs more measures for sound insulation
- do not use clean brickwork for a house dividing wall
- do not place electrical sockets at the same place in a house dividing wall
- prevent circulation sound in air ducts
- prevent circulation sound through reflecting surfaces like open able windows
- seal duct holes for central heating between rooms
- place the sound sensitive rooms carefully in the building
- do not use a fire place with a share smoke duct
- when using parquet or tiles, include a sound absorbing layer and provide deviation with all walls
- make sure shared stairs are vibrant free supported
- ceilings in shared spaces should be facilitated with sound absorbing ceilings

Protection against sound from installations
- use low-sound installations

- place the installations as resilient or hanging, places services in a separate space
- place sanitary fittings free from the separating walls
- do not fix ducts to the separating walls

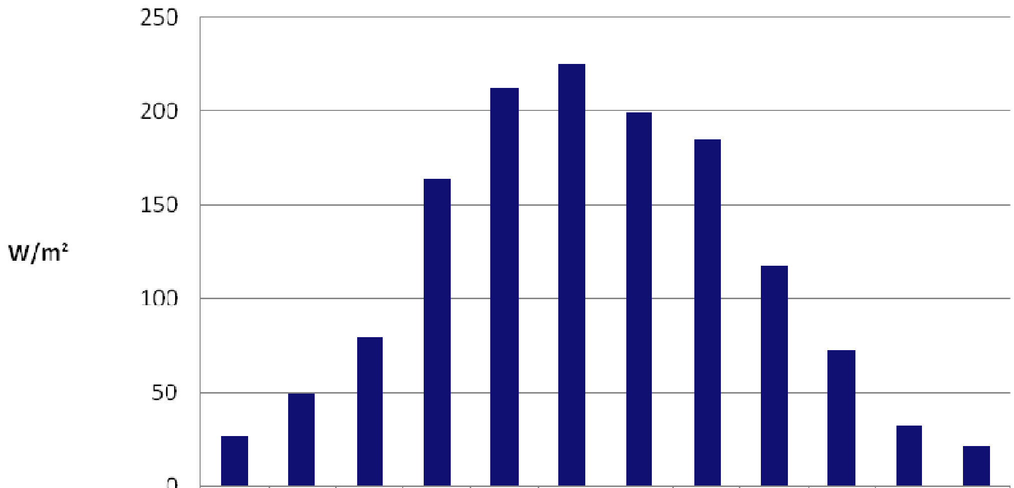
11 Background: CO_2 emissions

In this section, some relevant background information for the ‘CO_2 emissions’ part of the main report is presented. This includes data for site analysis of the Netherlands and analysis in the systems level.

11.1 Site analysis data

The global solar irradiation on a horizontal surface throughout the whole year is presented in Figure 56 in order to exhibit the seasonal differences in the solar power availability.

Global solar irradiation per month



	Jan	Feb	Mrc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Global Irradiation	27	49	80	164	212	225	199	185	117	73	33	21

Figure 56: Monthly total global solar irradiation on a horizontal surface, the Netherlands, data source: NEN5060, table A.2

Figure 57 shows the solar path diagram of De Bilt, Netherlands and it is obtained by using the building simulation software IES-VE. The reason to choose De Bilt as the reference location is that the Dutch norm NEN 5060 uses the same location as the reference for climatic data of the Netherlands.

Solar path in De Bilt

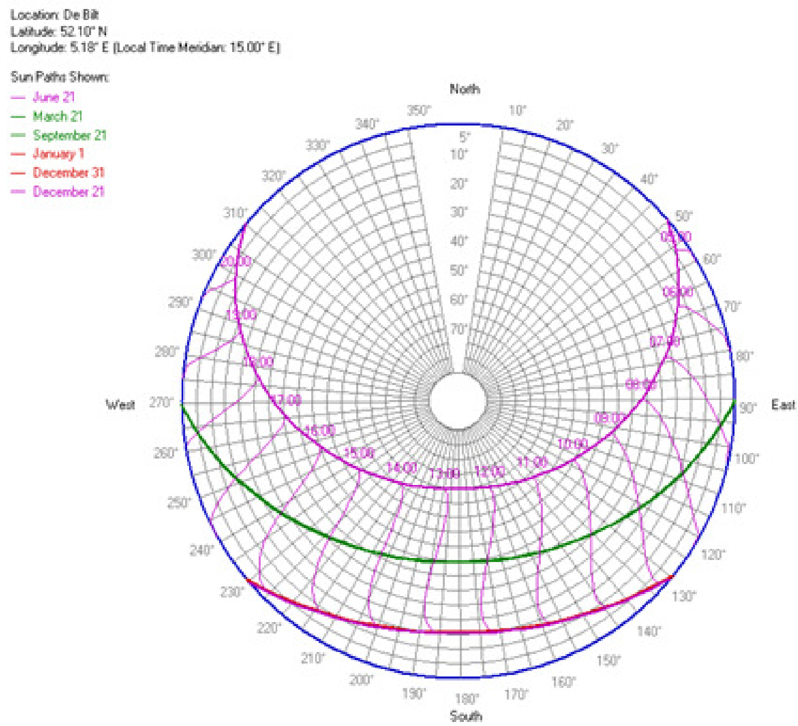
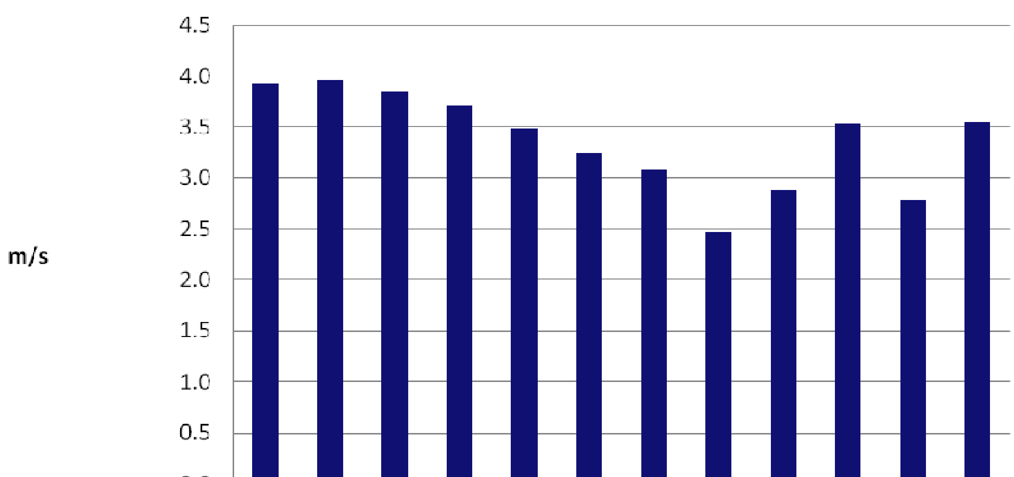


Figure 57: Solar path in De Bilt, Netherlands (Drawn by using IES-VE which is a building simulation tool)

In order to observe the variations of the average wind speeds per month is presented in Figure 58. It show the relatively more stable distribution compared to the solar irradiation as expected. Expected wind directions are given in Figure 59.

Wind speed averages per month



	Jan	Feb	Mrc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Wind Speed	3.9	4.0	3.9	3.7	3.5	3.2	3.1	2.5	2.9	3.5	2.8	3.5

Figure 58: Monthly average wind speed in the Netherlands, source: NEN5060

Wind direction possibility in a year

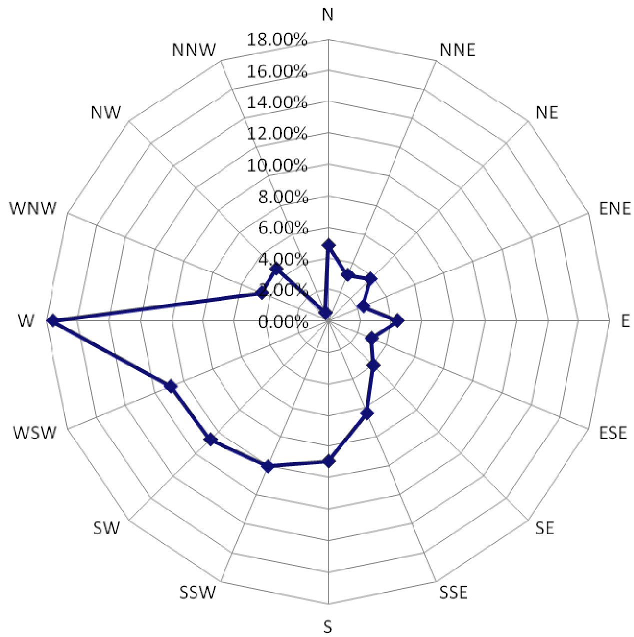


Figure 59: Percentage of the wind directions in De Bilt, the Netherlands, source: NEN5060

In order to decide on the heat extraction value for the design of the size of the systems, the information presented in Figure 60 is used as the guideline.

Soil properties in the Netherlands

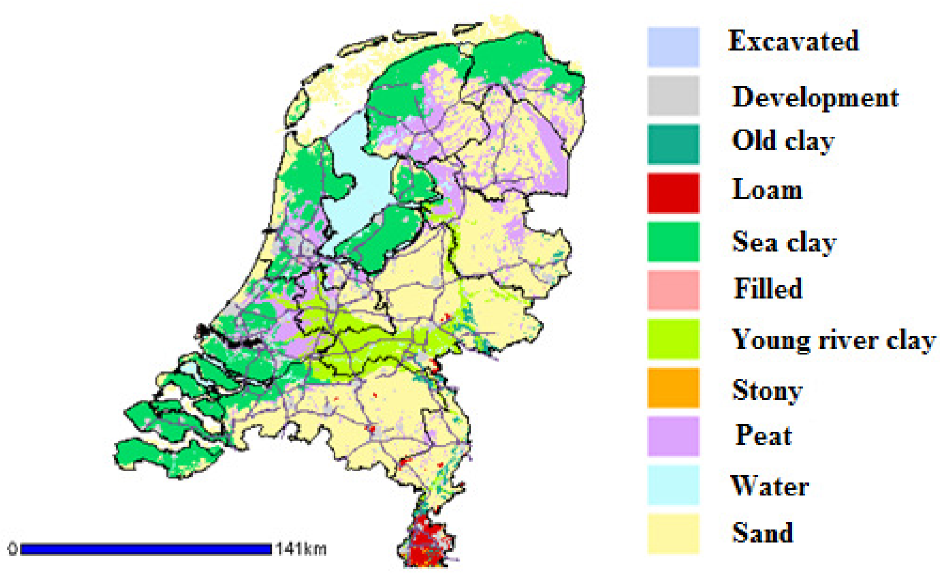


Figure 60: Soil types in the Netherlands, source: http://www.bodemdata.nl/bodemdatanl/

The applicability of vertical ground heat exchangers in the Netherlands, the map of the suitability of the Netherland's ground is shown in Figure 61.

Suitability of the soil for excavation

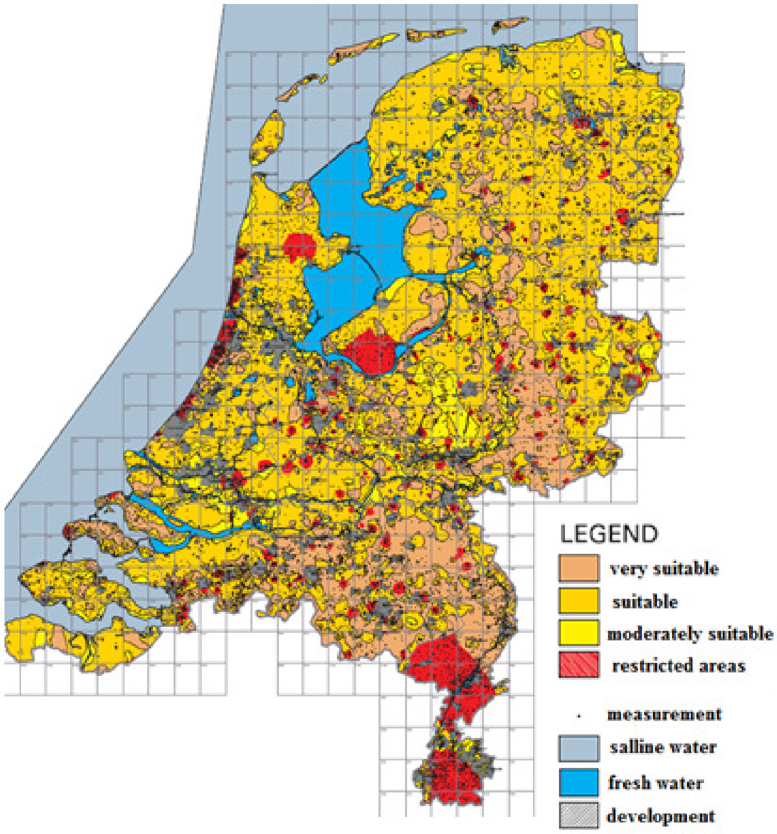


Figure 61: Possibilities of applying vertical ground heat exchangers in NL, source: If Technology and TNO, 2001.

11.2 System Analysis Data

In this section relevant information for the systems that are analyzed is presented. This includes the working principles, configurations, results and calculation principles.

11.2.1 Photovoltaic Solar Panels

The efficiencies of these cells are defined by NEN 5128 (Table 42) and these are the values used for energy calculations in the Netherlands. They are presented in Table 73.

Table 73: PV cell efficiencies, source: NEN 5128

Type of cell	Efficiency
Mono-crystalline	15%
Multi-crystalline	14%
Amorphous	6%

On the other hand, PV cells produce DC power which cannot be used directly in the house and DC-AC inverters should be installed. The reduction factor is estimated according to NEN 5128 (Table 40) for roof integrated and moderately ventilated PV system, and it is 0.67.

The shadowing factor is also defined by NEN 5128 which takes into account the losses due to shadowing on the PV panels. However, it is estimated to be 1.0 according to the table 33 of NEN 5128, i.e. no influence on the power calculations.

So, annual total energy production can be calculated by using the following formula:

$$Total\ energy\ production\ =\ 1100\ kWh/m2 \times 0.67 \times 0.14 \times Area$$

The following table shows the available system sizes of a specific supplier as a representative of the market.

Table 74: Example PV system sizes as available in the market, source: Oskomera

Peak Power- W	Surface Area -m^2	Expected Generation (kWh/year)
615	4.4	450
2050	14.7	1510
4510	32.3	3325
7560	54.1	5580

11.2.2 Urban Wind Turbines

The following figure show the results of the field tests conducted between 1 April 2008 and 31 August 2010 in Zeeland province of the Netherlands.

	Opbrengst in kWh									
	WRE 060	**Skystream**	**Airdolphin**	**Swift**	**WRE 030**	**Energy Ball**	**Passaat**	**Montana**	**Turby**	**Ampair**
apr-08	48	175	42	22	1	6	56	265	6	1
mei-08	41	171	29	12	20	4	39	207	27	7
jun-08	25	106	17	7	8	2	33	169	19	19
jul-08	29	118	19	8	11	3	33	170	19	18
aug-08	39	143	24	12	18	4	42	200	22	21
sep-08	32	133	21	6	6	2	31	155	13	16
okt-08	0	151	28	17	27	6	45	199	20	18
nov-08	53	260	49	44	78	12	75	311	34	31
dec-08	44	196	38	20	43	6	47	229	36	26
jan-09	69	240	44	42	75	10	62	256	6	27
feb-09	42	163	31		45	6	40	196	0	21
mrt-09	64	254	50		72	11	74	335	44	39
Totaal 1ste jaar	**485**	**2109**	**393**	**191**	**404**	**73**	**578**	**2691**	**247**	**245**
	WRE 060	**Skystream**	**Airdolphin**	**Raum**	**WRE 030**	**Energy Ball**	**Passaat**	**Montana**	**Turby**	**Ampair**
apr-09	20	110	18	19	21	3	28	153	17	17
mei-09	53	213	40	53	58	6	59	48	39	31
jun-09	18	99	13	28	19	2	26	183	16	17
jul-09	23	111	17	43	23	3	33	201	17	20
aug-09	15	79	12	29	15	2	20	65	0	13
sep-09	51	216	41	98	61	7	69	120	2	38
okt-09	30	127	24	57	33	4	39	183	22	24
nov-09	94	340	68	70	104	11	114	283	54	46
dec-09	50	231	46	79	51	6	71	343	42	36
jan-10	49	164	33	27	55	7	53	291	31	24
feb-10	64	229	46	64	67	7	71	295	36	34
mrt-10	59	251	48	67	104	7	78	151	51	40
Totaal 2de jaar	**526**	**2171**	**406**	**633**	**612**	**65**	**660**	**2315**	**326**	**341**
	WRE 060	**Skystream**	**Airdolphin**	**DonQi**	**WRE 030**	**Energy Ball**	**Passaat**	**Montana**	**Turby**	**Ampair**
apr-10	38	186	34		44	5	54	28	43	31
mei-10	49	213	41		60	7	65	350	48	38
jun-10	30	143	25		37	5	44	245	36	26
jul-10	12	66	10	8	12	1	18	104	0	11
aug-10	56	198	37	40	68	7	61	263	0	30
Totaal 3de jaar	**185**	**805**	**148**		**222**	**24**	**240**	**990**	**127**	**136**

Figure 62: Field test results from province Zeeland
Source:
http://provincie.zeeland.nl/milieu_natuur/windenergie/kleine_windturbines/de_turbines

11.2.3 Heat Pumps

Efficiency of a heat pump is expressed as coefficient of performance (COP) and it is defined as (ASHRAE, 2009):

$$COP = \frac{Useful\ heat}{Net\ Energy\ Supplied\ from\ external\ sources}$$

The COP of natural gas fired heat pumps are lower than electric heat pumps as shown below (Senter Novem).

- electric heat pump: from 2.5 to 5.0
- gas-motor heat pump: from 1.2 to 2.0
- absorption heat pump: from 1.0 to 1.5

The natural gas fired heat pumps are not suitable for small scale applications, at least for 10 houses with around 45 kW capacity (SenterNovem,2010). Also absorption heat pumps have a low COP compared to the electric driven heat pumps. Therefore, only electric heat pumps will be studied in this project.

Several types of electric heat pumps exist and they can be categorized for the heat source and sink, heating distribution fluid (ASHRAE Handbook, 2008):

- Air-to-air heat pumps: the most common heat pumps, air circuits can be interchanged by motor-driven or manually operated dampers to obtain either heated or cooled air for the conditioned space
- Water-to-air heat pumps: These heat pumps rely on water as the heat source and sink, and use air to transmit heat to or from the conditioned space.
- Water-to-water heat pumps: These heat pumps use water as the heat source and sink for cooling and heating.
- Ground-Coupled Heat Pumps: These use the ground as a heat source and sink. A heat pump may have a refrigerant-to-water heat exchanger or may be direct-expansion
- Air-to-water heat pumps without changeover: These are generally hot water heat pumps.

Since heat transport medium is chosen to be water in the previous chapters, water-to-water or air-to-water heat pumps will be evaluated in this study.

Although the COPs of different types of heat pumps are presented above, the generation efficiencies of these systems should be considered for an objective comparison. These are given for different types of sources in Table 75.

Table 75: Generation efficiencies of different types of heat pumps with different sources, source: NEN 5128

Electric heat pump generation efficiency= COP x Efficiency of the grid		
Source	T_{supply}<35 ^{o}C	35 ^{o}C< T_{supply}<45 ^{o}C
Brine	1.716	1.600
Outdoor air	1.482	1.365
Ground water	1.950	1.794

As expected, lower supply temperatures yield higher efficiencies. As mentioned previously, low temperature heating will be used in all the concepts, therefore the first column with temperatures lower than 35^{o}C are relevant for this study.
Electric heat pumps can be used to supply warm tap water in residential buildings. As the supply temperatures increase, expected performance, i.e. COP, of the heat pump diminishes. The COPs for domestic hot water supply is given in the following table according to NEN 5128.

Table 76: Electric heat pump efficiencies for DHW generation, source: NEN 5128

Sources	Exhaust Ventilation Air	Other sources combined with a boiler
COP	2.2	1.4
Generation Efficiency	0.86	0.55

11.2.4 Solar Thermal Collectors

There are two types of solar collectors which are used commonly in today’s practice. These

are: flat plate and vacuum tube collectors.
Flat plate collectors; circulate water in the pipes under the collector plate which collects the solar irradiation. This is the most common type of solar thermal collector type for domestic hot water applications. Achievable range of water temperature is generally in the range of 30-70^{o}C.

Flat Plate Collectors

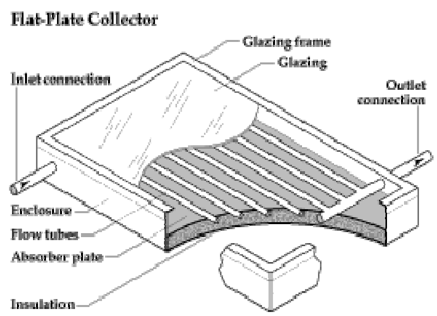


Figure 63: Flat plate solar collectors, source: US Department of Energy

Vacuum tube collectors; are made of row of glass tubes which contain a glass outer tube and a metal absorber, Thanks to the evacuated space between outer glass tube and the absorber, the losses are decreased and high temperatures can be achieved, in a range of 75-175^{o}C. Two types can be distinguished; direct flow or heat pipe configurations. If the system circulates the water in the pipes it is called a direct flow system and if the heat is transferred to the water through a different medium which circulates in the pipes, it is a heat pipe configuration. Since the glass tubes are vulnerable to the impacts and if the hot water is circulated in the pipes, in case of damage to the pipes, the system may become out of service. Therefore, the heat pipe configuration is taken into account for the scope of this study.

Evacuated Tube Collectors

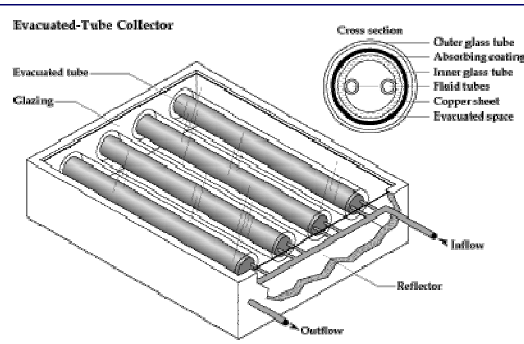


Figure 64: Evacuated tube solar collectors, source: US Department of Energy

11.2.5 Ventilation Heat Recovery

Plate heat exchangers in cross flow configuration are the most common type of heat recovery units (AIVC, 2004). These units are investigated in this study. An illustration of the unit is shown in Figure 65.

Cross-flow heat exchanger

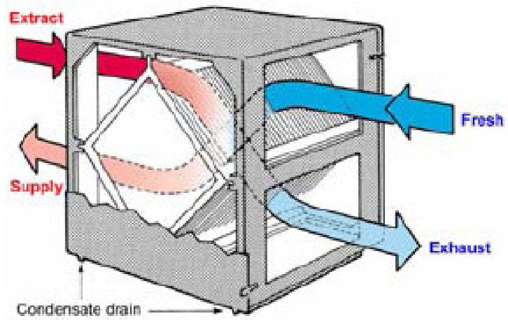


Figure 65: Cross-flow heat exchanger, source: AIVC

The efficiency of these units is generally calculated with the exhaust and supply temperature, which is given in the following formula as:

$$\eta_{hx} = \frac{\left(T_{supply} - T_{outdoor}\right)}{\left(T_{exhaust} - T_{outdoor}\right)}$$

In this equation supply air temperature is measured after at the downstream of the heat exchanger while exhaust air temperature is measured at the upstream of the heat exchanger. Although the efficiency of the heat recovery unit in the reference house is specified as 95%, it is not clear if this is the way of calculations for that estimation.
In order to show the benefits of using heat recovery, following figure shows the calculated temperatures of air flowing in and out of the heat recovery unit in a winter week.

Air temperatures in heat recovery unit

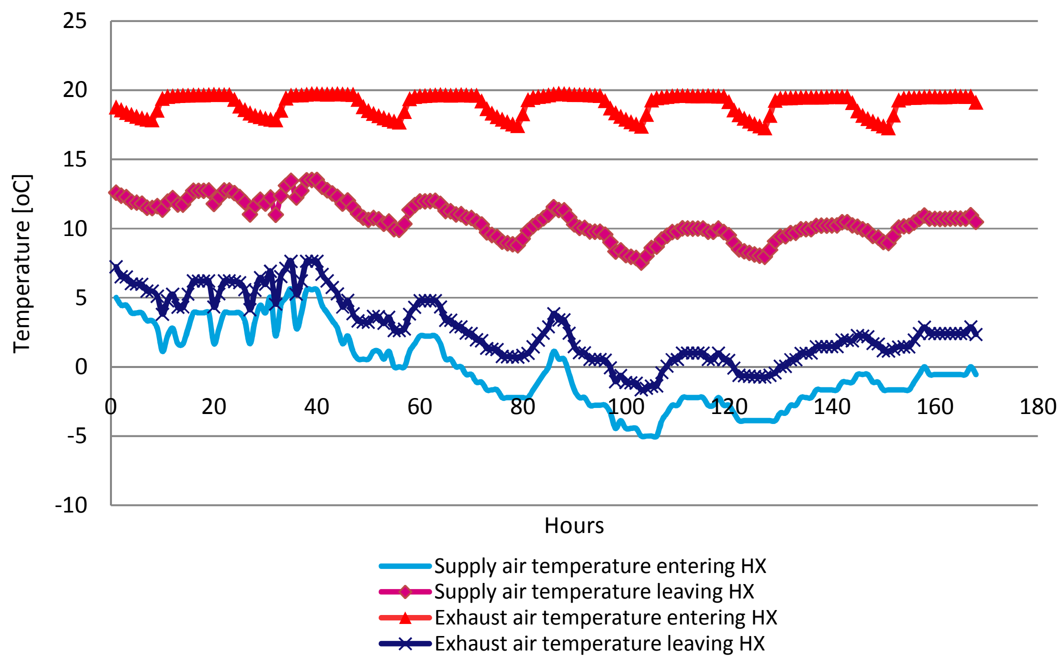


Figure 66: Air temperatures in the heat recovery unit during a week in winter, to exhibit the performance, source: eQuest

12 Background: Water use

The average household water consumption in the Netherlands is given in Table 77.

Table 77: Average Household Water Consumption in the Netherlands in litres/person/day, source: Vewin, 2007

	1995	1998	2001	2004	2007
Bath (Hot)	9	6.7	3.7	2.8	2.5
Shower (Hot)	38.3	39.7	42	43.7	49.8
Bathroom sink	4.2	5.1	5.2	5.1	5.3
Toilet flush	42	40.2	39.3	35.8	37.1
Washing of hands	2.1	2.1	1.8	1.5	1.7
Washing machine	25.5	23.2	22.8	18	15.5
Washing up by hand	4.9	3.8	3.6	3.9	3.8
Dishwasher	0.9	1.9	2.4	3	3
Food preparation	2	1.7	1.6	1.8	1.7
Drinking water	1.5	1.5	1.5	1.6	1.8
Other	6.7	6.1	6.7	6.4	5.3
Total	**137.1**	**132.0**	**130.6**	**123.6**	**127.5**

Monthly precipitation totals are presented in the following figure in order to show the seasonal variations for recycling option.

Monthly precipitation

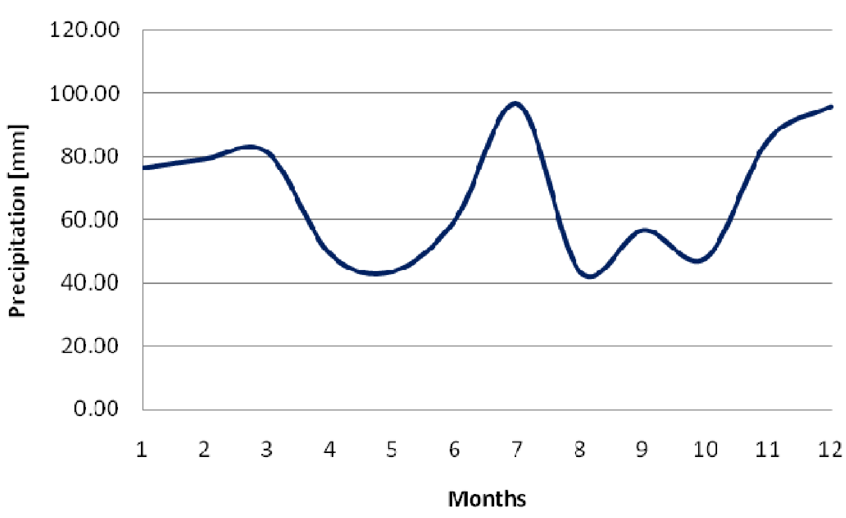


Figure 67: Precipitation monthly totals in the Netherlands, source: NEN5060

For the calculation of the required energy for domestic hot water, the use pattern is determined. This is based on average values by NEN 5128 in different classes and gives details of hot water use in a day, with total volumes, flow rates, required temperatures and available temperatures. According to these values, hot tap water flow rate is 5.5 l/min and maximum demanded temperature is 55^{o}C while maximum supply temperature is given as

40°C. On the other hand, the total hot water demand is 227 l/day as Class 3 (CW3) is selected as the hot water use pattern in the reference house which includes regular showering rates but includes 2 times per day. Seasonal and daily variations in hot water use are not reflected in NEN 5128, so these average values will be used for the design and will be regarded as the maximum values. The use pattern can be seen in . Two peaks represent the shower times during the day.

Table 12-78: Domestic hot water use in a house per day, source: NEN 5128

Time	Total volume liters	Tap flow rate l/min	Desired temperature °C	Available temperature °C	Use type
7:00	4	3,5	40	25	sink
7:15	73*	5,5*	40	40	shower
7:30	4	3,5	40	25	sink
8:00	1	3,5	55	40	rinsing
9:00	1	3,5	40	25	hand washing
9:05	1	3,5	40	25	hand washing
10:00	1	3,5	55	40	rinsing
10:30	1	3,5	40	25	hand washing
10:35	0,5	3,5	40	25	short tapping
10:45	1	3,5	40	25	hand washing
11:00	1	3,5	55	40	rinsing
11:30	1	3,5	40	25	hand washing
11:32	1	3,5	40	25	hand washing
11:34	1	3,5	40	25	hand washing
13:00	5	3,5	55	40	rinsing
13:05	5	3,5	55	40	dish washing
13:25	2	3,5	55	40	rinsing
13:27	2	3,5	55	40	rinsing
13:29	2	3,5	55	40	rinsing
14:00	1	3,5	40	25	hand washing
14:30	1	3,5	40	25	hand washing
14:35	0,5	3,5	40	25	short tapping
14:45	1	3,5	40	25	hand washing
14:48	1	3,5	40	25	hand washing
14:51	0,5	3,5	40	25	short tapping
15:00	2	3,5	40	25	hand washing
16:00	1	3,5	40	25	hand washing
16:10	0,5	3,5	40	25	short tapping
16:20	0,5	3,5	40	25	short tapping
16:30	1	3,5	55	40	rinsing
18:00	5	3,5	55	40	rinsing
18:05	5	3,5	55	40	dish washing
18:25	2	3,5	55	40	rinsing
18:27	2	3,5	55	40	rinsing

18:29	2	3,5	55	40	rinsing
19:30	1	3,5	40	25	hand washing
19:35	1	3,5	40	25	hand washing
19:40	0,5	3,5	40	25	short tapping
19:45	1	3,5	40	25	hand washing
19:50	1	3,5	40	25	hand washing
20:00	1	3,5	55	40	rinsing
20:10	2	3,5	55	40	rinsing(naspoelen)
21:00	1	3,5	40	25	hand washing
22:00	1	3,5	55	40	rinsing
22:30	1	3,5	40	25	hand washing
23:00	2	3,5	55	40	rinsing
23:15	4	3,5	40	25	sink
23:30	73*	5,5*	40	40	shower
23:45	4	3,5	40	25	sink

* class CW3 determined according to NEN 5128

Literature

NEN 5128+A1 (nl): Energy performance of residential functions and residential buildings – Determination method

13 Background: Economic value

IGG building costs advisors cooperated in this project to assist on the cost estimations of the several measures and concepts. They also assisted in building up the annuity mortgage model and advised on the assumptions for ground prices and additional costs in order to calculate the selling price of the concepts.
Assistance was given by:

- J.J. de Wilde (Jeroen)
- V. van Sabben (Vincent)
- M. Onderwater (Marc)

Since the firm is directing for the Dutch market, their spreadsheets and work is al in Dutch. The overviews of cost estimation are kept in Dutch in order to prevent mistakes by translation.
This appendix chapter includes all background information concerning the economic value.

13.1 Mortgage interest rate

The interest rate is assumed on 5% for comparison of the projects. This rate is chosen based on the bandwidth of interest in the past seven years (see Figure 68).

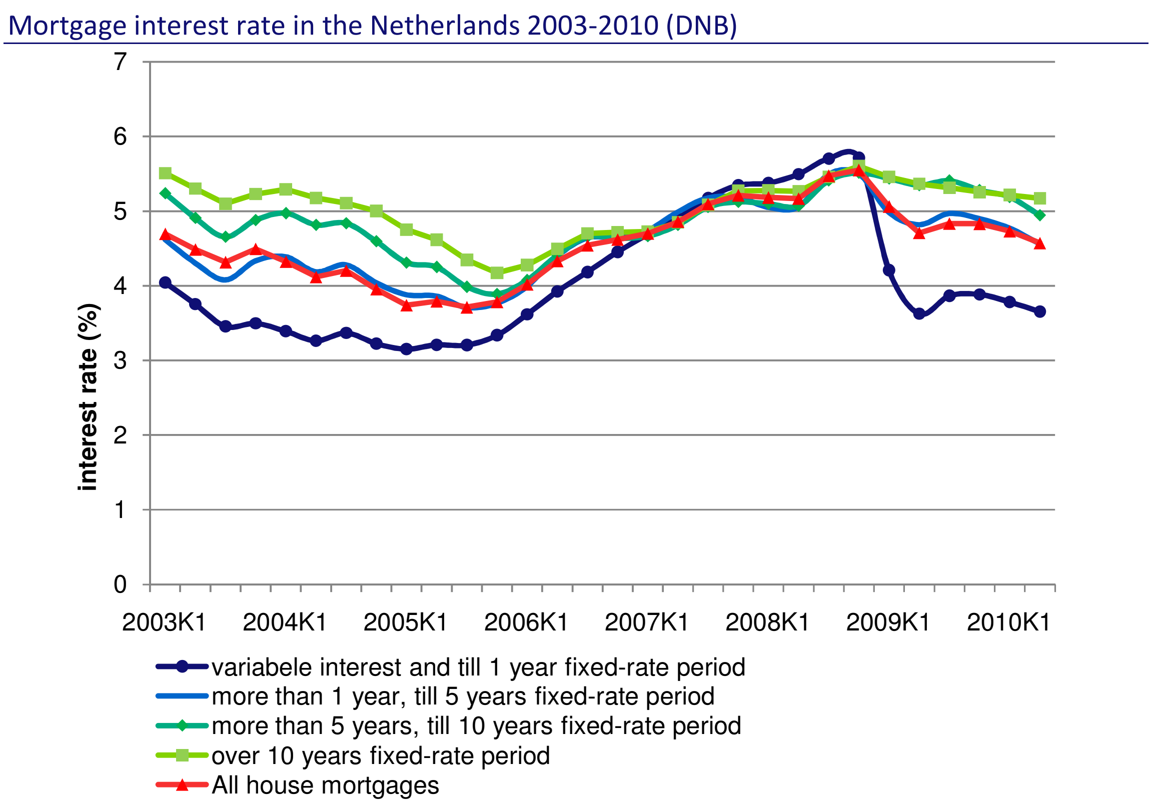


Figure 68: Mortgage interest rate in the Netherlands 2003-2010. Source: De Nederlandse Bank, Rentes van in Nederland gevestigde mfi's op deposito's en leningen, met bijbehorende volumes, 14/09/2010

The effect of differences in mortgage rate is represented in Figure 69. This graph shows the comparison in total expenditure between the reference house and the passive concept. Energy price increase is assumed as discussed under the assumptions in the report. The interest rate is changed in steps of 1% and varies between the range as was found in Figure 68. As can be read from Figure 69 the interest rate affects the difference in total expenditure a lot, increasing it for this case with 4,000 - 6,000 euro per percentage change.

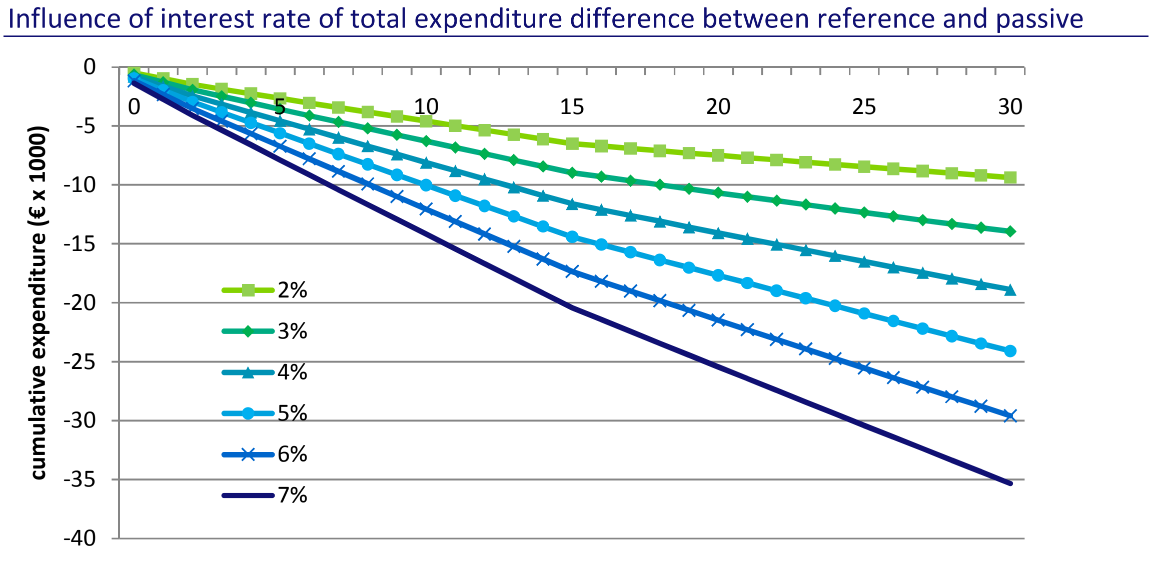


Figure 69: Influence of interest rate on difference in total expenditure

13.2 Fixed costs energy

Fixed costs for energy are deducted from a comparing website in energy prices. These equal for all suppliers in the Netherlands. In calculations, the tax reduction is not taken into account.

Table 79: fixed annual costs for electricity and gas, source: www.energieprijzen.nl

fixed costs	electricity	gas
fixed delivery costs	20.04	20.04
periodical connection costs	16.56	22.44
fixed costs transport	18.00	18.00
capacity tariff	105.12	69.6
system services	5.18	0.00
meter costs	25.33	21.27
tax and network costs	32.34	24.95
total network costs	202.53	156.26
subtotal fixed costs	**222.57**	**176.3**
tax reduction, tariff 2010 (not taken into account)	-318.62	0.00
total fixed costs	**-96.05**	**176.3**

13.3 Building costs

The element method is used to calculate the building costs per building part and the results of this are presented in the several tables below, per concept.

SenterNovem Referentiewoning

Bouwkostenraming op basis van Quickscan

IGG BOINTON DE GROOT BOUWKOSTENADVIES PLANVISIE

Algemene gegevens

Project	Afstudeerders		
opdracht:	SenterNovem Referentiewoning		
status	CONCEPT		
peildatum:	1 August 2010		
meting:	conform NEN 2580		
bruto vloeroppervlak	BVO	157	m²
bruto inhoud	BIH	428	m³
bebouwd oppervlak	TBB	52	m²
aantal bouwlagen onder peil		3	lagen
aantal bouwlagen boven peil		-	lagen
geveloppervlak dicht	BGD	35	m²
geveloppervlak open	BGO	25	m²
bruto dakoppervlak	BDT	78	m²

Niveau 2 Bouwkosten in elementclusters

code	omschrijving	hoev.	eh	€ / eh	totaal
2	**BOUWKUNDIGE WERKEN**				
2.A	constructie onderbouw	52	m²	169	8,821
2.B	constructie bovenbouw	157	m²	143	22,476
2.C	afbouw gevel	60	m²	284	17,063
2.D	afbouw daken en plafonds	78	m²	82	6,356
2.E	inbouw (excl. inbouw gebruiker)	157	m²	48	7,546
2.F	afwerkingen	157	m²	31	4,884
2.G	overige bouwkundige voorzieningen	-	incl	--	--
2.H	Sloopwerkzaamheden	-	m²	--	--
	TOTAAL BOUWKUNDIGE WERKEN				**67,145**
3	**INSTALLATIES**				
3.A	W-installaties	157	m²	25	3,927
3.B	Klimaatinstallaties	157	m²	55	8,626
3.C	E-installaties	157	m²	28	4,446
3.D	transportinstallaties	-	m²	--	--
	TOTAAL INSTALLATIES				**16,998**
4	**VASTE INRICHTING**				
4.A	vaste inrichting	157	m²	19	3,000
	TOTAAL VASTE INRICHTING				**3,000**
5	**TERREINVOORZIENINGEN**				
5.A	terreinvoorziening	-	m²	--	--
	TOTAAL TERREINVOORZIENINGEN				**--**
6	**INDIRECTE BOUWKOSTEN**				
6.A	indirecte bouwkosten	18.5%	over	87,144	16,096
	TOTAAL INDIRECTE BOUWKOSTEN				**16,096**
	TOTAAL BOUWKOSTEN, excl. BTW	**157**	**m²**	**658**	**103,240**

Berekening bouwkosten incl. btw

TOTAAL BOUWKOSTEN, excl. BTW	**103,240**
BTW 19 %	**19,616**
TOTAAL INCLUSIEF BTW	**122,855**

Passive concept

Bouwkostenraming op basis van Quickscan

BOINTON DE GROOT BOUWKOSTENADVIES PLANVISIE

Algemene gegevens

Project	Afstudeerders		
opdracht:	ARUP		
status	CONCEPT		
peildatum:	1 August 2010		
meting:	conform NEN 2580		
bruto vloeroppervlak	BVO	154	m²
bruto inhoud	BIH	439	m³
bebouwd oppervlak	TBB	52	m²
aantal bouwlagen onder peil		3	lagen
aantal bouwlagen boven peil		-	lagen
geveloppervlak dicht	BGD	29	m²
geveloppervlak open	BGO	17	m²
bruto dakoppervlak	BDT	89	m²

Niveau 2 Bouwkosten in elementclusters

code	omschrijving	hoev.	eh	€ / eh	totaal
2	**BOUWKUNDIGE WERKEN**				
2.A	constructie onderbouw	52	m²	179	9,365
2.B	constructie bovenbouw	154	m²	150	23,076
2.C	afbouw gevel	46	m²	359	16,572
2.D	afbouw daken en plafonds	89	m²	115	10,307
2.E	inbouw (excl. inbouw gebruiker)	154	m²	70	10,707
2.F	afwerkingen	154	m²	45	6,930
2.G	overige bouwkundige voorzieningen	-	incl	--	--
2.H	Sloopwerkzaamheden	-	m²	--	--
	TOTAAL BOUWKUNDIGE WERKEN				**76,957**
3	**INSTALLATIES**				
3.A	W-installaties	154	m²	31	4,785
3.B	Klimaatinstallaties	154	m²	68	10,399
3.C	E-installaties	154	m²	32	4,864
3.D	transportinstallaties	-	m²	--	--
	TOTAAL INSTALLATIES				**20,048**
4	**VASTE INRICHTING**				
4.A	vaste inrichting	154	m²	19	3,000
	TOTAAL VASTE INRICHTING				**3,000**
5	**TERREINVOORZIENINGEN**				
5.A	terreinvoorziening	-	m²	--	--
	TOTAAL TERREINVOORZIENINGEN				**--**
6	**INDIRECTE BOUWKOSTEN**				
6.A	indirecte bouwkosten	18.5%	over	100,005	18,472
	TOTAAL INDIRECTE BOUWKOSTEN				**18,472**
	TOTAAL BOUWKOSTEN, excl. BTW	**154**	**m²**	**769**	**118,476**

Berekening bouwkosten incl. btw

TOTAAL BOUWKOSTEN, excl. BTW	**118,476**
BTW 19 %	**22,511**
TOTAAL INCLUSIEF BTW	**140,987**

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Active concept

Bouwkostenraming op basis van Quickscan

IGG BOINTON DE GROOT BOUWKOSTENADVIES PLANVISIE

Algemene gegevens

Project	Afstudeerders
opdracht:	ARUP
status	CONCEPT
peildatum:	1 August 2010

meting:	conform NEN 2580		
bruto vloeroppervlak	BVO	157	m²
bruto inhoud	BIH	442	m³
bebouwd oppervlak	TBB	52	m²
aantal bouwlagen onder peil		3	lagen
aantal bouwlagen boven peil		-	lagen
geveloppervlak dicht	BGD	37	m²
geveloppervlak open	BGO	22	m²
bruto dakoppervlak	BDT	80	m²

Niveau 2 Bouwkosten in elementclusters

code	omschrijving	hoev.	eh	€ / eh	totaal
2	**BOUWKUNDIGE WERKEN**				
2.A	constructie onderbouw	52	m²	163	8,528
2.B	constructie bovenbouw	157	m²	133	20,823
2.C	afbouw gevel	59	m²	244	14,404
2.D	afbouw daken en plafonds	80	m²	77	6,188
2.E	inbouw (excl. inbouw gebruiker)	157	m²	66	10,436
2.F	afwerkingen	157	m²	57	9,027
2.G	overige bouwkundige voorzieningen	-	incl	--	--
2.H	Sloopwerkzaamheden	-	m²	--	--
	TOTAAL BOUWKUNDIGE WERKEN				**69,406**
3	**INSTALLATIES**				
3.A	W-installaties	157	m²	31	4,798
3.B	Klimaatinstallaties	157	m²	180	28,224
3.C	E-installaties	157	m²	31	4,941
3.D	transportinstallaties	-	m²	--	--
	TOTAAL INSTALLATIES				**37,962**
4	**VASTE INRICHTING**				
4.A	vaste inrichting	157	m²	19	3,000
	TOTAAL VASTE INRICHTING				**3,000**
5	**TERREINVOORZIENINGEN**				
5.A	terreinvoorziening	-	m²	--	--
	TOTAAL TERREINVOORZIENINGEN				**--**
6	**INDIRECTE BOUWKOSTEN**				
6.A	indirecte bouwkosten	18.5%	over	110,368	20,386
	TOTAAL INDIRECTE BOUWKOSTEN				**20,386**
	TOTAAL BOUWKOSTEN, excl. BTW	**157**	**m²**	**833**	**130,754**

Berekening bouwkosten incl. btw

TOTAAL BOUWKOSTEN, excl. BTW	**130,754**
BTW 19 %	**24,843**
TOTAAL INCLUSIEF BTW	**155,597**

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Hybrid concept

Bouwkostenraming op basis van Quickscan

Algemene gegevens

Project	Afstudeerders		
opdracht:	ARUP		
status	CONCEPT		
peildatum:	1 August 2010		
meting:	conform NEN 2580		
bruto vloeroppervlak	BVO	154	m²
bruto inhoud	BIH	439	m³
bebouwd oppervlak	TBB	52	m²
aantal bouwlagen onder peil		3	lagen
aantal bouwlagen boven peil		-	lagen
geveloppervlak dicht	BGD	29	m²
geveloppervlak open	BGO	17	m²
bruto dakoppervlak	BDT	89	m²

Niveau 2 Bouwkosten in elementclusters

code	omschrijving	hoev.	eh	€ / eh	totaal
2	**BOUWKUNDIGE WERKEN**				
2.A	constructie onderbouw	52	m²	179	9,365
2.B	constructie bovenbouw	154	m²	152	23,338
2.C	afbouw gevel	46	m²	337	15,566
2.D	afbouw daken en plafonds	89	m²	114	10,223
2.E	inbouw (excl. inbouw gebruiker)	154	m²	70	10,707
2.F	afwerkingen	154	m²	45	6,930
2.G	overige bouwkundige voorzieningen	-	incl	--	--
2.H	Sloopwerkzaamheden	-	m²	--	--
	TOTAAL BOUWKUNDIGE WERKEN				**76,129**
3	**INSTALLATIES**				
3.A	W-installaties	154	m²	31	4,785
3.B	Klimaatinstallaties	154	m²	87	13,381
3.C	E-installaties	154	m²	32	4,864
3.D	transportinstallaties	-	m²	--	--
	TOTAAL INSTALLATIES				**23,030**
4	**VASTE INRICHTING**				
4.A	vaste inrichting	154	m²	19	3,000
	TOTAAL VASTE INRICHTING				**3,000**
5	**TERREINVOORZIENINGEN**				
5.A	terreinvoorziening	-	m²	--	--
	TOTAAL TERREINVOORZIENINGEN				**--**
6	**INDIRECTE BOUWKOSTEN**				
6.A	indirecte bouwkosten	18.5%	over	102,159	18,869
	TOTAAL INDIRECTE BOUWKOSTEN				**18,869**
	TOTAAL BOUWKOSTEN, excl. BTW	**154**	**m²**	**786**	**121,028**

Berekening bouwkosten incl. btw

TOTAAL BOUWKOSTEN, excl. BTW	**121,028**
BTW 19 %	**22,995**
TOTAAL INCLUSIEF BTW	**144,024**

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13.4 Additional costs

Voorbeeld bijkomende kosten
Graduation project

RAMING INVESTERINGSKOSTEN VOLGENS NEN 2631

code	omschrijving		hoev.	eh	€ / eh	subtotaal	totaal	€ / bvo	% bouwk.
OPDRACHT:	Graduation project								
STATUS:	Concept								
PEILDATUM:	6 September 2010								
BVO (M²):	880								
BOUWKOSTEN:	€ 1,072,000								
	uitgangspunten planning								
	voorbereidingstijd	10 mnd							
	bouwtijd	10 mnd							
	woningen	8							
	oppervlakte / woning	110 m²							
1	GRONDKOSTEN		NEN 2631, par. 3.1						
	markt koop								
	referentiewoning		8	won	35,000	280,000			
			8	won			280,000		
	TOTAAL GRONDKOSTEN						280,000		26.1%
2/6	BOUWKOSTEN		NEN 2631, par. 3.2						
	markt koop								
	referentiewoning		880	m²	900	792,000			
			880	m²			792,000		
	TOTAAL BOUWKOSTEN		880	m²			792,000	900	73.9%
5	TERREININRICHTING								
	n.v.t.		-	m²	-	-			
	TOTAAL TERREININRICHTING		-	m²			-	-	-
	Aanbestedingsrisico	niet meegenomen							
	TOTAAL BOUWKOSTEN INCL. GRONDKOSTEN						1,072,000	1,218	100.0%
7	INRICHTINGSKOSTEN		NEN 2631, par. 3.3						
	TOTAAL INRICHTINGSKOSTEN						-	-	-
8	BIJKOMENDE KOSTEN		NEN 2631, par. 3.4						
			880	m²			792,000		
	TOTAAL BOUWKOSTEN		880	m²			792,000	900	73.9%
5	TERREININRICHTING								
	n.v.t.		-	m²	-	-			
	TOTAAL TERREININRICHTING		-	m²			-	-	-
	Aanbestedingsrisico	niet meegenomen							
	TOTAAL BOUWKOSTEN INCL. GRONDKOSTEN						1,072,000	1,218	100.0%
7	INRICHTINGSKOSTEN		NEN 2631, par. 3.3						
	TOTAAL INRICHTINGSKOSTEN						-	-	-
8	BIJKOMENDE KOSTEN		NEN 2631, par. 3.4						
a.	Honoraria en verschotten								
	projectmanagement		2.00%	over	792,000	15,840			
	adviseur bouwkosten		0.35%	over	792,000	2,772			
	architect		4.30%	over	792,000	34,056			
	constructeur		4.00%	over	174,240	6,970			
	adviseur installaties		3.60%	over	221,760	7,983			
	grond- / milieuonderzoek		1.0	pst	15,000	15,000			
	aanbestedingskosten		1.0	pst	10,000	10,000			
	verschotten		7.00%	over	92,621	6,483			
	toezicht tijdens bouw	*0.20*	10.0	mnd	12,000	24,000			
	totaal honoraria en verschotten						123,104	140	11.5%
b.	Heffingen & aansluitkosten								
	leges bouwtoezicht		2.00%	over	792,000	15,840			
	OZ belasting tijdens bouw		0.20%	over	792,000	1,584			
	aansluitkosten (excl. trafo)		1.00%	over	792,000	7,920			
	overig		0.50%	over	792,000	3,960			
	totaal heffingen & aansluitkosten						29,304	33	2.7%

c.	**Verzekeringen**									
	CAR verzekering opdrachtgever			-	over	-	-			
	overige verzekeringen			-	over	-	-			
	totaal verzekeringen							-	-	-
d.	**Aanloopkosten**									
	schoonmaken 1e oplevering			-	over	-	-			
	totaal aanloopkosten							-	-	-
e.	**Financieringskosten**									
	bouwrijp maken	*5.50%*	0.80	13	mnd	-	-			
	grond	*5.50%*	0.50	15	mnd	277.200	9,529			
	heffingen	*5.50%*	1.00	13	mnd	29.304	1,791			
	honoraria	*5.50%*	0.40	20	mnd	123.104	4,514			
	bouwkosten	*5.50%*	0.40	10	mnd	792.000	14,520			
	afsluitkosten			1.0%	over	533.946	5,339			
	totaal financieringskosten							35,693	41	3.3%
f.	**Risicoverrekening & peildatumverschijning**									
	peildatumverschuiving bouwkosten			-	mnd	-	-			
	totaal risicoverrekening & peildatumverschijning							-	-	-
g.	**Onvoorzien & planwijzigingen**									
	honoraria en heffingen			2.50%	over	152.400	3,810			
	programmawijzigingen			0.50%	over	792.000	3,960			
	bestekswijzigingen			3.00%	over	792.000	23,760			
	totaal onvoorzien & planwijzigingen							31,530	36	2.9%
h.	**Reclame & afzetkosten**									
	notariskosten / kadastraal recht			0.40%	over	1,425.600	5,702			
	makelaarscourtage koop			1.00%	over	1,425.600	14,256			
	leegstand	*5.50%*		1	mnd	78.408	6,534			
	waarborg nieuwbouwwoningen			0.31%	over	1,425.600	4,419			
	totaal reclame & afzetkosten							30,912	35	2.9%
i.	**Overige kosten**									
	kunstwerken			0.00%	over	1,072.000	-			
	diversen			-	pst	-				
	totaal overige kosten							-	-	-
	TOTAAL BIJKOMENDE KOSTEN							250,543	285	23.4%
NETTO INVESTERINGSKOSTEN (INCL. GROND)								1,322,543	1,503	123.4%
9	**PROJECTONTWIKKELINGSKOSTEN**									
	algemene kosten			2.00%	over	1,322.543	26,451			
	winst & risico			5.00%	over	1,322.543	66,127			
	TOTAAL PROJECTONTWIKKELINGSKOSTEN							92,578	105	8.6%
	VERREKENING BTW									
	BTW over investeringskosten			19.00%	over	1,695.121	322,073			
	TOTAAL VERREKENING BTW							322,073	366	30.0%
TOTAAL INVESTERINGSKOSTEN INCLUSIEF GRONDKOSTEN (INCL. BTW)								1,737,194	1,974	162.1%

13.5 Mortgage model

The model as used for calculation of total expenditure over 30 years is described in the main report. Here a sample of this model is presented including the general assumptions and the calculation for the reference house.

Table 80: Sample of mortgage model

general figures	value	source
mortgage interest (%)	0.07	assumption for 30 years
mortgage period	30.00	assumption
gas fixed costs/yr	176.300	energieprijzen.nl
electricity fixed costs/yr	222.570	energieprijzen.nl
woodpellets price	0.271	(based on 1000kg) www.proflame.nl
scenario woodpellets	1.00	-
water (euro/m3)	1.680	milieucentraal, incl. tax and fixed costs
feedin electricity (eur/kW	0.23	
DH fixed costs yr	344.87	

A: reference house: topic	input	source		topic	result	source
ground costs	30,000	IGG	14.23%	building costs Δ ref	0	
building costs	103,240	IGG		additional costs Δ ref	0	
additional costs	32,370	IGG		selling price Δ ref	0	
VON price	210,870	IGG		selling price < socrat	4,130	
				annuity	16,993	formula
gas usage (m3/yr)	1225.0			Primary energy (GJ/y	73.8	
woodpellet use (kg/yr)	0.0			EPC	0.74	
electricity use (kWh/yr)	3329.0			EPC red	26%	
feedin elect (kWh/yr)	0.0			ENE1 credit	8	
water use (m3/year)	93.0			cum. Exp Δ ref low	-	
replace boiler (>15yr)	2880.0			cum. Exp Δ ref low	-	
replace balanced vent (:	3570.0					

Year	year	wp price/kg	low gas price/m3	high gas price/m3	low gas diff.	high gas diff	feedin tariff	low electricity price/kW	high electricity price/kW	additional investment	annuity	investment	energy: low	energy: high	water costs	interest	payback	cumulative expenditure low energy	cumulative expenditure high energy
										6,450	537,855	n/a	64,753	65,453	4,843	302,804	235,051	607,451	608,152
0	2010	0.27	0.430	0.430	21.890	21.890	-0.23	0.229	0.229		16993	210,870	1,844	1,844	156	14,761	2,232	18,993	18,993
1	2011	0.27	0.433	0.433	21.890	21.890	-0.22	0.229	0.229		16993	208,638	1,846	1,846	156	14,605	2,389	37,989	37,989
2	2012	0.27	0.435	0.435	21.890	21.890	-0.22	0.228	0.228		16993	206,249	1,849	1,849	156	14,437	2,556	56,988	56,988
3	2013	0.27	0.438	0.438	21.890	21.890	-0.22	0.301	0.301		16993	203,694	2,093	2,093	156	14,259	2,735	76,230	76,230
4	2014	0.27	0.440	0.440	21.890	21.890	-0.22	0.301	0.301		16993	200,959	2,096	2,096	156	14,067	2,926	95,476	95,476
5	2015	0.27	0.443	0.443	21.890	21.890	-0.22	0.301	0.301		16993	198,033	2,099	2,099	156	13,862	3,131	114,724	114,724
6	2016	0.27	0.446	0.446	21.890	21.890	-0.22	0.301	0.301		16993	194,902	2,102	2,102	156	13,643	3,350	133,976	133,976
7	2017	0.27	0.448	0.448	21.890	21.890	-0.22	0.300	0.300		16993	191,552	2,104	2,104	156	13,409	3,585	153,230	153,230
8	2018	0.27	0.451	0.451	21.890	21.890	-0.22	0.300	0.300		16993	187,967	2,107	2,107	156	13,158	3,836	172,486	172,486
9	2019	0.27	0.454	0.454	21.890	21.890	-0.22	0.300	0.300		16993	184,131	2,110	2,110	156	12,889	4,104	191,746	191,746
10	2020	0.27	0.457	0.457	21.890	21.890	-0.22	0.300	0.300		16993	180,027	2,113	2,113	156	12,602	4,391	211,009	211,009
11	2021	0.27	0.456	0.458	21.890	21.890	-0.22	0.300	0.301		16993	175,636	2,114	2,117	156	12,295	4,699	230,272	230,275
12	2022	0.27	0.456	0.459	21.890	21.890	-0.22	0.301	0.301		16993	170,937	2,114	2,121	156	11,966	5,028	249,536	249,545
13	2023	0.27	0.455	0.460	21.890	21.890	-0.22	0.301	0.302		16993	165,909	2,115	2,124	156	11,614	5,380	268,800	268,819
14	2024	0.27	0.454	0.462	21.890	21.890	-0.23	0.301	0.303		16993	160,530	2,115	2,128	156	11,237	5,756	288,065	288,097
15	2025	0.27	0.454	0.463	21.890	21.890	-0.23	0.302	0.303		16993	154,773	2,116	2,132	156	10,834	6,159	307,330	307,378
16	2026	0.27	0.453	0.464	21.890	21.890	-0.23	0.302	0.304	6,450	17731	155,064	2,116	2,136	156	10,855	6,876	327,333	327,401
17	2027	0.27	0.453	0.466	21.890	21.890	-0.23	0.302	0.305		17731	148,188	2,117	2,140	156	10,373	7,358	347,337	347,428
18	2028	0.27	0.452	0.467	21.890	21.890	-0.23	0.303	0.305		17731	140,830	2,117	2,143	156	9,858	7,873	367,342	367,458
19	2029	0.27	0.452	0.468	21.890	21.890	-0.23	0.303	0.306		17731	132,958	2,118	2,147	156	9,307	8,424	387,347	387,493
20	2030	0.27	0.451	0.470	21.890	21.890	-0.23	0.304	0.307		17731	124,534	2,119	2,151	156	8,717	9,013	407,352	407,531
21	2031	0.27	0.451	0.471	21.890	21.890	-0.23	0.304	0.307		17731	115,520	2,119	2,155	156	8,086	9,644	427,359	427,573
22	2032	0.27	0.450	0.473	21.890	21.890	-0.23	0.304	0.308		17731	105,876	2,120	2,160	156	7,411	10,319	447,366	447,620
23	2033	0.27	0.450	0.474	21.890	21.890	-0.23	0.305	0.309		17731	95,557	2,121	2,164	156	6,689	11,042	467,374	467,671
24	2034	0.27	0.449	0.476	21.890	21.890	-0.23	0.305	0.310		17731	84,515	2,122	2,168	156	5,916	11,815	487,382	487,727
25	2035	0.27	0.449	0.477	21.890	21.890	-0.23	0.306	0.310		17731	72,700	2,122	2,173	156	5,089	12,642	507,392	507,787
26	2036	0.27	0.448	0.479	21.890	21.890	-0.24	0.306	0.311		17731	60,058	2,123	2,177	156	4,204	13,527	527,402	527,851
27	2037	0.27	0.448	0.480	21.890	21.890	-0.24	0.307	0.312		17731	46,531	2,124	2,181	156	3,257	14,474	547,413	547,919
28	2038	0.27	0.447	0.482	21.890	21.890	-0.24	0.307	0.313		17731	32,058	2,125	2,186	156	2,244	15,487	567,425	567,992
29	2039	0.27	0.447	0.483	21.890	21.890	-0.24	0.307	0.313		17731	16,571	2,126	2,190	156	1,160	16,571	587,438	588,070
30	2040	0.27	0.446	0.485	21.890	21.890	-0.24	0.308	0.314		17731	0	2,126	2,195	156	0	17,731	607,451	608,152

Literature

Energieprijzen website: http://www.energieprijzen.nl/rekentool/s

14 Details of parametric study

The reference house was chosen as a starting point for the applicability of the new house concept. Therefore, the changes to be made will be deducted from the current spatial planning and architectural design. In order to gain insight in the performance of several components in the SenterNovem reference house, a list of variants has been set up which are all tested on their influence on overheating, heating energy and financial impact. Overheating and heating energy were simulated by use of the building simulation program Equest, the financial impact of the measures was estimated by the building cost consultants of IGG.

For this sensitivity study, some parameters remained fixed, for certain reasons as is presented in Table 81. In the first phase, each possible measure is changed individually and the results are compared to find the best performing measures. Reasonable combinations of measures are deducted from these results and tested on their combined performance. The parametric options are presented in Table 82.

Table 81: Fixed parameters for reference house

Fixed parameter	Details
Heating system	Heating system is fixed as being a high efficiency gas fired boiler, with unlimited capacity. Heat emission is provided by baseboards in the living room, bedrooms and bathroom.
Ventilation system	Ventilation is provided by a balanced mechanical ventilation system with heat recovery. The flow is deducted from the demand in building decree and is on continuously.
Equipment schedule	The schedule is based on GIW/ISSO 2008 for calculation of overheating hours, the height of power is deducted from average household values by Milieucentraal (Appendix 15)
Lighting schedule	The schedule is based on GIW/ISSO 2008 for calculation of overheating hours, the height of power is deducted from average household values by NEN 5128 (= 6kWh/(m^2.yr) (Appendix 15)
Occupancy schedule	The schedule is based on GIW/ISSO 2008 for calculation of overheating hours. (Appendix 15)
Temperature setpoints	The setpoints are deducted from GIW/ISSO 2008: bedrooms 18°C, living room 20°C, bathroom 22°C and other spaces 15°C. A setback of 5°C accounts between 23.00-07.00 for living, bath- and bedrooms.
Hot water schedule	This schedule is deducted from NEN 5128 and is presented in (Appendix 15)
Climate	The ASHRAE climate file for Amsterdam is applied. Latitude 52.3 degrees; Longtitude -4.8 degrees; Altitude 0 degrees; Time zone -1. Orientation is North-South

Table 82: parametric options for the reference house; xx stands for the option number (01, 02, 03, etc)

Sensitivity options					
	Window size[4]	Reference house	**01**	**02**	**03**

Ws-nf-xx	North façade	m^2	7.02	+ glazed door ($2m^2$): 9.02 m^2	Window height +30%, tot. 9.0 m^2	Window height -30%, tot. 4.99 m^2
Ws-sf-xx	South façade	m^2	13.27	-50% glass[5] doors, tot. 4.4 m^2	Window height +30%, tot.12.4 m^2	Window height -30%, tot. 10.1 m^2
Ws-nr-xx	North roof[3]	m^2	1.0	Extra window 1+1=2	Width * 4 1*4=4	Height * 4 1*4=4
Ws-sr-xx	South roof	m^2	0.0	1 window: 1 m^2	-	-

	Window type[1]	Reference house	**1.5: Uglass 1.31**	**1.1: Uglass 1.08**	**0.8: Uglass 0.8**
Wt-uv-xx	All glazing, U-value glass[2]	Double **Uglass 1.65** (Uwindow 1.8); shgc 0.68; LT 0.72 (2615)	Double **Uglass 1.48** (Uwindow 1.59); shgc 0.65; LT 0.77 (2665)	Triple **Uglass 1.08** (Uwindow 1.48); shgc 0.58; LT 0.70 (3603)	Triple **Uglass 0.8** (Uwindow 1.08); shgc 0.47; LT 0.66 (3623)
	Window type[1]	Reference house	**1.5 (shgc)**	**1.1 (shgc)**	**0.8 (shgc)**
Wt-uv-xx	Fixed solar heat gain coefficient	Double **Uglass 1.65** (Uwindow 1.8); shgc 0.68; LT 0.72 (2615)	Simplified: SC 0.78; Uglass 0.8, LT 0.66, outs. Emissivity 0.84	Simplified: SC 0.78; Uglass 0.8, LT 0.66, outs. Emissivity 0.84	Simplified: SC 0.78; Uglass 0.8, LT 0.66, outs. Emissivity 0.84

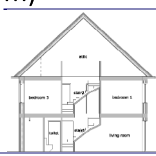
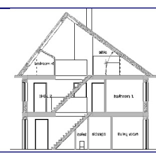
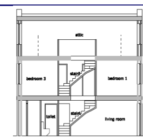
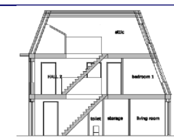
	Building mass	Reference house	Lw-wf	Hw-co
Bm-xx-xx	Description	Traditional/ mixed heavy	Light weight, wood frame	Heavy weight, concrete
	Heat capacity	295 kJ/m^2K user area	84 kJ/m^2K user area	508 kJ/m^2K user area
	Constructions	See paragraph 14.1.1	See paragraph 14.1.1	See paragraph 14.1.1

	Shading	Reference house	Me	Fo.5	Fo.2
Sh-sf-xx	South	No shading	**M**oveable **E**xterior on 300 W/m^2 (diff & dir); multiplier 0.3	**F**ixed **O**verhang on all windows: 0.5 m	**F**ixed **O**verhang on all windows: 0.2 m
Sh-nf-xx	North	No shading	**M**oveable **E**xterior on 300 W/m^2 (diff & dir); multiplier 0.3	**F**ixed **O**verhang on all windows: 0.5 m (except roof and hall)	**F**ixed **O**verhang on all windows: 0.2 m (except roof and hall)

	Insulation m^2K/W	Reference house	+2	+4 (passiv)
In-tot-xx	walls	3	5	7
	roof	4	6	8

	gr. floor	3	5	7
In-wa-xx	walls	3	5	7
In-ro-xx	roof	4	6	8
In-fl-xx	gr. floor	3	5	7

	Infil-tration	Reference house	1.42	0.4	0.15
If-qv-xx	Qv;10;kar ($dm^3/s/m^2$)	0.625	1.42 natural vent building decree	0.4 min. building decree	0.15 Passive House

	Roof size	Reference house	01 Opt. for PV	02 Flat roof	03 Wall/roof area
Rs-sh-xx	Roof shape	42 degrees roof, equal on north and south; **77.8 m^2** (roof perimeter 14.4 m)	36 degrees on south; **78.3 m^2** (roof perimeter 14.5 m)	Flat roof, extra floor area (10 m^2); **48.5 m^2** (roof perimeter 8.92 m). Extra wall: 30.9 m^2	Smaller wall area, larger roof; **86 m^2** (roof perimeter 15.9 m). Less wall: 15.45 m^2
					

1. The glass types are chosen from the DOE2 glass library as is used for input in Equest simulation program. The numbers between brackets indicate the chosen glass type. All are calculated based on wooden/vinyl framework.
2. The Dutch parameter ZTA (zontoetreding absoluut) coincides with the American parameter SHGC (solar heat gain coefficient). They both express the percentage of solar energy which is transmitted through the glass by direct radiation and absorption.
3. Sizes of roof windows are chosen based on the necessary amount of window surface to achieve 2% Average Daylight Factor in the attic zone
4. Windows as mentioned here are the standard windows (combination of small open able and larger closed) as can be found in kitchen and all three bedrooms).
5. Size is chosen, on the minimum need for daylight availability to achieve 2% Average Daylight Factor.

The measures as presented in Table 82 result in a total of 38 variants. The results of the sensitivity study are presented graphically per topic of measures. Afterwards the lists of best performing measures compared to the reference house are given in

Table 83 till Table 85, from which the combined packages are deducted. The values for energy reductions per measure are indicative. During parametric study some flaws in the reference house model were discovered, but kept as was used in the beginning of this sensitivity study. The results mainly show the amount of improvement or worsening compared to the reference situation. Also, the different measures cannot be directly added to combine the effects of both.

Table 83: Best measures for heating energy reduction

Best on heating energy reduction, per topic (concept HE-topic)		
Δ GJ	Description	Code
-5.27	Insulation improvement of walls, floor and roof with Rc +4	in-tot-+4
-5.04	Window type: U-value to 0.8, with solar heat gain coefficient as reference house	inwt-uv-0.8 (st. shgc)
-3.97	Roof size: low wall surface (extra roof on south, partial flat)	rf-sh-lw
-2.70	Infiltration: characteristic opening size of skin to qv 0.2	if-qv-0.2
-0.65	Window size: addition of window on south roof	ws-sr-01
-0.70	Building mass: Heavy weight, concrete structure	bm-hw-co
0.46	Shading: North façade with moveable exterior shading (on 300 W/m^2)	sh-nf-me

Table 84: Best measures for overheating hours reduction

Best on overheating hours reduction, per topic (concept OH-topic)		
Δ hours	Description	Code
-386	Shading: South façade with moveable exterior shading (on 300 W/m^2)	sh-sf-me
-344	Window size: reduction of glass doors on ground floor by 50%	ws-sf-01
-334	Window type: U-value to 0.8, with accompanying SHGC as given by DOE2	wt-uv-0.8
-185	Infiltration: characteristic opening size of skin to qv 1.4	if-qv-1.4
-19	Roof size: shape of roof with 36 degrees on south	rf-sh-36
-12	Building mass: Heavy weight, concrete structure	bm-hw-co
18	Insulation improvement of walls, floor and roof with Rc +4	in-wa-+2

Table 85: Measures reducing both overheating hours and heating energy

Measures which reduce both overheating and heating energy (concept HE+OH)			
Δ GJ	Δ hrs	Description	Code
-0.79	-138	Window type: U-value to 1.1, with accompanying SHGC	wt-uv-1.1
-0.70	-12	Building mass: Heavy weight, concrete structure	bm-hw-co
-0.33	-54	Window size: reduction of window heights by -30%	ws-nf-03
-0.22	-334	Window type: U-value to 0.8, with accompanying SHGC	wt-uv-0.8

Table 86: Package of best measures for overheating hours and heating energy reduction

Best measures on overheating or heating energy, conflicts excluded (concept HE-OH)		
Δ GJ	Description: best measures heating energy. (top down, non conflicting)	Code
-5.27	Insulation improvement of walls, floor and roof with Rc +4	in-tot-+4
-5.04	Window type: U-value to 0.8, with solar heat gain coefficient as reference house	inwt-uv-0.8 (st. shgc)
-3.97	Roof size: low wall surface (extra roof on south, partial flat)	rf-sh-lw
-2.70	Infiltration: characteristic opening size of skin to qv 0.2	if-qv-0.2
-0.70	Building mass: Heavy weight, concrete structure	bm-hw-co
Δ hrs	Description: best measures overheating. (top down, non conflicting)	Code
-386	Shading: South façade with moveable exterior shading (on 300 W/m^2)	sh-sf-me
-344	Window size: reduction of glass doors on ground floor by 50%	ws-sf-01
-334	Window type: U-value to 0.8, with accompanying SHGC as given by	wt-uv-0.8

	DOE2	
-185	Infiltration: characteristic opening size of skin to qv 1.4	if-qv-1.4
-134	Shading: North façade with fixed overhang, length 0.5	sh-nf-fo.5

The results from this analysis are presented in Figure 30. The measures to reduce heating energy result decrease it by 67%. But the overheating increases by 654%. The contrary accounts for the combination in which the measures on overheating prevention are combined. This gives a heating energy increase of 30% but decreases the overheating hours with 95%. 'OH+HE' and 'OH-HE' represent the combinations which should address both overheating and heating energy reduction. The measures of OH+HE do reduce overheating, but heating energy demand is increased by 3.5%. The best results are found for the top 5 of measures which perform well on overheating or heating energy. Heating energy is reduced by 36%, though overheating is increased by (only) 102%.

Overheating and heating demand for combined options

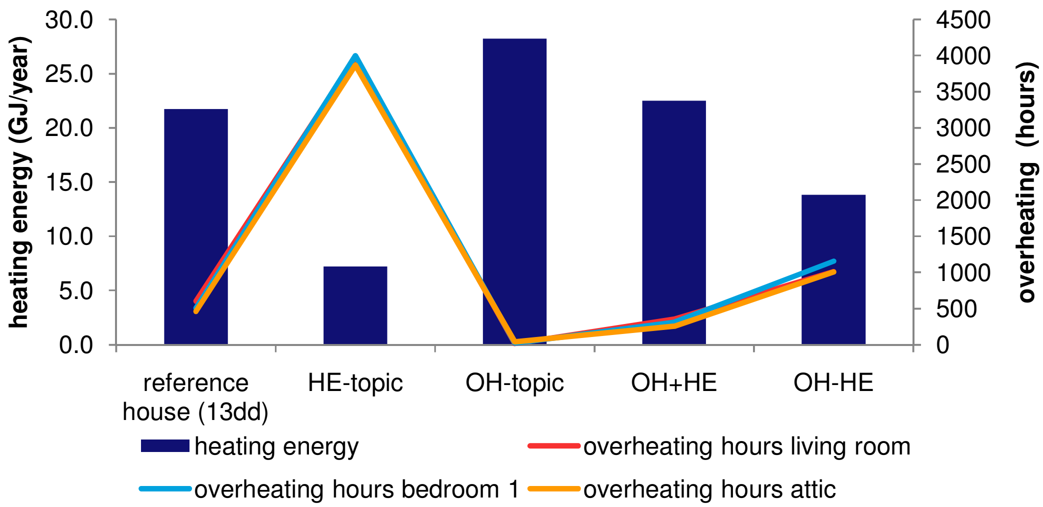


Figure 70: Overheating and heating demand for combined options

In reality, only a check for energy reduction will be necessary, since the possibility to open windows if temperatures increased was not included in the current model. The option with largest decrease in energy is therefore chosen for the concept with improves building skin.

If one would also include the financial aspects, of these energy reducing measures, insulation will be the best.

Cost comparison

Based on cost indications by IGG, a comparison of the costs per measure has been made and is included in the total selling price of the houses as total. The costs are compared to those of the reference situation. Some measures show a reduction of this selling price (like smaller windows, different roof size), but most of the majors give an increase in selling price.

The additional investment per saved GJ on heating energy is compared for all options. If the heating energy did not increase (equal or higher than the reference house), the option was not presented in Figure 31. Positive values are given to measures which reduce costs AND energy, negative values are given to measures which increase costs, but reduce energy.

Investment per GJ reduction of heating energy

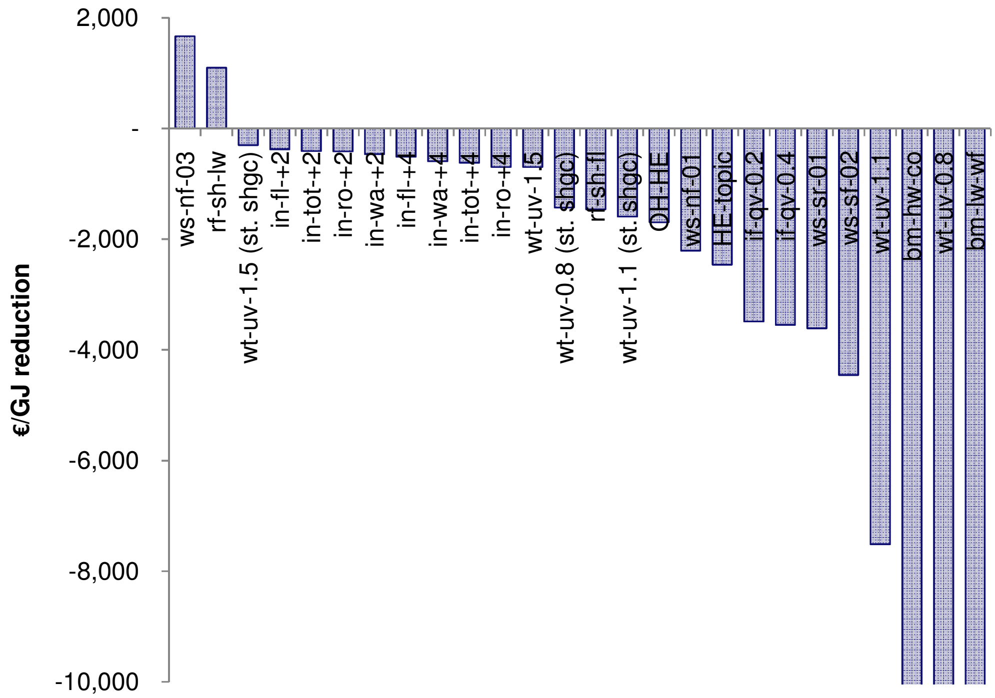


Figure 71: Euro per saved GJ (positive = investment reduction/saved GJ; negative = additional investment/saved GJ). Abbreviations refer to parametric options as presented in Table 82.

From this graph, it is clear that insulation measures of closed partitions are the most feasible in terms of energy reduction. Also the change of window transmission to a lower level is feasible up to a small increase, especially if the solar heat gain coefficient is kept equal to the reference house value. Although this is not a realistic solution increase of infiltration values might still be feasible, but the price per GJ is 7 times the value of the average insulation value. Change of the building mass to higher or lower weight is basically very expensive, so the energy reduction which it results in does not justify this. Although, the improvement on environmental impact when using more natural materials like wood could improve the level of sustainability but unfortunately this will not be expressed in financial advantage for the house buyer/user.

14.1.1 Building materials in parametric study

Table 87: Building materials in parametric study

	Material Name	Thickness (mm)	Conductivity (W/m2K)	Density (kg/m3)	Spec. Heat (Btu/lb-°F)	R-Value (m2K/W)
Ewall_lw-wf	Air res wall ext	n/a	n/a	n/a	n/a	0.13
	Wood Hd 3/4in (WD11)	19	0.52	721	1255	n/a
	Air layer 40mm (NEN 1096)	n/a	n/a	n/a	n/a	0.09
	Plywd 3/8in (PW02)	9	0.38	545	1213	n/a

	Min wool 90mm R0.036	104	0.12	18	841	n/a
	GypBd 3/4in (HF-E1)	19	2.38	1602	837	n/a
Eroof_lw-wf	Air res wall ext	n/a	n/a	n/a	n/a	0.13
	Hol ClayTile 3in (CT01)	76	1.77	1121	837	n/a
	Plywd 1/2in (PW03)	13	0.38	545	1213	n/a
	Air layer 40mm (NEN 1096)	n/a	n/a	n/a	n/a	0.09
	Min wool 90mm R0.036	122	0.12	18	841	n/a
	Plywd 1/2in (PW03)	13	0.38	545	1213	n/a
	Air res wall int	n/a	n/a	n/a	n/a	0.04
Iwall_lw-wf	GypBd 3/4in (HF-E1)	19	2.38	1602	837	n/a
	Min wool 90mm R0.036	90	0.12	18	841	n/a
	GypBd 3/4in (HF-E1)	19	2.38	1602	837	n/a
Efloor_lw-	Air res flr ext	n/a	n/a	n/a	n/a	0.17
	Plywd 3/4in (PW05)	19	0.38	545	1213	n/a
	Min wool 90mm R0.036	91	0.12	18	841	n/a
	Air res flr ext	n/a	n/a	n/a	n/a	0.17
Ifloor_lw-wf	Plywd 3/8in (PW02)	9	0.38	545	1213	n/a
	Min wool 90mm R0.036	90	0.12	18	841	n/a
	GypBd 3/4in (HF-E1)	19	2.38	1602	837	n/a
Ewall_ref	Air res wall ext	n/a	n/a	n/a	n/a	0.13
	Brick 100mm	100	2.14	1699	841	n/a
	Air layer 40mm (NEN 1096)	n/a	n/a	n/a	n/a	0.09
	Min wool 90mm R0.036	90	0.12	18	841	n/a
	Gypsum block 100mm	405	3.28	1899	841	n/a
	Stucco 1in (SC01)	25	2.37	1858	837	n/a
	Air res wall int	n/a	n/a	n/a	n/a	0.04
Eroof_ref	Air res wall ext	n/a	n/a	n/a	n/a	0.13
	Hol ClayTile 3in (CT01)	76	1.77	1121	837	n/a
	Plywd 1/2in (PW03)	13	0.38	545	1213	n/a
	Air layer 40mm (NEN 1096)	n/a	n/a	n/a	n/a	0.09
	Min wool 90mm R0.036	122	0.12	18	841	n/a
	Plywd 1/2in (PW03)	13	0.38	545	1213	n/a
	Air res wall int	n/a	n/a	n/a	n/a	0.04
Iwall_ref	Gypsum block 100mm	100	3.28	1899	841	n/a
Efloor_ref	Air res flr ext	n/a	n/a	n/a	n/a	0.17
	Min wool 90mm R0.036	90	0.12	18	841	n/a
	Conc HW 140lb 4in (HF-C5)	101	5.68	2243	837	n/a
	Conc LW 80lb 2in (CC23)	51	1.18	1281	837	n/a
	Air res flr ext	n/a	n/a	n/a	n/a	0.17

Ifloor_ref	Conc HW 140lb 6in (HF-C13)	152	5.68	2243	837	n/a
Ewall_hw_co	Air res wall ext	n/a	n/a	n/a	n/a	0.13
	Conc LW 80lb 2in (CC23)	51	1.18	1281	837	n/a
	Air layer 40mm (NEN 1096)	n/a	n/a	n/a	n/a	0.09
	Min wool 90mm R0.036	100	0.12	18	841	n/a
	Conc HW 140lb 6in (HF-C13)	200	5.68	2243	837	n/a
	Stucco 1in (SC01)	25	2.37	1858	837	n/a
	Air res wall int	n/a	n/a	n/a	n/a	0.04
Eroof_hw_co	Air res wall ext	n/a	n/a	n/a	n/a	0.13
	Hol ClayTile 3in (CT01)	76	1.77	1121	837	n/a
	Plywd 1/2in (PW03)	13	0.38	545	1213	n/a
	Air layer 40mm (NEN 1096)	n/a	n/a	n/a	n/a	0.09
	Min wool 90mm R0.036	90	0.12	18	841	n/a
	Plywd 1/2in (PW03)	13	0.38	545	1213	n/a
	Conc LW 80lb 2in (CC23)	450	1.18	1281	837	n/a
	Air res wall int	n/a	n/a	n/a	n/a	0.04
Iwall_hw_co	Com Brick 4in (HF-C4)	101	2.38	1922	837	n/a
Efloor_hw_co	Air res flr ext	n/a	n/a	n/a	n/a	0.17
	Min wool 90mm R0.036	90	0.12	18	841	n/a
	Conc HW 140lb 4in (HF-C5)	101	5.68	2243	837	n/a
	Conc LW 80lb 2in (CC23)	51	1.18	1281	837	n/a
	Air res flr ext	n/a	n/a	n/a	n/a	0.17
Ifloor_hw_co	Conc HW 140lb 6in (HF-C13)	152	5.68	2243	837	n/a

15 Details and Modelling of Concepts

15.1 Concepts in detail

In this part of the appendices, the details of the concept design are presented for the reference house and active, passive and hybrid concepts.

The details of the reference house, active and passive concepts are given in the same table to show the differences of the concepts which are compared to find the optimum solution. In a separate table, being the optimum solution the hybrid concept is explained in detail.

Table 88: Specifications of the reference house, the active and the passive concept

	Reference House	Active Concept	Passive Concept
Source of Energy	Natural Gas	Electricity	Natural Gas
Generation/Conversion System Space Heating	HR 107 Combi-boiler	Water to water Heat Pump with vertical ground source heat exchanger	HR 107 Combi-boiler
Capacity [kW]	8.5	6.5	4.5
Supply Temperature [^oC]	90	36	36
Return Temperature[^oC]	70	30	30
Efficiency (%)	95	COP=4.4	97.5
Distribution System Space Heating	HT Radiators	LT floor heating	LT floor heating
Energy Transport Medium	Water	Water	Water
Max. Specific Power Output	2.2 kW	97 W/m^2	97 W/m^2
Total floor area required	-	74 m²	43 m²
Domestic Hot Water Supply	HR 107 Combi-boiler	Flat Plate Collector , Heat Pump and Immerse Heaters	Flat Plate Collector and HR 107 biler
Capacity	19 kW	9 kW immerse heaters and 6 m^2	12 kW and 6 m^2
Efficiency	67.5%	COP_{HP}=3.6	67.5%
Shower Heat Recovery	No	Yes, Pipe type	Yes, Pipe type
Ventilation Principle	Balanced Mechanical Ventilation	Balanced Mechanical Ventilation	Natural inlet, mechanical exhaust
Heat Recovery (efficiency)	Yes (0.56)	Yes (0.56)	Optional Exhaust Air-to-Water Heat Pump
Electricity Generation	No	Evaluated Optional	No
Size		Optional 38 m^2	-
Energy Storage	No	Yes	Yes
Type	-	Water tank placed in the heat pump unit	Water tank connected to solar

			thermal collector
Capacity	-	180 liter	300
Storage Minimum Temperature	-	55°C	55°C
System Control and Appliances			
Thermostat	Analog	Analog	Analog
Appliances	Conventional	A++	A++
Energy Saving	None	Stand-by killers	Stand-by killers
Water Saving	No	Yes	Yes
Measures	None	6-liter flush toilets Flow regulators; Low flow shower heads	6-liter flush toilets Flow regulators; Low flow shower heads

Sizes of the several rooms in the concepts are presented in Table 89. After this the drawings of the concepts are presented, and also the list of input values for building materials.

Table 89: Overview of house and room sizes for all concepts

House size		Abbreviation	Reference	Passive	Active	
bruto vloeroppervlak		BVO	156.99	154.04	157.02	m²
bruto inhoud		BIH	427.53	438.94	441.77	m²
bebouwd oppervlak		TBB	52.33	52.34	52.34	m²
aantal bouwlagen boven peil			3.00	3.00	3.00	st
geveloppervlak dicht		BGD	34.82	29.04	37.24	m²
geveloppervlak open		BGO	25.31	17.09	21.90	m²
geveloppervlak totaal		BGT	60.13	46.13	59.14	m²
dakoppervlak dicht		BDD	76.57	81.46	79.16	m²
dakoppervlak open		BDO	0.97	8.01	0.96	m²
bruto dakoppervlak		BDT	77.55	89.47	80.12	m²
Floor	Room size excl. walls, h>1.5 m		Reference	Passive	Active	
0	living room + kitchen		36.59	31.97	33.54	m²
	hall		5.44	4.49	4.8	m²
	toilet		1.17	1.86	1.88	m²
	stair		0.98	1.40	1.43	m²
	metering cupboard		0.33	0.27	0.34	m²
	storage room		-	3.54	3.51	m²
1	bedroom 1		16.36	10.96	12.43	m²
	bedroom 2		9.91	10.19	11.89	m²
	bedroom 3		5.77	6.28	6.85	m²
	bathroom		5.37	4.90	4.89	m²
	toilet		-	1.83	2.06	m²
	crossover		3.74	4.23	4.23	m²
	stair		2.52	2.61	2.61	m²

2	attic	30.12	-		m²
	north attic	-	12.15	11.01	m²
	south attic	-	12.38	14.60	m²
	stair	2.3	2.87	2.66	m²
	services	-	4.38	5.16	m²
ext	terrace	9.61	9.61	9.61	m²

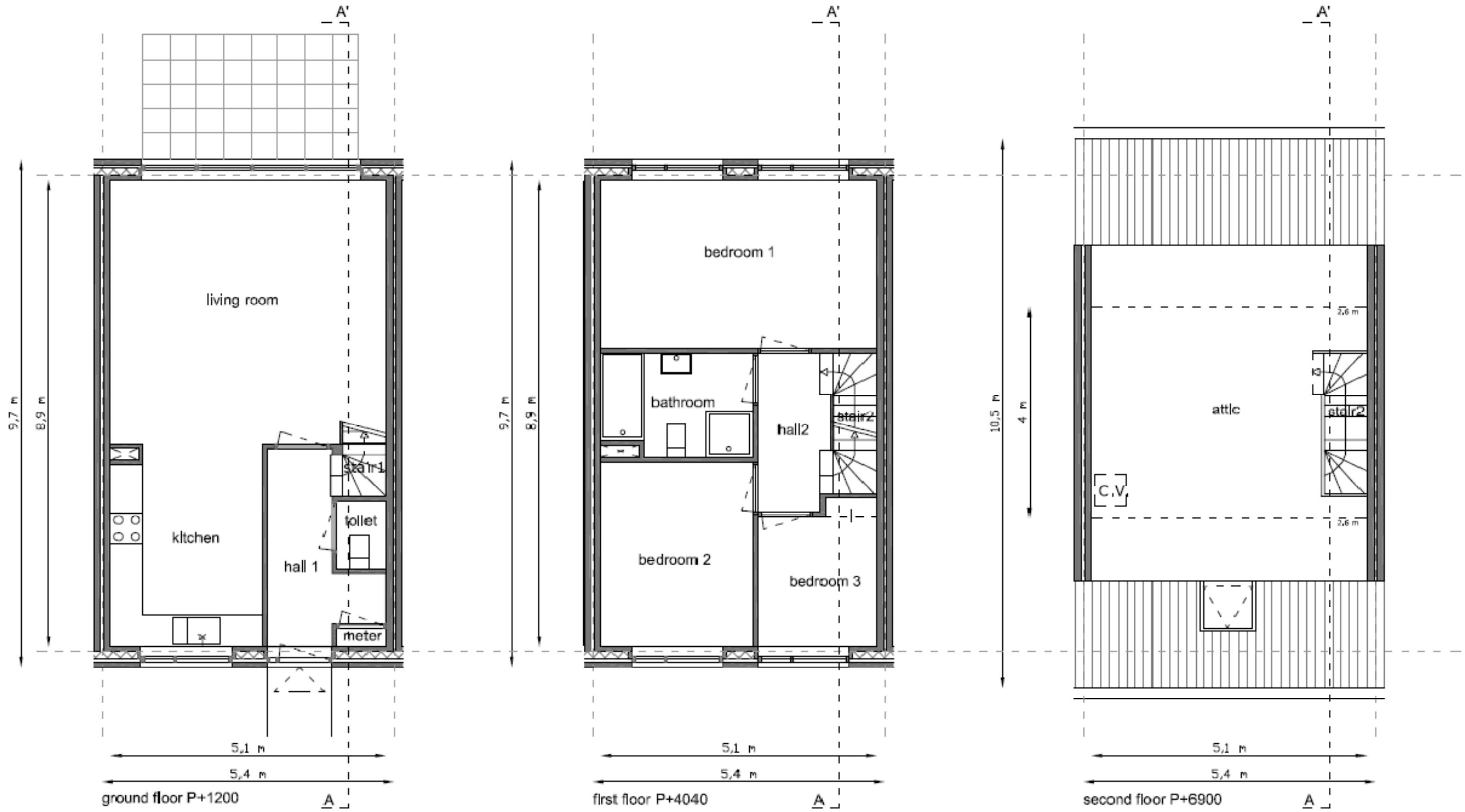
15.2 Drawings

In the next pages the drawings of concepts can be found they are listed in below and will are presented in that order. It should be noted that the drawing pages do not include page numbers.

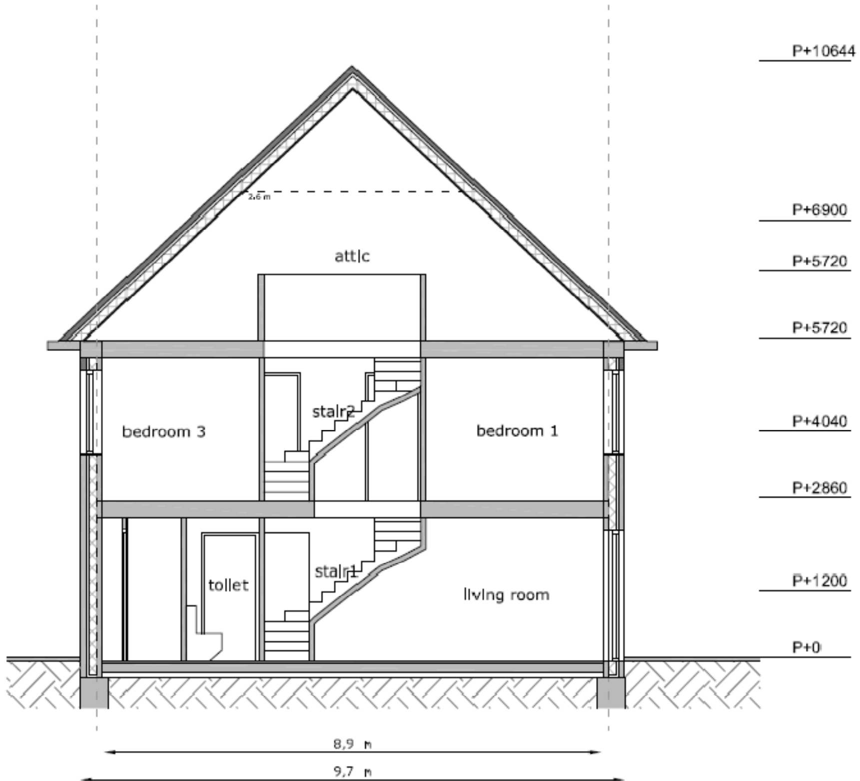
Table 90: Overview of drawings as can be found in the next pages

Concept	Drawing name
Reference house	Space plans
	Section
	Views
Passive concept	Space plans
	Section
	Views
Active concept	Space plans
	Section
	Views

The hybrid concept is based on the passive concept and the layout in drawings does not differ from the passive concept. Therefore for layout of the hybrid concept it is referred to the passive concept.

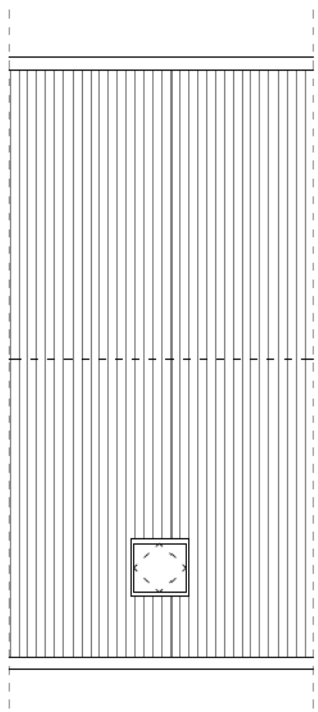


N	Concept	SenterNovem Reference
	Drawing name	Space plans
	Scale	1:100

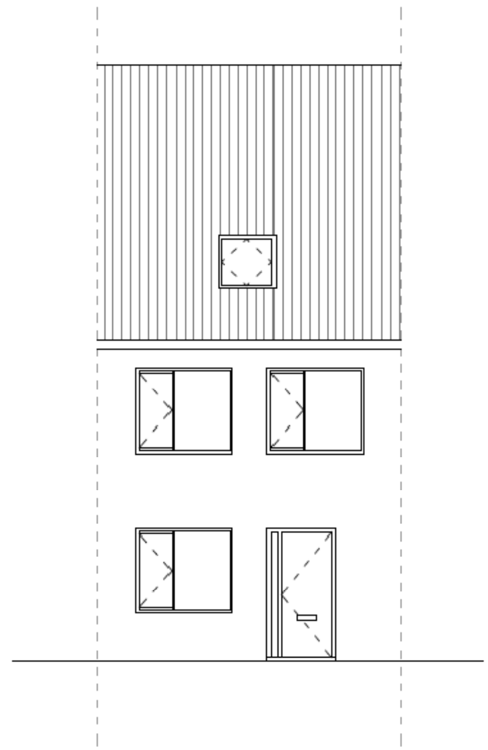


section A-A'

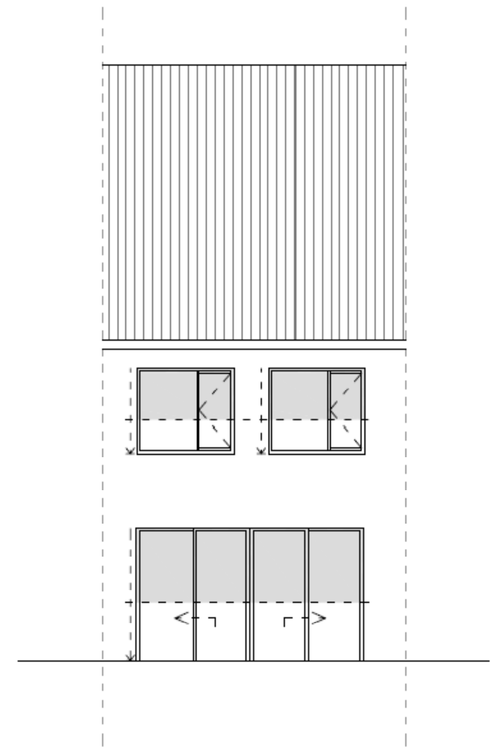
N	Concept	SenterNovem Reference
	Drawing name	Section A-A'
	Scale	1:100



roof view

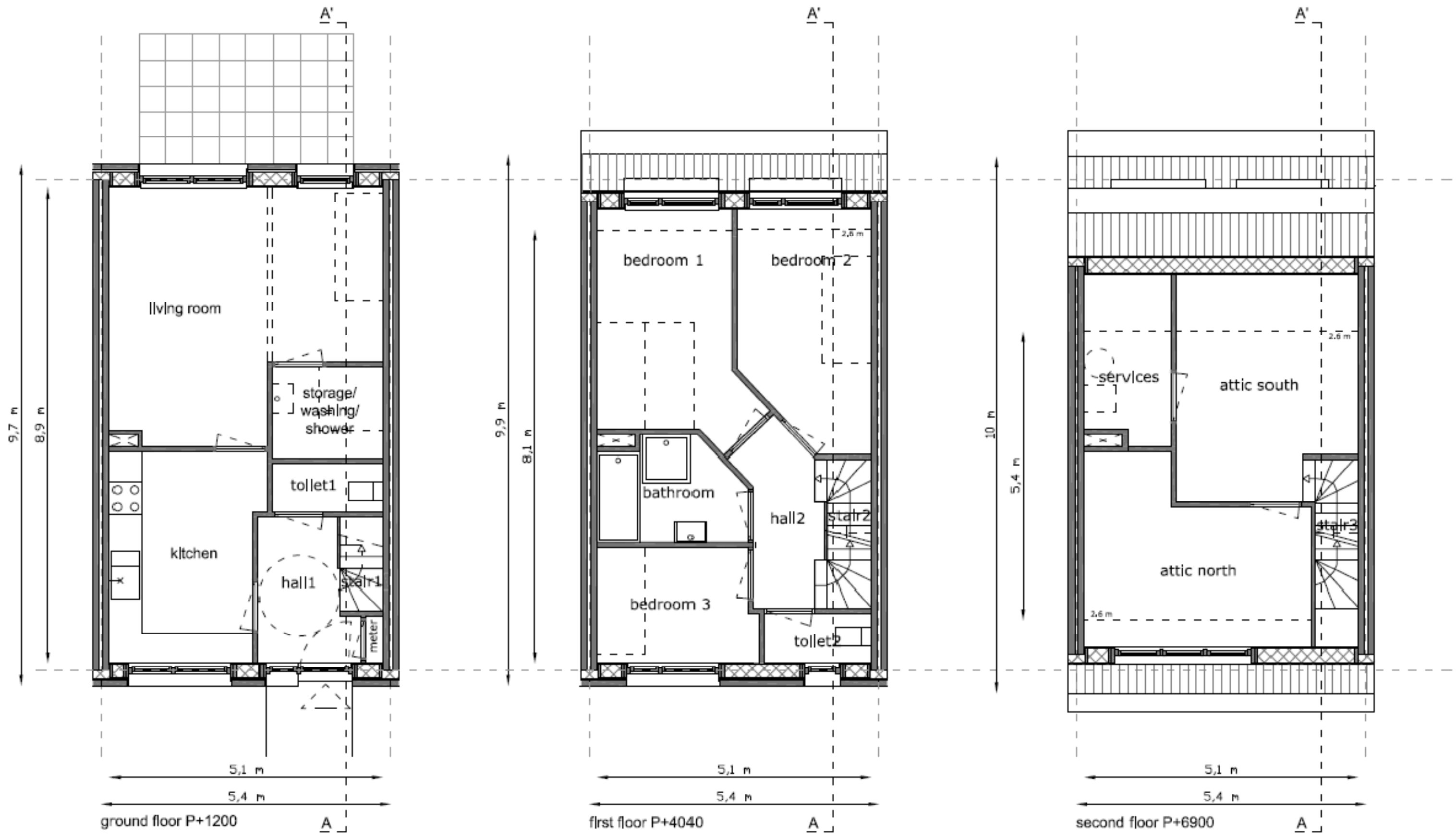


north facade

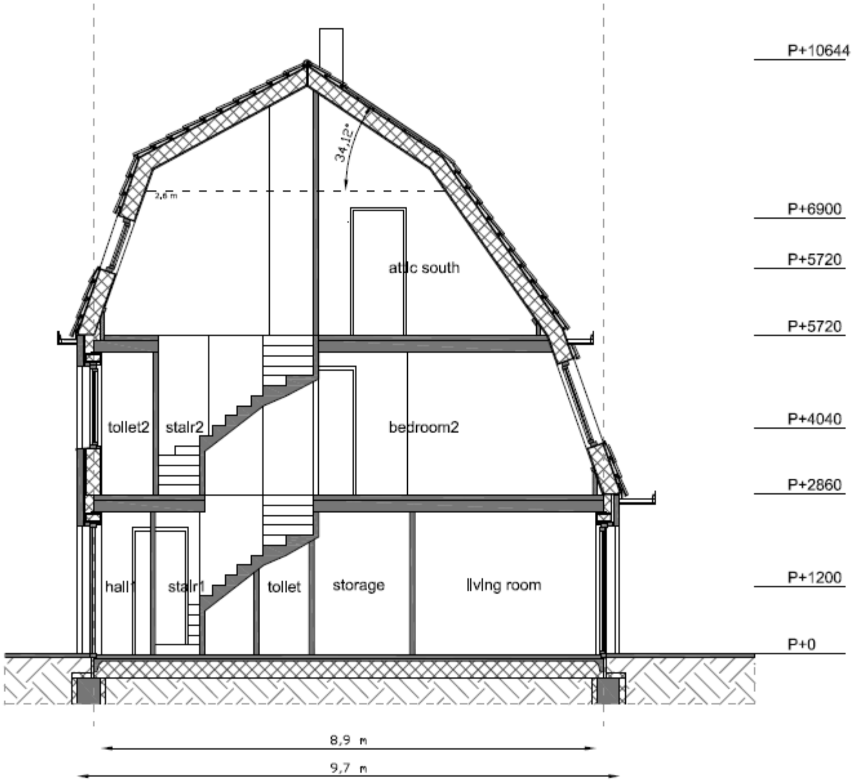


south facade

Concept	SenterNovem Reference
Drawing name	Views
Scale	1:100

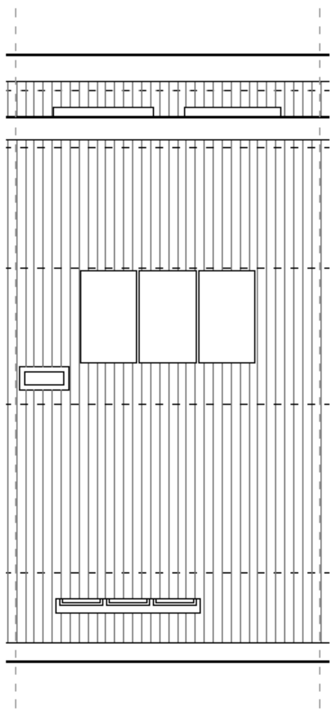


N		
	Concept	Passive
	Drawing name	Space plans
	Scale	1:100

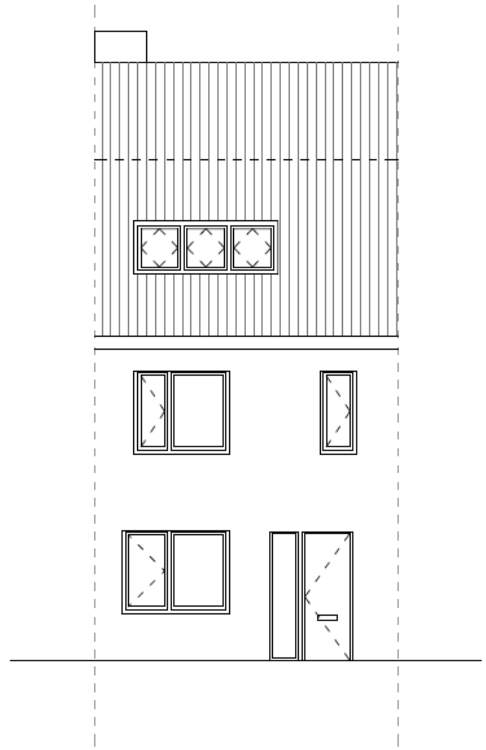


section A-A'

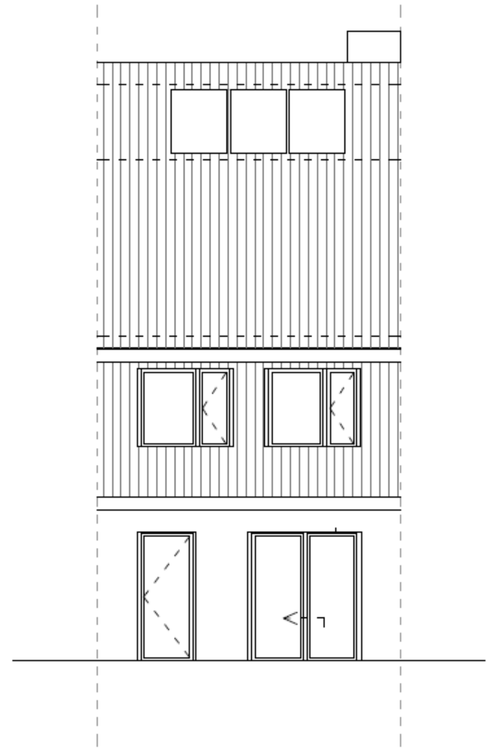
N		
	Concept	Passive
	Drawing name	Section A-A'
	Scale	1:100



roof view

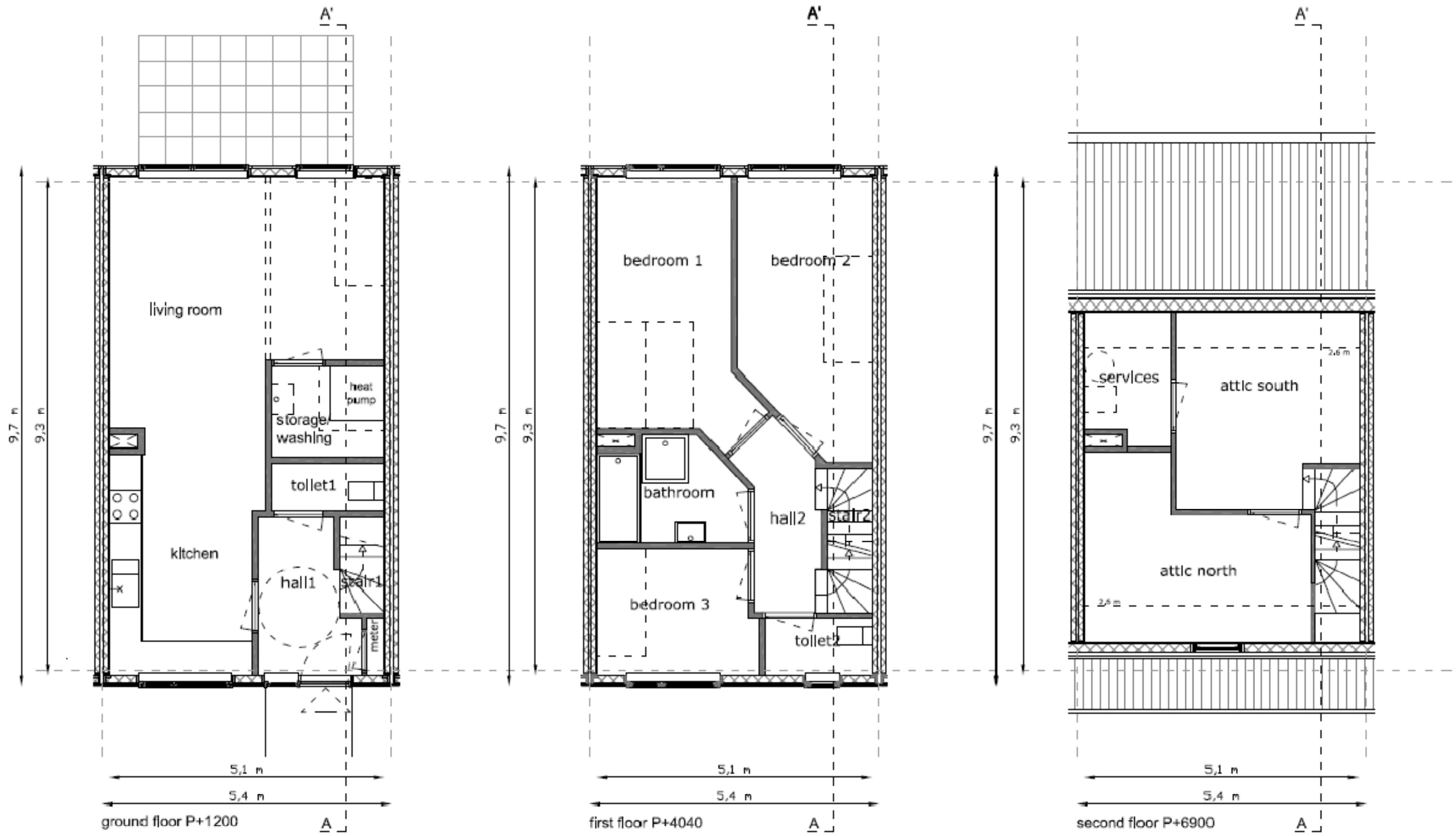


north facade

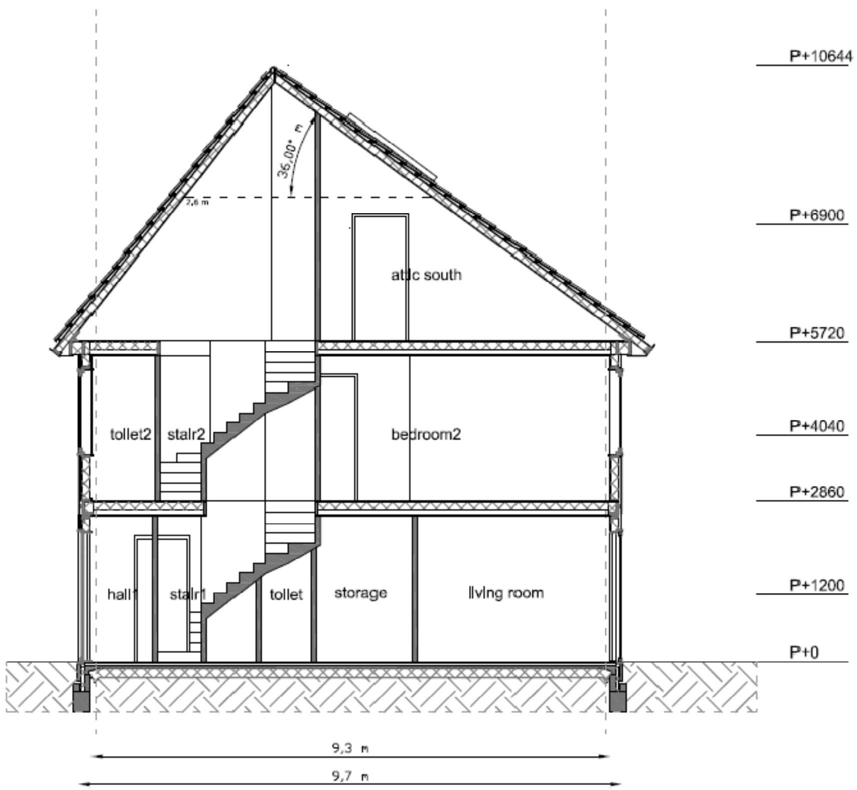


south facade

Concept	Passive
Drawing name	Views
Scale	1:100

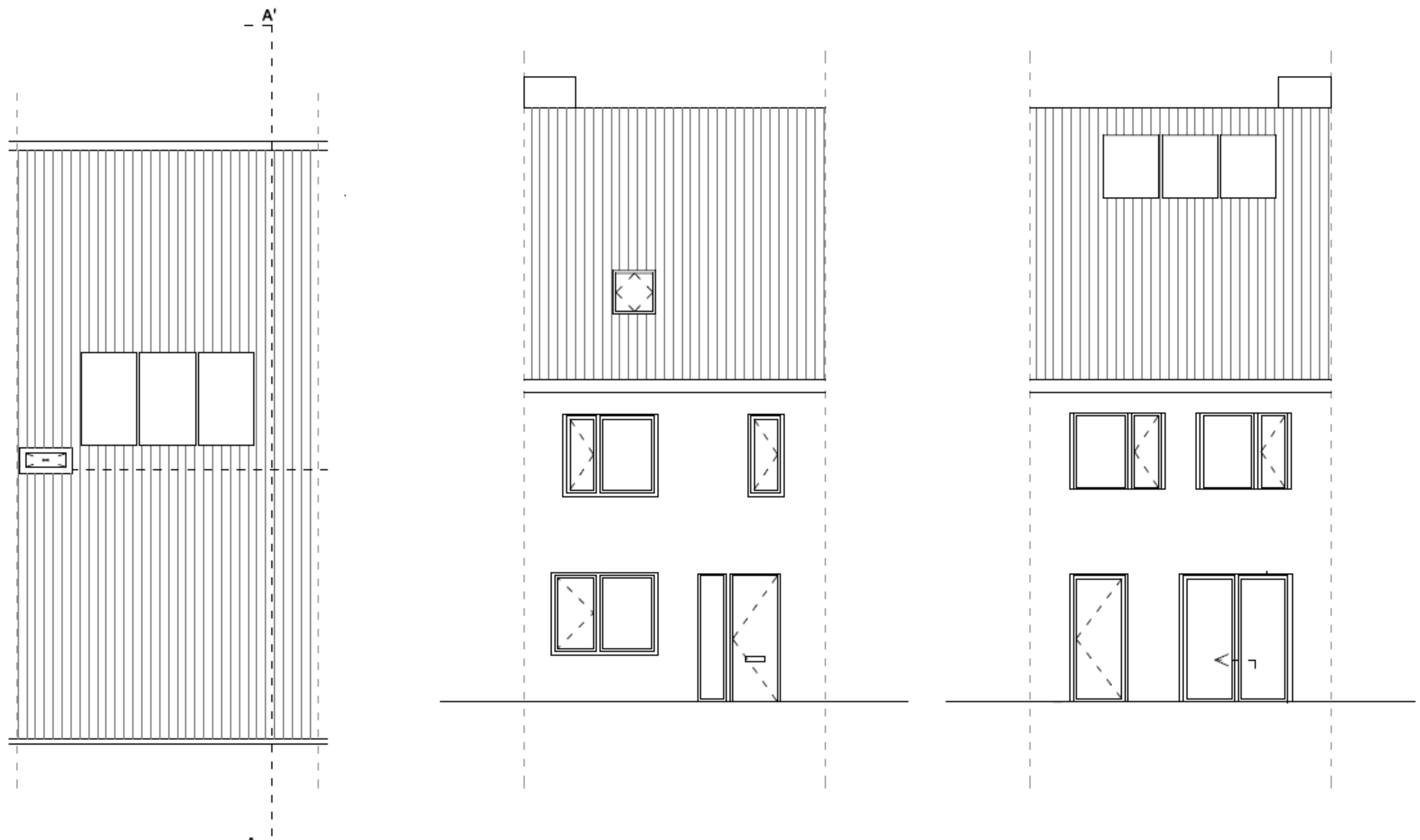


N	Concept	Active
	Drawing name	Space plans
	Scale	1:100



section A-A'

N		
	Concept	Active
	Drawing name	Section A-A'
	Scale	1:100



roof view   north facade   south facade

Concept	Active
Drawing name	Views
Scale	1:100

15.3 Building materials

Skin packages for the reference house are deducted from SBR reference details for brickwork structures. Construction packages for the active house are deducted from SBR reference details, for wood frame structures. For the passive concept they are deducted from the SBR reference details for Passive Houses, as could be found in the toolkit publication. The numbers refer to the numbers of the details from where these details are deducted.

TB = abbreviation for Tabellenboek

Ctc = abbreviation for center-to-center distance between structural parts (in dutch: h.o.h. = hart-op-hart afstand)

Table 91: Building material characteristics for reference house

Reference house	thickness	conductivity	density	specific capacity	heatresistance	Surface absorptance	source
External wall construction	mm	W/mK	kg/m^3	J/kgK	m^{2}K/W	-	**301.2.3.01**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Stucco plaster	2.5	0.721	1900	840	0.003		TB
Gypsum blocks 100 mm	100	1.0	1900	840	0.100		TB
Mineral wool 90 mm incl.	90	0.036	1700	840	2.500		TB
Air layer 36 mm	36				0.090		NEN 1086
Brick 100 mm	100	0.65	1750	840	0.511		TB
Air resistance wall external	-	-	-	-	0.040		NEN 1086
total					**3.32**	**0.88**	
External roof construction							**401.2.3.01**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 10 mm	10	0.17	700	1880	0.059		TB
Mineral wool 120mm + structure ctc 600mm	120	0.03848	117.5	840	3.119		TB, calc.
Air layer 36 mm	36				0.090		NEN 1086
Roof tiles (Dutch model)	1000	100000	39.1	840	0.000		TB (p.283)
Air resistance wall external	-	-	-	-	0.040		NEN 1086
total					**3.437**	**0.87**	

Internal wall construction							-
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Gypsum blocks 100 mm	100	1.0	1900	840	0.100		TB
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
total					**0.33**	**0.7**	
Internal floor construction							**301.2.3.01**
Air resistance floor internal	-	-	-	-	0.100		NEN 1086
Concrete floor 150 mm	150	1.731	2240	840	0.087		TB
Air resistance floor internal	-	-	-	-	0.100		NEN 1086
total					**0.287**	**0.65**	
Ground floor construction							**101.0.3.02**
Air resistance floor external	-	-	-	-	0.170		NEN 1086
Light concrete cover floor 50mm	50	0.65	1150	840	0.077		TB
Rib board floor 290 mm	290	0.072	107.3	1470	4.028		TB (middle)
Air resistance floor external	-	-	-	-	0.170		NEN 1086
total					**4.445**	**0.7**	
Adjacent wall construction							**204.2.3.02**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Brick 100 mm	100	0.721	1875	840	0.139		TB
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
total					**0.399**	**0.7**	
	center glass U-Value	glass + frame U-Value	solar heat gain coefficient	shading coefficient	visible transmittance		
Glazing	W/m^2K	W/m^2K	-	-	-		**2615**
Double Low-E (e3=.2) clear, 2 panes, fill: Argon, frame: wood/vinyl	1.647	1.817	0.68	0.79	0.72		DOE-2 glass library

Table 92: Building material characteristics for active concept

Active concept	thickness	conductivity	density	specific capacity	heatresistance	Surface absorptance	source
External wall construction	mm	W/mK	kg/m^3	J/kgK	m^{2}K/W	-	**202.4.2.01**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 12.5 mm	12.5	0.17	700	1880	0.074		TB
mineral wool 140mm incl. structure ctc 600 mm	140	0.03884	117.5	840	3.605		TB, calc.
wood fibre board 9 mm	9	0.15	525	1470	0.060		TB (middle)
Air resistance wall external	-	-	-	-	0.040		NEN 1086
total					**3.908**	**0.78**	
External roof construction							**401.2.3.01**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 10 mm	10	0.17	700	1880	0.059		TB
Mineral wool 120mm incl. structure ctc 600mm	120	0.03848	117.5	840	3.119		TB, calc.
Air layer 36 mm	36				0.090		NEN 1086
Roof tiles (Dutch model)	1000	100000	39.1	840	0.000		TB (p.283)
Air resistance wall external	-	-	-	-	0.040		NEN 1086
total					**3.437**	**0.87**	
Internal wall construction							-
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 12.5 mm	12.5	0.17	700	1880	0.074		TB
Mineral wool 89mm incl. structure ctc 600mm	89	0.03884	117.5	840	2.291		TB, calc.
Multiplex board 12.5 mm	12.5	0.17	700	1880	0.074		TB
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
total					**2.699**	**0.7**	
Internal floor construction							**301.4.2.01**
Air resistance floor internal	-	-	-	-	0.100		NEN 1086

Multiplex board 12.5 mm	15	0.17	700	1880	0.088		TB
Air layer 27 mm	27				0.090		NEN 1086
Mineral wool 89mm incl. structure ctc 600mm	80	0.0401	117.5	840	1.995		TB, calc.
Air layer 140 mm	140				0.090		NEN 1086
Hard wood floor board	18	0.17	800	1880	0.100		TB
Air resistance floor internal	-	-	-	-	0.100		NEN 1086
total					**2.563**	**0.65**	
Ground floor construction							**101.4.1.02**
Air resistance floor external	-	-	-	-	0.170		NEN 1086
Light concrete cover floor 50mm	50	0.65	1150	840	0.077		TB
Rib board floor 290 mm	290	0.072	107.3	1470	4.028		TB (middle)
Air resistance floor external	-	-	-	-	0.170		NEN 1086
total					**4.445**	**0.7**	
Adjacent wall construction							**202.4.2.01**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 15 mm	15	0.17	700	1880	0.088		TB
Mineral wool 90mm incl. structure ctc 400mm	89	0.04226	117.5	840	2.106		TB, calc.
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
total					**2.454**	**0.7**	
	center glass U-Value	glass + frame U-Value	solar heat gain coefficient	shading coefficient	visible transmittance		
Glazing	W/m^2K	W/m^2K	-	-	-		**2615**
Double Low-E (e3=.2) clear, 2 panes, fill: Argon, frame: wood/vinyl	1.647	1.817	0.68	0.79	0.72		DOE-2 glass library

Table 93: Building material characteristics for passive concept

Passive concept	thickness	conductivity	density	specific capacity	heatresistance	Surface absorptance	source
External wall construction	mm	W/mK	kg/m^3	J/kgK	m^{2}K/W	-	**101.0.1.01.T2**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 12.5 mm	12.5	0.17	700	1880	0.074		TB
Multiplex board 12.5 mm	12.5	0.17	700	1880	0.074		TB
High quality insulation (PIR)	240	0.023	30	1400	10.435		Powerroof
Wood fibre board	25	0.15	525	1470	0.167		TB (middle)
Air layer 36 mm	36				0.090		NEN 1086
Brick 100 mm	100	0.65	1750	840	0.511		TB
Air resistance wall external	-	-	-	-	0.040		NEN 1086
total					**11.52**	**0.88**	
External roof construction							**401.1.1.01.T1**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Multiplex board 12.5 mm	12.5	0.17	700	1880	0.074		TB
Multiplex board 12.5 mm	12.0	0.17	700	1880	0.071		TB
High quality insulation (PIR)	275	0.023	30	1400	11.957		Powerroof
Wood fibre board	25	0.15	525	1470	0.167		TB (middle)
Air resistance wall external	-	-	-	-	0.040		NEN 1086
total					**12.437**	**0.87**	
Internal wall construction							-
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Gypsum plaster	5	0.5	1300	840	0.01		TB
Sand lime blocks	80	0.9	1900	1880	0.089		TB
Gypsum plaster	5	0.5	1300	840	0.01		TB
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
total					**0.369**	**0.61**	
Internal floor construction							**301.1.01.T1**
Air resistance floor internal	-	-	-	-	0.100		NEN 1086

Light concrete cover floor	60	0.65	1150	840	0.092		TB
Light concrete internal floor	200	0.65	1150	840	0.308		TB, middle
Air resistance floor internal	-	-	-	-	0.100		NEN 1086
total					**0.6**	**0.65**	
Ground floor construction							**101.0.1.01.T2**
Air resistance floor external	-	-	-	-	0.170		NEN 1086
Light concrete cover floor	60	0.65	1150	840	0.092		TB
Cassette board floor 359	350	0.035	137.9	840	10		TB (middle)
Air resistance floor external	-	-	-	-	0.170		NEN 1086
total					**10.432**	**0.7**	
Adjacent wall construction							**204.1.1.01.T**
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
Concrete wall	120	2	2400	840	0.06		TB, middle
Air resistance wall internal	-	-	-	-	0.130		NEN 1086
total					**0.32**	**0.65**	
	center glass U-Value	glass + frame U-Value	solar heat gain coefficient	shading coefficient	visible transmittance		
Glazing	W/m²K	W/m²K	-	-	-		**2641**
Double Low-E (e3=.1) clear, 2 panes, fill: Argon, frame: fibreglass/vinyl	1.476	1.59	0.65	0.75	0.77		DOE-2 glass library

Literature

Bone, A.H.L.G., Bouwkunde Tabellenboek, (2003), tenHagen&Stam bv, Den Haag

Jansen, D.; Joosten, L.; Clocquet, R.; Raijmakers, T., Uitwerkingsinstructie Toolkitconcepten Passiefhuis, Eengezinsrijwoning Ri7 en Twee-onder-een-kapwoning, (2009), SBR, Rotterdam

15.4 Models in eQUEST

In this part of the appendices, it is meant to list the assumptions and the modelling details for the simulation of different concepts. This will clarify how the simulation work has been carried out and show the limitations/basis of the performance comparison.
First of all, common assumptions are listed and the modelling strategies of different systems are presented. The models are explained in line with the structure of eQUEST being Water-Side HVAC and Air-Side HVAC. The details of the building materials are put in the eQUEST models therefore the explanations of the modelling strategy is only given for the 'active' systems and the ventilation strategies.

15.4.1 Common Assumptions

For all the models incorporated in this study, some assumptions have been made.
The room heating set temperatures are determined according to the GIW/ISSO publication as given in the 'Thermal Comfort' part of the main report, and accordingly following scheme is assumed. Table 94 presents whether specified spaces are heated or unheated.

Table 94: Thermal comfort assumptions for simulation of concepts in eQUEST

Space	07.00 – 23.00	23.00 – 07.00	Condition
Living room and kitchen	20°C	15 °C	Heated
Bedrooms	20 °C	15 °C	Heated
Bathroom	22 °C	15 °C	Heated
Traffic areas and toilets	15 °C	15 °C	Unheated
Attic rooms	20°C	15 °C	Heated

In eQUEST for the simulation of the HVAC systems it is necessary to define the type of the system, and for the modeling of the three concepts and the reference house 'Packaged Variable-volume Variable Temperature' system type is selected. The selection is based on the availability of heat recovery system, the capability to change the specifications of the supply/return fans and the possibility to simulate operable windows.
The explanation for the use of this system is given by the DOE-2 library as:
It is used almost exclusively for small (~5,000 ft2) commercial buildings but it can be used with modular building systems (e.g., one or two PVVT units for each floor of a multi-storey building).
Although the system is not meant for the residential buildings, it gives the possibility to model both balanced mechanical ventilation with heat recovery and the natural ventilation. On the other hand, the ventilation flows within the house from room to room could be approximated by manipulating the return and supply fans.
The scheme of the system as given in the 'Air Side HVAC' menu of eQUEST is presented in Figure 72. The dashed lines present the inactive elements of the system.

Packaged Variable-volume Variable Temperature in eQUEST

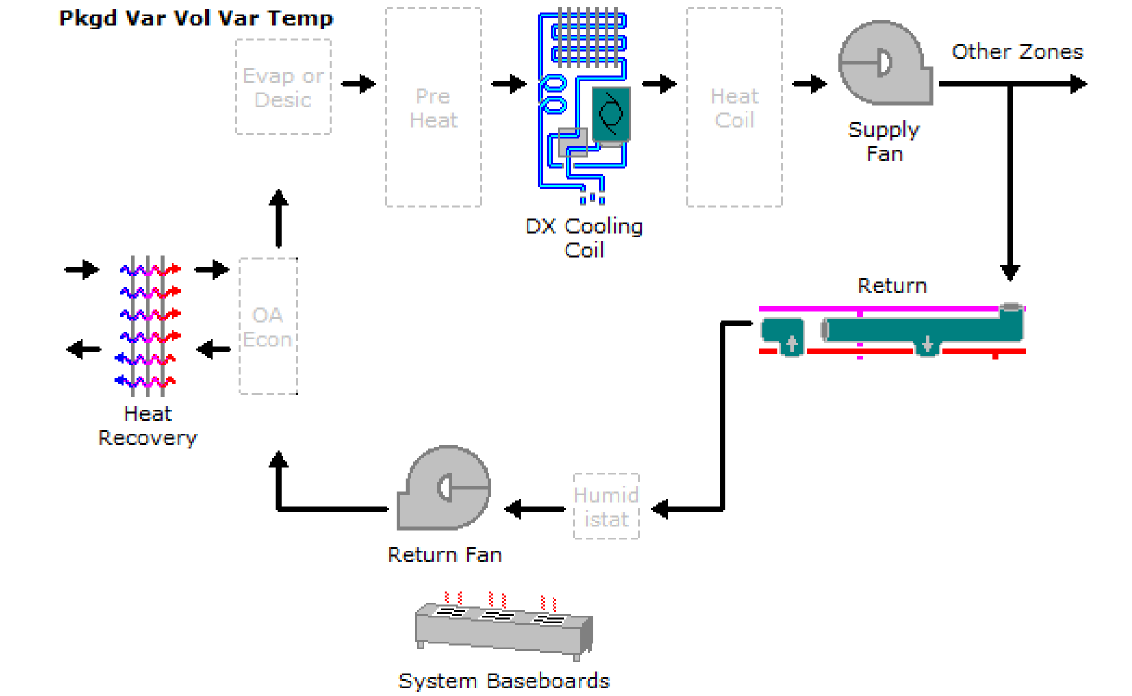


Figure 72: The default system scheme in eQUEST

The following assumptions are made for further detailing of the concepts:

- The climate file of Amsterdam obtained from the DOE website has some differences with the climate data given by NEN 5060. The differences are neglected.
- The central heating and cooling are not available, so the DX cooling coil is turned off by means of the schedules all year long.
- Rooms are heated by elements per zone, therefore system baseboards are defined as 'not installed' in the options menu.
- The system runs without an economizer, i.e. fixed fraction of outdoor air is supplied to the rooms.
- In order to simulate the overflow of fresh ventilation air to different rooms, a certain fraction of the return air circulated back to the rooms based on the ventilation demands.
- The default supply and return fan operation curves are suitable for the simulation purposes of this study.
- The supply and return fans operate at 180 Pa, which is specified as 0.72 water inches in eQUEST.
- The sensible effectiveness of the heat recovery unit is calculated as 0.66 according to the formulas given previously. The outside air temperature is accepted as 5°C as the average value of the outdoor temperature throughout a year based on the eQUEST climate data. The supply temperature is estimated as 10°C in average based on the example data provided by measurements in Denmark (Kragh et. al., 2005). Lastly, the exhaust air temperature is assumed to be 20°C in average as being the set temperature for ventilated rooms.
- The floor heating is modelled by the baseboards. Although it is possible to simulate radiant slab heating, if this is defined as the default scheme for the zone then it is not possible to simulate the air flows in the specific zone. Therefore, the baseboards are

assumed to be an accurate way of simulating the floor heating by changing the temperature settings of the hot water loop.

- Low temperature heating is assumed for the active and the passive concepts. The temperature class is assumed to be TK36 with a supply temperature of 36^{o}C and return temperature of 30^{o}C.

15.4.1.1 Equipment schedules

Equipment schedules which are put in eQUEST are based on the advices by the GIW/ISSO publication given in Table 97. In eQUEST this schedule is also used to determine the internal loads due to equipments. The values in the table marked as 'grey' cells are halved in the passive, the active and the hybrid concepts to simulate the effect of the stand-by killers.

Since the equipment schedules are only defined in fractions, the table given in GIW/ISSO is translated to the fractions and the maximum value is specified in the eQUEST input file as given in Table 97. It should be noted that the values in the GIW/ISSO publication are given to calculate the overheating hours which yielded high energy consumption of equipments compared to the average values in the literature. The maximum value is manipulated in order the result of the simulations to comply with these values and to simulate the effect of the energy efficient appliances in the concepts. These are given in Table 95.

Table 95: Equipment load value input for eQUEST models

	Equipment internal load (W)
GIW/ISSO	150
Reference house	90
Active, passive and hybrid concepts	60

15.4.1.2 Occupancy schedules

The occupancy schedules are also determined according to the GIW/ISSO publication. The fractions are inserted as schedules in eQUEST as shown in Table 97. The multipliers of these are defined by the type of the room and the size of the room, as given in the following table.

Table 96: Internal loads due to occupancy in eQUEST

Type of room	Occupancy internal load
Livingroom	(30 m^2 x 8.3 W/m^2) + (Additional m^2 x 2 W/m^2)
Bedrooms-Attic rooms	100 W
Bathroom-Traffic spaces	10.4 W/m^2

These values are kept the same for the reference house and all the concepts.

15.4.1.3 Lighting schedules

The lighting schedules are defined as in Table 97, but the multipliers are manipulated in order to comply with the average values in the reference house and in order to simulate the effect of the efficient lighting in the concept models. The load value given by GIW/ISSO resulted in too high lighting energy consumption which may be due to the fact that it is given for overheating calculations.

On the other hand, the effect of daylight availability in the design, the artificial lighting is turned on and off based on the set points of daylight availability and the demand in the specific room.

15.4.1.4 Domestic hot water schedules

The domestic hot water demand is put in the eQUEST by using schedules. The schedule is baed on the user pattern as given in NEN 5128. For the reference house, the demand is calculated by the energy required to supply the amount of liters for each hour by the following formula:

$$Q = mass \times specfic\ heat \times (T_{tap} - T_{supply})$$

In this formula, is determined as 55^{o}C and is determined by the cold water supply which also depends on the ground temperatures. For the reference house, is calculated by eQUEST depending on the ground temperatures.

Table 97: The schedules as the input for all the models

Equipment Schedule

Space\Hours	00-02	02-04	04-06	06-08		08-10	10-12	12-14	14-16		16-18	18-20	20-22	22-24	
Living room and kitchen	0.37*	0.37*	0.37*	0.37*	0.83	0.83	0.67	1.0	0.67		1.0	0.67	1.0	1.0	0.37*
Bedrooms and Attic	0.17*	0.17*	0.17*	0.83		0.83	0.83	0.83	0.83		0.83	0.17*	0.17*	0.17*	
Bathroom	0.17*	0.17*	0.17*	0.17*	1.0	0.37	0.17*	0.37	0.17*		0.17*	1.0	1.0	0.37	0.17*

Lighting Schedule

Space\Hours	00-02	02-04	04-06	06-08		08-10	10-12	12-14	14-16		16-18	18-20	20-22	22-24	
Living room and kitchen	0.0	0.0	0.0	0.0	1.0	0.15	0.0	0.0	0.0		0.0	0.35	1.0	1.0	0.0
Bedrooms and Attic	0.0	0.0	0.0	0.25		0.1	0.0	0.0	0.0		0.0	0.25	0.0	0.0	0.25
Bathroom	0.0	0.0	0.0	0.0	0.8	0.5	0.0	0.5	0.0		0.0	0.8	0.0	0.5	0.0

Occupancy Schedule

Space\Hours	00-02	02-04	04-06	06-08		08-10	10-12	12-14	14-16		16-18	18-20	20-22	22-24	
Living room and kitchen	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3		0.3	0.3	0.3	0.3	0.0
Bedrooms and Attic	0.5	0.5	0.5	0.5		0.5	0.5	0.5	0.5	0	0.0	0.35	0.0	0.0	0.5
Bathroom	0.0	0.0	0.0	0.0	0.55	0.4	0.0	0.4	0.0		0.0	0.55	0.0	0.4	0.0

**Halved for the active, passive and hybrid concepts*

Domestic Hot Water Schedule

Hours	0-2	2-4	4-6	6-8		8-10		10-12		12-14		14-16		16-18		18-20		20-22		22-24	
Reference house (CW3)	0.0	0.0	0.0	0.0	0.98	0.012	0.024	0.042	0.048	0.0	0.19	0.06	0.024	0.036	0.0	0.19	0.05	0.036	0.012	0.024	1.0

The domestic hot water schedules are presented in Table 97. For the domestic hot water calculations of the active, passive and the hybrid concept, the model created in Excel is used since eQUEST is not capable of simulating solar thermal collectors. The excel model is explained in detail in the following parts of the appendices.

15.4.2 Reference house model

The modeling procedures as presented in the main report is followed but the variations in the reference house model is presented in this part.

15.4.2.1 Water-Side HVAC

As specified previously, the reference house is heated by high temperature radiators in combination with a high efficiency condensing boiler. The domestic hot water is generated with the same boiler which supplies the space heating.

These are simulated in 'Water-Side HVAC' part; the scheme is shown in the following figure.

Water-Side HVAC of reference house

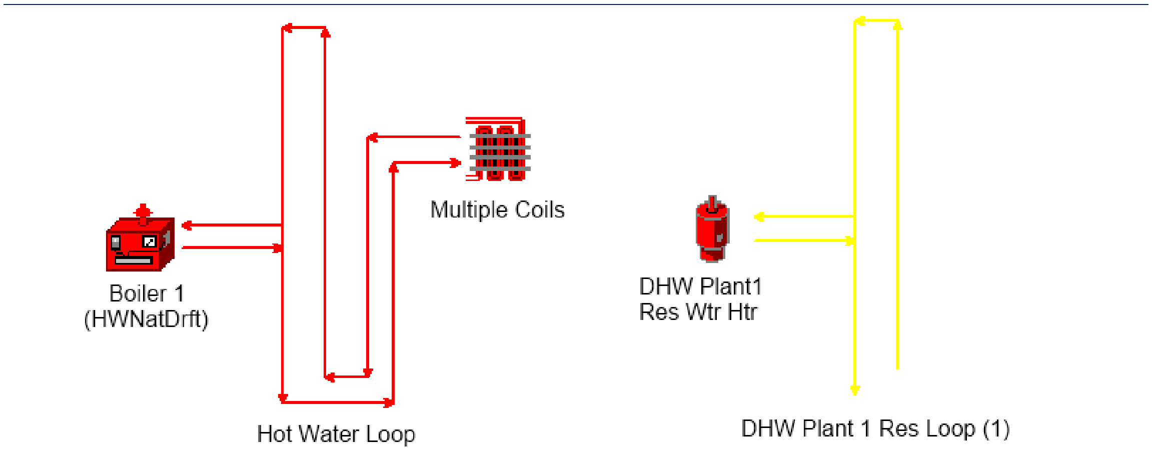


Figure 73: The reference house model in eQUEST

In this scheme, hot water loop represents the circulation loop for the radiators located in the rooms which is represented by 'multiple coils'. DHW stands for domestic hot water and represents the domestic hot water supply loop and the corresponding boiler. Although the reference house is equipped with a combi-boiler supplying both hot water and domestic hot water loops, it is not possible to attach two loops to one boiler in eQUEST. Therefore, this configuration is assumed to sufficiently model the behavior of the system.

Boiler 1, being the space heating supply, has an efficiency of 95% as specified in the specifications of the reference house. DHW loop loads are defined by the schedules as presented previously and the efficiency of the DHW boiler is assumed to be 67.5% as given by NEN5128. The partial load characteristics of these boilers are given by eQUEST defaults and these defaults are regarded as suitable to model the boilers.

The hot water pump which is attached to 'Hot Water Loop' is defined in this part of the model. Since the manipulation of the default pumps results in several errors in the model, the defaults are remained but the results are checked for their compliance with the literature values. In reference house model, resulting 256.5 kWh of pump electricity consumption is considered to be realistic when compared to the EPC calculation values which is around 300 kWh.

15.4.2.2 Air-Side HVAC

In this part of the model, the distribution systems are defined. It includes the ventilation strategy, thermal zone characteristics and the heating/cooling distribution specifications.
In the reference house, the ventilation strategy is balanced mechanical ventilation with a central heat recovery unit. The ventilation scheme determined according to the ventilation demands by the building decree is presented in the following table.

Table 98: Ventilation scheme of the reference house

Room Name	Total Ventilation Demand (l/s)	Mechanical Inlet (l/s)	Mechanical Exhaust (l/s)	Inflow from Rooms (l/s)	From Rooms
living room	32.93	32.93	32.93		
hallway	3.81	3.81			
toilet ground floor	7.00		7.00	4.31	hallway
				0.69	stair gf
				2.0	metering
stair ground floor	0.69	0.69			
metering	2.00	2.00			
bedroom 1	14.7	14.7			
bedroom 2	8.92	8.92			
bedroom 3	7.00	3.50		3.50	bedroom 2
bathroom	14.0		17.52	12.11	bedroom 1
				5.41	bedroom 2
cross over	2.62		9.62	2.62	bedroom 1
				1.76	stair 1st floor
				5.24	bedroom 3
stair 1st floor	1.76			1.76	stair2
attic (>1.5 m)	18.5	18.5	18.5	1.61	stair3
stair attic	1.6			1.61	attic (>1.5 m)

This ventilation scheme was simulated by three different HVAC systems for three floors which allowed simulating the effect of the overflows between spaces. Each of the HVAC systems has its own heat recovery unit but the three systems in total are assumed to model the mechanical ventilation with central heat recovery.

The windows are scheduled to be operated if the indoor air temperature is above 25^{o}C

(77^{o}F) and the fans are assumed to be turned down if the windows are open.
The living room, bedrooms, bathroom and the attic are heated by the baseboard units which are the models of radiator panels.

15.4.3 Active concept model

The changes to the eQUEST defaults are incorporated the most in the active concept model, especially in the water-side HVAC part since a ground coupled water-to-water heat pump is supposed to supply the heating demand of the concept. The details of the 'work-around' steps are given in the following parts.

15.4.3.1 Water-Side HVAC

The ground source heat pumps in eQUEST can be modelled by selecting the default scheme 'Water Loop HP' which simulates the water-to-air heat pumps and it is not possible to simulate the natural ventilation of the rooms with operable window if this scheme is selected.

Therefore, to simulate the ground source water-to-water heat pump in eQUEST, the following procedure has been followed which yielded reasonable results at the end:

1. Create a 'chiller' of the type 'water-to-water heat pump'
2. Create an independent circulation loop of the type 'lake/well'
3. Create a ground loop heat exchanger of the type 'lake/well'
4. Select the ground loop heat exchanger circulation loop as the condenser water loop of the chiller.
5. The temperature schedule of the ground loop will be automatically calculated by eQUEST using the ground temperatures defined by the climate file.
6. The chilled water loop should be attached to one of the zones for the chiller to start operating, HVAC System 2 in Figure 74. This zone is chosen as one of the duct zones which will affect the indoor climate at a negligible level.
7. The hot water loop is attached to the coils that supply hot water to the baseboards in the zones.

This workaround results in a scheme as shown in the following figure.

Ground source heat pump model eQUEST

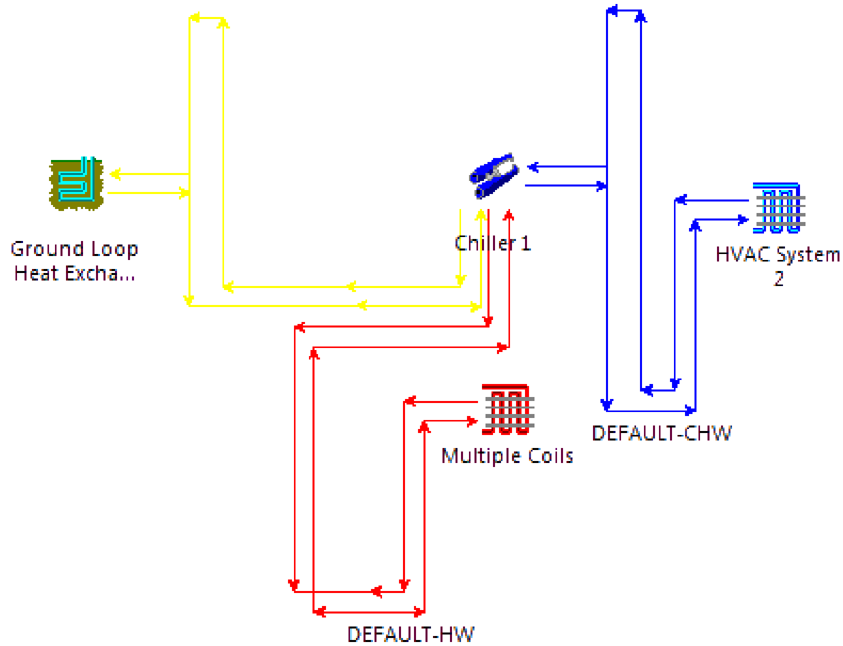


Figure 74: Ground source heat pump configuration in eQUEST

The results of the simulations show a reasonable value for electricity consumption as specified.
Since the resulting pump electricity consumption is unrealistically high around 3500 kWh, the pump energy consumption is calculated by exporting the heat demand hourly data to excel. After having the data exported, the pumps, both ground loop and circulating, are assumed to operate at full power whenever the heating is necessary. The pumps' capacities are estimated by the installation manual of the heat pump supplier. The circulation pump is assumed to have 40 W power while the pump attached to the ground heat exchanger loop is assumed to have 60 W power. The resulting total pump electricity consumption is calculated around 550kWh/year.

Domestic hot water supply of the active concept is estimated by the excel model developed for this project and it will be explained in the following parts of the appendices.

15.4.3.2 Air-Side HVAC

The ventilation scheme in the active model is similar to the reference house since mechanical ventilation with heat recovery is the ventilation strategy. The following table summarizes the ventilation flows in the rooms as specified by the building decree.

Table 99: Ventilation flow of the active concept

Room Name	Total Ventilation Demand (l/s)	Mechanical Inlet (l/s)	Mechanical Exhaust (l/s)	Inflow Rooms (l/s)	fromRooms
living room	28.77	28.77	28.77		
hallway	3.15	4.02	0.00		
toilet gf	7.00		7.00	4.02	hallway
				0.98	stair gf
				2	metering
stair gf	0.98	0.98	0.00		
metering	2.00	2.00			
storage	7.00	7.00	7.00	7.00	living room
bedroom 1	11.19	5.60	5.60	5.60	cross over
bedroom 2	10.70	5.35	5.35	5.35	cross over
bedroom 3	7.00	3.50	3.50	3.50	cross over
bathroom	14.00		14.00	5.60	bedroom 1
				3.00	bedroom 3
				5.40	bedroom 2
cross over	2.96		0.00	21.00	stair2
stair 1st floor	1.83	21.00	0.00		
toilet 1st floor	7.00		7.00	7.00	cross over
attic north room	6.57	3.29	3.29	3.29	
attic south room	8.19	4.09	4.09	4.09	
services space	7.00		7.38	3.29	attic north
				4.09	attic south
stair attic	1.68	7.38	0.00		

As in the reference house, this ventilation scheme is modeled by using three HVAC systems, PVVT type, for each floor. In this way, it is possible to approximate the effect of internal flows and the resulting fan electricity consumption is at reasonable levels, i.e. around 600kWh/year.

The windows are scheduled to be operated if the indoor air temperature is above 25^{o}C (77^{o}F) and the fans are assumed to be turned down if the windows are open.
The living room, bedrooms, bathroom and the attic are heated by the baseboard units which are the models of low temperature floor heating.

15.4.4 Passive concept model

Since the passive concept is based on the high efficient boiler for space heating and domestic hot water, the water-side HVAC system can be assumed to be the same as the reference house. The only difference between the two is the low temperature set points for the hot water loops in the passive concept due to the low temperature floor heating. Moreover, the efficiency of the boiler for space heating is assumed to increase from 95%to 97.5%.
The modeling strategy of the ventilation system in the passive house is different than the

active concept and reference house.

15.4.4.1 Air-Side HVAC

The ventilation principle for the passive house is determined to be natural inlet and mechanical exhaust. Accordingly, following ventilation flows are calculated based on the demands by the building decree.

Table 100: Ventilation flows for the passive concept

Room Name	Total Ventilation Demand (l/s)	Flow from outside (l/s)	Mechanical Exhaust (l/s)	Inflow from Rooms (l/s)	Rooms
living room	19.1	19.1	0.0		
kitchen	21.0	10.5	21.0	3.1	hallway
				0.98	stair gf
				2	metering
				4.4	living room
hallway	3.1	3.1	0.0		
toilet gf	7.0	0.0	7.0	7.0	storage
stair gf	1.0	1.0	0.0		
metering	2.0	2.0	0.0		
storage	7.0	0.0	0.0	7.0	living room
bedroom 1	9.0	9.0	0.0		
bedroom 2	8.3	4.2	0.0	4.2	bedroom 1
bedroom 3	7.0	7.0	0.0		
bathroom	14.0	0.0	14.0	3.5	bedroom 3
				7.7	living room
				2.8	cross over
cross over	3.0	0.0	0.0	8.3	stair 1floor
stair 1st floor	1.8	0.0	0.0	2.0	cross over
toilet 1st floor	7.0	0.0	7.0	3.5	bedroom 3
				3.5	cross over
attic north room	9.5	4.7	9.5	4.7	attic south room
attic south room	8.9	6.8	4.2	2.1	services space
services space	7.0	2.1	4.9	4.9	bedroom 1
stair attic	1.7	0.0	2.0	2.0	Stair attic

In order to simulate the natural ventilation, the outdoor air is incorporated to the infiltration values so that the cooling/heating of the outside air can be simulated. For each zone specified above, a HVAC system is defined and the flows between the rooms are simulated by the imaginary fans which do not consume electricity and do not change the temperature of the flow passing through it. Internal flows are modeled by 'Outside Air from System' option in eQUEST which specifies the specific thermal zone where the air comes from. On the other hand, in thermal zones where the internal flow is from more than one adjacent zone then the air is taken from directly outside but the it is pre-heated by electric heaters to avoid the extra loads due to the outside air supply. The pre-heaters are set to temperatures estimated based on the air supplying rooms. In the last phase, excessive electricity consumption for pre-heating is extracted from the total energy use.

Due to the fact that many HVAC systems are introduced for the simulation of the natural ventilation, pumps energy consumption for heating distribution is unrealistically high. In order to reach reasonable results, a pump of 40 W power is assumed to run at full power whenever the heating load is available. The heating load data is exported from the eQUEST results to excel and the pumps energy consumption is calculated.

For realistic ventilation fans electric energy use, only the exhaust fans in the specified zones are assumed to have a power requirement. This strategy resulted in reasonable fan energy consumption for natural ventilation principle.

15.4.5 Hybrid concept model

The only change in the hybrid concept compared to the passive concept is the ventilation strategy being the balanced mechanical ventilation with heat recovery. The heat generation system is assumed to be the same as the passive concept therefore it is not necessary to give the same details in this part.

The following ventilation flows is incorporated in the hybrid concept model. The strategy to simulate the internal flows is the same way as in the active concept and reference house models. So, for each floor a separate HVAC system is defined and the heat recovery systems are assumed to be sufficient to simulate the central heat recovery unit.

Table 101: Ventilation flows for the hybrid concept

Room Name	Total Ventilation Demand (l/s)	Mechanical Inlet (l/s)	Mechanical Exhaust (l/s)	Inflow Rooms (l/s)	fromRooms
living room	19.06	21.87	0.00		
kitchen	21.00		21.00	3.15	hallway
				0.98	stair gf
				2.0	metering
				14.9	living room
hallway	3.15	3.15	0.00		
toilet1	7.00		7.00	7.00	storage
stair gf	0.98	0.98	0.00		
metering	2.00	2.00			
storage	7.00			7.00	living room
bedroom 1	9.02	4.51	4.51	4.51	cross over
bedroom 2	8.33	4.17	4.17	4.17	cross over
bedroom 3	7.00	3.50	3.50	3.50	cross over
bathroom	14.00		14.00	4.51	bedroom 1
				3.5	bedroom 3
				4.16	bedroom 2

				1.82	cross over
cross over	2.96		0.00	21.00	stair 1st floor
stair 1st floor	1.83	21.00	0.00		
toilet 1st floor	7.00		7.00	7.00	cross over
attic north room	9.47	4.73	4.73	4.73	stair attic
attic south room	8.90	4.45	4.45	4.45	stair attic
services space	7.00		9.18	4.73	north room
				4.45	south room
Stair attic	1.68	9.18	0.00		

15.5 DHW and Solar thermal collector model

As explained in the main report, a tool is required to estimate the performance of the solar thermal collectors for the active, passive and hybrid concepts since eQUEST is not capable of modelling solar thermal collectors.

First of all, the efficiency of the solar thermal collectors is to be determined to calculate the total yield in a year. In order to determine the efficiency of the solar thermal collectors, the following formula is used which is the quadratic formula (F.Cuadros et al., 2007).

$$\eta = \eta_0 - k_1 \frac{\Delta T}{P} - k_2 \frac{\Delta T^2}{P}$$

In this equation η stands for the collector efficiency, η_0 for optical efficiency of the collector and $k_1 \& k_2$ are heat loss coefficients, which are defined by the manufacturers. In this case, Viessmann Vitosol 200T for evacuated tubes and Vitosol 200F for flat plate collector are taken as the sample. Optical efficiency and heat loss coefficients are found in the product specs. P is the global solar irradiation on horizontal surface which is obtained from the climatic data by NEN5060. Temperature difference is the gradient between the collector fluid inlet temperature and the outdoor air temperature. The collector fluid inlet temperature is assumed to be constant 45oC which is taken from the literature (F.Cuadros et al., 2007).

The corresponding data is put in the excel model and the following result is obtained for a year for flat plate collector and evacuated tube collectors. As can be seen from Figure 75, the maximum efficiency of these two types of collectors is comparable while the evacuated tube collectors' overall efficiency is higher since it is efficient in longer periods.
The domestic hot water demand per hour is determined by translating the user pattern values as given in NEN 5128. The resulting schedule is presented in the following table:

Table 102: Domestic hot water pattern oer hour, source: NEN5128, CW2

Domestic hot water									
hour	00-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15
litres	0	55	1	2	3.5	4	0	16	5
hour	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
litres	2	3	0	16	4.5	3	1	2	57

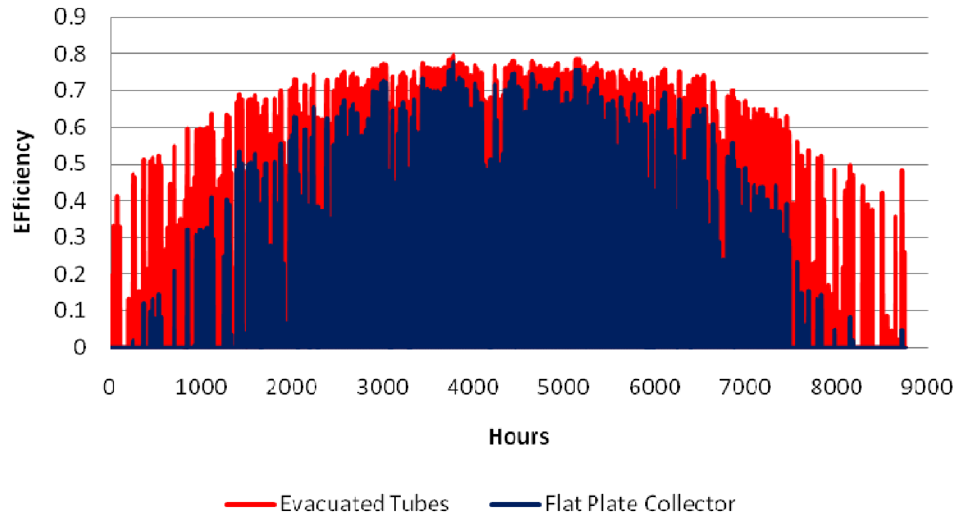


Figure 75: Efficiency of solar thermal collectors over a year

The solar thermal collectors are assumed to be connected to the short term thermal storage tank of 200-300 liters. In this model, the storage tank is regarded as the heart of the system as presented in the scheme of the solar thermal system, Figure 76. The water in the storage tank is heated via gas fired boiler or a heat pump, electric heating if necessary and solar thermal collector. Shower heat recovery helps to increase the cold water temperature at the inlet.

Domestic hot water supply

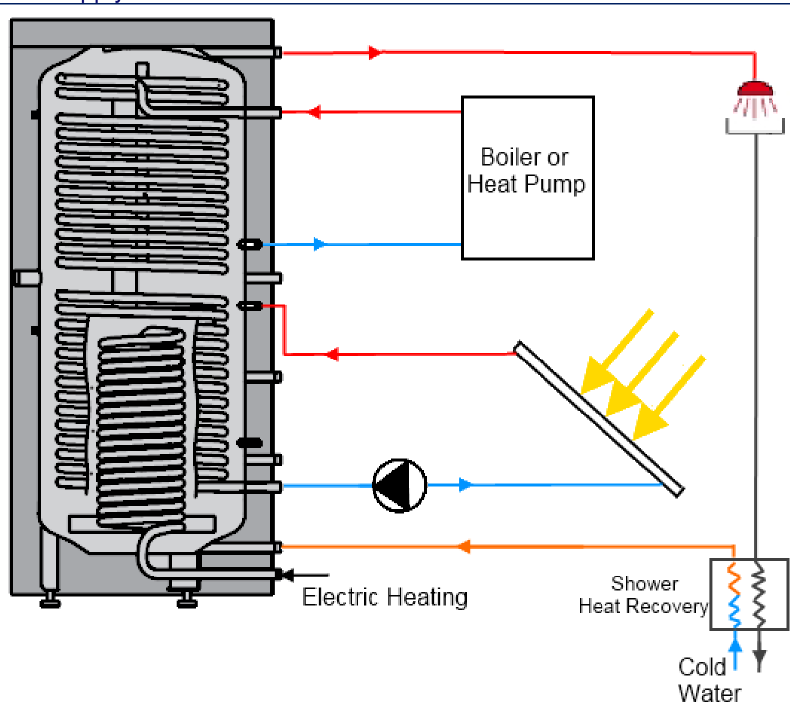


Figure 76: Domestic hot water storage combined with solar thermal collector

The calculations for the solar thermal collector and domestic hot water supply are based on this scheme. Accordingly, an energy balance for the storage tank is formulated as given in the following equation.

$$V_t \times \rho_w \times C_{p,w} \times (T_{t,f} - T_{t,i}) = Q_{st} + Q_{supp} - Q_{loss} + V_{DHW} \times \rho_w \times C_{p,w} \times (T_{w,o} - T_{w,i})$$

In this equation:

V_t : Storage volume of the tank

ρ_w : Density of water, assumed to be constant 1000 kg/m^3

$C_{p,w}$: Specific heat of water, assumed to be constant 4.18 kJ/(kg*K)

$T_{t,f}$: The average temperature of water in storage tank at the end of 1 hour period

$T_{t,i}$: The average temperature of water in storage tank at the beginning of 1 hour period

Q_{st} : Solar thermal energy input to the storage tank

Q_{supp} : Supplementary heat input by gas fired boiler, immerse heaters or the ground source heat pump, depending on the concept definition.

Q_{loss} : Heat loss from the storage tank to the environment

V_{DHW} : Volume of the domestic hot water requirement in an hour, interpreted from NEN5128

$T_{w,o}$: Temperature of the water leaving the tank, i.e. average storage tank temperature

$T_{w,i}$: Temperature of the water entering the tank, i.e. cold water supply temperature after heat recovery

The thermal energy input by the gas fired boiler, immerse heaters or the ground source heat pump is calculated by assuming the supplementary heat will keep the storage tank temperature at 55^{o}C in order to prevent algae generation. Whenever the tank temperature drops below 55^{o}C, i.e. when water is drawn from the tank or the temperature drops due to heat loss, the supplementary heating is put into use.

Solar thermal energy input to the storage tank is calculated by using the hourly global irradiation on the roof surface which is obtained by using eQUEST. The thermal losses from the solar thermal collector to the storage tank are assumed to be 5% and the resulting equation is as follows:

$$Q_{st} = I \times A_c \times 0.95$$

In this equation:

I : Global irradiation per area on the surface of the solar collector, exported from eQUEST

A_c : Collector absorber area, assumed to be 6 m^2

It should be noted that the solar thermal input is assumed to be zero if the storage tank temperature is above 90^{o}C in order to avoid phase change in the storage tank, which might be the case during the summer period.

The heat loss to the environment where the storage tank is located is calculated with the flowing formula:

$$Q_{loss} = UA \times (T_a - T_t)$$

In this equation:

UA : Heat transfer coefficient of the storage tank, assumed to be 1.18 W/K as in PZE study (ECN, 2001)

T_a : Ambient temperature, assumed to be 15^{o}C, set temperature of the services space

T_t : Average tank water temperature

In the calculations, the heat recovery from shower waste water is incorporated in $T_{w,i}$, i.e. cold water inlet temperature to the storage tank after the shower heat recovery. The calculation is based on the manufacturer data and the flow rates as specified in NEN5128. The cold water temperature after the heat recovery is calculated by:

$$Q_{hr} = V_{tap} \times \rho_w \times C_{p,w} \times \left(T_{cw} - T_{w,i}\right)$$

In this equation,

Q_{hr} : Shower heat recovery input energy to the cold water, assumed to be 7.2 kW for 5.5 Litres per second (Dutch Solar Systems B.V., douchepijp)

V_{tap} : Volumetric flow of the water supply, which is assumed to be 5.5 litres per second as defined by NEN 5128

T_{cw} : Cold water temperature supplied by the grid, which is assumed to be equal to the hourly ground temperature exported from eQUEST

Therefore, whenever shower water is available, i.e. two times a day, cold water temperature is increased and for the rest of the time it is assumed to be equal to the ground temperature as given by eQUEST.

As a result of the calculations, the yearly energy consumption for domestic hot water supply is estimated and the storage tank temperatures are estimated. To give an example, the following figure shows the storage tank temperature for the passive house.

Water temperature in the storage tank

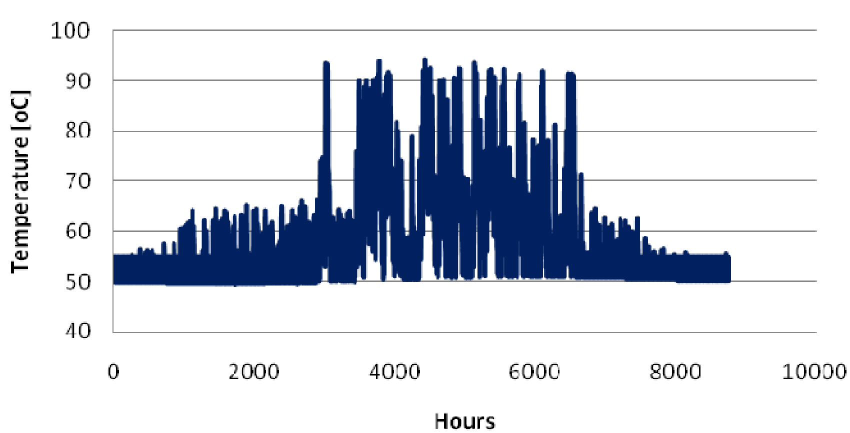


Figure 77: Thermal storage tank temperature during a year of operation

15.6 Average Daylight Factor

As discussed in the main report, for calculation of the Average Daylight Factor, the BRE-formula was used. Main assumptions for all concepts are presented in Table 103.

Table 103: Assumptions daylight calculation

Assumptions daylight calculation		
reflection	wall	0.7

	ceiling	0.8
	floor	0.3
visible transmittance		0.767
maintenance factor		1

Results for the several concepts are presented below. For the hybrid concept, the results equal the ones of the passive concept.

Table 104: Results on Average Daylight Factor for reference house

Reference house					
floor	room	surface (m^2)	wall length	wall surface	ADF (%)
ground floor	living room	39.4	30.37	78.962	4.95
first floor	bedroom 1	18.2	17.43	45.318	4.75
	bedroom 2	10.2	12.94	33.644	3.67
	bedroom 3	6.8	10.44	27.144	4.94
second floor	attic	30.8	25.31		0.67
total floor area		105.4			
demand 80% with 2%		84.3			
achieved area with 2%		74.64			
achieved % of area> 2%		70.80%		not ok	

Table 105: Results on Average Daylight Factor for passive concept

Passive concept						
floor	room (VR)	floor surface	ceiling surface	wall length	wall surface	ADF (%)
ground floor	living room	21.0	21.0	19.9	51.6	2.0
	kitchen	10.8	10.8	13.7	35.7	2.0
first floor	bedroom 1	11.8	10.0	11.2	45.0	2.0
	bedroom 2	11.1	9.3	10.0	41.8	2.0
	bedroom 3	6.3	6.3	10.4	26.9	2.3
second floor	attic north	14.6	27.5	0.0	37.8	2.2
	attic south	16.0	35.9	0.0	49.5	0.0
total floor area		91.5				
demand 80% with 2%		73.2				
achieved area with 2%		75.54				
achieved % of area> 2%		82.6%		ok		

Table 106: Results on Average Daylight Factor for active concept

Active concept						
floor	room (VR)	floor surface	ceiling surface	wall length	wall surface	ADF (%)
ground floor	living room	33.5	33.5	30.1	78.2	2.5
first floor	bedroom 1	12.4	12.4	15.6	56.6	2.0
	bedroom 2	11.9	11.9	14.7	54.1	2.1
	bedroom 3	6.8	6.8	10.8	28.0	2.3

second floor	attic north	7.3	10.8		23.3	2.7
	attic south	9.1	13.0	0.0	32.2	0.0
total floor area		81.1				
demand 80% with 2%		64.9				
achieved area with 2%		72.01				
achieved % of area >2%		88.8%		ok		

15.7 Environmental impact of building materials

Table 107 below gives the results of the building materials impact as results from the data input in Greencalc+ V2.20 and conversion to shadow prices.

Table 107: Results of Greencalc calculation of environmental impact by building materials

Environmental effect	Quantity	Shadow price	reference per house quantity		passive concept		active concept		hybrid concept	
Emissies										
Broeikaseffect (100j)	kg CO_2 eq.	€ 0.05	663.8	€ 33.19	625.7	€ 31.29	501.2	€ 25.06	636.6	€ 31.83
Ozonlaagaantasting	kg CFC-11 eq.	€ 30.00	0.0001	€ 0.00	0.0001	€ 0.00	0.0001	€ 0.00	0.0001	€ 0.00
Humane toxiciteit	kg 1.4-DB eq.	€ 0.09	138.8	€ 12.49	179.7	€ 16.17	116.5	€ 10.49	181.3	€ 16.32
Aquatische toxiciteit (zoet water)	kg 1.4-DB eq.	€ 0.03	7.1	€ 0.21	8.6	€ 0.26	6.1	€ 0.18	8.7	€ 0.26
Terrestische toxiciteit	kg 1.4-DB eq.	€ 0.06	0.8	€ 0.05	1.4	€ 0.08	1.8	€ 0.11	1.4	€ 0.08
Fotochemische oxidantvorming	kg C_2H_4 eq.	€ 2.00	0.1	€ 0.20	0.4	€ 0.80	0.3	€ 0.60	0.4	€ 0.80
Verzuring	kg SO_2 eq.	€ 4.00	2.8	€ 11.20	2.9	€ 11.60	3.1	€ 12.40	2.9	€ 11.60
Eutrofiering	kg PO_4 eq.	€ 9.00	0.4	€ 3.60	0.4	€ 3.60	0.4	€ 3.60	0.4	€ 3.60
Uitputting										
Biotische grondstoffen	mbp	€ 0.16	42.1	€ 6.74	38.3	€ 6.13	39.6	€ 6.34	38.3	€ 6.13
Abiotische grondstoffen	kg Sb eq	€ 0.16	208	€ 33.28	173.8	€ 27.81	184.3	€ 29.49	174.9	€ 27.98
Energiedragers	kg Sb eq	€ 0.16	31.7	€ 5.07	32.7	€ 5.23	27.9	€ 4.46	33.4	€ 5.34
				€ 106.03		**€ 102.97**		**€ 92.73**		**€ 103.95**
Built area; shadow price / BVO	BVO		157.00	€ 0.68	152.10	€ 0.68	157.00	€ 0.59	152.10	€ 0.68
Percentage below price 0.8 euro/BVO				16%		15%		26%		15%
BREEAM-NL credits achieved				1		1		2		1

15.8 Assessment of spatial comfort

Table 108: Results of spatial comfort assessment according to BREEAM-NL demands

spatial design	reference size (m^2)	passive size (m^2)	active size (m^2)	BREEAM-NL demand	reference assessment	reference assessment	reference assessment
Outdoor space							
size	9.61	9.61	9.61	8.58	ok	ok	ok
width	4.00	4.00	4.00	1.50	ok	ok	ok
conclusion outdoor space					**ok**	**ok**	**ok**
accessibility: visitors							
entrance path	-	1.61	1.61	1.20	-	ok	ok
entrance height	-	-		0.02	-	ok	ok
front door: width	0.90	0.90	0.90	0.85	ok	ok	ok
front door: space internal space width	1.19	1.54	1.54	1.50	not ok	ok	ok
front door: space internal space length	3.97	2.82	3.04	1.50	ok	ok	ok
internal height difference	-	-	-	0.02	ok	ok	ok
halls without doors: width	1.16	1.42	1.42	0.90	ok	ok	ok
halls with doors on side: width	1.16	1.42	1.42	1.10	ok	ok	ok
toilet: width	0.91	0.90	0.90	0.90	ok	ok	ok
toilet: length	1.29	2.08	2.08	1.20	ok	ok	ok
conclusion visitors					**not ok**	**ok**	**ok**
accessibility: total house (ground floor when useable as house)							
all internal height difference	2.60	-	-	0.02	not ok	ok	ok
internal doors: width	0.90	0.90	0.90	0.85	ok	ok	ok
bathroom width1	2.00	2.08	2.08	2.15	ok	ok	ok
bathroom length1	2.82	2.70	2.70	2.15			
bathroom width2	2.00	2.08	2.08	0.90			
bathroom length2	2.82	2.70	2.70	2.50			
kitchen: turning circle, radius	2.21	2.04	2.04	1.50	ok	ok	ok
kitchen: distance counter-wall	2.21	2.04	2.04	1.50	ok	ok	ok
conclusion total house					**not ok**	**ok**	**ok**

16 Summary

DESIGN OF AN AFFORDABLE AND SUSTAINABLE HOUSE CONCEPT FOR THE NETHERLANDS

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ABSTRACT
This research handles the analysis and design of sustainable and affordable house concepts in the Netherlands, focusing on the row house typology. Sustainability is defined based on 6 value domains and an assessment method is used which is able to combine all topics of interest. Each topic is analyzed based on the description of assessment, the performance of current housing stock and the possibilities for improvement of that topic. All outcomes of preliminary work, interviews with experts and topic analysis were combined in two conceptual directions: passive and active. These concepts were assessed and compared in order to find the performance and robustness of them. The recommendations for improvement which could be concluded from that were implemented in a hybrid concept. This performs within the boundaries of an accepted selling price and could reduce the ecologic impact of the house concept.

Keywords: row house, Netherlands, active, passive, sustainability, affordability, BREEAM-NL, eQUEST, assessment methodology

INTRODUCTION
Growing concerns about impending global warming and scarcity of energy sources lead to the efforts to use different energy sources and use the sources more efficiently. Since the energy consumption of the building sector constitutes for about 40% of the energy demand (Monitweb), buildings became one of the focus points of these efforts. Introduction of sustainable energy technologies and reducing energy demands have been in the heart of the endeavour to improve the environmental performance of buildings.
Although in some fields the focus on sustainable development has become broader, the regulations in the Netherlands still focus on energy reduction in buildings, by use of the energy performance coefficient (EPC).
To describe the significance of broadening the perspective of sustainability in the Netherlands and the Dutch governmental policy have been taken as a starting point.

Sustainability policies are constructed from the National Environmental Policy Plans (NEPP) (in Dutch: Nationaal Milieubeleids Plan = NMP), of which the latest version is NEPP 4, dated in 2001 and considers the strategy until 2030. This report gives an overview of the governmental policy to mitigate the environmental burdens on future generations. The plan concludes on the positive effect of environmental policy, because it resulted in the dissolving or manageability of environmental problems. It discusses 7 environmental problems which show that energy reduction is not the only topic to which attention should be given. It also considers the depletion of resources, general health, safety and quality of life.
Since the amount of energy, water and materials which is used by the residential buildings is significant, it is important to improve the performance of new built houses in this sector in order to reach the goals which were set in NEPP 4. It is therefore the topic of this study to find an appropriate example for the design of a new-built house for the Netherlands, which can be affordable for the target group which will be specified later and complies with the governmental aims to reduce the impact of the discussed environmental problems.

PRELIMINARY STUDY

A preliminary study addressed the assessment of 6 sustainable housing case studies. It clearly showed a narrow approach of sustainable building design: solutions are mainly found for experimental projects instead of general concepts which are applicable to a large group of citizens. The focus lacked attention in each of the six value domains as described by Rutten (1996). In basic value the attention was low for acoustics, spatial design and internal air quality. The economic value of the case studies was given very low attention, except for benefits from energy reduction. The latter is the most addressed topic in the case studies. Other parts of the ecological value were given medium or very low attention (building materials, land use and flora/fauna). Strategies to improve the future value of the case studies were hardly found. Manageability and ease of operation and maintenance was sometimes enhanced by user guides, but extra focus could be given to the design of simple systems with low maintenance. Local conditions were generally included in the designs. So the focus in sustainability lacked attention in the applicability and feasibility of the projects in order to be accessible to a large share of the population.

METHODOLOGY

The main challenge of this study is to find a solution for the design of an affordable and sustainable house for the Netherlands, which is defined in the research question:
What is the optimum combination of the design strategies and measures to achieve high basic, environmental and economic value in the design of a 'sustainable' and 'affordable' single family house in the Netherlands?
The main research question is broad and directs the answer of it into design decisions based on reasoned argumentation. The general methodology is based on the primary definition of objectives (as deducted from the preliminary study). From here some specific topics of interest can be defined. These objectives and specific topics are studied within the boundary conditions which define the house typology and costs boundaries. In order to guide the design process into an integral attention for sustainability, the same tool as in the preliminary study is used (BREEAM-NL). Guided by this framework, each specific topic of interest is analyzed in order to find the current practice and possible improvements. The combination of these analyses results into recommendations for a passive (measures which do not consume energy to perform) and an active (energy based solutions) concept. The

concepts are assessed according to the defined assessment method and are compared to a reference house that represents the current building practice. The comparison of these concepts and analysis of the results lead to recommendations for improvement of both. These recommendations are combined into a hybrid concept that represents the concessions which result from all influencing topics of interest. It represents the strategies to use in order to design an affordable and sustainable house for the Netherlands and will thereby answer the main research question.

Boundary conditions

As stated in the introduction, the Netherlands is chosen as location for the design. It is the aim of the contributing parties to find a housing concept for this country. The boundary conditions are defined for the Netherlands as a whole, which accounts for the climate and the national building regulations. The demand for amount of houses to be built in the Netherlands will increase in the coming years (with about 50,000 a year between 2006 and 2020). This demand could be filled in by new built homes. The most demanded house type is a single family home, in the owner-occupied property in the low-price cost range. Following the figures in Socrates 2006, the specifications are summarized in Table 109. A reference row-house from SenterNovem (with balanced ventilation and heat recovery; EPC 0.74) was chosen to represent the current stock.

Topics of interest

The studied topics of interest are deducted from the preliminary study, the demands as found in the Dutch policy program and the definition of sustainability as given by the six value domains. The topics and the level of depth in this study are presented in Table 109.

Overall objectives		
Sustainable design	Affordable design	Integral design
Boundary conditions		
Region: the Netherlands	House type: single family row-house, balanced ventilation with heat recovery, 130 m^2 user area	Price range: Low selling price (< €219,400), owner occupied property
Specific points of interest		
General topic	Specific topic	Level of study
High basic value: Health, comfort, ease of use and safety.	Thermal comfort	High
	Indoor air quality	High
	Visual comfort	High
	Acoustic comfort	High
	Domotica	Medium
	Safety - accessibility	Low
High ecologic value: CO2 emission by use or built, water consumption, waste management.	CO2 emission during use	High
	Embodied energy	Medium
	Carbon footprint of residents	Medium
	Water consumption	Medium
	Water recycling	Medium
	Household waste	Low
High economic value: Affordability	Building costs	Medium
	Return of investment	Medium

High strategic value:	Technical flexibility	Medium
Flexibility	Usability of different users	Medium
High functional value:	Use of proven technologies	Low
Operation, maintenance	Choice of low maintenance solutions	Low
High local value:	Use of local know-how	Low
Applicability	Compatibility with local regulation	Medium

Table 109: Specifications of aimed house type and defined topics of interest for this study

BREEAM-NL v1.2 (Residential)

Two studies by DHV and by Dobbelsteen conclude in a positive result for the use of BREEAM in the Netherlands, if a broad spectrum of topics needs to be handled. In 2008, the Dutch Green Building Council (DGBC) started translation of BREEAM to BREEAM-NL. Since March 2010, a beta version for residential buildings is published (v.1.2). When 'BREEAM-NL' is mentioned, it refers to this residential version. The assessment of a building is based on a list of credits which complies with the Dutch law and regulation, practice guidelines and building practice. All credits are divided in categories, which are weighted by importance: management, health and comfort, energy, transport, water, materials, waste, land use & ecology and pollution.

One of the reasons to choose BREEAM-NL as assessment method is the concrete categorization of topics and criteria. By this, the applicable topics for the project could be chosen some topics are left out for different reasons, being the phase of design, (conceptual, not being built) the lack of exact location details, the scope in objectives or the capabilities of the design team and time frame of the study. The total amount of criteria reduces thereby from 39 to 13 and the amount of maximum achievable credits reduces from 89 to 37. Unfortunately, not all topics of interest as described in the objectives chapter can be expressed in BREEAM-NL credits. Some of them are implicitly taken into account by use of BREEAM-NL as guideline (functional value and applicability), for others a specific assessment method had to be developed (economic value, which is expressed in payback time and investment per BREEAM-NL credit).

RESULTS: ANALYSIS AND DESIGN

Due to the large amount of parameters to be included in the study, the amount of concepts is kept to a limited number. The concepts are given a specific direction, to be diverse in their basis. The concepts will be differentiated, based on their typology of:

- Passive design strategies, which focus (investment) is in passive systems: they are characterized by their direct interaction between the building fabric and the environment. They do not produce power and do not need any mechanical devices or significant mechanical energy in order to operate.
- Active design strategies, which focus (investment) is in active systems: they are designed to utilize the environment to avoid or meet a significant proportion of the residual demand. These systems either produce power, or they operate in conjunction with some mechanical devices to utilize renewable energy to provide heating/cooling.

Each topic is analyzed on the applicability of BREEAM-NL (or otherwise description of new method), the performance in current practice and the options for improvement in the several designs.

Thermal comfort

Thermal comfort is assessed according to BREEAM-NL (HEA10) by calculating the amount of overheating hours (max. 300) over the Predicted Mean Vote (PMV) value of +0.5. This value indicates for e.g. a living room a temperature of 26.5 °C in summer situation, which could be found on hourly basis by using the dynamic building simulation tool eQUEST. Looking at outdoor temperatures, about 93% of the year heating would be necessary and 3% of hours would be overheating. The demands could be achieved by passive or active means. The passive means to achieve the heating demands include enhancement of building skin properties in terms of insulation and air tightness values, but also could be found in position of thermal zones. Prevention of overheating could be achieved by changing window types and solar shading. The choices to be made in this are numerous and are partly made based on the economic analysis of several measures under 'economic value', under 'spatial comfort' and by the definition of the passive and active concept.

Active systems which could assist in achieving these demands were studied. The most advantageous type is the floor heating option, which has a lower energy consumption, high thermal comfort and indoor air quality. The disadvantage of slow response could be solved by higher insulation values of the building skin.

Indoor air quality

The quality of indoor air is assessed by BREEAM-NL (HEA8) which defines the demands according to a maximum level of CO_2 concentration. The minimum ventilation flows for houses which comply with this can be found in the Dutch Building Decree (e.g. 0.9 $dm^3/s/m^2$ for user areas). The flows should be assured by help of at least mechanical exhaust. Ventilation can be applied by either designed measures or in an uncontrolled way. The limits for infiltration are prescribed in the Building Decree and will be applied for the active concept. For the passive concept air tightness is improved in order to control the flow. To comply with the regulations and the description of passive design, natural inlet and mechanical outlet is applied for the passive concept and a balanced ventilation system with heat recovery is applied in the active concept.

Visual comfort

Visual comfort is assessed based on the amount of available daylight in BREEAM-NL (HEA1) by the BRE Average Daylight Formula. This takes into account window area, partitions area, window transmission, the visible sky angle and the average reflection factor of the skin. The demanded daylight factor of 2% in at least 80% of all user area should give the house a day lit appearance and a low amount of supplementary electric lighting would be needed. Transmission factor is a topic of study, and also the sky angle due to overhangs was designed. Fixed assumptions were taken for distance of obstructions and reflection factors.

In order to improve the house energy performance, improvements were assumed in artificial lighting types for both the active and passive concepts. Since the reference house does not comply with the 80% area with 2% ADF demand (results in 71%), both the passive and active concept were given increased (or different placed) window sizes.

Acoustic comfort

Demands for acoustic comfort are given in BREEAM-NL (HEA13), which include the noise insulation values of external, internal and adjacent skin partitions. The characteristic services sound level is e.g. limited by 30 dB(A). A short description of building parts showed the achievement of noise insulation characteristics for the building skin. Details of connections were deducted from the design guide in NPR 5070 and 5086 for all concepts. Assessment on this topic was done based on this general description, combined with the specifications from product suppliers on the noise production by building services.

Spatial comfort

The analysis on spatial comfort combines the assessment of three BREEAM-NL topics (HEA14, HEA15 and HEA16): private outdoor space, flexibility and accessibility. The demands are given by means of minimum areas, widths and specifications of expandability or changeability of structure. The accessibility of the reference house was assessed and concluded not to be accessible for disabled people. A suggestion of changed spatial planning for the ground floor was made in order to improve the future use by elderly or disabled. Expandability of the reference house was concluded to be possible in vertical direction, with a light weight structure on top. The adapted spatial planning for accessibility was applied in both the passive and active concept.

CO_2 emissions

Since this topic is weighted high in BREEAM-NL (ENE1: 19%) this was given high attention. Again eQUEST was used to simulate the reference house and several concepts to find the energy performance of the chosen measures. This tool integrates passive and active measures and the calculation is based on American Department of Energy (DOE) software.

Assessment of CO_2 emissions occurs based on primary energy use during the operation period. The amount of reduction compared to the regulated value is expressed in credit points. The analysis on CO_2 emissions focused on the available sources in the Netherlands and the possible systems to apply. It results in an advice to use solar energy for both heat and electricity generation (with roof inclination between 30-40°). Wind application is not recommended due to the low performance of small scale wind turbines which results from large variations of wind available. Ground source technologies are advised, since the ground typology in most parts of the Netherlands has a reasonable thermal capacity. Biomass systems are not recommended due to the lack of applicability: the supply and distribution of wood pellets is too time intensive.

Conclusions from the system analysis are to use a high efficiency boiler (comparable to reference house) for the passive concept and a ground source (water-water) heat pump for the active concept. Solar thermal panels are advised for supply domestic hot water (DHW) and are combined with the boiler for the passive concept and the heat pump for the active concept.

User behaviour

Although user behaviour is not explicitly specified by BREEAM-NL assessment, the result of changes in the concept on this topic will be expressed in end energy use are therefore taken into account under CO_2 emissions. Based on literature research form ECN and TNO (Paauw 2009), it could be concluded that feedback can have a positive effect on reduction of energy consumption. Combined with the assumed energy pattern for a large group of households, for the concepts some assumptions could be made. These include analogue thermostats, temperatures of 20°C, windows closed while heating, stand-by killers on electric equipment and energy efficient appliances. Hot water schedules will not be influenced since users are found to adapt this.

Building materials

The effect of building materials on the environment is assessed in BREEAM-NL (MAT1) by use of the shadow price. This price is calculated from the impact of nine environmental aspects of the building materials (greenhouse effect, damage to ozone layer, humane-, aquatic-, and terrestrial toxicity, photochemical oxidants, acidification and eutrophication).
The tool GreenCalc+ (V2.2) was used to calculate the impact of these environmental aspects. Analysis of the reference house showed a large impact by floors, facades and internal walls. Changes in design could reduce this price (by wood use or mechanical instead of balanced ventilation) but also could increase it (concrete structure or use of ground source heat pump). The passive design will be based on a heavy weight structure, and the active house will be based on wood structure to compensate the negative effect of the ground source heat pump as was recommended for CO_2 emission reduction.

Water use

Water use is assessed in BREEAM-NL (WAT1 and WAT5) in a prescriptive way by giving the types of water saving measures and the options for water recycling. Toilet, shower and use of the washing machine count up to the biggest share of all household water use. The total use is about 93 m^3 per year as deducted from yearly averages per household. Several systems were assessed which either reduce the water or recycle the rain water. Based on possible savings and needed investment, in the new concepts only water saving taps, 6 liter toilets and low flow shower heads were applied. For reduction of heat demand, shower heat recovery systems were applied. Assessment is based on the presence of these water saving measures and is expressed in BREEAM-NL credit points.

Waste

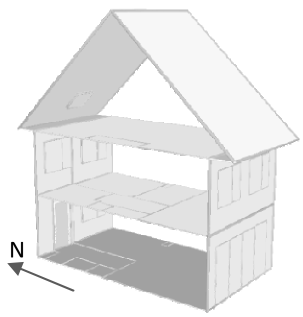
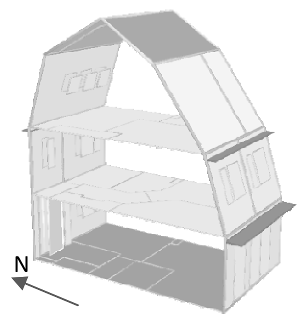
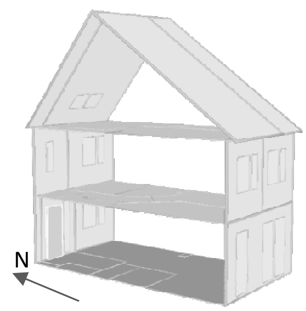
Waste production is divided in BREEAM-NL (WST3, WST5) under construction- and household waste. Only the latter one is assessed, since the conceptual phase of this project made the first unpractical. Household waste is produced in 79 kg/yr/inhabitant in organic types and for 26 kg/yr/inhabitant in green waste. The required size of space in a house would be 40 litres for paper, 0.4*0.6 metres for recyclable waste and 140 litres for compost in the garden. These measures are applied in all concepts.

Economic value

The economic value of a house is highly depended on a list of assumptions. The ground prices, energy prices, additional costs or selling prices depend on time and market situations. Also the economic value of a design is not assessed in any topic of BREEAM-NL. Therefore a method based on an annuity mortgage over 30 years is applied for comparison of the concepts. The selling price is calculated by use of a fixed 30,000 euro ground price, building costs estimations with assistance of IGG and also their assumptions on additional costs per concept. Assessment occurs based on payback time compared to the reference house, the selling price (with boundary of €219,400) and selling price per achieved BREEAM-NL credit.
The building costs of the reference house lie mainly in structural works (63%) of which more than half in building structure and facades. Therefore possible reductions could be found in reducing the façade area and decreasing window sizes. In the payback calculations energy prices as interpreted from ECN (2010) and CPB (Bollen e.a. 2004) predictions were used (about 0.5% increase per year) but sensitivity was also presented on different energy price

increasing.
On influence of passive measures a sensitivity study was employed which resulted in a recommendation for insulation measures and an increased roof size, resulting in lower façade costs and lower heating demand. Triple glazing options were found not to be feasible due to the small amount of energy reduction per invested euro. By hand of Net Present Value analysis some active systems were assessed and all found to be not feasible in the predicted energy prices. They do not pay back the investments within the technical life time.

RESULTS: CONCEPTS AND COMPARISON
From all topics of study, results, conclusions and advice are compiled and could be translated into the two concepts for design. The main line of the concepts was defined by the passive/active definitions and the recommendations from each topic analysis. It should be noted that the passive concept is not the same as the known Passive House.

Reference house	Passive concept	Active concept
		
Rc values skin: 3-4 m2K/W Uwindow: 1.8 W/m2K Air tightness: 0.62 $dm^3/s/m^2$ Balanced ventilation Heat recovery on vent. air Gas fired boiler, combi High temp. radiators No water saving options Artificial lighting 50 lm/W	**Rc values skin: 7-8 m2K/W** **Uwindow: 1.3 W/m2K** **Air tightness: 0.15 $dm^3/s/m^2$** Mechanical exhaust vent. **Solar thermal collectors 6 m^2** Gas fired boiler, combi **Low temp. floor heating** **Low flow tap, toilet, shower** **Artificial lighting 25 lm/W**	Rc values skin: 3-4 m2K/W Uwindow: 1.8 W/m2K Air tightness: 0.62 $dm^3/s/m^2$ Balanced vent. + heat recov. **Solar thermal collectors 6 m^2** **Vert. ground src. Heat pump** **Low temp. floor heating** **Low flow tap, toilet, shower** **Artificial lighting 25 lm/W**

Assessment of these concepts is performed within the framework of BREEAM-NL criteria by help of separate tools for energy and thermal comfort (eQUEST), daylight (ADF), materials (Greencalc), costs (mortgage model), and specifications from drawings or product suppliers.
Thermal comfort was assured in all concepts, as well as indoor air quality (although assured by different systems). The difference could mainly be found in annual energy use for heating and electricity demands. The heat demand did not differ much between the concepts, since the gain from increased insulation values of the passive concept was lost by the ventilation principle. The ground source heat pump affected significantly the primary energy use for

space heating, but the investment costs could not be paid back by this reduction due to low (and limited increasing) energy prices. By means of the solar thermal panels, primary energy use for DHW could be reduced by 10-12 GJ/year.
Daylight design was improved for both passive and active concept, and therefore the demand is now met. Combined with energy efficient lighting, this resulted up till 47% reduction of electricity for artificial lighting. Acoustic comfort was assured by using the building details as prescribed, combined with well designed ventilation systems. Accessibility was assured by the adapted space plan, which also resulted in a storage space for household waste. The water use of the concepts was reduced to 62 m^3 per year by the presented measures. Both the passive and active concept appeared to be more expensive than the reference, although the passive concepts just stayed below the set boundary of €219,400 for selling price. Still this concept is 9% more expensive than the reference and by the achieved reductions and predicted energy prices could not be paid back within 30 years of mortgage. From sensitivity on possible changes of energy prices it was concluded that feasibility for the passive concept would occur from 4.8% and for the active annual energy price increase higher than 15%. The small difference as result of difference in building materials and the difference in use of primary energy was reflected in the BREEAM-NL weighted percentage of credit points. The selling price per percentage was lowest for the passive (3466), a bit higher for active (3699) and highest for the reference house (5898).
Since the passive concept performed best in terms of sustainability and affordability, this concept is chosen for further improvement. Balanced ventilation with heat recovery is implemented and district heating is considered as an option to replace gas fired boiler. This results in higher investment costs (exceeding boundaries) due to the ventilation system, but a high reduction in heating energy. The annual energy costs increased compared to the passive concept, due to a different mix of electricity (increased for fans) and natural gas (reduction). The district heating results in a comparable financial situation with the gas fired boilers but the environmental performance is improved in terms of CO_2 emissions. Also in terms of energy price robustness, this option is not feasible yet since the price is indicated according to the gas prices.

CONCLUSIONS

The main conclusions from comparison lead to the best performance of the passive concept. The selling price lies within the acceptable boundary and the energy performance is higher than the reference house, although the 9% additional selling price is not paid back within the mortgage period. Robustness of this concept on energy price changes and changing in energy use by the residents is highest of all concepts. Although the selling price exceeds the boundary by 5,000 euro, the hybrid concept is advised as result of this concept since the benefits in primary energy use are major. It has more options for sustainable performance in the future when considering the possibility of ‘green’ electricity generation. Also the selling price per weighted BREEAM-NL percentage is lower, although this difference is not significant.
From the designed concepts it became clear that measures to achieve a higher level of sustainability are more costly than the current practice. This results either from the larger amount of materials, the complexity of the systems or the higher attention for details which asks more man-hours during built. In building design, reductions could be found in changing the roof, wall or window area.

RECOMMENDATIONS

The broadness of scope characterized this research and its outcomes. The amount of topics addressed was large and therefore the level of depth in which they were addressed was not in highest detail. Recommendations are therefore given for further research on several topics. There is potential to improve the use of building materials (amount and type), to improve the efficiency of spatial planning and to focus more on user behaviour. The price for sustainability could only partly be reduced in building parts, but improvements could be found in project and process efficiency. Increasing the project scale could enhance the feasibility of the technologies, such as collective heat pumps and geothermal district heating. The quality of BREEAM-NL as tool was acceptable, but lacked the integration of affordability. Also the assessment character was not satisfying during design phase.

REFERENCES

Bollen, J., Manders, T. and Mulder, M. (2004) *Four futures for energy markets and climate change,* CPB Netherlands Bureau for Economic Policy Analysis, The Hague

BREEAM-NL v1.2 bèta (2010) *Keurmerk voor duurzame vastgoedobjecten, Beoordelingsrichtlijk Nieuwbouw*, Dutch Green Building Council, Rotterdam

Clocquet, R., Boonstra, C. and Joosten, L. (2008) *Instrumenten Beoordeling en Promotie Duurzame Kantoren*, DHV B.V., published under authority of SenterNovem

Dobbelsteen, van den, A.A.J.F (2008) *Modelvergelijking voor de Nederlandse Green Building Tool,* TU Delft, faculty of Architecture, Climate Design & Sustainability, Delft

ECN (2010) *Referentieramingen energie en emissies 2010-2020,* ECN, Petten

Nijenmanting, F.C. and Senel, M.S. (2010) *Assessment of sustainable housing projects*, unit Physics of the Built Environment of faculty Architecture, Building and Planning, unit Sustainable Energy Technology of faculty Mechanical Engineering, Eindhoven University of Technology, Eindhoven, master projects

Paauw, J. and Roossien,B. (2009) *Energy pattern generator- understanding the effect of user behaviour on energy systems,* ECN, Petten, Netherlands

Poulus, C and Heida, H.R. (2006) *Woningmarktverkenningen, Socrates 2006,* ABF Research, Delft

Rutten P.G.S. (1996) *Strategisch bouwen*, Eindhoven University of Technology, Eindhoven, inaugural speech

SenterNovem (2006) *Referentiewoningen nieuwbouw*, Sittard

Monitweb: http://www.energie.nl/index4.html, visited 03/09/2010, Energy information website by ECN

VROM (2001), *Nationaal Milieubeleidsplan 4 (NMP4) 'Een wereld en een wil: werken aan duurzaamheid'*, The Hague, nota, article code 1076

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