Houses As Energy Delivering Systems
- a conceptual design -

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Institution & Mentors

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Acronyms and Abbreviations

A/V  Air to Volume Ratio
ATS  Architecture Towards Sustainability
BAT  Best Available Technology
C2C  Cradle to Cradle
CED  Cumulative Energy Demand
CHP  Combined Heat Power
DH  District Heating
DHR  Drain Water Heat Recovery
DHW  Domestic Hot Water
ECN  Energy research Centre of The Netherlands
EPC  Energy Performance Coefficient
EPN  Energy Performance Standard
EU  European Union
g-value  Transmission Coefficient of Glazing
HR  Heat Recovery
IAQ  Indoor Air Quality
kWh  Kilo Watt Hour
LCA  Life Cycle Analysis
PE  Primary Energy
PH  Passive House
PHC  Power-Heat Coupling
PHPP  Passive House Planning Package
PRF  Primary Source Factor
PV  Photovoltaic(s)
PVT  Combined Photovoltaic Thermal Collector
Rc-value  Thermal Heat Resistance
SHR  Subsoil Heat Recovery
TE  Trias Energetica
TFA  Treated Floor Area
TNO  Netherlands Organisation for Applied Scientific Research
U-value  Thermal Heat Conductivity
VROM  Dutch Ministry of Housing, Spatial Planning and the Environment
01 Introduction

This chapter introduces the research topic and gives an overview of the structure of the thesis.
01.01 Introduction to the Research Topic

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” [WCED, 1987]

Sustainability gets a more and more important issue in daily practice. Be it in the supermarket when we select products for its organic ingredients or in the moment when we decide to buy an environmentally friendly car. Driving force in this process is the increased awareness of limited fossil resources and progressing global warming.

Due to this slow growing awareness the countries of the EU have given their commitment to counter these effects. EU-policies were developed to limit the use of fossil fuels and reduce the emission of carbon dioxide, which causes global warming.

The construction sector is one of the biggest consumers of natural resources. The Dutch built environment consumes one third of the national total energy [Opstelten et al, 2007]. Households in The Netherlands consume 15% of the national primary energy [Dril et al., 2005].

The Dutch research institutes TNO and ECN have set up a strategic co-operation, called 'Building Future' with the target of a fossil fuel free built environment in The Netherlands by 2050 [Opstelten et al, 2007]. Part of this co-operation is the programme 'WAELS III - Woning als Energieleverend Systeem, which was initiated by TNO, ECN, and the University of Technologies Eindhoven (TU/e) in 2006.

This research 'Houses As Energy Delivering Systems' is embedded into 'WAELS III'. It aims at the design of a sustainable and feasible building concept with minimized energy demands. This thesis investigates and evaluates technologies and design approaches, which contribute to the desired vision of the 'fossil fuel free built environment'.

01.02 Initial Research Question

The discussion above leads to the following premises:

- A big variety of energy-efficient technologies and design approaches are available.
- The building as a design and the process of designing are very complex.

Based on these premises, the following research question can be formulated:

- What are suitable technologies and strategies to design a building with a minimized energy consumption?
02 Analysis of State-of-the-Art Knowledge and Technology in Building Design

Chapter Two analyses the current standards and developments in the building sector with the focus on the design process of a residential building, the building design itself, and the building's performance.
02.01 Analysis of the Design Approach

02.01.01 Introduction
Design is a powerful tool. The more one understands the design implications of decisions made during the process, the more likely a good result will be achieved. Energy efficiency, inconvenience, and poor indoor environmental quality can be built into a building unintentionally. The likelihood that these problems will surface in a building can be reduced with a careful design.

An intelligent building design is the first strategy that should be used to reduce the need for fossil-fuel energy. Within this category there are a number of design techniques that are no-cost or low-cost. These strategies can dramatically reduce a building’s energy demand.

02.01.02 Trias Energetica (for more information, see Appendix B)

One of the most popular strategies, which are currently used in the field of sustainable design, is the Trias Energetica (see also Appendix B). This approach was developed at the Delft University of Technology with the intention to promote the use of renewable energy. This strategy is used in many industrial fields, amongst others in the building sector.

This three step approach can be utilized to reduce a building’s energy demand in a logical way (Figure 1).

Figure 1: Three step approach in the ‘Trias Energetica’ with the purpose to minimize the use of fossil fuels

Three steps are identified towards the goal of a reduced demand of fossil-fuels:
1. Limit the energy demand through energy saving;
2. Use renewable sources to meet the remaining energy requirement;
3. Use fossil fuels as efficiently and cleanly as possible.
1 The first step of this strategy affects the design process from the very beginning. It incorporates measures and techniques, which range from macro-scale (urban design) down to micro-scale (building detail design). Most of these interventions involve passive solar design (see also Appendix A), which optimizes the building's design settings with sophisticated and intelligent approaches, with the intention to create a high-performance building by utilizing free energy from the sun.

2 The second step implies the use of internal waste-flows of the building to gain energy. Exhaust ventilation air and hot waste-water is used to recycle heat by means of air heat exchanger and waste-water heat exchanger respectively. This reuse-process will reduce the energy demand even further. Now, renewable sources are utilized by using energy from sun, wind, water, ground, or biomass. For instance, photovoltaic collectors and solar thermal collectors are installed on the building's roof to produce electricity for household appliances and heat for domestic hot water or space heating purposes. The temperature-differences between ground and ambient air can be used for the precondition of the building's ventilation air in winter and summer and biomass is utilized as a carbon dioxide-neutral combustion material.

3 In the last step of the Trias Energetica conventional fossil-fuels are used to cover the rest of the energy demand. In case the prior two steps are well executed, this step might be even dispensable.

For more information on this strategy is referred to Appendix B. Passive solar design is discussed in Appendix A.

02.01.03 Cradle to Cradle

The Cradle to Cradle (C2C) design framework is a revolutionary approach to nothing less than the re-design of human industry. McDonough & Braungart [2002] state in their book 'Cradle to Cradle: Remaking the Way We Make Things': 'the overarching design framework humans exist within has two essential elements: mass (the Earth) and energy (the sun)'. The planetary system is an enclosed system, where almost nothing goes in or out. This leads to the conclusion that within the system Earth basic elements are valuable and finite.

The authors take the nature as an example and state that it "operates according to a system of nutrients and metabolisms in which there is no such thing as waste". "The earth's major nutrients are cycled and recycled. Waste equals food." [McDonough & Braungart, 2002] Based on this statement two kinds of material flows on the planet were identified: biological metabolism - the cycle of nature, and the technical metabolism - the cycle of industry (Figure 2, Figure 3).

![Figure 2: Biological Metabolism](image)

**Figure 2:** Biological Metabolism: Materials that flow optimally through the biological metabolism are called biological nutrients. Products conceived as biological nutrients are called products of consumption. [McDonough, 2002]
Figure 3: Technical Metabolism: A technical nutrient is a material, frequently synthetic or mineral, that remains safely in a closed-loop system of manufacture, recovery, and reuse, maintaining its highest value through many product life cycles. Technical nutrients are used in products of service. [McDonough, 2002]

With the right design of products and materials waste flows can safely feed these two metabolisms and consequently may prevent the human waste. To achieve this, products and processes have to be understood from the very beginning until the very end of their lifecycles.

This idea is translated by Andy van den Dobbelsteen [2008] (Appendix E) into a design process for buildings. Waste flows of material, energy, and water are productively re-incorporated into new production and use phases (i.e. recycling processes). The optimal use of nature resources is striven (Figure 15).

In the study C2C Park 2020 [Dobbelsteen et al, 2008] a six step strategy for the C2C application in the building sector is elaborated (Appendix E). This design process involves also passive design measures as described in Appendix A.

02.01.04  **Sustainability Approach**

When building a house to improve one’s personal quality of life the three domains of economy, ecology, and society must be addressed under long term conditions. For visualization, the model ‘Triple P’ - People, Planet, and Prosperity - has been developed. The term Triple P refers to the concept of the triple bottom line as formulated by John Elkington in his book ‘Cannibals with Forks’ [Elkington, 1997]. According to the triple
bottom line concept, equal weight should be given in corporate activities to the following three mentioned aspects (Figure 5).

![Figure 5: Sustainable Development according to Elkington (three spheres of sustainability – economy, social welfare, and environment); source: [Stofberg and Duijvestein, 2006]](image)

Sustainable housing means sustainable living; it is not just about saving energy. “It also means that people are happy to live where they live and that they live in a healthy environment” [IEA, 2006]. The International Energy Agency [2006] emphasizes three main aspects of sustainable housing (Figure 6).

![Figure 6: Three main aspects of sustainable housing; source: [IEA, 2006]](image)

**Preservation of global environment**
1. Energy saving and utilization of natural and unutilized energy resources
2. Resources saving (reduction and recycling of waste materials)
3. Appropriate use and recycling of water resources

**Healthy and pleasant living environment**
1. Indoor and outdoor temperatures, heat and air
2. Indoor and outdoor light, noise, vibration

**Harmony between the house and the environment**
1. Harmony with the living environment
2. Artificial supplementation of the natural environment and landscaping according to site conditions
3. Harmony with the local community or the creation of local community

---

**02.01.05 Integrative Approach**
To improve all three spheres of sustainability an integrated approach might be necessary, which addresses the wide range of complex issues within the fields of building physics, environmental sciences, architecture, and marketing. Sustainable building design views the individual building systems and components not as isolated entities, but as closely connected and interacting with the rest of the building. A significant reduction of the energy-related environmental impacts of buildings is only achieving by synergy across a broad range of goals [IEA Annex 31, 2005a]. The best way to respond to this issue is an integrated approach (Figure 7).

A strategy, which covers the idea of an integrated approach, is the district heating network with a centralized energy production and a centralized energy storage. The conventional and solar-assisted district design approach is elaborated in Appendix D.

**02.01.06 Alternative Design Strategies**

There are considerably more design strategies available which could find its application in the building design process. Most of them have the same major objective, to save the humans' resources and contribute to a more sustainable lifestyle.

All these approaches have their minor, individual objectives, for instance the promotion of carbon dioxide neutral processes and products or the strengthening of social aspect in the sustainability concept (chapter 02.01.04).

To give a small overview on the variety of approaches, the following methods must be mentioned:

**Cumulative Energy Demand (CED):** The CED method has the intention to allow an objective comparison of the environmental impact of products and services. For this method the whole lifecycle of a product or service is considered and all embodied direct and indirect energy is taken into account. This assessment method can be used as a good basis, in form of a database, for other sustainable approaches. [VDI, 1997][Frischknecht & Jungbluth, 2004a][Hastings & Wall, 2007a]

**Architecture Towards Sustainability (ATS):** This approach intents to enable the building designer to increase his/her awareness of the actions' and decisions' impact on the environment made during the design process. A building design exceeds its boundaries on various scales and affects individual as well as community levels. Therefore, ATS supports the designer to get a clear picture of his/her differentiated responsibilities. [Hastings & Wall, 2007a][UNEP, 1992][Hui, 2002]
Life-Cycle-Analysis (LCA): A life cycle assessment supports planners by providing information on different environmental aspects like primary energy consumption, resources consumption, etc. Also shifts of environmental burdens are addressed by considering products and services from cradle to grave. Thus, the interaction of measures taken during the design process and the natural environmental system can be analysed. [Brunner et al., 2006][ISO, 1997-2000][IEA Annex 31. 2005a+c][RMIT, 2001]

02.02 Analysis Design Objectives

Design objectives intend to give the designer, builder, and homeowner a basic understanding of design considerations, necessary building components, and used systems. These criteria prescribe the framework for the building design.

Each chosen design objective is significantly important to the success of a project, although it is just one aspect of what it takes to achieve a good result. A truly successful project is one where project goals are identified early in the process and where the mutual dependencies of all building systems are co-ordinated simultaneously during the planning phase. All these dependencies must be understood, evaluated, and appropriately applied by the designer.

Every building project demands the skills of a team of professionals in various design disciplines and the involvement of the stakeholders. During their decision making processes all these participants need to be orientated towards a unique set of program goals and technical requirements for the project.

The following aspect could be part of a building program setup:
- Accessible,
- Aesthetics,
- Cost-effective,
- Functional, Comfortable,
- Historic preservation,
- Productive, Performance,
- Secure,
- Sustainable, Energy-efficiency, Adaptable, Flexible,
- Etc.

02.03 Analysis Building Standard

02.03.01 Introduction

The purpose of the building standards system is to safeguard people in and around buildings and also to promote energy efficiency and conservation by regulating minimum energy requirements. Within this section the focus is laid on the energy requirements of new buildings in The Netherlands.

02.03.02 Dutch Building Standard

In The Netherlands the building related standards are specified in the 'Bouwbesluit 2003' [VROM, 2005] and affect 5 aspects: safety, health, usability, energy-efficiency, and environment.

Energy conservation in buildings is expected to contribute significantly to the reduction of greenhouse gas emissions in The Netherlands. Energy efficiency policy in The Netherlands is ambitious both in terms of targets and available resources. Energy
performance certification of buildings is a key instrument in this policy. For this reason the energy-efficiency requirements for new built dwellings have been tightened in January 2006. This strengthening of the building regulations is promoted by the Dutch government with the purpose to decrease the CO2 production of the built environment.

EPN & EPC

The Energy Performance Standard (EPN) for new buildings was introduced in 1995 and is mandatory part of the Dutch Building Code. The EPN enables the calculation of the integral energy performance of a new house and its heating, ventilation, air-conditioning and lighting. The EPN concerns both residential and non-residential buildings with the intention to reduce the use of fossil fuels in the built environment. [VROM.nl]

This Energy Performance Standard consists of a standardised method for the calculation of an Energy Performance Coefficient (EPC). The required EPC has been steadily reduced from 1.4 in 1995 to 0.8 in 2006 [VROM, 2005]. The energy consumption for houses with a specific EPC varies according to the number and behaviour of the inhabitants. The lower the EPC value of a building the lower is the building's average energy consumption (Figure 8).

![Energy-label for Dutch dwellings](source: SenterNovem.nl)

Reference Dwelling

On behalf of the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) SenterNovem has introduced in 2006 a paper [SenterNovem, 2006] with examples and reference dwellings to illustrate the effect of certain energy-saving measures within the EPC-calculation. These references function as theoretical templates with required qualities and quantities. The reference date for these examples is the 1st Jan 2006, when the EPC value was tightened to 0.8.

This representative paper indicates six dwellings types. Each dwelling type has a certain market share to new built dwellings in Holland. The terraced dwelling (row house) has currently the biggest market share of approximately 50%. Three quarter of that share is covered by mid-terraced buildings, which leads to 36.5% total market share. 20% of these dwellings are put on the rental market and the remaining 80% are sold. [SenterNovem, 2006]
The reference dwelling has the following characteristics (Figure 9):

- Inner distance wall to wall  5.1 m
- Depth of the dwelling  8.9 m
- Storey height  2.6 m
- Net (usable) space  124.3 m²
- Exterior building surface  156.9 m²
- Gross building volume  323.2 m³
- Surface-to-Volume ratio  0.49/m

Figure 9: SenterNovem Reference Dwelling - Mid-terraced house; source: [SenterNovem, 2006]

Architectural characteristics are:

- Rc-value façade  3.0 m²K/W, U-value  0.33 W/m²K
- Rc-value roof  4.0 m²K/W, U-value  0.25 W/m²K
- Rc-value slab  3.0 m²K/W, U-value  0.33 W/m²K
- U-value windows  1.8 W/m²K,
- U-value entrance door  2.0 W/m²K,
- External sun-shading yes
- A heat recovery system for ventilation air is installed.
- The annual energy consumption is between 359 MJ/m² and 340 MJ/m².

Space Requirements
The following list represents the common building practice for space requirements with different functions within a one family dwelling [Broos, 2008]:

- Living room / dining room  35-40 m²
- Kitchen  15-19 m²
- Master bedroom  18-20 m²
- Bedroom  12 m²
- Bathroom  7 m²
- Toilet  2 m²
- Hall  6-8 m²
02.03.03 Passive House Standard

Introduction
The Passive House Energy Standard is the leading standard for energy efficient design and construction. In Europe already more than 6000 passive house units have been successfully built and completed. Positive feedback from inhabitants has confirmed what had been projected: not only energy costs can be reduced drastically, but also the comfort of living increases significantly by using an energy efficient construction [Passivhaus Institut, 2007].

Energy efficiency is the key to high thermal comfort as well as very low energy costs. Excellent insulation, high quality windows and heat recovery make it possible to reduce the energy demand significantly. Products suitable for passive houses have been developed in Europe, can be produced locally and installed by local craftsmen.

Definition of the Passive House standard
The term ‘Passive House’ (PH) refers to a construction standard, which is based on passive solar design (see also Appendix A). The standard can be met by using a variety of technologies, designs and materials.

Passive Houses are buildings which assure a comfortable indoor climate in summer and in winter without using a conventional heat distribution system. To permit this, it is essential that, under climatic conditions prevailing in Central Europe, the building’s annual space heating requirement does not exceed 15 kWh/(m²a). By meeting this requirement the rest space heat demand can be easily covered by heated ventilation air. For this purpose, of course, a ventilation system is required – a system which is necessary in any case. The second requirement to a Passive House building is the limitation of the primary energy consumption to 120 kWh/m²a.

The passive use of free heat gains (from the sun and internal sources) is essential to keep the building at a comfortable indoor temperature throughout the heating period. To achieve these high performances efficient technologies were developed and are applied in current PH-projects [www.passiv.de].

Basic elements of the Passive House approach are [Feist et al., 2001]:
• Super-insulation,
• Combining efficient heat recovery with supplementary supply air heating,
• Passive solar gains,
• Electric efficiency by means of efficient appliances,
• Meeting the remaining energy demand with renewable sources.

Costs
The PH standard offers a cost-efficient way of minimizing the energy demand of new buildings in accordance with the global principle of sustainability. It creates the basis of a complete coverage of the remaining energy demand of new buildings completely by renewable sources, while keeping the affordability of extra costs [UNEP, 2007]. The cost-efficiency depends on many factors. Whether extra investment costs are effective or not depends, for instance, on the future development of energy prices and the rate of interests. More information on this topic can be found in the literature [Feist et al., 2005] [Hastings & Wall, 2007a] [Darup, 2006].
02.04 Analysis Building Energy-Performance

According to the Dutch Information Centre for Environment 'Milieu Centraal' the average Dutch household consumes 3402 kWh electricity and 1652 m³ gas per annum (Figure 10, Figure 11).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Demand (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1204</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>385</td>
</tr>
<tr>
<td>Cocking</td>
<td>63</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1652</strong></td>
</tr>
</tbody>
</table>

*Figure 10: Average gas consumption of the Dutch household per annum in 2006; source: [Milieu Centraal, 2006]*

<table>
<thead>
<tr>
<th>Activity</th>
<th>Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing and drying</td>
<td>708</td>
</tr>
<tr>
<td>Cooling</td>
<td>590</td>
</tr>
<tr>
<td>Lighting</td>
<td>543</td>
</tr>
<tr>
<td>Heating and Domestic Hot Water</td>
<td>500</td>
</tr>
<tr>
<td>Electrical Devices</td>
<td>1061</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3402</strong></td>
</tr>
</tbody>
</table>

*Figure 11: Average electricity consumption of the Dutch household per annum in 2006; source: [Milieu Centraal, 2006]*

The authors of the national publication on passive houses [PEP, 2006] reveal in their information package the following picture of energy consumption in a new built semi detached dwelling (Figure 12).

*Figure 12: Primary Energy Consumption of a new built semi-detached dwelling per annum classified by function; source: [PEP, 2006]*
The paper summarizes that the building's annual primary energy consumption of 131 kWh/(m²a) can be achieved with the following typical architectural characteristics [PEP, 2006]:

- Rc-value façade 6.7 m²K/W, U-value 0.15 W/m²K
- Rc-value roof 6.7 m²K/W, U-value 0.15 W/m²K
- U-value windows 1.25 W/m²K,
- U-value entrance door 1.25 W/m²K,
- External sun-shading yes
- heat recovery system for ventilation air

To complete the picture, the SenterNovem reference dwelling (§ 02.03) consumes between 340 MJ/m² and 359 MJ/m² per annum. This corresponds to a primary energy consumption of 94-100 kWh/m²a.

Of course, there are plenty of other case studies available on this topic (see reference list).

02.05  Analysis Building Technology

02.05.01  Introduction
The success of high-performance buildings is a result of good design, but also of the capabilities of high-performance systems and their components, which are selected to work together efficiently as a whole system. This paragraph illustrates some of the technologies that are used in buildings with low energy consumption.

The first objective in a building design that intents to reduce the energy demand, is to ensure that the heat inside the building remains inside during the heating season, and that in summer the heat outside stays outside. This is the job of the envelope. For comfort and energy reasons, the envelope must be airtight. This in consequence requires a ventilation system, which guarantees a supply of fresh air over the year and the elimination of surplus heat in summer. The third job of the building services is the efficient production and distribution of heat and electricity.

The following aspects were selected for the analysis within this paragraph:
- Ventilation System (natural + mechanical ventilation, components),
- Air to air heat exchanger (HR),
- Subsoil heat exchanger (SHR).

A very good overview on heating and cooling technologies is found in [Ala-Juusela, 2004].

02.05.02  Ventilation System
(For the elaborated analysis of ventilation strategies is referred to Appendix C.)

The transmission losses through the building skin are minimized in thermally well insulated buildings. To reduce a building’s energy consumption and ensure a good air-quality a well-controlled and energy-efficient ventilation system with heat recovery is inevitable. At a low budget, home ventilation must provide superior service, for example to avoid heat stratification, drafts, noise, sound transport, and dust propagation. To add another issue, the ventilations system may also be expected to transport the heat needed for space heating.

Natural ventilation and passive cooling techniques can support this approach. They are sustainable and well accepted by occupants when optimal controlled. Unfortunately, today’s ventilation concepts often become a question of using either natural or mechanical ventilation.
Whereas mechanical ventilation has long been accepted in commercial and institutional buildings occupants are more critical when it concerns their home environment.

A ventilation technology, which utilizes advantages of both approaches (natural and mechanical ventilation), is the hybrid ventilation (HV) technique. (Elaborated report, see Appendix C)

Hybrid ventilation is based on a two-mode system, in which the operation mode varies according to the season (or days) between mechanical and natural forced ventilation. This strategy results in a high user satisfaction, which is favoured by the occupant's possibility to control their environment. Since for high performance buildings (§ 02.03) a mechanical ventilation system is inevitable, the hybrid ventilation concept may balance the disadvantages of those systems.

The major objective in hybrid ventilation is given by the application of a good control strategy for occupied hours and non-occupied hours of the building.

02.05.03 Air to air heat exchanger

Once the envelope is super insulated, very little heat needs to be delivered to the rooms to keep them warm. The utilization of internal heat gains from household appliances and inhabitants benefit these circumstances. The utilization is achieved by heat exchange. Indeed, the amount of heat is so small that it is no longer useful to invest heavily in the heat delivery system [Hastings & Wall, 2007b].

Therefore, a simple, low cost solution must be found. It is the ventilation system which may be a feasible solution since it can deliver fresh air as well as the required heat. This is a standard approach in North American homes, but new territory in many other countries. Buildings with a very small heating demand offer ideal conditions for air heating.

Because so little heating power is needed, the volume of air needed for hygiene reasons is sufficient to deliver the required heat at temperatures below 55°C [Hastings & Wall, 2007b].

To increase the performance of such a system different heat exchangers can be incorporated into the ventilation system. Air to air heat exchanger are part of these technologies. A big part of the energy stored in the polluted air can be recovered. A bi-directional heat recovery process between the exhaust air flow and fresh air inflow utilizes this energy as free, environmental friendly heat gains.
Subsoil Heat Exchanger

Another technique to gain free energy is the utilization of the ground. Ground heat can be extracted by ground coils, bore holes, and slab on ground techniques [Ala-Juusela, 2004].

Subsoil heat exchangers (SHR) are not only used to pre-heat ventilation air in winter, it can be also used as for pre-cooling in summer. A simple calculation tool from the Passivhaus Institut in Darmstadt / Germany [Pfluger, 1999] allows an estimation of SHR-performances.

For the maritime climate in Bremen / Germany, with quite similar conditions to the North of The Netherlands, an annual heat load of 1000 kWh/a and an annual cooling load of 700 kWh/a is utilized with a pipe length of 20 metre (Figure 13).

![Annual Temperature Profile](image)

Figure 13: Temperature curvature of ambient, ground, and inflow to the building for a Subsoil Heat exchanger (length 20m, depth 1.5m, ventilation rate 120m²/h); software [Pfluger, 1999]
03 Detailing the Research Question

Based on the previous analysis, the scope of this research is defined in chapter 03. This chapter elaborates on the initial research question resulting in several detailed research questions.
03.01 Introduction

This chapter emerges the initial research question based on the analyses presented in the previous chapter. This leads to three detailed research questions.

03.02 Conclusion of the Previous Chapters

The first part of the analysis gives a first insight into design strategies, which are used for the design of sustainable and energy-efficient buildings. These strategies present logical steps for a suitable process within the building design approach. 'Trias Energetica' and 'Cradle to Cradle' enable the designer to gain a structured approach towards the goal of achieving a high performance building. Passive solar design support these approaches. By integrating, for instance, the district into the design considerations a more efficient, holistic result can be achieved. A strategy based on integration is the solar-assisted district heat.

In the second part design objectives, which are commonly used, are described. These objectives form the template for each building design process and fix the leitmotif of every design.

Building standards were analysed in the third part with the focus on current building standards and sophisticated standards. The SenterNovem institute has set up some reference buildings for the Dutch market. The mid-terraced house is the most popular in The Netherlands. The Passive House Standard is the best developed standards in energy-efficient building construction with the focus on the utilization of passive solar energy. Although this standard focuses on the reduction of a building's heating demand, it provides the opportunity for a successful start of the design process. Assessment tools based on this standard are available.

Building performances, with the focus on energy consumption, are investigated in paragraph 02.04. Domestic hot water and space heating demand have the biggest share in the energy consumption of a building. Therefore it would be logical to tackle these issues in first place.

Selected building technologies are investigated in the fifth part. The hybrid ventilation strategy in combination with subsoil heat exchange show big potentials for free energy gains.

03.03 Conclusion

In the introduction of the thesis the initial research question is formulated:
- What are suitable technologies and strategies to design a house with very low energy consumption?

The following research questions are emerged:
- What are reasonable measures to improve the energy performance of the SenterNovem mid-terraced reference building?
- What is the energy-saving potential and efficiency of these measures?
- Can an integrative, district design improve a buildings energy-efficiency significantly?
04 Methods

This chapter describes the methodology, which was used within the attempt to answer the research question. This includes an explanation of the instruments used, the sample, i.e. the initial building design, and the actual design process.
04.01 **Instruments**

This paragraph gives an overview on the instruments used for the design process. This is an iterative procedure (§ 04.03) that has to exploit sophisticated strategies and technologies. Design instruments helped to structure the process and calculation & assessment instruments supported the evaluation of its performance.

04.01.01 **Design Approach**

One of the most suitable and sophisticated approaches, which is currently used in sustainable building design is the concept of the ‘Trias Energetica’ (§ 02.01.02). It illustrates a logical three step approach to reduce a building’s energy demand (Figure 14). This clear structure formed the basis for this research.

1. Limit demand for energy through rational use of energy
2. Use renewable energy to fulfil remaining demand
3. Use fossil fuels, if necessary, as efficiently and cleanly as possible

![Energy Demand](Trias Energetica)

‘Trias Energetica’

*Figure 14: Three step approach in the ‘Trias Energetica’ with the purpose to minimize the use of fossil fuels*

Additionally, the concept of ‘Cradle to Cradle’ (C2C) developed by William McDonough and Michael Braungart (§ 02.01.03) is used within this research. The implementation of a cyclical flow for materials in appropriate, continuous cycles through an ecologically intelligent design [McDonough & Braungart, 2002] will support the research’s objective on sustainability (§ 04.02.01).

The concept of C2C has been translated into a design approach for the built environment. This six-step-approach (Appendix E) is based on the fundamental idea that waste flows of material, energy, and water are productively re-incorporated into new production and use phases, i.e. a recycling process, and the optimal uses of natures resources is striven (Figure 15) [Dobbelsteen et al, 2008].
Both design strategies ‘Trias Energetica’ and ‘Cradle to Cradle’ were used within this research as general templates in modified form. All in all the three steps of Trias Energetica are used within this research. Whereas the focus is on step one and two. To emphasise the reuse of energy, the ‘recycling philosophy’ of Cradle to Cradle (C2C) is interpolated between the first and second step of Trias Energetica. Considering the C2C approach the energy-content is the major focus.

**04.01.02 Calculation & Assessment Tools**

For the analysis of the design’s performance the European Standard ‘EN 832 – Thermal performance of buildings – Calculation of energy use for heating – Residential buildings’ [EN 832, 1998] has been used. This standard is used for an optimisation of the building’s space heating and domestic hot water (DHW) performance.

![Passivhaus Planning Package (PHPP), 2004](image)

Based on the standard EN 832 several programs where developed to assist during the design purpose of buildings. From the analysis it was concluded (§ 03.02) that the German ‘Passive House’ standard is one of the most developed and sophisticated standards in building design with the aim to minimize the building’s energy demand. This assumption led to the logical decision to use the evaluation software ‘Passive House Planning Package 2004’ from the Passivhaus Institut in Darmstadt / Germany [PHPP, 2004]. Since this program is Excel based, modifications and adaptations were possible. This program supports evaluations for ventilation, heat load, DHW, electricity, and district heating.
04.02  Initial Building Design

(With reference to Appendix G)

In this paragraph the analysed initial building design is defined in terms of design objectives, architecture & construction, and energy concept. With the results of the evaluation, which are part of this methodology, a final building design is described in chapter 05.

04.02.01  Design Objectives

The design objectives formulate the basis for the whole building design. These can be also described as the philosophy behind the building concept. The following major objectives were chosen for the building’s design:

- Sustainable
- Adaptable
- Robust
- Simple
- Operational & Functional
- Comfortable

- Sustainable: Is the covering objective, which describes the socio-economical and socio-ecological performance of the design. Its superior goal is the minimization of the burdens for future generations without reducing the life quality of current generations. (§ 02.01.04)

- Adaptable: Is part of the sustainability concept. It can be addressed with some simple strategies: flexibility (i.e. allows for minor shifts in space planning), convertibility (i.e. allows for changes in use within the building), and expandability (i.e. facilitates additions to space in a building) [IEA Annex 31, 2004]. The International Energy Agency [IEA, 2004] came to the conclusion that the capability to respond to changing circumstances “may decrease the resource use within the building sector by 20 to 30 %”.

- Robustness: In long-term perspective the buildings environment will undergo major developments. Energy prices (Appendix F), building technologies, building materials and etcetera as well as the conditions during the building’s operation will change in time [Brand, 1995] [Ulrich, 1995]. To maintain the buildings initial performance, or even improve it, the design has to be (energetically) upgradeable. This can be achieved by an outsourcing of building functions like the energy production and storage to the district level (Appendix D).

- Simple: Pertains to building elements and their mutual interconnection. The idea of “Doing more with less” [Fuller, 1980] supports a sustainable approach and asks for a design solution which enables occupants to understand their home and its operation (especially the building services). This in return is beneficial to the target of decreasing the energy demand [Simon & Simon, 2004].

- Operational & Functional: Pertains to the building’s functional programming, spatial needs and requirements, as well as the system performance.

- Comfort: The occupants’ well-being (physical and psychological comfort) is an essential part of the sustainable approach [IEA, 2006].

Beyond the major objectives other issues should be naturally covered with the design of the building. This thesis cannot cover all of them and pays less attention to the following minor Objectives:
• Cost-effective: Covers the selection of building elements on the basis of cost estimation.
• Aesthetics: Pertains to the physical appearance of the building, its elements, and spaces.
• Security: Pertains to physical protection of occupants and property.

04.02.02 Architecture & Construction

The choice of certain design objectives (§ 04.02.01) naturally effects the building’s layout, its structural system, and building details. Every decision made during the design process causes two new decision processes. This complexity has to be structured logically. For the research’s methodology the ‘sample’ got divided into a (a) initial building design (basic sample) and (b) design parameters (variable factors). Both components are outlined in this paragraph.

(a) Initial Building Design:
The basic layout of the building is orientated on the reference building design of a Dutch mid-terraced dwelling (§ 02.03.02), which can be explained by the fact that this building type has the biggest market share in The Netherlands (36.5 % of the new built dwellings) [SenterNovem, 2006].

Nevertheless, the initial building design is not a one-to-one copy of the SenterNovem reference building. It has its own architectural and structural characteristics.

Qualitative Characteristics (see Appendix G):
• The considered building is a mid-terraced building (row house) with two storeys, a slab on grad (no basement) and a flat roof (Figure 16, Figure 18, Figure 19).

Figure 16: West and east elevations of the basic building design ‘mid-terraced building’, which was analysed during the design process; characteristics are the two storeys, slab on grad (no basement), and flat roof

• The chosen building form benefits the design objectives (§ 04.02.01) with compactness, simplicity, expendability.
The building compactness of the initial design is improved compared to the SenterNovem reference building. By using a building form without a pitched roof the compactness is improved by 6.5 %, which is beneficial to the energy consumption (Appendix B) [Erhorn et al., 2001].

Furthermore, the building structure is simplified to load bearing building partition walls with floors spanning from one partition to the other (Figure 20). This structural system is a standardized method in the Dutch construction industry (‘Casco’) and ensures simple junction details with a high quality standard.
Houses As Energy Delivering Systems

- The flat roof may allow an adaptation to changed user demands in the future by expanding the building space on the building top. It provides space for building services (Figure 21) and active solar energy production. Of course, a third story will affect the characteristics of the building's bearing structure. The roof can be accessed via the building-block's gable, which ensures external access to building services independently from a single dwelling.

- The building is orientated to the south. This allows an optimal utilization of passive heat gains at the south façade in winter and a controlled sun irradiation access to the building in summer by simple exterior shading devices (Figure 22).

- An open plan layout is used to maximise the building's adaptability. By ensuring that only the building partition walls are load-bearing the material demand is reduced.

- The north and south facades are prefabricated lightweight timber stud walls (Figure 16). This allows a simplified production process in the factory, which results in a high
quality product. In the end, timber is used as a material for the façade construction because it is a renewable resource.

- The building partition walls include an insulation layer of 80 mm to minimize the heat load for the heating system and improve the sound insulation quality to adjacent buildings.
- The initial building services include a ventilation system with heat recovery from ventilation air as used in the SenterNovem reference (Figure 21).
- The building services are located on the building top to support the open plan layout and allow the easy access for maintenance from the outside.
- To prevent an overheating of the building during the summer additional exterior shading devices in form of overhangs are installed (Figure 22).

![Figure 22: Overhang as exterior shading device - Excess of solar irradiation over the year](image)

- The façade is a non-load-bearing timber structure built as a timber stud wall construction, which is filled with insulation (Figure 23).

![Figure 23: Cross section detail 'exterior wall and window connection'; the timber facade is insulated with two insulation layers an equipped with high performance windows, which minimize the building’s heat losses; detailed description (Appendix G)](image)

- The windows are equipped with external roller blinds with a 50% temporary shading efficiency. This feature is not standard in Dutch dwelling and will be favourable for the interior comfort control.
Quantitative Characteristics (see also Appendix G):

- Inner distance wall to wall: 5.62 m
- Depth of the dwelling: 12.34 m
- Storey height: 2.65 m
- Net (usable) space: 128.4 m²
- Exterior building surface (facades plus roof): 157.3 m²
- Gross building volume: 340.3 m³
- Surface-to-Volume ratio: 0.46/m
- U-value exterior wall: 0.33 m²K/W
- U-value roof: 0.25 m²K/W
- U-value slab: 0.33 m²K/W
- U-value windows: 1.8 W/m²K
- U-value entrance door: 2.0 W/m²K
- External sun-shading: yes
- Heat recovery system for ventilation air: 78% efficiency
- Heat production: Condensing Boiler Gas

The building layout includes typical dwelling functions, which conform to common space requirements in Holland (§ 02.03.02):

- Living room / dining room: 45 m²
- Kitchen: 20 m²
- Master bedroom: 20.4 m²
- Bedroom: 2x13.5 m²
- Bathroom: 7.6 m²
- Toilet: 1.35 m²
- Hall: 6.1 m²

(b) Design parameters:

To achieve an optimal result, adjustments have to be made to the former described initial building design. Design variables were identified for that purpose, which were used in the iterative design process (§ 04.03).

The following aspects were treated as an optimization problem during the design process:

- Insulation thickness exterior wall,
- Insulation thickness roof,
- Insulation thickness building slab (ground floor).

Furthermore, other parameters were considered to achieve a good final design:

- Windows,
- Subsoil heat exchanger,
- Solar domestic hot water production,
- Energy saving household appliances and devices,
- Production of Energy,
- Grade of occupation.
04.03 Data Collection and Analysis

1. Initial Building Design (Reference)

In the former step the initial building design was described, which forms the basis for the assessment process. This initial design orientates on building standards found in the analysis. Nevertheless, this design has its own characteristics, which support the design objectives. By using the Passive House Planning Package a performance calculation was first executed. The observed results are the reference for the comparison to further results.

2. Optimization of the Envelope

To start within the variety of design parameters, the envelope was optimized. Since standard building elements like walls, roof, and slab are built up by a multitude of different components, an infinite variety in element characteristics is possible. From the analysis of case studies different standard elements were chosen to be optimized for the assessment process. More specific, the insulation layers of the building elements wall, roof, building slab were investigated with the focus on cost-effectiveness. That means that extra investment costs in material and labour should preferably be balanced by cost-savings. For this purpose information from literature was utilized. A precise calculation was not executed. This can be explained by the fact that that simplicity was emphasised and that the use of more detailed and more reliable information for cost estimations would have caused an extensive research. After finding the optimum in insulation thicknesses, these specifications were applied to the reference design.

3. Improvement of the initial building design

More aspects in improving the building design were investigated without cost-optimization. Those options were applied and the results were plotted.

4. Final Building Design

After an extensive summary and a discussion of the results of the former evaluations, the final building design is specified with all its characteristics. (Reference Design x Design Parameters = Optimal Design)

This design forms the foundation for further considerations within the district concept.

5. District Design

For the district design the produced results were used in form of an energetically optimized final building design. Within this step the co-generation of power and heat in a centralized district plant are investigated. Motivation for this step is the use of an integrative approach to achieve optimal results.
Houses As Energy Delivering Systems

The holistic design within this research covers the levels from ‘detail’ to ‘district’. The levels of ‘town’ and ‘region’ were not considered.

Caused by the variety of different design factors (§ 04.02.02), the design process turned out to be very complex, which was approached by an iterative design process (Figure 25).

Figure 24: Levels of intervention; by integrating a higher level within the design a more holistic result is achieved; the design process gets more complex in consequence

Figure 25: Iterative design process during the design process; several iterative steps are necessary to achieve an optimal result;
Chapter Five represents the results gained from assessment process.
**05.01 Introduction**

In a first step the results of the initial building design evaluation are presented (§ 05.01). The second part shows the results from the design parameter investigation (§ 05.03 - § 05.05). These results are discussed in § 05.06 before the final building design is chosen and analysed in § 05.07. The consequences for the district design are illustrated in § 05.08, which is followed by the final discussion in § 05.09.

**05.02 Result 1 - Initial Building Design**

This paragraph represents a selection of observations gained from the assessment of the Initial Building Design as described in § 04.02. The elaborated results are compiled in Appendix G.

The following features are already included in the initial building design:
- Condensing gas boiler (covers 100% space heating + 100% DHW)
- Exterior temporary shading (roller blinds) with 50% efficiency
- Dishwasher and washing machine have only cold water supply
- The share of energy-saving light features within the building is about 20%

From the first assessment, the following results were conducted:
- Annual space heat requirement: 3905 kWh/a
- Specific annual space heat requirement: 30 kWh/m²a
- Specific primary energy requirement: 115 kWh/m²a
- Annual heat load: 2780 W
- No overheating problems are observed during the summer

<table>
<thead>
<tr>
<th>Total Primary Energy (PE) Requirement:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating (51.7 % share)</td>
</tr>
<tr>
<td>DHW (48.3 % share)</td>
</tr>
<tr>
<td>Electricity Demand - Household Appliances</td>
</tr>
<tr>
<td>Electricity Demand - Auxiliary Electricity</td>
</tr>
<tr>
<td>Non-electrical Demand, Gas-Cooking</td>
</tr>
<tr>
<td>Total PE</td>
</tr>
</tbody>
</table>

The temporary exterior shading is no standard in current buildings. It is more likely to prevent overheating during summer. In the current configuration it has according to the calculations hardly influence on the overheating problem. The solar aperture is decreased by approximately 50% by the external roller blinds.
05.03 **Result 2 - Building Envelope**

In a first step, a reduction of transmission losses through the building envelope is targeted by improving the thermal characteristics of the skin. This includes façade, roof, building slab (ground floor), and windows.

A comprehensible decision criterion is used to enable a logical decision process regarding the choice of building element characteristics. Within this assessment the cost-effectiveness supports the decision process (§ 04.03).

The results of the optimization problem for the single design parameter is illustrated in the first section (§ 05.03.01), followed by the results for comprehensive application of all design parameters (§ 05.03.02).

**05.03.01 Optimization Problem**

The following design parameters were investigated during this assessment process:

- Exterior wall insulation thickness,
- Roof insulation thickness,
- Building slab insulation thickness,
- Windows.

Starting point for each assessment was the initial building design (§ 05.01). Only one parameter is changed at a time.
(a) Exterior wall insulation thickness
The exterior wall insulation was investigated with the target to find the most cost-effective thickness considered over a calculation time of 20 year.

**General data for the cost calculation:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rate of interests</td>
<td>3.5%</td>
<td>[Hastings &amp; Wall, 2007a]</td>
</tr>
<tr>
<td>Calculation time for interest</td>
<td>20 years</td>
<td></td>
</tr>
<tr>
<td>Price for natural gas (end 2007)</td>
<td>0.79 €/m³</td>
<td>[CBS, 2008] (Appendix F)</td>
</tr>
<tr>
<td>Caloric value for Natural Gas</td>
<td>10.4 kWh/m³</td>
<td>[<a href="http://www.zentralheizung.de">www.zentralheizung.de</a>]</td>
</tr>
<tr>
<td>Specific Gas price</td>
<td>0.075 €/kWh</td>
<td></td>
</tr>
<tr>
<td>Future Gas Price increase</td>
<td>0.069 €/a</td>
<td>(Appendix F)</td>
</tr>
<tr>
<td>Reference insulation thickness - wall</td>
<td>100 mm</td>
<td>(§ 04.02)</td>
</tr>
<tr>
<td>Extra insulation costs (labour &amp; material)</td>
<td>0.90 €/(cm m²)</td>
<td>[Darup, 2006]</td>
</tr>
<tr>
<td>Exterior Wall Area</td>
<td>43.97 m²</td>
<td></td>
</tr>
</tbody>
</table>

**Plot of the result from the cost calculation:**

![Plot of the result from the cost calculation](image)

*Figure 27: Total costs (investment plus energy losses) of insulation added to the exterior wall, with a calculation time of 20 years*

The energy consumption costs and the investment costs are summed up and depicted as a function of insulation layer thickness (Figure 27). The optimum is found with the minimum of the summation-curve. With a calculated period of 20 year the optimum is a wall insulation thickness of 240 mm. With additional exterior wall investment costs of € 811,- (18.44 €/m²) the annual heating demand of the building is be reduced by 543 kWh/a.
(b) Roof insulation thickness

General data for cost calculation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rate of interests</td>
<td>3.5%</td>
<td>[Hastings &amp; Wall, 2007a]</td>
</tr>
<tr>
<td>Calculation time for interest</td>
<td>20 years</td>
<td></td>
</tr>
<tr>
<td>Price for natural gas (end 2007)</td>
<td>0.79 €/m³</td>
<td>[CBS, 2008](Appendix F)</td>
</tr>
<tr>
<td>Caloric value for Natural Gas</td>
<td>10.4 kWh/m³</td>
<td>[<a href="http://www.zentralheizung.de">www.zentralheizung.de</a>]</td>
</tr>
<tr>
<td>Specific Gas price</td>
<td>0.075 €/kWh</td>
<td></td>
</tr>
<tr>
<td>Future Gas Price increase</td>
<td>0.069 €/a</td>
<td>(Appendix F)</td>
</tr>
<tr>
<td>Reference insulation thickness - roof</td>
<td>100 mm</td>
<td>(§ 04.02)</td>
</tr>
<tr>
<td>Extra insulation costs (labour &amp; material)</td>
<td>0.75 €/(cm m²)</td>
<td>[Darup, 2006]</td>
</tr>
<tr>
<td>Roof Area</td>
<td>69.35 m²</td>
<td></td>
</tr>
</tbody>
</table>

Plot of the result from the cost calculation:

Figure 28: Total costs (investment plus energy losses) for the insulation layer in the roof, with a calculation time of 20 years

Figure 28 shows the optimum insulation thickness to be about 24 cm. This will cause extra investment costs of approximately €1073.- but is more than balanced by energy costs saving of about 1913,- Euro in 20 year operation. Compared to the initial building design, with typical Dutch element characteristics (100 mm insulation), an insulation thickness of 38 cm is still more cost-effective. The insulation thickness of 24 cm reduces the annual heating demand of the building by 625 kWh/a.
(c) Building slab insulation thickness

General data for cost calculation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rate of interests</td>
<td>3.5%</td>
<td>[Hastings &amp; Wall, 2007a]</td>
</tr>
<tr>
<td>Calculation time for interest</td>
<td>20 years</td>
<td></td>
</tr>
<tr>
<td>Price for natural gas (end 2007)</td>
<td>0.79 €/m³</td>
<td>[CBS, 2008](Appendix F)</td>
</tr>
<tr>
<td>Caloric value for Natural Gas</td>
<td>10.4 kWh/m³</td>
<td>[<a href="http://www.zentralheizung.de">www.zentralheizung.de</a>]</td>
</tr>
<tr>
<td>Specific Gas price</td>
<td>0.075 €/kWh</td>
<td></td>
</tr>
<tr>
<td>Future Gas Price increase</td>
<td>0.069 €/a</td>
<td>(Appendix F)</td>
</tr>
<tr>
<td>Reference insulation thickness - slab</td>
<td>80 mm</td>
<td>[§ 04.02]</td>
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<tr>
<td>Extra insulation costs (labour &amp; material)</td>
<td>1.10 €/(m² cm)</td>
<td>[Darup, 2006]</td>
</tr>
<tr>
<td>Building Slab Area</td>
<td>69.35 m²</td>
<td></td>
</tr>
</tbody>
</table>

Plot of the result from the cost calculation:

Figure 29: Total costs (investment plus energy losses) for the insulation layer in the building slab, with a calculation time of 20 years

Figure 29 illustrates that the optimum thickness for the insulation layer of the building slab is found at 180 mm. The cost neutral range for additional investment costs goes up to 36 cm insulation thickness (compared to 8 cm reference thickness). The 18 cm insulation achieves a reduction of the annual heating demand of 644 kWh/a and requires an extra investment of 1110,- Euro (compared to the initial design).
(d) Windows

Improved window parameters are chosen from the literature review and applied to the initial building design without taking other measures. A cost-effective optimization was not executed for this building element.

**Windows & Door properties:**

<table>
<thead>
<tr>
<th>Element</th>
<th>Specification</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window Glazing</td>
<td>4:-16- 4-16:-4, Argon 90%:</td>
<td>g-value = 0.520</td>
</tr>
<tr>
<td></td>
<td>Unitop 0.60-52 – UNIGLAS; Uniglas GmbH &amp; Co. KG, Montabaur, Germany; <a href="http://www.uniglas.net">www.uniglas.net</a></td>
<td>Ug-value = 0.60 W/m²K</td>
</tr>
<tr>
<td>Window Frame</td>
<td>Timber / Purenit / PU – frame:</td>
<td>Uf-value = 0.72 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Buck - VÖRDE Passive House Windows; H. Buck GmbH, Bremervörde, Germany; <a href="http://www.fenster-buck.de">www.fenster-buck.de</a></td>
<td></td>
</tr>
<tr>
<td>Total Window</td>
<td></td>
<td>U-value = 0.85 W/m²K</td>
</tr>
</tbody>
</table>

The following key-features are already included into the initial building design:
- Condensing gas boiler (covers 100% space heating + 100% DHW)
- Exterior temporary shading (roller blinds) with 50% efficiency

New feature applied to the building design:
- Improved high performance windows

The following results were conducted during the assessment of the initial building design plus new windows:
- Annual space heat requirement: 2891 kWh/a
- Specific annual space heat requirement: 23 kWh/m²a
- Specific primary energy requirement: 107 kWh/m²a
- Annual heat load: 2330 W

The annual space heating demand is reduced by 26% compared to the initial building design with lower window qualities. A heat demand reduction of 1014 kWh per annum is achieved (equivalent to 97.5 m³ natural gas). Energy savings of 3108,- Euro are achieved in 20 years operation.

According to Darup [2006] windows with a U-value of 0.8 W/m²K cause additional investment cost of 100-150 € per m² window area. With a window area of 16.25 m² in this building design, an extra investment of 1625,- to 2437,- Euro is necessary, which is compensated by the savings in energy costs.
Performance of the Building with an Improved Envelope

After the investigation of every single design parameter all improved aspects are applied to the initial building design to gain statements on the overall performance of the improved envelope. The improvements are applied in the following sequence: wall, roof, slab, window & door.

The following parameters were changed with respect to the initial design:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Old Value</th>
<th>New Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum insulation thickness - wall</td>
<td>240 mm</td>
<td>0,17 W/m²K</td>
</tr>
<tr>
<td>Optimum insulation thickness - roof</td>
<td>240 mm</td>
<td>0,13 W/m²K</td>
</tr>
<tr>
<td>Optimum insulation thickness - slab</td>
<td>180 mm</td>
<td>0,17 W/m²K</td>
</tr>
<tr>
<td>Windows</td>
<td>0,85 W/m²K</td>
<td></td>
</tr>
<tr>
<td>Door</td>
<td>0,80 W/m²K</td>
<td></td>
</tr>
</tbody>
</table>

The following key-features are already applied to the building design:
- Condensing gas boiler (covers 100% space heating + 100% DHW)
- Exterior temporary shading (roller blinds) with 50% efficiency

New feature applied to the building design:
- Improved building envelope

Reduction of the heat demand by improved envelope

![Graph showing the reduction of heat demand](image)

Figure 30: Four steps to the improved building envelope: Through these energy efficient measures, the yearly heating energy demand is reduced by 67% compared to the initial building design.

Relative Performance per Building Element

![Graph showing relative performance](image)

Figure 31: Relative Performance per building element area [m²]
The following key-results were conducted during the calculation:

- Annual space heat requirement: 1299 kWh/a
- Specific annual space heat requirement: 10 kWh/m²a
- Specific primary energy requirement: 93 kWh/m²a
- Annual heat load: 1208 W

**Total Primary Energy (PE) Requirement:**

<table>
<thead>
<tr>
<th>Service</th>
<th>Share</th>
<th>PE Demand [kWh/m²a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating (28,1% share)</td>
<td>12,4</td>
<td></td>
</tr>
<tr>
<td>DHW (71,9% share)</td>
<td>31,7</td>
<td></td>
</tr>
<tr>
<td>Electricity Demand - Household Appliances</td>
<td>36,7</td>
<td></td>
</tr>
<tr>
<td>Electricity Demand - Auxiliary Electricity</td>
<td>8,3</td>
<td></td>
</tr>
<tr>
<td>Non-electrical Demand, Gas-Cooking</td>
<td>4,3</td>
<td></td>
</tr>
<tr>
<td>Total PE</td>
<td>93</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 32: Primary Energy Demand - improved building envelope**

**05.04 Result 3 - Utilization of Free Energy**

This paragraph presents the observations from the application of selected techniques and technologies, which aim to the utilization of free energy to reduce the buildings energy consumption.

Investigated aspects are:
- Subsoil Heat Recovery (SHR),
- Solar domestic hot water production (Solar DHW),
- Energy saving devices.

Basis for this assessment was the initial building design with an improved envelope form chapter 05.03.02.

**05.04.01 Subsoil Heat Recovery (SHR)**

With the utilization of the soil properties beneath the building a preconditioning of ventilation air is achieved. The SHR is used for pre-warming the ventilation air in winter and pre-cooling in summer. The efficiency of the heat recovery of the subsoil heat exchanger is set at 33%.

The following key-features are already applied to the building design:
- Condensing gas boiler (covers 100% space heating + 100% DHW)
• Exterior temporary shading (roller blinds) with 50% efficiency
• Improved building envelope

New feature applied to the building design:
• Subsoil heat exchanger (33% efficiency)

The following key-results were conducted from the calculation:
• Annual space heat requirement: 1144 kWh/a
• Specific annual space heat requirement: 9 kWh/m²a
• Specific primary energy requirement: 92.2 kWh/m²a
• Annual heat load: 1198 W

**Total Primary Energy (PE) Requirement:**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating (26,1% share)</td>
<td>11.0 kWh/m²a</td>
</tr>
<tr>
<td>DHW (73.9% share)</td>
<td>31.9 kWh/m²a</td>
</tr>
<tr>
<td>Electricity Demand - Household Appliances</td>
<td>36.7 kWh/m²a</td>
</tr>
<tr>
<td>Electricity Demand - Auxiliary Electricity</td>
<td>8.3 kWh/m²a</td>
</tr>
<tr>
<td>Non-electrical Demand, Gas-Cooking</td>
<td>4.3 kWh/m²a</td>
</tr>
<tr>
<td>Total PE</td>
<td>92.2 kWh/m²a</td>
</tr>
</tbody>
</table>

**Figure 33: Primary Energy Demand - Improved building envelope, SHR**
05.04.02 Solar DHW

The domestic hot water (DHW) demand can be partly or completely covered by solar hot water production via thermal collectors. Vacuum tube based solar collectors mounted at an optimal angle on the roof were investigated to cover a fraction of the building's hot water consumption. The PHPP 2004 software allows a rough estimation of the solar DHW production. This calculation includes an estimated hot water storage of 420 litre to balance the diurnal phase shift between solar DHW production and demand.

The following plot illustrates the achieved solar share in dependence of the solar collector area:

Harvey [2006] states that the standard size for solar thermal collectors on small scale (for a household) is about 1 to 1.5 m² per person, which corresponds to 6 m² for 4 persons-household. In combination with 50-80 litres storage volume per m² collector area an annual solar net energy of 350-380 kWh/m²a can be produced. (Appendix D)

From Figure 35 it is observed, that the solar fraction is about 67% of the DHW. This corresponds to 2082 kWh per annum, which equals Harvey's estimation of 350 kWh/m² collector area.

The investment cost per m² of heated area amount to 20-25€ [Harvey, 2006]. This corresponds to an investment of 2570-3210 € per household.

The following key-features are already applied to the building design:
- Condensing gas boiler
- Exterior temporary shading (roller blinds) with 50% efficiency
- Improved building envelope
- Subsoil heat exchanger (33% efficiency)

New feature applied to the building design:
- 6m² Solar thermal collectors (covers 67% of the DHW demand)

The following key-results were conducted during the calculation:
- Annual space heat requirement: 1144 kWh/a
- Specific annual space heat requirement: 9 kWh/m²a
- Specific primary energy requirement: 74,0 kWh/m²a
- Annual heat load: 1198 W
Total Primary Energy (PE) Requirement:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>kWh/m²a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating (46,1% share)</td>
<td>11,0</td>
</tr>
<tr>
<td>DHW (53,9% share)</td>
<td>12,9</td>
</tr>
<tr>
<td>Electricity Demand - Household Appliances</td>
<td>36,7</td>
</tr>
<tr>
<td>Electricity Demand - Auxiliary Electricity</td>
<td>9,1</td>
</tr>
<tr>
<td>Non-electrical Demand, Gas-Cooking</td>
<td>4,3</td>
</tr>
<tr>
<td>Total PE</td>
<td>74,0</td>
</tr>
</tbody>
</table>

Figure 35: Primary Energy Demand - Improved building envelope, SHR, 6m² Solar Thermal Collector Area

05.04.03  Energy saving devices

Additional measures are taken to reduce the building electricity demand. Since the biggest share on the primary energy demand is caused by household appliances, energy efficient features are applied in this field.

The following key-features are already applied to the building design:
- Condensing gas boiler (covers 100% space heating + 33% DHW)
- Exterior temporary shading (roller blinds) with 50% efficiency
- Improved building envelope
- Subsoil heat exchanger (33% efficiency)
- 6m² Solar thermal collectors (covers 67% of the DHW demand)

To optimize the electricity consumption within the building the following measures were additionally taken:
- Connection of the Dishwasher to the domestic hot water network,
- Connection of the washing machine to the domestic hot water network,
- Using an 80% fraction on energy saving lighting features.

The following key-results were conducted during the calculation:
- Annual space heat requirement: 1144 kWh/a
- Specific annual space heat requirement: 9 kWh/m²a
- Specific primary energy requirement: 63,1 kWh/m²a
- Annual heat load: 1198 W
### Total Primary Energy (PE) Requirement:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating (43.7% share)</td>
<td>11.0 kWh/m²a</td>
</tr>
<tr>
<td>DHW (56.3% share)</td>
<td>14.2 kWh/m²a</td>
</tr>
<tr>
<td>Electricity Demand - Household Appliances</td>
<td>24.4 kWh/m²a</td>
</tr>
<tr>
<td>Electricity Demand - Auxiliary Electricity</td>
<td>9.2 kWh/m²a</td>
</tr>
<tr>
<td>Non-electrical Demand, Gas-Cooking</td>
<td>4.3 kWh/m²a</td>
</tr>
<tr>
<td><strong>Total PE</strong></td>
<td>63.1 kWh/m²a</td>
</tr>
</tbody>
</table>

The DHW demand is slightly increased. This is caused by the connection of the dishwasher and washing machine to the domestic hot water network.

#### 05.05 Result 4 - Production of the Remaining Energy Demand

### 05.05.01 Wood Pellet Combustion System

Alternatively to the conventional heat production via the gas boiler a Wood Pellet Combustion System [Svebio, 2004], with only indirect release of heat via the ventilation air, is now considered.

The following key-features are already applied to the design:
- Exterior temporary shading (roller blinds) with 50% efficiency
- Improved building envelope
- Subsoil heat exchanger (33% efficiency)
- 6m² Solar thermal collectors (covers 67% of the DHW demand)
- Dishwasher and washing machine are connected to the domestic hot water supply
- 80% energy-saving light features are used

New feature, applied to the building design within this assessment:
- Wood Pellet Combustion System (only indirect release of heat)
Selected results from the calculation:

- Annual space heat requirement: 1144 kWh/a
- Specific annual space heat requirement: 9 kWh/m²a
- Specific primary energy requirement: 42.2 kWh/m²a
- Annual heat load (important for ventilation system capacity): 1149 W

**Total Primary Energy (PE) Requirement:**

<table>
<thead>
<tr>
<th></th>
<th>Specific Primary Energy Demand [kWh/m²a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>2.5</td>
</tr>
<tr>
<td>DHW</td>
<td>2.4</td>
</tr>
<tr>
<td>Electricity Demand - Household Appliances</td>
<td>24.4</td>
</tr>
<tr>
<td>Electricity Demand - Auxiliary Electricity</td>
<td>8.6</td>
</tr>
<tr>
<td>Non-electrical Demand, Gas-Cooking</td>
<td>4.3</td>
</tr>
<tr>
<td>Total PE</td>
<td>42.2</td>
</tr>
</tbody>
</table>

**Primary Energy Demand - with Wood Pellet Combustion**

- Heating: 2.5 kWh/m²a
- DHW: 2.4 kWh/m²a
- Household Appliances: 24.4 kWh/m²a
- Auxiliary Energy: 8.6 kWh/m²a
- Non-electrical Demand, Gas-Cooking: 4.3 kWh/m²a
- Total PE: 42.2 kWh/m²a

*Figure 37: Primary Energy Demand - Improved building envelope, SHR, 6m² Solar Thermal Collector Area, energy saving devices*
05.06 Summary & Discussion of Results 1-4

The results 1-4 (§ 05.01 - § 05.05) show the observations made during the assessment process. In a first step, the energy demand of the building was limited by reduced transmission losses via the building skin. In the second step free energy was utilized to cover a part of the energy demand. In a third step the alternative production of the rest demand was assessed.
05.06.01  *Accounting the Annual Heating Demand*

The accounted annual heating demand of the initial building design is compared to the improved building design (including measures from Results 1-4) in the following figures (Figure 38 and Figure 39).

**Initial Design:**

*Accounting of the Annual Heat Demand -Initial Design-

![Graph showing the accounted annual heat demand for Initial Design](Figure 38: Accounting of the Annual Heat Demand -Initial Design-)

**Improved Design:**

*Accounting of the Annual Heat Demand -Improved Design-

![Graph showing the accounted annual heat demand for Improved Design](Figure 39: Accounting of the Annual Heat Demand -Improved Design-)
Discussion of Figure 38 and Figure 39
Specific losses and gains are broken down per building element. The following observations are made:

- The heating losses could be almost halved from 69.9 kWh/m²a to 36.4 kWh/m²a.
- Losses via windows are reduced by 60%, which corresponds to the improved transmission factor from 2.0 W/m²K to 0.85 W/m²K.
- Ventilation losses are not significantly reduced due to the fact that no measures were taken regarding the ventilation system.
- The building skin (including wall, roof, building slab) characteristics were improved and their losses were reduced by 42%.
- The relative share of solar and internal gains to the heat production could be increased from 57% to 76%, while the conventional heat production by combustion decreases from 43% to 24% share.
05.06.02  The specific annual heat demand

The specific annual heat demand is broken down to each month of the year.

Initial Design:

![Initial Design Graph]

Improved Design:

![Improved Design Graph]

Discussion of Figure 40 and Figure 41

The following observations are made:

- The total losses could be almost halved (as observed before).
- The heat requirement (dark coloured), which has to be additionally produced, has vanished in April and October due to the improved building envelope.
- From April till October no conventional heating is required. The total losses are balanced by solar and internal heat gains.
- From November to January is a 'conventional' heat production of 8.9 kWh/m² is required (equals the annual space heat requirement of 1144 kWh/a per 128 m² treated floor area).
- The biggest heat demand is required in January, which causes a peak demand of 2.6 kWh/m².
- Due to the reduced peak demand in January from 6.8 to 2.6 kWh/m² the heat can be provided via the ventilation system, which was hardly possible with the initial design.
- A relative increase of cooling load in summer is observed. The cooling load increased from 9.6 to 12.3 kWh/m²a during the summer (April to October). This surplus heat of 345.6 kWh per year is removed from the building interior by natural ventilation (average summer ventilation rate 0.53/h) and an overheating problem is prevented.
- The surplus heat of 345.6 kWh/a may completely balanced by subsoil heat exchange, calculated in § 02.05.04 with a annual cooling load capacity of 700 kWh/a.
• Subsoil heat exchange, thus pre-cooling of ventilation air in summer, and external overhangs at the façade are not considered in this calculation. Both techniques will support a prevention of overheating.

05.06.03 Additional Observations from Result 1-4

• Figure 30 illustrates the four steps to the envelope improvement and its effect on the annual heat demand. A reduction of 2606 kWh per year is achieved, which consists of 21% from extra wall insulation, 23% from extra roof insulation, 10% from additional slab insulation, and 45% from high performance windows. (§ 05.03)
• The energetically best improvement per area building element is achieved with new windows (Figure 31). Better windows are approximately six times more effective than improved wall insulation. This indicates the importance of high performance windows for the total building performance.
• Considering the optimization problem, the most cost-effective investment is achieved with additional wall insulation. The most expensive option is an improvement in the thermal properties of the building slab. The average window cost-effectiveness of € 1.71 indicates that investments into high-performance windows are as reasonable as wall and roof insulation. (Figure 42)
• Also indicated in (Figure 42) is the cost-effectiveness of the solar domestic hot water production. The performance estimation shows that solar DHW is highly competitive to interventions that improve the building envelope.

Cost-Effectiveness per Building Element

![Cost-Effectiveness per Building Element](image)

Figure 42: Relative Cost-Effectiveness per Building Element, comparison of investment [€] per annual saved energy [kWh/a].

• In consequence of the decreased heat demand, the annual heat load is more than halved, which is important for the distribution of the remaining heat demand via the ventilation system.
• This effect leads to savings in the conventional heating system, since this is not necessary anymore.
• The subsoil heat exchanger (SHR) (§ 05.04.01) achieves a 12% reduction in the annual heat requirement. This accounted in the primary energy demand by only 9% improvement, which is caused by the smaller utilization ratio of free gains. The SHR is not utilized for summer-cooling within the calculation.
• 6 m² of applied solar thermal collectors (§ 05.04.02) cover 67% of the domestic hot water (DHW) demand of the building. The remaining DHW-demand is covered by the conventional heating system. The Primary energy demand of DHW is reduced by 40% in consequence.
• Energy saving devices (§ 05.04.03) reduce the primary energy (PE) share of household appliances by 33%, which implicates a reduction in electricity consumption and a slight increase in the DHW demand. This additional improvement of the total PE demand is basically achieved by the fact that the primary energy factor for electricity (2.7 kWh/kWh) is worse than for gas (1.1 kWh/kWh). This means that natural gas is more efficient for heat production than electricity.

• The same effect is observed for the application of wood pellet combustion (§ 05.05.01). The primary energy factor of wood pellets with 0.2 kWh/kWh indicates the more environmental friendly combustion method. This is expressed in a remarkable reduction of the primary energy demand by 77% for heating and 83% for DHW.

• The grade of occupation has minor influence on the building's performance. The building is designed for occupying 4 persons. With an increase of this occupancy the total required ventilation rate (30 m³/(P*h)) has to be increase. The ventilation losses will rise in consequence and the annual heating demand has to be adapted to this new situation. With six persons in this household the heating demand will increase by 7.5%.

• A high quality finishing and detailing was assumed for the initial design. This ensures a limitation of uncontrolled ventilations through the building skin. The air-tightness of initial building design complies with the Passive House Standard. The average new built Dutch house has approximately a 3.5 times higher infiltration than the requirements of the Passive House Standard allow [PEP, 2006]. This bigger infiltration would cause an increase of the annual heating demand by 20% for the initial design.
05.07  **Result 5 - Final Building Design**

Within this paragraph the building design is finalized in a description and performance illustration before the level of interventions is extrapolated to the district level.

05.07.01  **Description of the final building design**

Detailed Drawings on the final design are found in Appendix H.

The following standard building elements where used for the design:

**Exterior Wall = timber stud wall (d=29.2 cm, U= 0.17 W/m²K):**

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaster Board</td>
<td>0.045 W/mK</td>
<td>22 mm</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040 W/mK</td>
<td>180 mm</td>
</tr>
<tr>
<td>Chipboard</td>
<td>0.130 W/mK</td>
<td>15 mm</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040 W/mK</td>
<td>60 mm</td>
</tr>
<tr>
<td>Gypsum Board</td>
<td>0.210 W/mK</td>
<td>15 mm</td>
</tr>
</tbody>
</table>

**Roof = concrete slab with insulation (d=47.0 cm, U= 0.13 W/m²K):**

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perimeter</td>
<td>0.040 W/mK</td>
<td>50 mm</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040 W/mK</td>
<td>240 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100 W/mK</td>
<td>180 mm</td>
</tr>
</tbody>
</table>

**Building slab (d=45.0 cm, U= 0.17 W/m²K):**

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parquet</td>
<td>0.130 W/mK</td>
<td>22 mm</td>
</tr>
<tr>
<td>Screed</td>
<td>1.050 W/mK</td>
<td>48 mm</td>
</tr>
<tr>
<td>Impact Sound Insulation</td>
<td>0.040 W/mK</td>
<td>30 mm</td>
</tr>
<tr>
<td>Concrete Ceiling</td>
<td>2.100 W/mK</td>
<td>160 mm</td>
</tr>
<tr>
<td>Polystyrene Foam</td>
<td>0.040 W/mK</td>
<td>180 mm</td>
</tr>
<tr>
<td>Putty Coat</td>
<td>0.800 W/mK</td>
<td>10 mm</td>
</tr>
</tbody>
</table>

**Partition Wall = three leaf concrete-insulation-concrete (d=49.0 cm, U= 0.40 W/m²K):**

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior Plaster</td>
<td>0.350 W/mK</td>
<td>15 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100 W/mK</td>
<td>190 mm</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.040 W/mK</td>
<td>80 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100 W/mK</td>
<td>190 mm</td>
</tr>
<tr>
<td>Interior Plaster</td>
<td>0.350 W/mK</td>
<td>15 mm</td>
</tr>
</tbody>
</table>
Windows & door:

<table>
<thead>
<tr>
<th>Element</th>
<th>Specification</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window Glazing</td>
<td>4:-16- 4-16-:4, Argon 90%: Uniglas GmbH &amp; Co. KG, Montabaur, Germany; <a href="http://www.uniglas.net">www.uniglas.net</a></td>
<td>g-value = 0.520  Ug-value = 0.60 W/m²K</td>
</tr>
<tr>
<td>Window Frame</td>
<td>Timber / Purenit / PU – frame: Buck - VÖRDE Passive House Windows; H. Buck GmbH, Bremervörde, Germany; <a href="http://www.fenster-buck.de">www.fenster-buck.de</a></td>
<td>Uf-value = 0.72 W/m²K</td>
</tr>
<tr>
<td>Door Door</td>
<td>Timber / Insulation – composite: VÖRDE Passive House Door; Brunkhorst Haustüren, Anderlingen, Germany; <a href="http://www.brunkhorst.de">www.brunkhorst.de</a></td>
<td>UD-value = 0.80 W/m²K</td>
</tr>
</tbody>
</table>

Heating concept

The annual heating demand of the building is reduced to a minimum by measures like increased insulation in walls and roof, controlled ventilation, reuse of ventilation heat et cetera. This annual heat demand does not require an extra heating system (e.g. floor heating, radiators) and is covered by the mechanical ventilation system as described above. After the recycling of exhaust air in combination with the utilization of preconditioned air via the subsoil heat exchanger, the ventilation air is heated by a hot water based air heater.

The hot water used for the air heater is supplied by a district heating network. A district heating system has several advantages compared with decentralized solution for every household (Appendix D). See also § 05.08 Result 6 – District Design.

Ventilation Concept

The major strategy in the ventilation of the building is based on the mechanical supply and exhaust of air. Mechanical ventilation in combination with natural ventilation and subsoil heat exchange (SHR) covers all demand in cooling and heating and has a very good energetically performance.

The surplus of heat gained during the summer month is easily removed from the building by natural ventilation supported by SHR.

In the winter months heat is recovered from the exhaust air and heated by the hot water based post-heater for inflow air. This demanded heat is provided by the district network.
05.07.02 Performance of the final building design

The following key-features are included into the final building design:

- Exterior temporary shading (roller blinds) with 50% efficiency
- High performance envelope (walls, roof, slab, windows)
- Subsoil heat exchanger (33% efficiency)
- 6m² Solar thermal collectors (covers 67% of the DHW demand)
- Connection of the Dishwasher to the domestic hot water network
- Connection of the washing machine to the domestic hot water network
- Use of 80% fraction on energy saving light features.

The following key-results were conducted during the calculation:

- Annual space heat requirement: 1144 kWh/a
- Total Heat Requirement of the DHW System: 3330 kWh/a
- Solar thermal collectors (6m²) heat production: 2227 kWh/a
- Electricity demand - household appliances: 1162 kWh/a
- Electricity demand - auxiliary: 409 kWh/a
- Annual heat load: 1198 W

To sum it up, the total heat requirement of the building is 4474 kWh per year (without solar production) and the total electricity demand is 1571 kWh per annum.

![Primary Energy Demand - Improved building design with gas boiler](Image)
05.08 Result 6 - District Design

Till now, reasonable measures have been taken to reduce the energy demand of a single building. Most measures are cost-effective for a reference time of 20 years (optimization problem § 05.03.01). To decrease a building’s energy demand even further either more investments in the building must be made or a more integrated approach has to be considered. A higher performance can be achieved by a broader view on the problem. For this purpose the level of interventions is extrapolated to the district (Figure 7).

In the first paragraph of this section the district concept is described. This is followed by an evaluation of different energy production options in the central district plant.

Each house within the district has the same characteristics as the final building design described in chapter ‘05.07 Result 5 – Final Building Design’. Of course, the building performance of the final building design refers to a mid-terraced house. For the end-terraced building an addition of 12.5% to the heat requirement is assumed, which is motivated by the fact that the SenterNovem reference buildings (SenterNovem, 2006) refer to that value.

05.08.01 District concept

Within the district respectively six houses (dwellings) are composed to one building block. Two building blocks are arranged in East-West direction to one district. This leads to a composition of 8 mid-terraced buildings and 4 end-terraced buildings. (Figure 44)

![Figure 44: Site plan of the district; with building units composed to a building block and served via the district service unit, which incorporates energy production and energy storage](image)

These 12 houses are connected to a district network which is fed by district heat from a centralized plant. The district service unit contains the central energy production and provides energy storage facilities. The district service unit is located at one gable wall of a building block, which minimizes heat losses and construction costs. The central energy production plant provides the buildings with hot water for space heating and domestic hot
Houses As Energy Delivering Systems

water. For the transport is an additional network required and district sub-stations at every building, which ensure the energy exchange.

There are different possibilities to generate the required energy to cover the energy demand of the district. These options focus on conventional energy production via co-generation of power and heat (CHP), which is much more efficient than local energy production in every single building. (Appendix D)

05.08.02 District heating (gas combustion), 0% power-heat coupling

The power-heat coupling (PHC) of 0% indicates that the district heating plant produces only heat. The combustion material is natural gas. The demand of the 12 households is bundled.

The district situation implies:
- 8 mid-terraced buildings
- 4 end-terraced buildings
- Treated Floor Area (TFA): 1536 m²

New feature, applied to the building design within this assessment:
- District heating with central heating plant (gas), 0% power-heat coupling

Selected results from the calculation:
- Total district heat requirement -space heating 14,3 MWh/a
- Total district heat requirement -DHW 40,0 MWh/a
- Total district electricity demand 13,9 MWh/a
- Solar thermal collectors (72m²) heat production 26,7 MWh/a
- Total district network heat losses (10%) 5,40 MWh/a
- Total Annual heat load for district heating plant 14,4 KW

Total Primary Energy (PE) Requirement for one building unit:
- Space heating (39,3% share) 11,0 kWh/m²a
- DHW (50,7% share) 14,2 kWh/m²a
- District heat distribution losses (10% share) 2,7 kWh/m²a
- Electricity Demand - Household Appliances 24,4 kWh/m²a
- Electricity Demand - Auxiliary Electricity 8,6 kWh/m²a
- Non-electrical Demand, Gas-Cooking 4,3 kWh/m²a
- Total PE 65,2 kWh/m²a
Figure 45: Primary Energy Demand of one mid-terraced building, incorporated into a district network - gas combustion with 0% power-heat coupling.
District heating (Combined Heat and Power), 35% power-heat coupling

The central district plant is equipped with a Combined Heat and Power (CHP) plant with 35% power-heat coupling (PHC). This means that with the power generation 35% of the waste heat is utilized to generate heat. The used combustion material is gas.

The district situation implies:
- 8 mid-terraced buildings
- 4 end-terraced buildings
- Treated Floor Area (TFA): 1536 m²

New feature, applied to the building design within this assessment:
- District heating with central heating plant (gas), 35% power-heat coupling

Selected results from the calculation:
- Total district heat requirement -space heating 14,3 MWh/a
- Total district heat requirement -DHW 40,0 MWh/a
- Total district electricity demand 13,9 MWh/a
- Solar thermal collectors (72m²) heat production 26,7 MWh/a
- Total district network heat losses (10%) 5,40 MWh/a
- Total Annual heat load for district heating plant 14,4 KW

Total Primary Energy (PE) Requirement:
- Space heating (39,3% share) 8,0 kWh/m²a
- DHW (50,7% share) 10,3 kWh/m²a
- District heat distribution losses (10% share) 2,0 kWh/m²a
- Electricity Demand - Household Appliances 24,4 kWh/m²a
- Electricity Demand - Auxiliary Electricity 8,6 kWh/m²a
- Non-electrical Demand, Gas-Cooking 4,3 kWh/m²a
- Total PE 57,6 kWh/m²a

![Primary District Energy Demand](image)

*Figure 46: Primary Energy Demand of one mid-terraced building, incorporated into a district network - gas combustion with 35% power-heat coupling*
05.08.04 District heating (Combined Heat and Power), 70% power-heat coupling

The central district plant is equipped with a Combined Heat and Power (CHP) plant with 70% power-heat coupling. This co-generation produces district heat from power generation by utilizing 70% of the waste heat. The used combustion material is gas.

The district situation implies:
- 8 mid-terraced buildings
- 4 end-terraced buildings
- Treated Floor Area (TFA): 1536 m²

New feature, applied to the building design within this assessment:
- District heating with central heating plant (gas), 70% power-heat coupling

Selected results from the calculation:
- Total district heat requirement -space heating 14.3 MWh/a
- Total district heat requirement -DHW 40.0 MWh/a
- Total district electricity demand 13.9 MWh/a
- Solar thermal collectors (72 m²) heat production 26.7 MWh/a
- Total district network heat losses (10%) 5.4 MWh/a
- Total Annual heat load for district heating plant 14.4 KW

Total Primary Energy (PE) Requirement:
Space heating (39.3% share) 5.1 kWh/m²a
DHW (50.7% share) 6.5 kWh/m²a
District heat distribution losses (10% share) 1.3 kWh/m²a
Electricity Demand - Household Appliances 24.4 kWh/m²a
Electricity Demand - Auxiliary Electricity 8.6 kWh/m²a
Non-electrical Demand, Gas-Cooking 4.3 kWh/m²a
Total PE 50.2 kWh/m²a

Primary District Energy Demand - gas combustion, 70% PHC

Figure 47: Primary Energy Demand of one mid-terraced building, incorporated into a district network - gas combustion with 70% power-heat coupling
05.09 Discussion of Results 5-6

This chapter reflects the results from chapter 05.07 and 05.08 with reference to the elaborated discussion in § 05.06.

With the extrapolation of the intervention-level from the building to the district a bundling of energy demands is achieved. The agglomeration of 12 buildings (in this case) is grouped to one energy-demanding party.

The district with 12 households has the following demand:
- Total district heat requirement -DHW, heating, losses 59.7 MWh/a
- Total district electricity demand 13.9 MWh/a
- Total Annual heat load for district heating plant 14.4 KW

The district has a solar DHW production with:
- Solar heat production 26.7 MWh/a
- Solar thermal collector area (12 x 6m²) 72m²
- Storage volume for DHW (12 x 420 litre) 5040 litre

05.09.01 Heat Production

The district has a grid-connected central energy plan with combined heat and power production. The district's primary energy demand varies with the chosen energy production variant. Figure 48 illustrates the effect of the chosen variant on the primary energy demand (for heating, hot water production, and distribution losses) per household.

![Primary Energy Demand of one Building Unit per District Heating Variant](image)

*Figure 48: Primary Energy Demand of one building unit per district heating variant; only the fractions of heating, DHW, and distribution losses are considered; excluding household appliances, auxiliary, and miscellaneous energy (which are the same per variant with 37.3 kWh/m²a)*

The production of heat without power-heat coupling (0% PHC) (Figure 48) is less efficient than the decentralized heat production in a single household (Figure 43). This is caused by additional distribution losses of 10% via the district heating network. The efficiency of the central district plant is improved with combined heat power production. A power-heat coupling of 70% achieves a 53% higher efficient than the option with no coupling.

By using an alternative combustion material the primary energy demand for heat is reduced to a minimum. Biofuels are considered as environmental friendly resources. They have a beneficial primary energy factor (PEF). Biomass is considered within the calculation with a PEF of 0.2 whereas natural gas has a PEF of 0.7. (See also District Heating Appendix D)
The utilization of a renewable resource to cover the heat demand complies with the Cradle to Cradle strategy. The earth's major nutrients are cycled and recycled (§ 02.01.03). Wood pellets are a renewable source of energy and do not contribute to climate change. The carbon dioxide that is released when pellets are burned is equal to the amount the tree consumed when it was growing. Wood pellets are also financially competitive with natural gas as a combustion material. To cover the district heat demand of 59.7 MWh per year 12.7 tons of wood pellets are necessary. With the current wood pellet price of 180 € per ton the kWh district heat would cost 3.8 Eurocent. The current price for gas is about double the price for wood pellets with 7.5 Eurocent per kWh. [www.propellets.de]

Another option to cover the rest heat demand could be a solar-assisted district heating system with a seasonal storage. As case studies show, to cover a 100% fraction of DHW and space heating very big investments into a solar heat storage system are necessary to balance the mismatch in demand and supply. The technology of seasonal heat storage is still in its infancy. Isolated pioneer projects show that the 100% fraction can be only achieved with big efforts. (Appendix D)
**05.09.02  Electricity Production**

The primary energy demand concerning the heat requirement could be minimized whereas the primary energy demand for the electricity requirement remains constant at 37.3 kWh/m²a. This affects the relative share of the PE requirements as indicated in Figure 49.

![Primary District Energy Demand - gas combustion, 70%](image)

As illustrated in Figure 49 the biggest share in the energy demand is caused by household appliances and auxiliary energy inside the building, which is the electricity demand respectively.

To cover also this fraction of the demand renewable sources have to be utilized. Photovoltaic systems and wind turbines can be efficiently integrated into the district system. The upgradeability of the district network benefits these strategies.

Volker Quaschning [2003] has developed a simple software to estimate roughly the performance of a grid-connected photovoltaic systems and a wind parks.

- **Performance Calculation for Grid-connected Photovoltaic Systems:**
  With a roof area of 69 m² per building unit the district provides a potential roof surface of 828 m² for photovoltaic collectors.
  For a rough estimation of a grid-connected District-Photovoltaic-System a usable roof area of 17.5 % is assumed (50 % usable ratio and 35 % occupation rate for a flat roof). This amounts to an effective collector area of 12 m² per building unit or 144.9 m² for the whole district.

The performance analysis calculated the following values:

<table>
<thead>
<tr>
<th>Location:</th>
<th>Netherlands (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal irradiance:</td>
<td>1180 kWh/(m² a)</td>
</tr>
<tr>
<td>gain/loss of slope:</td>
<td>17.6 %</td>
</tr>
<tr>
<td>roof surface:</td>
<td>828 m²</td>
</tr>
<tr>
<td>usable ratio:</td>
<td>50 %</td>
</tr>
<tr>
<td>occupancy:</td>
<td>35 %</td>
</tr>
<tr>
<td>module efficiency:</td>
<td>12.5 %</td>
</tr>
<tr>
<td>Performance Ratio PR:</td>
<td>0.7</td>
</tr>
<tr>
<td>installable capacity:</td>
<td>18.11 kWp</td>
</tr>
<tr>
<td>annual output:</td>
<td>17594 kWh/a (electricity)</td>
</tr>
<tr>
<td>specific output:</td>
<td>971.4 kWh/kWp (electricity)</td>
</tr>
</tbody>
</table>
Wind Park Performance Analysis:
For the wind turbine option a standard wind converter with a power of 200 kW is chosen to demonstrate the potential of this variant. As a location Rotterdam is chosen.

The performance analysis calculated the following values:

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam</td>
<td></td>
</tr>
<tr>
<td>Wind energy converter</td>
<td>Enercon E30 (200 kW)</td>
</tr>
<tr>
<td>Nominal converter power</td>
<td>200 kW</td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>30 m</td>
</tr>
<tr>
<td>Rotor area</td>
<td>707 m²</td>
</tr>
<tr>
<td>Maximum power coefficient</td>
<td>0.399</td>
</tr>
<tr>
<td>Number of converters</td>
<td>1</td>
</tr>
<tr>
<td>Total wind park power</td>
<td>0.2 MW</td>
</tr>
<tr>
<td>Mean wind speed</td>
<td>5.83 m/s</td>
</tr>
<tr>
<td>Mean wind power</td>
<td>235.6 W/m²</td>
</tr>
<tr>
<td>Mean wind park power</td>
<td>0.049 MW</td>
</tr>
<tr>
<td>Annual wind park output</td>
<td>426.22 MWh/a</td>
</tr>
<tr>
<td>Mean households (1571 kWh/a)</td>
<td>271</td>
</tr>
<tr>
<td>Full load hours</td>
<td>2131 h/a</td>
</tr>
<tr>
<td>Estimated total costs</td>
<td>65,000 €</td>
</tr>
</tbody>
</table>

The district with 12 households has the following electricity demand:

- Total district electricity demand 13.9 MWh/a

The Grid-connected Photovoltaic Systems has the following characteristics:

- Effective usable roof area (50% of 828 m²) 414 m²
- Effective collector area (12 x 12 m²) 144.9 m²
- Installable capacity 18.1 kW
- Annual output 17.6 MWh/a
- Mean household (1.571 MWh/a) 15
- Estimated total costs 65,000 €

The Grid-connected wind turbine has the following characteristics:

- Nominal converter power 200 kW
- Rotor area 707 m²
- Annual Wind turbine output 426 MWh/a
- Mean household (1.571 MWh/a) 271
- Estimated total costs 200,000 €

This estimation shows that the grid-connected photovoltaic system with 144.9 m² collector area and the wind turbine could supply the demanded electricity for the district. The photovoltaic system pretty much matches the demand within the district. The wind turbine is oversized and could supply 271 households with electricity. Not covered with this calculation is the problem of the phase shift between demand and supply. Within this estimation it is assumed that the electricity grid is able to compensate this mismatch.
Houses As Energy Delivering Systems

05.09.03 Result Summary

The primary heating demand of the building is reduced to a minimum. This demand is supplied by the district heating system with combined heat and power production. The most sustainable solution is achieved with biomass as a combustion material. The fraction (two third of the total demand) of the primary electricity demand is covered by either a grid-connected district-photovoltaic-system or a grid-connected wind turbine. Both variants will produce a surplus of electricity. (Figure 50)

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**Primary District Energy Demand**

- Heating
- DHW
- Distribution losses
- household appliances
- auxiliary energy
- miscellaneous energy

---

**Figure 50: Primary Energy Demand for Heat and Electricity**

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**Figure 51: District Components and characteristics**
Conclusions & Recommendations

This chapter presents the main conclusions and formulates a number of recommendations.
06.01 A Summary of Major Findings

- The Dutch building standard has a high potential for an increased energy-efficiency. A significant reduction of the building's energy demand can be achieved with reasonable measures.
- Highly insulated buildings comfort their occupants with a good indoor climate. In combination with a sophisticated ventilation concept the overheating problem in the summer can be overcome.
- The heating demand for a high performance building could be halved. The heating period is reduced from seven month to five month per year. As a side effect, the peak load could be halved, too. This benefits a simplification of the heating system.
- High performance windows benefit a heating demand reduction most.
- The cost-estimation shows that with a long term perspective (in this case 20 years) on investments financially reasonable design improvements can be made.
- Additional investments into a better exterior wall insulation are most cost-effective.
- Investments into solar DHW production are highly competitive with other energy demand reducing interventions.
- At a certain point the optimization of the space heating and domestic hot water demand reaches its limits. From this point onwards high investments into the building are necessary to reduce the demand by a fraction.
- A district heating system with combined heat and power production achieves higher efficiencies than the small-scale heat production in a single household.
- By using biomass (wood pellets) as an alternative combustion material to produce the remaining heat demand the ecological balance is improved significantly.
- The price for district heat from wood pellets is around half the price of natural gas.
- It takes very big efforts to cover 100% of the heat demand by solar thermal production.
- After all optimization interventions household appliances cover more than half of the requested primary energy demand.
- A reasonable sized grid-connected district-photovoltaic-system can cover more than the demanded electricity within the district.
- A grid-connected wind turbine supplies more electricity to the district than needed.
- The supplier's electricity net has to function as compensator to balance the mismatch in electricity demand and supply.
- The district energy demand can be completely covered without fossil fuels.
06.02 Conclusions

- The final building design requires high building standards and occupants that understand and support the concept of an energy-efficient house. High performances are only achieved with high quality details, a good planning and a good execution. There are catalogues available for the Passive House Standard with details, which include solutions to achieve high standards for details and finishing. To give an example: The building's air-tightness is crucial to the total performance. When increasing the infiltration by factor two the building's annual heat demand will increase by 24%. Concerning the air-tightness, requirements for the Passive Houses are approximately three times stronger than for the average new build dwelling in The Netherlands. Thus, high quality standards are essential for a high performance.

- The building performance sensitivity towards the occupants' behaviour is rather small during the summer period. Uncontrolled heat gains are limited via external overhangs and external roller blinds. The surplus of heat is removed by natural ventilation through open windows, which is easy controllable by the occupants. The cooling concept is additionally supported by the subsoil heat exchanger.

- Throughout the heating season the occupants' influence is rather big. The building uses internal heat gains as a heating source. One third of the total heat gains is delivered by the heat gains from the occupants and household appliances. The occupants need to be informed about the effects of uncontrolled ventilation during the winter term via open windows and doors. Since the building is integrated into a district system and the heat is delivered by a central plant, it can be assumed that one case of uncontrolled ventilation will cause no problems. It will cause an increased demand to the district and decrease the performance of the particular building unit.

- The cost-effectiveness of energy-efficient interventions is highly dependant on the future price increase of fossil fuels. For the optimization problem a moderate annual average gas price increase of 8.7% is assumed for the next 20 years. This assumption is based on the gas price development during the last 10 years. Since the gas price is linked to the oil price, this assumption has to be considered as rather conservative. The current price for oil is $130/barrel, whereas the World Trade Organisation took $128 for its worst future scenario. Experts predict a much higher oil price within the next month ($250/barrel). This of course will influence the cost-effectiveness of energy-saving measures. For instance: With an assumed gas price increase of 17.5% for the next 20 years the optimum insulation thickness of wall, roof, and building slab can be increased by another 60 mm. This will decrease the annual heat requirement by 20%.

- The calculated optimum insulation thicknesses of wall (240 mm), roof (240 mm), and slab (180 mm) are much bigger compared to the initial design. This will cost valuable living space inside the house since the external boundaries of the building are usually prescribed by the municipality. New, sophisticated insulation materials with a better thermal resistance can be used to minimize this insulation thickness. Vacuum Insulation Panels (VIP) for instance have better insulation characteristics than mineral wool. Although the price for VIP is higher, with the increase of energy prices they become more feasible.

- The used Passive House Standard is suitable for the energy-efficient design of buildings with the aim to reduce the heating demand. This standard reaches its limits when considering the overheating problem in summer. It does not utilize free cooling sources in its considerations to a sufficient scope.
• Investments into high performance buildings have to be treated as long term investments to gain full financial benefits. The Homeowners' motivation to achieve a high-performance building has to be stimulated by financial incentives.

• Since household appliances have an energy demand share of more than 50%, these fraction should be tackled first. Of course, the designers influence usually stops at the building's doorstep. Therefore other bodies and institutions have to take part of improvement process by, for instance, educating the homeowners or subsidising energy saving household appliances.

• For the design and construction of high-performance buildings suitable technologies and design strategies are available. To apply and utilize these technologies and techniques good background knowledge is required from the designer. Therefore, the key to a further propagation of high-performance standards is the education of the designers and stake holders.

• Since the seasonal storage problem is yet not solved sufficiently the required heat demand production depends on combustion materials. A complete cover of space heating and domestic hot water by free solar energy can only be achievable with big efforts. As long as there is no adequate heat storage technology the use of biomass as a combustion material is the most sustainable solution.

• The efficiency of the electricity production via a district-photovoltaic-system depends on the supplier's electricity grid. This has to compensate the mismatch in demand and supply. Since this conceptual design involves only one district with 12 houses it will have minor impacts on the photovoltaic-system's performance. In case this conceptual district design is multiplied national solutions have to be found.

• The extrapolation of the intervention-level from the building to the district creates the opportunity for a cost-effective and sustainable energy production. The district systems ensures the energetically upgradeability for the future whereas the performance of the single building unit is rather independent from future developments. This effect could be achieved by a simplification of the building services. With reasonable measures an energy producing district is designed.

06.03 Implications of the Findings

This research shows that with reasonable improvements in the building's design significant energy demand reductions can be achieved. By integrating the district into the design considerations a sustainable result is achieved. By using only renewable resources for the energy production a 'green' building district is achieved.

06.04 Limitations of the Study

The used simplified cost calculation, which formed the basis for the optimization process, may not be fully reliable. This cost-efficiency consideration is used for a motivation of the decision process. Nevertheless, the calculations on the building's energy demand are reliable.

The focus within this research is on the energy content of buildings. Besides the issue energy also the issues water and materials have to be addressed to get a sustainable result.

This thesis basically aimed at an accumulation of knowledge in this field. Furthermore it was targeted on increasing the author's sensitivity and awareness of the impact of potential interventions taken during the design process.
06.05 Recommendations

After the extensive investigation of a building's energy content, other issues like water cycles and material cycles within the building should be optimized to achieve a comprehensive sustainable result.

The cost-efficiency calculation should be extended to motivate fundamental decisions and support the idea of the high-performance building.

Other building types, besides the terraced house, should be optimized on energy, water, and material usage.
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Appendix A  Thesis Key Paper 'Passive Solar Design'
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01 Introduction

Passive solar design is the basis for many design approaches. Its attractiveness can be explained by the fact that with an intelligent design a building's energy demand can be significantly reduced without high financial expenditures.

02 What is Passive Solar Design?

Passive solar design refers to a group of building design strategies that utilizes the sun's energy to reduce the need for mechanical heating, cooling and lighting. When combined with basic energy conservation and energy efficiency practices, these strategies can actually increase the indoor-comfort of buildings and can achieve dramatic reductions in energy costs.

These strategies include passive solar heating, day-lighting, natural ventilation, ground-coupled heating and cooling, and peak-load reduction by thermal mass.

In passive solar design the building as a whole as well as the building elements take advantage of natural energy characteristics in materials and air created by exposure to the sun. Passive systems are simple, have few moving parts, and require minimal maintenance and no mechanical systems.

The following aspects are considered within this section:
- Passive Solar Heating (§ 03)
- Passive Solar Cooling (§ 04)
- Daylight (§ 05)

03 Passive Solar Heating

03.01 Introduction

The mechanism of heating and cooling equipment is usually referred to as a system. A building design is worked out and a heating/cooling system is specifically designed for the house.

This system can be partly be substituted in passive building design and is integrated into building elements and materials. Windows, walls, floors, and the roof are used to collect, store, release, and distribute required heat. These components are also a major element in passive cooling design (§ 04).

It should be understood that passive solar design does not necessarily imply an elimination of standard mechanical systems, although recent designs show a high efficiency of this strategy, implicate a reduction of the size of the traditional heating systems and reduce the amount of non-renewable fuels needed to maintain comfortable indoor temperatures, even in the coldest climates.

Two primary elements of passive solar heating are required:
- South facing windows;
- Thermal mass to absorb, store, and distribute heat.
Three approaches are used for passive systems:
(a) Direct gains,
(b) Indirect gains,
(c) Isolated gains.

03.02 Direct gain design
The simplest of these approaches is the direct gain design. Sunlight is admitted to the space and a part of it is converted to thermal energy. The walls and the floor are used for solar collection and thermal storage by intercepting radiation directly or indirectly. The thermal mass is activated by conducting excessive heat to its core. At night, when outside temperatures drop and the interior space cools, the heat flow into the storage masses is reversed and heat is given up to the interior space in order to reach equilibrium.

Direct gain design is simple in concept and can employ a wide variety of materials and combinations of ideas that will depend greatly upon the site and topography; building location and orientation; building shape (depth, length, and volume); and space use.

03.03 Indirect gain design
In this approach, thermal storage materials are placed between the interior habitable space and the sun. Hence, there is no direct heating. A dark coloured thermal storage wall is placed just behind a south facing glazing instead (called Trombe Wall). Sunlight enters through the glass and is immediately absorbed at the surface of the storage wall where it is either stored or eventually conducted through the material mass to the inside space.

The same principle is used by an attached greenhouse space and by roof pond collectors. Both approaches use a fan-assisted ventilation.

03.04 Isolated gain design
The isolated gain design approach uses a medium (fluid or air) to collect heat in a flat plate solar collector installed on the roof. Heat is transferred through ducts or pipes by natural convection to a storage tank, where the collected cooler air or water is displaced and forced back to the collector (Fig. 12). This stored collector heat is utilized during cold night hours.

04 Passive Solar Cooling
04.01 Introduction
The apparent concern about 'sustainable building design' has caused a re-examination of alternative technologies and systems. Published research has shown that a return to alternative energy sources, techniques and systems can be used to satisfy a major portion of the cooling needs in buildings. Natural and passive cooling strategies manage cooling needs without the extensive requirement of additional energy or the use of other major mechanical systems.

For orientation reasons once should take a closer look at regions with a Mediterranean climate. Without understanding the physical processes involved, people used natural driven cooling techniques for hundreds of years. People in temperate climates keep their homes cool by using natural driven forces like breezes through windows, water evaporating from fountains in their courtyard, as well as large amounts of stone and earth absorbing daytime heat.
04.02  Characteristics
Passive cooling is based on the interaction of the building with its surroundings. Strictly speaking, passive cooling is an approach without causing additional energy expenses. Before adopting a passive cooling strategy, one must be aware of the local climate.

In fact, the literature distinguishes ‘passive cooling’ and ‘natural cooling’. Passive cooling refers to techniques which are used to prevent or modulate heat gains. Natural cooling refers to the use of natural heat sinks for excess heat dissipation from interior spaces. By combining both techniques “it is possible to prevent overheating problems, decrease cooling loads, and improve comfort conditions in buildings” [Santamouris & Asimakopolous, 1996].

In general, the strategy covers the following approaches:
(a) Prevention of exterior and interior heat gains;
(b) Heat gain modulation;
(c) Heat dissipation.

04.03  Heat gain prevention
The prevention of heat gains involves the following design techniques:
- microclimate and site design,
- solar control,
- building form and layout,
- thermal insulation,
- behavioural and occupancy patterns, and
- internal gain control.

Several of the techniques mentioned are also applied in passive heating design. To reduce a building's cooling load a consequent prevention of the external and the internal heat load should be targeted in first place. To give an example: A good sealed building implies a minimization of the infiltration of cold air in winter and a prevention of uncontrolled exfiltration of conditioned air in summer prevented. Another example: With regard to internal heat gain control, best available technologies (BAT) for electrical household devices will not only reduce the electrical consumption, BAT produces also less unintentional heat [Fenna, 2000][Eichhammer, 2000].

04.04  Heat gain modulation
Heat gain modulation utilizes a building’s thermal mass to extenuate high temperature fluctuations. In regions with high daily temperature-fluctuations this strategy can perform best.

04.05  Heat dissipation
After utilizing the potentials of prevention and modulation techniques the remaining surplus of heat has to be removed. The following natural heat sinks are used for this purpose:
- ventilation;
- ground cooling;
- evaporative cooling;
- radiative cooling.

Natural and forced ventilation are the primary means for a reduction of cooling load in buildings. Whereas forced ventilation is depending on mechanical devices like fans, natural ventilation is driven by the sun’s energy (wind, natural stack effect, etc.). Due to the variability of, for instance, wind speed and direction, natural ventilation can be pretty unreliable. However, a careful building design can help to enhance the natural driven ventilation in a building. For instance, one of the techniques used for natural ventilation is
the solar chimney. By strengthening the natural stack effect a significant amount of surplus heat can be removed from the building (figure).

**Ground cooling** is a concept that gained popularity in the late 1970s and it is enjoying a revival in recent years. Air is drawn into the house through underground tubes (buried deeper than 1.50m), which has the effect of pre-cooling (preconditioning) the air before entering the building. The deeper the tubes in the ground the less annual soil temperature fluctuations and the higher the temperature difference to ambient air in summer.

Again, this technique could be used for both passive solar cooling and heating. Air is pre-heated in winter and pre-cooled in summer.

Advantages: low energy cost; environmentally friendly; cooling in summer and pre-heating in winter; with an application of a filter hygienically unobjectionable. Disadvantages: high initial building costs; additional space demand; performance varies depending on soil conditions and weather conditions; regular filter exchange necessary.

## 05 Daylight

The smart use of natural light becomes a more important strategy in sustainable building design since it can contribute to the three aspects social, economical, and environmental quality. Sophisticated daylight strategies can reduce a building’s energy consumption and improve the quality of the light inside the house.

The art of proper day-lighting design is not so much about how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects. Besides windows or skylights it involves a balancing of heat gain and loss, glare control, and variations in daylight availability.

There is naturally a strong interaction between all these factors. This challenges the designer to find the right window properties based on the day-lighting issue and the heat conserving efforts.

Junghans & Hastings [2002] state the following parameters that influence human's perception of light in a room:

- Window proportion;
- Window position;
- Cross-section of the window opening in the wall;
- Treatment of room surfaces;
- Glare protection.
Appendix B  The application of 'Trias Energetica' as a design strategy
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Introduction

For the successful design of a complex product like a building, fundamental and consistent decisions have to be made during the design process. Several design strategies can be used to achieve a design with a high performance. Structured approaches are indispensable with regard to building design and the reduction of the building’s energy demand. One of these design strategies is the Trias Energetica.

What is Trias Energetica?

The design strategy Trias Energetica (TE) was developed at the Delft University of Technology (Duijvestein, C.) to promote the use of renewable energy within the built environment. Scientists from the research institute SenterNovem have introduced the term ‘Trias Energetica’ in 1996 [Lysen, 1996]. This strategy identifies three simultaneous steps towards a more renewable energy supply:

1. Limit the energy demand through energy saving;
2. Use renewable sources to meet the remaining energy requirement;
3. Use fossil fuels as efficiently and cleanly as possible (Figure 1).

The application of this strategy within the design process of a building is quite complex and will probably vary in detail from project to project. A more detailed approach is given in the next paragraphs.

The application of Trias Energetica

Within this paragraph every step of the TE approach is elaborated more in more detail and illustrated with examples for the design practice.

First step: limiting the energy demand

Limiting the energy demand is the first logical step in the TE since ‘not needed energy’ is the most ‘ecological energy’. The rational use of energy within the built environment starts...
with an intelligent urban design and good architecture. In combination with the passive design approach optimal results can be achieved.

03.01.01 Urban design and architecture

Considering the urban design and the building’s architecture, the following factors influence a building’s energy demand:

- Location, orientation, urban planning;
- Building orientation, building form, compactness;
- Building layout, zoning;
- Building skin in interaction with its environment.

Location: Passive solar design implicates a consideration of local climate conditions, such as temperature, solar radiation, and wind. Thus, meteorological factors affect the passive energy utilization [Simon & Simon, 2004].

Urban planning: When optimising a building towards the use of active and passive solar gains, little efforts in the arrangement of a district’s master plan will be beneficial [Simon & Simon, 2004]. Guidelines [DOE, 2005][Wortmann et al., 2002] recommend that the building’s southern exposure should be clear of large obstacles that block the sunlight (e.g. tall buildings, trees).

Building orientation: Although a true southern exposure is optimal to maximize solar gains and to allow an easy heat and cold control of the south façade it is neither mandatory nor always possible. Provided that the building faces south within a maximum deviation of 20-30 degrees [DOE, 2005], 45 degrees [Wortmann et al., 2002] the passive solar gains can be used to its maximum. According to the U.S Department of Energy [2005] south-facing glazing will still receive about 90 percent of the optimal winter solar heat gain.

Compactness: According to several resources, a compact building design reduces the transmission losses through the building’s envelope. The compactness is expressed by the building’s surface-to-volume ratio (A/V-ratio) and is reduced by minimalistic facades and roofs without dormers or bays. The reduction of the A/V-ratio by 0.1/m benefits the building’s specific annual heating demand with 10 kWh/m²a [Erhorn et al., 2001]. Also construction costs can be reduced in consequence of a simplified building form. Disadvantageous to a compact building form is the increased overheating potential during the summer and the natural light penetration during the winter.

Building layout: The layout of a building includes the internal arrangement of functions and rooms. Thermal zones (zoning), internal orientation of rooms, compartmentation are design aspect that have to be considered are heat flows, natural ventilation, passive solar gains etc. are modelled with these design parameters.

For instance, an optimized design ensures that heat losses in one room are used as gains in the adjacent rooms by locating the room with the biggest heat demand in the building’s centre. This ‘principle of an onion skin’ has the disadvantage of an increased ‘core temperature’ during the summer months.

Considering the temperate climate of Central Europe, non heated rooms should be located in the north of the building, low heated rooms (like bedrooms and kitchen) should be located in the north and northeast, and normal heated rooms orientated to the south [Simon & Simon, 2004] [Weber, 2001].
Building skin: The authors of the book ‘Sustainable Solar Housing’ [Hastings & Wall, 2007a] state that the biggest potentials for energetically improved building design are found in the reduction of the building’s transmission losses and ventilation losses (Figure 2).

Figure 2: Energy losses of a terraced house; source: Hastings & Wall, 2007a

Figure 2 illustrates that almost half of the energy losses in a conventional terraced house is caused by the poor insulation properties of the building skin and a part of these transmission losses is attributed to leakiness of the building envelope, i.e. uncontrolled ventilation.

Thus, the solution to a better building design has to include:

- A reduction of transmission losses by an improved thermal envelope and a thermal bridge free construction;
- A prevention of infiltration losses by an airtight envelope.

The improvement of the thermal envelope (i.e. walls, windows, roof, and foundation-slab) is achieved by a lower thermal conductivity of the used material. These building materials and products are available in a big variety with predefined properties. The air-tightness of the envelope on the other hand has a high dependency on detail-design and the execution of building details during construction process. To secure a high-performing air-tightness of the building, professional energy auditors use a Blower Door Test to determine the envelopes quality.

As already stated all these solutions depend on a well executed design and construction process. More elaborated descriptions and informations can be found in the literature [Hastings & Wall, 2007a+b][IEEA, 2008][Simon & Simon, 2004].

**03.01.02 Passive solar design**

A passive design involves techniques that facilitate free resources during the operation of a building without the need of active means (mechanical building services etc). Passive solar design can reduce heating and cooling energy bills, increase spatial vitality, and improve the comfort. Flexible passive design principles typically facilitate energy benefits with low maintenance risks during the building’s lifespan. It integrates a combination of building features to reduce the need for mechanical cooling, heating, and artificial lighting.

03.02 Second step: using renewable sources

This second step of the TE involves active means, i.e. measures that depend on mechanical systems and building services. But before the renewable sources are utilized, the building’s energy demand can be further reduced by recycling existing energy flows.

03.02.01 Energy recycling

The next logical step (after the reduction of the building’s energy demand) is the utilization of waste flows, which is also part of the Cradle to Cradle approach. By using recycling energy in form of heat, which is already inside the building, the energy demand of the building can be further reduced.

Sources for the energy recycling within the building envelope are the exhaust air from ventilation and the waste water.

Air heat exchanger: After the first step in the Trias Energetica no spaces should be excessively ventilated while at the same time a certain air-quality has to be fulfilled. A minimum air exchange rate, which depends on occupation and space, is necessary to ensure these requirements. This asks for controlled ventilation by means of mechanical building service devices. With the mechanical ventilation system the option appears to reuse warm exhaust heat flows to preheat cold inflowing air by means of a heat recovery system. Counter flow heat exchangers achieve performances of 80 to 90% [IEEA, 2008][Ala-Juusela, 2004].

Waste-water heat exchanger: Another option to recycle energy waste flows within the building is the utilization of wastewater. Figure 2 illustrates that one fifth of the overall energy losses is caused by hot water production. The strategy for a reduction of domestic hot water (DHW) losses includes in the first place a decrease of hot water consumption by the occupants and in the second place the energy reuse by drain-water heat recovery (DHR). It uses the same principle as heat exchangers for ventilation air. Heat from waste-water is used to preheat cold water from the suppliers’ network. This principle requires a local DHW production and a steady warm waste-water flow, e.g. from a shower. These requirements limit the performance of such a system to 30 to 50% [DOE, 2005][Hastings & Wall, 2007a].

03.02.02 Utilization of renewable sources

Within this step renewable sources are used to cover as much as possible of the remaining building’s energy demand in a sustainable way. Considering renewable sources, energy for the building can be utilized from the sun (PV, PVT, thermal collectors), wind (wind turbines), water (heat exchange with floating waters via heat pumps), ground (heat exchange via subsoil heat recovery, earth collector, heat pump), biomass (combined heat and power production), and renewable electrical power from the suppliers net.

Sun: Active solar design capture the sun’s energy by means of solar thermal collectors, photovoltaic (PV) collectors, and a combination of both (PVT). They are usually mounted on the roof of the building but they can also be integrated into the façade.

Solar thermal systems are supported by a storage system on daily, monthly, or annual basis. A heat transfer system distributes the heat to the appropriate places in the house. Generally, an active solar heating system serves the buildings domestic hot water demand (DHW) or both DHW and space heating. Depending on system size, design, and climate a typical industrial manufactured solar hot water system covers 50-60% of the hot water demand.
A combi-system for DHW and space heating has naturally lower performances (usually 10-30%) since the space heating demand of a building is much higher than for domestic hot water. Planners try to increase the system’s efficiency via long-term heat storage [Ala-Juusela, 2004], which allows the utilization of the summer sun to heat the building in winter. In consequence of reasonable higher efforts, the costs for solar combi-systems are much higher than for solar domestic hot water systems. [Furbo et al., 2003][Milles, 2000]

Like thermal collector systems the performance of PV-systems depends on the local intensity of the solar radiation. The average solar radiation is decreased by the atmosphere, clouds etc. Nevertheless, the average annual global irradiation, received by an optimal inclined PV-panel in the Netherlands, is about 1180 kWh/m²a [Suri et al., 2007].

Similar to the thermal use of sun’s irradiation the daily and annual mismatch between the natural energy supply and the occupant’s demand reduces the systems efficiency. The problem of local electricity storage can be solved by connecting the building to the electricity grid and using it to cover peaks in local electricity production and demand. Of course, the issue of electricity storage is not solved by this; it is just shifted to the suppliers’ network.

**Ground:** The activation of the soil properties underneath the building for cooling and heating purposes is another option in utilizing free energy. Caused by the big mass of the soil, annual temperature fluctuations are pretty small compared to the ambient air. The ground temperature in the Netherlands varies between 10°C in winter and 14°C in summer whereas the average air temperature varies from 2°C in winter to 17°C in summer [KNMI, 2002]. These circumstances allow an activation of soil properties for, for instance, a preconditioning of air or, in combination with a heat pump, the pre-warming of hot water for DHW and space heating purposes. Different systems are available, from ground coils to bore holes and building slab integration [Ala-Juusela, 2004].

**Biomass:** The utilization of biomass is usually realized in combination with combustion systems. Instead of using fossil fuels, energy is produced by means of wood, corps, landfill gas, garbage, alcohol fuels etc. This energy can be either produced locally in the building or centralized, with higher efficiencies, in a district heating system.

**03.03 Third step: using fossil fuels efficiently**

This step represents the last one in the Trias Energetica. In case that there may still be a demand for energy after the initial two steps, conventional means are used to generate the required energy. Gas, oil, coal and other fossil fuels are burned in a combustion system.
Appendix C  Hybrid ventilation as a part of the energy concept
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Hybrid Ventilation

01 Introduction

In thermally well insulated buildings the transmission losses through the building skin are minimized. To decrease the building’s energy demand by minimizing ventilation losses and ensuring good air quality at the same time, a well-controlled and energy-efficient ventilation system with heat recovery is inevitable. Natural ventilation and passive cooling techniques can support this approach. They are sustainable and well accepted by occupants when optimal controlled. Unfortunately, today’s ventilation concepts often become a question of using either natural or mechanical ventilation.

In the past mechanical and natural ventilation systems have developed separately (Figure 1). For both systems the focus in their recent development was on the minimization of the energy consumption while maintaining a comfortable and healthy indoor environment.

Figure 1; Development of natural and mechanical systems; [Heiselberg, 2002]

02 Characteristics of Hybrid Ventilation

Generally, the purpose of ventilation is to provide acceptable indoor air quality and thermal comfort.

A hybrid ventilation system fulfils these requirements by using both natural ventilation and mechanical systems. It utilizes different features of these systems at different times of the day, season, or year. In hybrid ventilation, mechanical and natural forces are combined in a two-mode system, in which the operation mode varies according to the season (or the individual days). Thus, the active mode takes advantage of ambient conditions at any time. This ventilation concept requires an intelligent control system that can switch automatically between natural and mechanical mode.

Hybrid ventilation has the following benefits (a) and obstacles (b):

(a) benefits
- hybrid ventilation utilizes the advantages of both ventilation systems
- it fulfils the high quality standards for the indoor environment, increases the energy savings, and supports the sustainable development
- it results in high user satisfaction favoured by the use of natural ventilation with the possibility of the occupant’s control
- it reduces environmental impacts and offers increased robustness and flexibility
- the installation costs for hybrid ventilation are on the same level as for conventional mechanical ventilation systems
(b) obstacles and problems

- one disadvantage is the uncertainty in performance of the system's natural ventilation component
- the mechanical (air conditioning) system could cause complaints from the occupants, especially when individual control and user information is neglected
- auxiliary energy is used to run the mechanical system (fans, heat recovery, heating coils, etc), which contradicts the aim of reducing the building's annual energy demand
- the design process is much more complex in comparison to conventional systems and it asks for an integrated approach from the very beginning
- the main challenge is found in the accurate adjustment of the control system
- the indoor air quality has to be maintained during the winter term and overheating problems avoided during the summer term

Major design objective: In hybrid ventilation design the challenge is to find a solution in which the natural part of the system is used as much as possible, while the mechanical part ensures the fulfilment of the requirements in situations where the natural part fails or is less energy efficient. [Jagpal, 2006]

Cost factor: Several case studies [Heiselberg, 2002] show that an estimation of the initial costs of hybrid ventilation systems is rather difficult as the installation often consists of both mechanical installations and building elements. In a comparison of installation costs between buildings with hybrid ventilation systems and in buildings with conventional ventilation systems it turns out that typically the installation costs for hybrid ventilation systems are at the same level as for conventional systems. In the commercial and public sector, the installation costs in hybrid ventilated buildings are approximately 20-25% of the total building costs.

Integrated approach: Like every building design an energy optimization requires an integrated approach. Issues like the design of the building itself and its passive and mechanical systems, which addresses factors like night cooling, noise, pollutions, fire safety, location and size of openings, features to enhance driving forces (solar chimney, passive stack), preconditioning, and heat recovery have to be addressed.

System components: The components for hybrid ventilation systems are the same as used for purely natural or mechanical systems. For the air distribution system appropriate components are low-pressure ductworks, low-pressure fans with advanced control, low-pressure static heat exchanger and air filters, and wind towers / solar chimneys or atria for the exhaust. To facilitate thermal comfort and air quality manually operated / motorised windows, vents, room temperature, CO₂ sensors, and a control system with weather station are necessary. [Heiselberg, 2002]

03 Hybrid Ventilation Principles

There is a wide range of hybrid ventilation principles and strategies. The concepts vary in the level of building integration and industrialization (standardization and prefabrication).

The main hybrid ventilation principles are:

- Natural and mechanical ventilation

This strategy is based on two fully autonomous systems where either one of them is used for the ventilation task. It covers for example mechanical ventilation for mechanical
ventilation for the winter season and natural ventilation for intermediate seasons and summer.

- **Fan-assisted natural ventilation**

  This system is based on natural ventilation combined with an extract or supply fan. It covers periods with weak natural ventilation (uncertainty in performance).

- **Stack- and wind-assisted mechanical ventilation**

  This principle is based on mechanical ventilation that makes optimal use of natural driving forces. In consequence, the pressure losses can be minimized.

### 04 Design Process of Hybrid Ventilation

The design process for hybrid ventilation systems is different from the one of a conventional mechanical ventilation, which could be installed in any building, in any location, and for any application. Mechanical ventilation systems are rather independent from the design phase of a building, whereas the success of a hybrid concept and its utilization of natural forces must be integrated from the very start.

In consequence of the ventilation system’s interaction with other design disciplines an integral, iterative process with a comprehensive design team is needed.

According to Jagpal [2006] the design process has four phases:

(a) The conceptual design phase – includes decisions on:
- the building form, size, function, and location;
- targets for indoor air quality, thermal comfort, energy use, and cost;
- the combination of mechanical ventilation and natural ventilation principles to be used (§ 03).

(b) The basic design phase aims to:
- estimate building heat, solar, and contaminant loads;
- design the hybrid ventilation layout;
- calculate required air flow rates and expected indoor air quality and temperature levels;
- estimate annual energy demand and peak power demand.

(Until this point the design is iterative.)

(c) The detailed design phase, where it is necessary to:
- re-evaluate contaminants, thermal loads and optimise source control;
- select types and location for ventilation components, control strategy and sensors;
- optimise the system for indoor climate, energy use, and costs through hourly calculations based on a reference year.

(d) The design evaluation phase controls whether the design meets the requirements.
Control Strategies for Hybrid Ventilation Systems

The whole system control strategy is essential for the performance of the hybrid ventilation system. The main challenge in the design of control systems is to find the right balance between implementation costs, operating costs, energy use, indoor climate, comfort, and robustness.

One advantage of natural ventilation is a higher user satisfaction due to individual control of indoor conditions. This feature should be maintained in the control strategy. Even though users should have the maximum possible control of their environment, automatic control is needed to support the users in achieving a comfortable indoor climate and to reduce the energy consumption during occupied and non-occupied hours. Simplicity and transparency of the user-system-interface is highly important and should help to understand the ‘technology’ easily to achieve a maximum performance [Mansson, 2002].

The control strategy for a building should at least include a winter and a summer control strategy. During the winter the indoor air quality (IAQ) is normally determining whereas during the summer overheating is the major problem. The control of ventilation for indoor air quality can either be manual controlled, simple timer controlled, direct measurement controlled, or a combination of these.

The control strategy has to cover among others the following tasks [Jagpal, 2006]:
- Indoor air quality during occupied and non-occupied hours;
- Room temperature;
- External solar shading;
- Night ventilation;
- Preconditioning of ventilation air;
- Severe weather override;
- Alternating between natural and mechanical mode;
- Information of the occupants.
Appendix D  Conventional and solar-assisted district heating
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**Introduction**

Two variants of the district heating system will be discussed in this paper. First, the conventional district heating system is outlined and in the second part the solar-assisted district heating is reflected.

### 01 Conventional District Heating

#### 01.01 Characteristics of Conventional District Heating

**Definition:** A district heating (DH) system consists of three major components: the centralized energy production, the consumer, and the district network. Water is heated in a centralized plant and distributed via pipes to the residential/commercial/industrial consumer’s premises where the heat is extracted from the network for space heating and/or domestic hot water preparation.

District heating systems facilitate the optimal use and combination of a large spectrum of energy carriers (Figure 1). The surplus of heat from electricity production based on conventional or renewable fuels, heat from waste incineration, geothermal heat, combustible renewable like biomass, solar thermal, and combined heat and power can be utilized within the system.

The fundamental idea of district heating is the utilization of waste flows from local fuel or heat sources that are recyclable. A competitive district heating system requires three elements:
- the suitable cheap heat source;
- the demands from the heat market;
- the pipes as a connection.

In consequence, heat distribution networks occur in areas with a concentrated demand for heat.

Today’s source for district heat is the combined heat and power generation (CHP). In the Netherlands almost 100% of existing DH networks is covered by CHP [Werner, 2006]. The fuel utilization of a co-generation plant achieves high efficiency, 85% by a 50% share of electricity and 35% by heat [Pierce, 1996].

District heating has the following advantages (a) and disadvantages (b):

(a) Advantages:
- district heating is more energy efficient due to the simultaneous production of heat and electricity in combined heat and power plants;
the large combustion units have a more advanced flue gas cleaning than single boiler systems, which produce about 30 percent less emissions to the environment than a separate production of heat and electricity [Puntila, 2004];

• DH gives the opportunity to use surplus heat from industry, which is significantly cheaper than other heating options;

• DH systems are easily energetically upgradeable rather in-dependent from the consumer;

• this ensures the opportunity to include a seasonal heat storage into the district network, which is cheaper than small solutions [Milles, 2000];

• in large systems district heating is very flexible; the operator can easily change the available heat source (with focus on the market conditions); this in return will keep the heat generation costs low;

• the district heating reliability is nearly 100% (circa one hour a year for repair work) [Puntila, 2004];

• the costumer benefits are: comfortable, simple and reliable delivery; less floor space for own heating equipment; smaller investment in own heating equipment; lower fire risk when avoiding fuel use in buildings; ‘pays for what he gets’ [Werner, 2006a].

(b) Disadvantages:

• district heating is a long-term commitment that fits poorly today’s liberalized markets with the focus on short-term returns on investments;

• the district heating network and the plant require high initial capital expenditure and financing;

• a district heating system is not profitable with just burning natural gas in large heat-only boilers, it needs a high efficient, sophisticated strategy.

01.02 The Energy Distribution

Hot water is produced in the central district plant and transported to the consumer via a well-insulated network of pipes. District heating systems consist of feed and return lines. Usually the pipes are installed underground (at a depth of 0.5 to 1.0 m). The temperature of district heating supply water varies between 65°C and 115 °C. During the summer season the supply of district heat only has to cover domestic hot water demand since space heating is not required. At costumer level a heat exchanger (substation) serves as an interface between the district heating network and the building’s network No extra boiler is needed in the house. Despite a well-insulated distribution network heat losses cannot prevented and account to less than 10 percent of the fed energy [Puntila, 2004] [Constantinesce, 2006].

01.03 Comparison of District Heating to other Heating Options

Ecologically: Constantinescu [2006] has compared the performance of district heating with other heating options. For this evaluation primary resource factors (PRF) where calculated encompassing all savings and losses from heat generation and distribution to the building. Figure 2 illustrates the performance of different heating systems.

<table>
<thead>
<tr>
<th>District heating</th>
<th>PRF</th>
<th>Building specific heating</th>
<th>PRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP gas</td>
<td>0,5</td>
<td>Gas boiler</td>
<td>1,3</td>
</tr>
<tr>
<td>CHP oil</td>
<td>0,8</td>
<td>Oil fired boiler</td>
<td>1,3</td>
</tr>
<tr>
<td>Biomass</td>
<td>0,1</td>
<td>Wood pellets</td>
<td>0,2</td>
</tr>
<tr>
<td>Oil</td>
<td>1,3</td>
<td>Heat pump</td>
<td>0,9</td>
</tr>
</tbody>
</table>

*Figure 2: Primary resource factors (PRF) of different heating systems; source: [Constantinescu, 2006]*

The PRF-value describes the ratio between the net fossil energy supply and the heat energy used in building during the year. The smaller the PRF-value the higher the
District Heating

utilization of the fossil resources. Values bigger than one indicate the greater total use of fossil fuels to deliver the same heat to the building.

The average PRF of district heating is lower than other common heating systems. This means that district heating is more efficient than individual building heating systems.

**Economically:** An international study [Werner, 2006b] shows that district heating prices are on national average lower than natural gas prices. The final heat costs for district heating in the Netherlands with 11.56 €/GJ is approximately 12% below the costs of natural gas 13.2 €/GJ. This consumer price is even more competitive (in Copenhagen circa 45% blow oil heating) in high-density areas with cheap local heat sources [New York Climate Summit, 1997].

02 **Solar-assisted District Heating**

02.01 **Characteristics of Solar-assisted District Heating**

**Definition:** Solar-assisted district heating DH is a conventional district heating system (§ 01) with integrated active service devices to utilize the sun’s solar radiation as free energy. The grade of utilization depends basically on the thermal collector area and the heat storage capacity of the system. The purpose of such a system is the activation of summer’s surplus on solar energy for the winter term.

02.02 **Case Studies**

In contrast to small solar-assisted building heating systems solar-assisted DH is still in a development phase. Several studies (Figure 3-6) were executed and several solar-assisted DH systems are currently tested under realistic operation conditions. [Milles, 2000][Harvey, 2006].

<table>
<thead>
<tr>
<th>Location</th>
<th>First year of operation</th>
<th>Housing type</th>
<th>Heated area (m²)</th>
<th>Annual heat demand (MWh)</th>
<th>Solar collector area (m²)</th>
<th>Storage volume (m³)</th>
<th>Solar fraction</th>
<th>Solar heat cost (€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamburg</td>
<td>1996</td>
<td>124 single-family units</td>
<td>14,800</td>
<td>1610</td>
<td>3000</td>
<td>4500 (hot water)</td>
<td>0.49</td>
<td>0.256</td>
</tr>
<tr>
<td>Friedrichshafen</td>
<td>1996</td>
<td>570 apartments in 8 buildings</td>
<td>39,500</td>
<td>4106</td>
<td>5600</td>
<td>12,000 (hot water)</td>
<td>0.47</td>
<td>0.158</td>
</tr>
<tr>
<td>Chemnitz</td>
<td>1996</td>
<td>1 office building, hotel and warehouse</td>
<td>4680</td>
<td>573</td>
<td>540 vacuum tubes</td>
<td>8000 (gravel/water)</td>
<td>0.30</td>
<td>0.240</td>
</tr>
<tr>
<td>Steinfurt</td>
<td>1998</td>
<td>42 apartments in 22 buildings</td>
<td>3800</td>
<td>325</td>
<td>510</td>
<td>1500 (gravel/water)</td>
<td>0.34</td>
<td>0.424</td>
</tr>
<tr>
<td>Necharsum</td>
<td>1999</td>
<td>6 blocks of flats, school, commercial centre</td>
<td>20,000</td>
<td>1663</td>
<td>2700 (5000 phase II)</td>
<td>20,000 (duct) (63,400 phase II)</td>
<td>0.50</td>
<td>0.172</td>
</tr>
<tr>
<td>Attenkirchen</td>
<td>1999</td>
<td>30 apartments</td>
<td>6200</td>
<td>487</td>
<td>800</td>
<td>500+9350 (hot water + duct)</td>
<td>0.55</td>
<td>0.170</td>
</tr>
<tr>
<td>Rostock</td>
<td>2000</td>
<td>108 apartments</td>
<td>7000</td>
<td>497</td>
<td>1000</td>
<td>20,000 (aquifer)</td>
<td>0.62</td>
<td>0.255</td>
</tr>
<tr>
<td>Hannover</td>
<td>2000</td>
<td>106 apartments</td>
<td>7365</td>
<td>694</td>
<td>1350</td>
<td>2750 (hot water)</td>
<td>0.39</td>
<td>0.424</td>
</tr>
</tbody>
</table>

Figure 3: Technical data concerning solar-assisted district heating systems constructed in Germany under the Solarthermie-2000 programme; [Harvey, 2006]
<table>
<thead>
<tr>
<th>System type</th>
<th>Collector area (m²)</th>
<th>System cost (€ per m² of collector)</th>
<th>Cost of heat (€/kWh)</th>
<th>Solar utilization</th>
<th>Solar fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small DHW</td>
<td>4-5</td>
<td>800-1300</td>
<td>0.13-0.62</td>
<td>40-20%</td>
<td>50-80%</td>
</tr>
<tr>
<td>Large DHW</td>
<td>100-1600</td>
<td>400-900</td>
<td>0.09-0.23</td>
<td>55-25%</td>
<td>20-60%</td>
</tr>
<tr>
<td>Combi-system, diurnal storage</td>
<td>15</td>
<td></td>
<td>0.40-0.50</td>
<td>25-18%</td>
<td>20-50%</td>
</tr>
<tr>
<td>Combi-system, seasonal storage</td>
<td>20-80</td>
<td></td>
<td>900-1900</td>
<td>23-12%</td>
<td>70-100%</td>
</tr>
<tr>
<td>District heat, no seasonal storage</td>
<td>100-1000</td>
<td></td>
<td>400-500</td>
<td>0.10-0.13</td>
<td>7-10%</td>
</tr>
<tr>
<td>District heat, with seasonal storage</td>
<td>3000-6000 (540-6000)</td>
<td></td>
<td>620-800</td>
<td>0.18-0.30 (0.16-0.42)</td>
<td>25-28% (30-62%)</td>
</tr>
</tbody>
</table>

*Figure 5: System costs and performance for a variety of solar thermal systems in Germany; [Harvey, 2006]*
Conclusions: Following conclusions can be drawn on basis of these studies [Milles, 2000][Harvey, 2006]:

- DH systems, which include large solar collector areas (bigger than 100 m²) in combination with short and long-term heat storage, are the most efficient approaches.
- Solar-assisted district heating systems with short-term heat storage can supply between 10-20 percent of the total heat demand for space heating and domestic hot water.
- Pilot projects, equipped with seasonal heat storage, cover between 40 and 60 percent of the total heat demand.
- The cost-benefit ratio of solar-assisted DH is better than for individual solar-assisted heating systems. This is caused by the low volume-to-surface-related system costs.
- Low return temperatures in the network increase the performance of the whole system (i.e. bigger temperature differences between feed and return flows benefit the absorption of produced heat in the substation).
- The decision for a specific type of seasonal heat storage largely depends on the geological and hydro-geological conditions and the chosen site.
- The heat load of a solar district heating system should correspond to at least 20-30 residential units [Imrie, 1997].
**02.03 Thermal Storage**

For a district heating system, which is designed to utilize as much solar energy as possible, the solar thermal heat storage is inevitable. The mismatch between the offer of solar energy in the summer term and the heating demand in winter asks for a buffer.

Generally it can be said that the bigger a storage tank (in a reasonable shape) the better the surface-to-volume ratio and the smaller the thermal losses of the tank. Several sizes are used:

(a) Short-term storage systems are used mainly for the preparation of hot water and they are able to store heat for one or two days. Therefore the solar fraction (percentage of a building's seasonal energy requirements that can be met by a solar energy devices or systems) of the total heat demand is limited to about 10-20%.

(b) Week storage system have a relatively large collector area per living area of 4 to 10 m²/m² and a solar fraction of 30-40%.

(c) Pulse-heating system, which is a new, innovative storage system with several solar and buffer tanks. Experiments show a remarkable reduction of heat losses, which in consequence increases the system performance to 40-70%. [Puntila, 2004]

(d) Seasonal heat storage systems can have quite different specifications and performances (Figure 6).

<table>
<thead>
<tr>
<th>Storage system</th>
<th>BTES</th>
<th>Hot-water tank</th>
<th>Gravel / water pit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage concept</td>
<td>Hot water circulates through pipes in the ground, to a maximum depth of 150m</td>
<td>Water-tight container buried underground</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>U-shaped coaxial plastic pipes with a 1,5-3m separation</td>
<td>Reinforced concrete, steel- or fibreglass-reinforced plastic, or a pit with a cover and lid, stainless steel cover</td>
<td></td>
</tr>
<tr>
<td>Maximum 7 minimum volumes</td>
<td>&gt;100,000m³ due to high lateral heat loss</td>
<td>Ma. 100,000m³, the largest store designed so far being 28,000m³</td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>Only in the covering layer, 5-10m from the surface</td>
<td>15-30cm ob top and at the sides, and also underneath if the pressure can be withstood</td>
<td></td>
</tr>
<tr>
<td>As with hot-water tank</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage volume/flat-plate collector area</td>
<td>8-10 m³/m²</td>
<td>1.5-2.5 m³/m²</td>
<td>2.5-4</td>
</tr>
<tr>
<td>Cost (€/m³) at 20,000 m³ storage volume</td>
<td>25</td>
<td>70-80</td>
<td>65-85</td>
</tr>
<tr>
<td>other characteristics</td>
<td>Easily constructed</td>
<td>Container store is costly</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 6: Characteristics of some alternative options for storing heat underground; [Harvey, 2006]*
Appendix E  Six Step Strategy - Cradle to Cradle

Excerpt of the six step strategy (cradle to cradle) for the building industry; the approach is not reproduced to its full contents of the original; source: [Dobbelsteen et al, 2008]

1. Smart urban planning & architecture
   • Location, orientation
   • Building form and orientation in interaction with its environment
   • Zoning, compartmentation
   • Building skin, interaction with its environment

2. Direct reuse
   • Energy: heat recovery from ventilation air
   • Water: heat recovery from waste water flows
   • Materials: reuse of waste building materials from the construction process

3. Reuse after storage
   • Energy: storage and use of residual energy (heat pump)
   • Water: reuse from sewage purification
   • Materials: recycling of building materials

4. Water and materials feed energy
   • Water feeds energy: biogas and biomass from sewage purification
   • Materials feed energy: biogas and biomass from compost production

5. Energy feeds materials and water
   • Energy feeds water: residual heat is used for sewage purification
   • Energy feeds materials: energy is used for the production process of materials

6. Waste becomes food
   • Energy: stored surplus of energy is used for agriculture production
   • Water: sewage purification feeds natural surface water
   • Materials: compost of organic materials

7. Sustainable input
   • Energy: sun (photovoltaic, solar collectors), wind (turbines), water (heat exchanger, heat pump), soil (heat exchanger, heat pump), biomass, sustainable electricity
   • Water: precipitation, groundwater, surface water
   • Materials: sustainable organic materials, recyclable materials

It is also recommended to read Dobbelsteen, 2008.
Appendix F  The Price for Energy

Development of the Gas price in The Netherlands during the last 10 years:

The average gas price increase is based on the development during the last ten years. A small gas consumption (till 500 m³) is chosen as a basis.

<table>
<thead>
<tr>
<th>Perioden</th>
<th>euro/1 000 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>296</td>
</tr>
<tr>
<td>1999</td>
<td>269</td>
</tr>
<tr>
<td>2000</td>
<td>290</td>
</tr>
<tr>
<td>2001</td>
<td>432</td>
</tr>
<tr>
<td>2002</td>
<td>451</td>
</tr>
<tr>
<td>2003</td>
<td>517</td>
</tr>
<tr>
<td>2004</td>
<td>558</td>
</tr>
<tr>
<td>2005</td>
<td>701</td>
</tr>
<tr>
<td>2006</td>
<td>760</td>
</tr>
<tr>
<td>2007</td>
<td>789</td>
</tr>
</tbody>
</table>

Source: Centraal Bureau voor de Statistiek, The Netherlands

The average annual gas price increase was calculated with € 68/1 000 m³. This complies to an annual increase of 8.7%.
### Appendix G  Initial Building Design-Drawings and Calculation Results

- Standard building elements:

**Exterior Wall** = timber stud wall (d=15.7 cm, U= 0.33 W/m²K): 

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity W/mK</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaster Board</td>
<td>0.045</td>
<td>22</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040</td>
<td>45</td>
</tr>
<tr>
<td>Chipboard</td>
<td>0.130</td>
<td>15</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040</td>
<td>60</td>
</tr>
<tr>
<td>Gypsum Board</td>
<td>0.210</td>
<td>15</td>
</tr>
</tbody>
</table>

**Roof** = concrete slab with insulation (d=33.0 cm, U= 0.25 W/m²K): 

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity W/mK</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perimeter</td>
<td>0.040</td>
<td>50</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040</td>
<td>100</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100</td>
<td>180</td>
</tr>
</tbody>
</table>

**Building slab** (d=34.0 cm, U= 0.33 W/m²K): 

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity W/mK</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parquet</td>
<td>0.130</td>
<td>22</td>
</tr>
<tr>
<td>Screed</td>
<td>1.050</td>
<td>48</td>
</tr>
<tr>
<td>Impact Sound Insulation</td>
<td>0.040</td>
<td>30</td>
</tr>
<tr>
<td>Concrete Ceiling</td>
<td>2.100</td>
<td>160</td>
</tr>
<tr>
<td>Polystyrene Foam</td>
<td>0.040</td>
<td>70</td>
</tr>
<tr>
<td>Putty Coat</td>
<td>0.800</td>
<td>10</td>
</tr>
</tbody>
</table>

**Partition Wall** = three leaf concrete-insulation-concrete (d=49.0 cm, U= 0.40 W/m²K): 

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity W/mK</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior Plaster</td>
<td>0.350</td>
<td>15</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100</td>
<td>190</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.040</td>
<td>80</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100</td>
<td>190</td>
</tr>
<tr>
<td>Interior Plaster</td>
<td>0.350</td>
<td>15</td>
</tr>
</tbody>
</table>

**Windows & Door:** 

<table>
<thead>
<tr>
<th>Element</th>
<th>Specification</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window</td>
<td>Triple Glazing 4-10-4-10-4, filled with air</td>
<td>g-value = 0.77</td>
</tr>
<tr>
<td>Glazing</td>
<td></td>
<td>Ug-value = 2.0 W/m²K</td>
</tr>
<tr>
<td>Window</td>
<td>Standard PVC - high quality</td>
<td>Uf-value = 1.6 W/m²K</td>
</tr>
<tr>
<td>Frame</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door</td>
<td>Timber</td>
<td>UD-value = 2.0 W/m²K</td>
</tr>
</tbody>
</table>
### Exterior Wall = timber stud wall (d=29.2 cm, U= 0.17 W/m²K):

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaster Board</td>
<td>0.045 W/mK</td>
<td>22 mm</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040 W/mK</td>
<td>180 mm</td>
</tr>
<tr>
<td>Chipboard</td>
<td>0.130 W/mK</td>
<td>15 mm</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040 W/mK</td>
<td>60 mm</td>
</tr>
<tr>
<td>Gypsum Board</td>
<td>0.210 W/mK</td>
<td>15 mm</td>
</tr>
</tbody>
</table>

### Roof = concrete slab with insulation (d=47.0 cm, U= 0.13 W/m²K):

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perimeter</td>
<td>0.040 W/mK</td>
<td>50 mm</td>
</tr>
<tr>
<td>Mineral Wool</td>
<td>0.040 W/mK</td>
<td>240 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100 W/mK</td>
<td>180 mm</td>
</tr>
</tbody>
</table>

### Building slab (d=45.0 cm, U= 0.17 W/m²K):

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parquet</td>
<td>0.130 W/mK</td>
<td>22 mm</td>
</tr>
<tr>
<td>Screed</td>
<td>1.050 W/mK</td>
<td>48 mm</td>
</tr>
<tr>
<td>Impact Sound Insulation</td>
<td>0.040 W/mK</td>
<td>30 mm</td>
</tr>
<tr>
<td>Concrete Ceiling</td>
<td>2.100 W/mK</td>
<td>160 mm</td>
</tr>
<tr>
<td>Polystyrene Foam</td>
<td>0.040 W/mK</td>
<td>180 mm</td>
</tr>
<tr>
<td>Putty Coat</td>
<td>0.800 W/mK</td>
<td>10 mm</td>
</tr>
</tbody>
</table>

### Partition Wall = three leaf concrete-insulation-concrete (d=49.0 cm, U= 0.40 W/m²K):

<table>
<thead>
<tr>
<th>Area of section</th>
<th>Heat conductivity</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior Plaster</td>
<td>0.350 W/mK</td>
<td>15 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100 W/mK</td>
<td>190 mm</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.040 W/mK</td>
<td>80 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.100 W/mK</td>
<td>190 mm</td>
</tr>
<tr>
<td>Interior Plaster</td>
<td>0.350 W/mK</td>
<td>15 mm</td>
</tr>
</tbody>
</table>

### Windows & door:

<table>
<thead>
<tr>
<th>Element</th>
<th>Specification</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window Glazing</td>
<td>4:-16- 4-16-4, Argon 90%: Unitop 0.60-52 – UNIGLAS; Uniglas GmbH &amp; Co. KG, Montabaur, Germany; <a href="http://www.uniglas.net">www.uniglas.net</a></td>
<td>g-value = 0.520, Ug-value = 0.60 W/m²K</td>
</tr>
<tr>
<td>Window Frame</td>
<td>Timber / Purenit / PU – frame: Buck - VÖRDE Passive House Windows; H. Buck GmbH, Bremervörde, Germany; <a href="http://www.fenster-buck.de">www.fenster-buck.de</a></td>
<td>Uf-value = 0.72 W/m²K</td>
</tr>
<tr>
<td>Door</td>
<td>Timber / Insulation – composite: VÖRDE Passive House Door; Brunkhorst Haustüren, Anderlingen, Germany; <a href="http://www.brunkhorst.de">www.brunkhorst.de</a></td>
<td>UD-value = 0.80 W/m²K</td>
</tr>
</tbody>
</table>
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01 Introduction

The title ‘houses as energy delivering systems’ already implicates a rather broad and comprehensive scale of the topic. But basically the matter is nothing else than designing a certain product for a certain client. This means, on the one hand, that the product has to meet certain criterions to cause the clients’ interests and on the other hand, that it has to fulfil several requirements to embody the properties of a sophisticated and energy efficient house.

To fulfil all these needs, a designer has to acquire a lot of background knowledge beforehand. This is a pretty difficult task when having hardly any experience in this area and will cost in consequence plenty of time and money to acquire this information. Of course, several examples show that a building with a positive energy balance is feasible but the real challenge lays in finding the ‘happy medium’ between additional financial interventions and getting sustainable benefits in return.

To achieve the breakthrough on the market a certain awareness of the Dutch housing market has to be present during the development of the new product. This asks for a certain sophisticated know-how. Thus, this inventory will support the research on the topic of strategies and technologies for the design of houses with a focus on a sustainable approach to an energy delivering building.

01.01 Objective

The thesis objective is described by the following GOAL:

The development of a sustainable strategy for the implementation of the ‘Energy Delivering House’ into the Dutch building sector.

This objective is characterized by the following frame:

- Sustainability (robustness of the strategy)
- Low energy / positive energy-balance
- Ecologically
- Affordable
- Marketability (wide market acceptance)
- Domestic dwelling (terraced standard house)

01.02 Reasons to Safe Energy

During the energy crisis in the 1970s the first initiatives on the issue of saving energy in the building sector have been taken. In several countries building regulations on the restriction of buildings’ energy consumption were introduced.

Important first steps were initiated by the ‘Club of Rome’. In the year 1968 the club was founded by scientists, manager and politicians as a global organization with 100 members. The club’s major subject with all its publications and discussions was nothing less than the future of mankind. Later, due to the increase of oil production the prices for energy decreased and the ‘motivation’ to save energy got lost.

At this point two new factors appeared:
• The publication of the reports by the Club of Rome, which proclaimed the limitedness of fossil fuels. In this statement a declining of fossil fuels in the 21st century was charted.
• The discovery of the Antarctic ozone hole in 1985 by British scientists caught the public’s attention. Investigations discovered, among other things, chlorofluorocarbons (CFC) as the reasons, which are produced by the human. This sharpened peoples’ view on the human impact on the nature.

In response to a growing scientific understanding a series of intergovernmental conferences focusing on climate change were held in the late 1980s and early 1990s. The series of discussion climaxed in the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, in June 1992 and put the topic of global warming on the political agenda. Scientists, intellectual leaders, and politicians from 150 countries -in particular from industrial nations- determined on this summit meeting a reduction of carbon dioxide emission. In consequence, several programs were initiated worldwide.

Based on the before mentioned recognitions a new approach, the theory of ‘Factor Four’, was charted by Weizsäcker et al. in 1997. The book’s outline is part of the outcome of the Club of Rome and based on the following statement:

“Doubling wealth and halving resource use thus jointly indicated the magnitude of the world problematic which the Club of Rome considers to be at the core of its activities. ‘Factor Four’, in a nutshell, means that resource productivity can – and should – grow fourfold. The amount of wealth extracted from one unit of natural resources can quadruple. Thus we can live twice as well – yet use half as much.” [Weizsäcker et al., 1997]

The authors describe a basic problem in the building sector; most planners, architects, and engineers are paid according to what they spend and not to what they save. This means that a more efficient design (in terms of saving the client’s money) is not attractive because it will directly reduce their profits and even worse, will force them to work harder for a smaller fee (because their fee is usually based on a fixed percentage of project’s cost).

Achieving big savings more easily than small savings requires ‘leap frogging’. Weizsäcker et al. [1997] argue that advanced resource productivity requires integration, not reductionism. This implicates thinking about the design challenge as a whole, not as a lot of disjointed little pieces. And since the building environment consumes up to one third of the energy, the building stock is representing a significant potential in reaching the targets of the carbon dioxide reduction.

01.03 Framework for this Paper

Also the members of the European Union have given their commitment to counter global warming. The countries of the EU developed individual programmes and strategies for a reduction of the carbon dioxide emission supported by EU-policies. One logical strategy is a reduction in use of fossil fuels, which is also motivated in the predicted limitation of them. Since the Dutch built environment consumes on third of the energy [Opstelten et al., 2007] it represents a big potential.

The Dutch research institutes TNO¹ and ECN² have set up a strategic co-operation, called ‘Building Future’ with the target of a fossil fuel free built environment in the Netherlands by 2050. The co-operation states its authority in the following sentence:

---
¹ Netherlands Organisation for Applied Scientific Research TNO
² Energy Research Centre of the Netherlands ECN
“Comfortable, healthy, and sustainable working and living in the built environment with minimal burdens for energy and environment” [TNO & ECN, 2004].

The strategic cooperation ‘Building Future’ was initiated to give impulses to a transition process in the construction sector for the near future. The initiators of this programme believe that energy neutrality in the Dutch built environment can be reached by the middle of this century [Opstelten et al., 2007]. The approach behind this transition process is illustrated in the following graph.

![Graph showing energy use from 2000 to 2050](image)

[source: Annual report 2006, ECN]

The green line (1) represents a scenario\(^3\) called ‘Business As Usual’ (BAS), which illustrates the energy consumption of the entire building stock (residential and non-residential) in the Netherlands. It is taking developments like future energy consumption, building stock, global and national developments, national turnover, and economy etc. into account. It is expected that the total primary energy consumption in the building sector remains approximately on a level of 1000 PJ\(^4\) per year.

The authors of the report ‘Bringing the energy neutral built environment in the Netherland under control’ [Opstelten et al., 2007] state that two significant trends contribute to a stabilization of the energy consumption. On the one hand, gas consumption will decrease caused by measures like improved building insulation and more efficient installations. On the other hand, higher cooling needs and an increased use of household appliances (like e.g. information and communication technologies (ICT)) will cause an enlargement in electricity consumption.

The blue graph (2) describes the desired transition process (‘Building Future’) in the Dutch building sector. With first implementations of new building concepts and new interventions in the year 2015, the energy use of the building stock will be diminished in 2050. This vision requires solutions, which are sophisticated enough to be applied in 2015.

From the orange chart (3) it can be concluded that with an application of interventions on district level the energy producing built environment is feasible.

---

\(^3\) See also §01.04

\(^4\) 3.6 PJ = 1 TWh
Thus, several ‘technological’ and ‘non-technological’ interventions have to be undertaken to reach this goal. In the paper of Opstelten et al. [2007] following methods are stated exemplary:

- using efficient installations and better insulation;
- continuous reduction of energy consumption in the building/household; and
- production of renewable energy on ‘building level’.

Within the frame work of ‘Building Future’ the programme ‘WAELS III’ (Woning Als EnergieLeverend Systeem) - in English: houses as energy delivering systems- was initiated by TNO, ECN, and the University of Technologies Eindhoven (TU/e) at the beginning of 2006. This project will contribute to the desired vision and is located in the field of new residential buildings. Basically, this project is focusing on the design of new concepts for energy-delivering buildings, with their necessary innovations and new developments in products and processes. The application of this new approach should be feasible for the year 2015.

This project is subdivided into three work-packages:

- WP (A) with the focus on the building concept;
- WP (B) active solar gains; and
- WP (C) long-term heat storage. [Bakker, 2006]

Within the work-package (C) the problem of the long-term heat storage should be solved with ‘new thermo-chemical materials’ (TCM). Energy is stored during the oversupply of sun’s radiation during the summer season by a phase-change in the material and is used reversal during the heating season in the winter term.

For the highly efficient gain of sun’s free energy, new and sophisticated active solar systems are developed in WP (B). Techniques like thermal collectors and combined systems (PVT) of photovoltaic (PV) and thermal collectors (T) are investigated.

In work-package (A) the results from the other groups will be integrated in a package. In combination with new knowledge and ideas, gained from literature studies and by interviewing experts from the field, the vision of the energy delivering resident building will be realized.

This thesis work is located in work-package (A). Essentially, this paper is build up on the same basis ‘the energy delivering house’ but is developed independently with a close interaction to the group WP (A).

01.04 Future Developments in the Netherlands

One of the major issues within this thesis is the development of a marketable product. It has to be prospectively sustainable in terms of a feasible building concept for the year 2015. Designing a product for the future implicates the prediction of the future. When talking about a forecast an analysis of the past and the present is inevitable.

One of the first steps in this section is therefore the outline of the past and the present situation in the Netherlands regarding project-relevant issues like demography and energy. With the help of different analysing techniques (e.g. scenarios) and the recognition of trends a statement for the future can be made subsequently.
To have a picture of the possible potential of interventions in the construction sector the primary energy consumption in the Netherlands is classified by sectors.

18% of the Dutch primary energy consumption is attributed to the household sector. The sector demands natural gas and electricity in particular. Natural gas is mainly used for heating residential properties and for powering hot water systems [Dril et al., 2005]. According to the Dutch ‘Milieu Centraal’ [2006] the average household in the Netherlands consumes 3402 kWh electricity and 1652m³ gas (or 34.58 GJ) annually. This consumption is covered by the following ‘consumers’ [Milieu Centraal, 2006]:

### Gas consumption of average household (2.3 persons) in 2006

<table>
<thead>
<tr>
<th>Activity</th>
<th>Demand (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>1204</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>385</td>
</tr>
<tr>
<td>Cocking</td>
<td>63</td>
</tr>
<tr>
<td>Total</td>
<td>1652</td>
</tr>
</tbody>
</table>

### Electricity consumption of average Household (2.3 persons) in 2006

<table>
<thead>
<tr>
<th>Activity</th>
<th>Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing and drying</td>
<td>708</td>
</tr>
<tr>
<td>Cooling</td>
<td>590</td>
</tr>
<tr>
<td>Lighting</td>
<td>543</td>
</tr>
<tr>
<td>Heating and Domestic Hot Water</td>
<td>500</td>
</tr>
<tr>
<td>Electrical Devices</td>
<td>1061</td>
</tr>
<tr>
<td>Total</td>
<td>3402</td>
</tr>
</tbody>
</table>
The authors of the report [PEP, 2006] reveal that residential buildings are using 65% of the overall energy consumption (131 kWh/m²a) for heating (incl. DHW). The upper figures refer to different building types in different unites. But, an objective comparison is required for a unified picture of buildings' energy consumption. In the report of ECN and TNO [Opstelten et al., 2007] this comparison is been done. The following graph is evaluating the building energy usage of different building types.

The upper figure shows that in the non-residential sector the energy used for building systems / building services (HVAC and lighting) is much higher than for the other sectors. This difference is caused by higher requirements to the working environment. A possible trend could tend to develop into the application of more building systems in the residential building stock, but not as extended as in the office environment.

It is remarkable that the 'commercial building sector' uses twice as much energy than the residential sector and new dwellings have a 'slightly' better consumption profile than the average residential. Thus, diminishing the annual energy consumption for a new dwelling of 131 kWh/m² will be the key issue for reaching the ambitious target of energy neutral built environment.

After charting the present energy consumption in Dutch households a possible picture of the future (2015-2050) is drawn. But it is obvious that the future cannot be predicted with a certainty. In fact, the prediction of the future can be distinguished into certainties and uncertainties.

HVAC- heating, ventilation, air-conditioning
Certain developments are described in trends. It is assumed that these developments will take place with a high probability. For instance, trends are found on statistic based analyses and assumption or on the interpretation of current developments. In this report a distinction is made between ‘hard trends’, which are based on numerical data, and ‘soft trends’, which are based on non-numerical assumptions.

Uncertain developments are processes, which are, compared to certain developments, are more unlikely to happen. They describe future pictures which are unsure. Researchers have developed principles to meet to unpredictable future more likely. For this purpose a scenario based approached is used. The WAELS project group at TNO is using this strategy.

How do scenarios work? The purpose is clear: developing a robust strategy to meet the ‘unpredictable’ future. In a first step the dominant uncertainties for the future are extracted from a research, which might involve literature studies and expert interviews. Two dominant uncertainties, e.g. future prices for energy and shortage in housing market, are used to draw four pictures of the future by using the uncertainty’s extremes. The investigator or designer now has the choice of four futures for the product. S/he can either adapt the product design to this future or s/he can try to find the least common dominating factors for all future pictures. With these common factors a robust base can be created on which the further design will build up.

Several authors prescribe in different papers certainties and uncertainties for the future Dutch situation. The report ‘Reference Projections – Energy and Emissions 2005-2020’ [Dril et al., 2005] for instance is charting trends in the Netherlands. The legitimation for this document can be find in the project ‘Reference projection Energy, Climate and Acidifying emissions’ worked out for the Dutch Ministry of Economic Affairs (EZ) and the Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM). The used scenario is illustrated in the picture below.

![Diagram](image-url)

**Figure 3.1.1 – Overview of the WLO scenarios**

Based on this analysis two future pictures were formulated. They create the quantitative framework for the analysis of possible future developments, fact based predictions where worked out. In the first picture, ‘Global Economy’ (GE), the emphasis lies on a high economic growth of the world economy. The second picture, ‘Strong Europe’ (SE), is based on a moderate growth.

Furthermore, statements to several important issues like the energy market, demography, economy, sector developments etc. are made in the paper. Information on developments in demography and energy consumptions is from particular interest.

- Demography:
In the field of demographic development it can be concluded that the growth of the population will decrease in comparison to the period 1971-2001. A growth can still be noticed on the basis of a free migration and a high birth rate. In 2020, the population will
have increased to about 17.6 million in Strong Europe and 17.9 million in Global Economy. The population growth affects the number of households and this in turn will influence the Energy consumption of the household sector.

<table>
<thead>
<tr>
<th>Reference Projections</th>
<th>Strong Europe</th>
<th>Global Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
<td>2010</td>
</tr>
<tr>
<td>Population [million]</td>
<td>16.1</td>
<td>16.8</td>
</tr>
<tr>
<td>Households [million]</td>
<td>6.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Persons per household</td>
<td>2.29</td>
<td>2.2</td>
</tr>
</tbody>
</table>

The energy demands from households depend mainly on the increase in population and economic growth. In both scenarios, (GE) and (SE), the average number of person per household drops considerably (table above).

-Energy Consumption:
In the Netherlands, the energy consumption in both scenarios remains energy-intensive.

As a result of a temperature increase caused by climate change the energy consumption will increase less rapidly. On the one hand, relative mild winters lead to less energy consumption in space heating but on the other hand, space cooling would cause more consumption of energy in the summer term, if necessary.
The investigation on the energy prices of the market led the authors of the paper [Dril et al., 2005] to the conclusion that the prices will increase slightly in the future. This statement is quite ‘hazardous’ when considering the common public opinion and several experts’ statements.

The economic growth has an important impact especially on the number of appliances per household. Along with a higher living standard a higher consumption takes place. From 2000 to 2020 the volume of private overall consumption per household in (SE) increases by 26% and in (GE) by 49%.

More electricity applications like home security, kitchen, and bathroom devices as well as telecommunication devices are causing an increase in energy consumption in the household.

![Graph: Final Electricity Consumption in the household sector](image)

The figure above shows the increase of the final electricity consumption in the Dutch household sector from circa 90 PJ in the year 2005 to 114 PJ (136 PJ) in 2020.

Important for further considerations is the fact that the electricity consumption for cooling will undergo a sharp increase. However, the contribution of cooling to the overall household energy consumption will remain limited; in SE the use for cooling is only 1% of the electricity consumption and in GE only 2%. [Dril et al., 2005]

Which other non-statistic based trends can be recognized in the Netherlands? Here, they are described as Soft Trends, which can hardly be quantified. The Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM) describes upcoming trends [VROM, 2001]:

From quantity to quality, from accommodations to housing environment, from a policy on housing to a policy on residential environment - this describes the current wave of transitions in the Netherlands. Besides, for many more years, an acute house shortage will determine the Dutch housing policy. This policy document points out that ‘the quality of a part of the Dutch housing stock and residential environments no longer satisfy contemporary requirements’. Stimulated by a growing economy the demand for space and quality will increase. In addition, an individualization and emancipation process will take. People want a say in how and where they live. They want to shape their own residential environment. The conventional off-the-rack approach of housing in the Netherlands cannot satisfy those demands adequately. Today’s citizens are seeking a tailor-made product that can provide comfort and fulfil a range of functions.
Basically, the following developments (trends) are affecting the Dutch housing market [VROM, 2001]:

- Individualization
- Information technology
- Internationalisation
- Emancipation
- Ageing of the population
- Multicultural society

The more quantifiable developments are described in the **Hard Trends**: In the future scenarios, by the Central Planning Bureau (CPB) [Dril et al., 2005], a few key points are charted:

- The population will continue to grow;
- The number of senior citizen aged 65+ will double, from 2 million in 1998 to 4 million in 2030;
- The number of households continues to rise;
- The size of an average Dutch household continues to shrink.
Energy, of course, is only one factor that must be considered if the goal is sustainable housing. But, what is 'sustainability' and how can it be defined? The Brundtland Commission on Environment and Development gives the following definition:

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” [WCED, 1987]

Basically it is meant that the mankind has only one planet. The today’s consumed resources will cause a lacking tomorrow. The upper definition implies a sustainable development that integrates social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations.

When building a house to improve one’s personal quality of life the three domains must be considered under long term conditions. For visualization, the model ‘Triple P’ - People, Planet, Profit/Prosperity - has been developed. The term Triple P refers to the concept of the triple bottom line as formulated by John Elkington in his book ‘Cannibals with Forks’ [Elkington, 1998]. According to the triple bottom line concept, equal weight should be given in corporate activities to the following three mentioned aspects.

(Sustainable Development according to Elkington (three spheres of sustainability – economy, social welfare, environment); source: Stofberg and Duijvestein, 2006)

All products and developments could be measured and judged under these viewpoints. For this purpose certain measures and tools are outlined in chapter 02.02.

To narrow the view on the concept of sustainability housing; this approach embodies lots of ideas with enormous potentials and a variety of possible solutions. Sustainable housing means sustainable living; it is not just about saving energy. “It also means that people are happy to live where they live and that they live in a healthy environment” [IEA, 2006, page 10]. The International Energy Agency [2006] emphasizes three main aspects of sustainable housing (see graph below).
Preservation of global environment
1. Energy saving and utilization of natural and unutilized energy resources
2. Resources saving (reduction and recycling of waste materials)
3. Appropriate use and recycling of water resources

Healthy and pleasant living environment
1. Indoor and outdoor temperatures, heat and air
2. Indoor and outdoor light, noise, vibration

Harmony between the house and the environment
1. Harmony with the living environment
2. Artificial supplementation of the natural environment and landscaping according to site conditions
3. Harmony with the local community or the creation of local community

[Three main aspects of sustainable housing, source IEA, 2006, page 11]

To illustrate the sustainable approach in the building sector three examples are discussed in subsequence: (1) materials and (2) bearing structure (3) adaptability.

1. In a residential case study by the ATHENA Institute, Canada [Trusty and Meil, 1999], a benchmarking on materials used for a new building with the focus on sustainability was made. The following graph illustrates the outcome of this research. Wood, steel, and concrete are evaluated on their impact on the environment.

![Results Summary: An Example of Benchmarking](source)

The benchmark points out that a timber based design is most sustainable in almost every category than a design based on steel and concrete. This evaluation is made for a single-
family home built for the Toronto market. Thus, this investigation is depending on the local boundary conditions of Toronto and it is not customized to other locations. According to the test results a wooden building design has the smallest ‘impact’ on the environment. Applied to the Dutch circumstances this result could be, fairly treated, turn out different.

In the Netherlands, the Forest Stewardship Council Netherlands (FSC) is promoting the use of sustainable produced timber. Considering the Dutch situation (limited resources for timber) the transport distance to the Netherlands is usually rather big and usually paired with additional negative economical effects. The best environmental score can be achieved with inland hardwood [Stofberg and Duijvestein, 2006], but the resource of this wood species is naturally limited. Thus, steel and concrete based building designs offer a serious alternative considering the concept of sustainability. Therefore, making a decision for one favourite material in the Netherlands based on a strong argumentation is pretty difficult.

2. Arets and Dobbelsteen [2002] have investigated building’s bearing structure in the commercial sector with the focus on sustainability. They say that the bearing structure of a building is one of the most important aspects in considering a sustainable concept. The bearing structure has the second largest impact on building’s environmental loads. Horizontal elements are causing about 80% of the load; especially the floor and roof play a very important role. In their paper they try to find an answer to the following question: depending on the span of a structural element, which material is ecologically and economically best?

Considering the shorter spans in the residential sector (up to 6 meter), wooden floors and hollow core slabs are the most environmental friendly elements; composite floor-decks cause the biggest burden. Additionally, when taking the economical factor into account hollow core slabs are the most favourable for short spans up to 7m; wooden floor (up to 6m) is still suitable and a composite floor decks is the most expensive solution.

In order to use as less material as possible, each material should be used most efficiently. Hence, the decision of which materials is most suitable depends very much on the function of the individual material. The investigation made clear that steel has the highest environmental impact. Even if one is considering the tensile strength timber performs still better.

The report comes to the following conclusion; the relation between material qualities and their environmental cost leads to:

- High strength concrete (like B65) has the lowest environmental cost with regard to compression-strength.
- Timber (especially glulam) has the lowest environmental cost with regard to tensile strength.
- Short spans timber (glulam) has the lowest environmental and integral cost; prestressed concrete is just a little bit worse.

3. As the worlds faces a shortage on resources and the existing building stock represents the largest financial, physical and cultural asset in the industrialized world [IEA, 2004], building’s adaptability is especially relevant. “A sustainable society is not possible until this key resource can be managed sustainable.” [IEA, 2004]. The Concept of Adaptability refers to the ability of buildings to accommodate substantial change in course of time. Unlike most other products, buildings are occupied for long periods and their use-phase can be more significant to the environment than all other phases combined.
When considering the framework of this thesis, especially the timeframe 2015-2050, another motivation for using the concept of adaptability is reasonable.

The future is unpredictable!

Which developments will take place in the society, economy, and environment in the near future? Which products will be developed within the next 20 years? Can we assume that these products will have a better performance than current products? Will the energy market in Europe, the Netherlands change significantly? Would it be wise to do some additional investments into the building to improve its performance in the near future? Many more questions can be stated and will be still unanswered.

An important role on the environmental impact of the product building plays the behaviour of the occupant. But this behaviour is pretty unpredictable and is close connected to the functional operation of the building.

The only ensured prediction is that the building will be changed in time.

How can this ‘change in time’ applied logically to the building? Depending on the ‘sharing layer’ [Brand, 1995] the change will take place either in rather short time or in a long term. Brand’s model of the ‘sharing layers of change’ embodies six layers:
- Site, “the site is eternal”
- Structure, lifetime from 30 to 300 years
- Skin, changes every 20 years
- Services, working guts of the building, lifetime 7 to 15 years
- Space plan, interior layout, commercial space 3 years and homes 30 years
- Stuff, changes weekly.

This approach is visualized in the following picture.

Thus, change is inevitable, both in the social, economic and physical surroundings, and in the needs and expectations of occupants. A building that is more adaptable will be utilized more efficiently, and stays longer in service. The building can respond to changes at a lower cost and the longer and more efficient service life may, in turn, translate into improved environmental performance over the lifecycle.

The concept of adaptability can be addressed with some simple strategies [IEA Annex 31, 2004]:
- flexibility, i.e. allows for minor shifts in space planning;
- convertibility, i.e. allows for changes in use within the building; and
- expandability, i.e. facilitates additions to space in a buildings.

Why predicting the future when you can adapt to the future?

The Chinese architect and interior designer Gary Change is specialized on the concept of adaptability In Hong Kong, he uses his flat (32 m²) as a laboratory to develop new ideas and actually live this philosophy. His apartment gives insights into the maximum possible.
The International Energy Agency [2004] comes to the conclusion that the capability to respond to changing circumstances may decrease the resource use within the building sector by 20 to 30%. Achieving adaptable designs and materials is depending upon additional investments. Those investments can achieve a significant improvement in the environmental performance of the world’s building stock in at least three ways:

- more efficient use of space (multi-functional);
- increased longevity; and
- improved operating performance.

Thus, over a building’s lifetime, change is inevitable. A building that is more adaptable will be utilized more efficiently and stays in service longer. This in consequence matches the definition of sustainability in an ideal way.

01.06 Integrated Design

The design of a sustainable building turns into a complicated task if one simultaneously addresses all the three spheres of sustainability – economy, social welfare, and environment. But it also shows the opportunity to improve all three. For instance, a lot of measures in ‘advanced’ sustainable building design are taking place without framing the whole building performance in an integrated approach. A design, for example, is only optimised with the focus on one issue like energy performance within economic constrains; it is not considering issues in comfort, environment, and aesthetics.

The solution for this problem is an integrated approach, which addresses the wide range of complex issues within the fields of building physics, environmental sciences, architecture, and marketing. Sustainable building design views the individual building systems and components not as isolated entities, but as closely connected and interacting with the rest of the building. Only by achieving synergy across a broad range of goals is it possible to significantly reduce the energy-related environmental impacts of buildings [IEA Annex 31, 2005a]. The best way to respond to this issue is an integrated approach.

The Integrated Design Process (IDP) addresses the multi-disciplinary nature of design. It is able to functionally integrate environmental performance with other major functions. Diverse design criteria need to be traded off against each other in order to make decisions for the ‘overall goodness’ of the design. IDP demands for the creation of a design team with a wide range of skills from technical experts, local stakeholders and partners. Furthermore, the close cooperation between the design team and the client is indispensable for the success of a successful building project.

By nature of the design process, the best possibility to influence the outcome of the end product is at the beginning (see figure below). Thus, well-integrated sustainable building can be achieved by measures in the early stage of the design process. A ‘whole system engineering’ approach may be used to support a broad thinking on technical options [IEA Annex 31, 2005a].
Compared to later phases, the planning process offers the widest scope for decision-making. Design decisions have a large (mostly indirect) effect on the entire life cycle of a building. They affect the maintenance and recycling ability as well as the energy expenditure required to run the building.

The planning process can be subdivided into several design stages ((a) Initiate and Development, (b) Design, (c) Construction, (d) Completion). With each consecutive stage the freedom of choice decreases while the degree of definition and detail increases.

For the complicated process of integrated design, it is useful to follow a structured approach in order to ensure proper consideration of all important issues, as well as to formalize the evaluation process and to make the value judgments as consistent and transparent as possible. For this purpose several tools are available, for example Multi-criteria decision-making [see chapter 02.04].

When talking about integration the incorporation of space or better the level of interventions can help to design an improved sustainable product. Stofberg and Duijvenstein [2006] conclude that the ‘level of interventions’ has a crucial role for the energy issue in a building design. The following picture illustrates these levels.

This model can even be extended by the next levels: province, country, and Europe. The better the integration into the superior layer the better the product. For instance, to illustrate an extreme picture of the future, Europe grows together, boundaries are removed, the European electricity market is international. Why not producing electrical
power with photovoltaic plants and a maximum efficiency in Spain and transport this power via open international electricity grid to the northern countries of the European Union? What are the obstacles for a realization of this picture? The basic problem lies in the mismatch of power and willingness. People, organisations, institutes might have the power but are not willing to change something or the other way around.

01.07 Innovation in the Dutch Building Sector

The construction sector is blamed to be over conservative and low on innovation. A number of studies have been done on this problem. One general conclusion is that the level of innovation in the construction sector needs to increase. The involvement of suppliers in the process of innovation has not occurred to the same extent in the construction sector like in other sectors. This is illustrated in the fragmented design process where suppliers are usually excluded from. Communication between internal networks is viral for the success of innovation.

There is no unique definition of ‘innovation’ but the OECD classifies it as: “A technological product innovation is the implementation/commercialisation of a product with improved characteristics such as to deliver objectively new or improved services to the customer. A technological process innovation is the implementation/adoptions of new or significantly improved production or delivery methods. It may involve changes in equipment, human resources, working methods or a combination of these.” [OECD, 1997, paragraph 24]

This definition uses both, the term of ‘technological product innovation’ and the term ‘technological process innovation’. Donkervoort & Geurts [2006] revive these terms in their definition of innovation in the building sector. They conclude that a break through in the construction sector, and not only there, can be only achieved by innovate both, the product and the process.

Innovation is caused by the pursuit of improvement in primary processes with the passion of who is initiating the improvement. Innovation in the building sector is basically initiated by three sub sectors [Donkervoort & Geurts, 2006]:

1. Architects and advisors are deciding during the design phase which materials and products are going to be used. There are leading during the design phase.
2. Contractors and construction firms have an important role during the realization of the building and initiating smart improvements in accelerating building processes, decreasing risks or instructions. Improvements are implemented by using existing products without restraining the freedom of design.
3. The suppliers of building products are looking for the niche in the market, they want to sell there products. Hence, they are developing new products or seeking for new markets for existing products. These products usually have to be accepted and applied within existing building processes.

Again, many different actions have been already initiated on what is believed to be the problem but a break-through is only achieved by improving processes and products at the same time. This approach is pictured in the following graph:
Regarding Lichtenberg [2002] restraining factors for innovation in the Dutch construction sector are:

- Fear for the unknown, to invest in high risk activities;
- Hesitations towards interaction with competitors or other players;
- The craft related and serving business attitude and lack of innovation experience;
- The financial position in relation to the expected investments;
- The limited scale of many companies and the limited available financial and human resources;
- Dependency of suppliers.

Furthermore, the small scale and fragmentation of the business as a whole, the complex market, and limited competition in Europe are other explanations for non innovation behaviour.

Compared to other industry sectors the budget for research and development in the building sector is infinitesimal. For example, a budget of 10-20% of the turn over in the pharmaceutical industry is invested into research and development (R&D). The Dutch construction related industry, in contrast, invests only 0.3% (50 million out of 16 billion turn over) into innovation; it is just a fraction [Lichtenberg, 2002]. 70% of the Dutch construction related companies appear not to be active in R&D.

Lichtenberg [2002] concluded in his thesis that the limited effort in Research and Development is based on ‘fear for the unknown’ and the determined static building sector. This facts lead to the conclusion that product and process development is not a part of companies’ philosophy.

After Lichtenberg the quite long product life cycle in the building sector is caused by this low R&D rate and the small-scale of competitors in this industry. Shorter life cycles would lead to new, innovative products with an improved performance. To give a comparison from the car related industry the average live cycle of a car is 11 years and it changes its owner every 4 to 5 years. Buildings and its components have usually a lifecycle of more than 50 years and they seem to last for an eternity. Referring to a car, the behaviour of consumers creates a competitive environment on the car market by always asking for new and improved products. Even if one have to admit that the car is still based on the same principle since it was invented by Gottlieb Daimler in 1886, the whole product development is characterized by a highly dynamic process.

Lichtenberg [2002] points out that within the next 10 years a major reorganization of the building market will take place. This will effect both, building processes (incl. the organizations and parties behind) and building products. New building concepts will be
developed in consequence. In the publication “built in 2020” [Walch, 2001] the authors chart the future house as a concept based product. Their idea, for instance, is the separation of the product building into 6 classes. The client will choose from this selection his/her favourite and can personalize the standard home with a variety of features. These new concepts show new opportunities and space for innovation simplifying and standardizing.

The construction process will be more industrialized and will be shifted from the site to the factory. The construction process suffers form the 3D-syndrome: Dirty, Dangerous and Difficult. With prefabrication components of the building are produced in the factory within a controlled working environment and will lead in consequence to a clean, fast and safety assembling on-site. This results in a higher quality. Furthermore, the main-contractor’s risks are smaller and lots of work is out-sourced to subcontractors in the prefabrication.

Several Dutch contractors are already producing in the factory. For instance, 50 per cent of the concrete based structures in the Netherlands are prefabricated in a factory. This development continues and will influence the whole construction sector. Exemplary, the concept of floating houses can be mentioned here to illustrate one feasible ‘extreme’, where the whole building is prefabricated in the factory and shipped to the site after (see picture below).

![Floating House, www.arkenbouw.nl, Urk, Netherlands; © Chris Geurs]

Traditional concepts will be challenged with new sophisticated approaches and without a decent marketing strategy the product won’t sale. ‘Marketing and Strategy’ is a core competence for innovation and not yet incorporated in the construction related industry. Marketing is inevitably connected to successful innovations (see chapter 02.03).
Strategies

For the successful design of a complex product, like a building, fundamental and consistent decisions have to be made. As already mentioned before (§ 01.06), the best opportunity to influence the product’s final performance is right at the beginning of the whole design process. A clear picture of the product at the start of its development will help to create a uniform process. For this purpose strategies, which frame the image of the product, have to be worked out and have to be function as the basis for further decisions.

Some of the subsequently examined strategies are already know since ancient time, some are new and some of them (so far) only applied unconsciously. For the implementation of these approaches several technologies can be used. Some technologies are described in a later chapter more in detail.

To create a sound product, principle choices in the fields of energy (§ 02.01), ecology (§ 02.02), and marketing & economics (§ 02.03) have to be made. To simplify and control the complex process multi-criteria decision-making (§ 02.04) can be applied.
02.01  Energy

Introduction

When talking about strategies in the context of ‘energy delivering houses’ one first have the use of photovoltaic panels on top of the building’s roof in mind. The layperson may think that this is enough. But the topic of energy-strategies is more comprehensive and obviously it cannot be avoided since the basic motivation for this research is to save energy.

The house as an energy delivering entity is already reality. Several examples of autarchic buildings or buildings supplying power to the electricity grid proof that it is currently possible to cover the household’s energy demand (and even more) by ‘free’ energy (renewable energy) completely. But these examples also illustrate that this comes along with the extensive application of building services, which means in consequence additional costs. This is the challenge, finding economically attractive solutions. The examples show that the more economical way is to use conventional energy as efficiently as possible to cover the last small fraction of the energy demand [Hastings and Wall, 2007a]. From this cognition a logical strategy is derived.

One of the most popular approaches in the Netherlands was developed at the Delft University of Technology and can be described in three steps:

1. Minimizing the demand of energy;
2. Using ‘free’ energy to cover as much as possible of the energy demand from the economical viewpoint; and
3. Using conventional energy to cover the rest demands.

Scientists from the institute ‘Novem’ (today SenterNovem) have introduced for this three-step strategy the term ‘Trias Energetica’ in the year 1996 (see picture below).

Of course, when applying the ‘Trias Energetica’ the following questions will come up: Is the ‘Trias Energetica’ generally suitable for the design of an energy delivering house? When the building is energy delivering, does this three-step-strategy have to be adapted? When the triangle represents the energy demand, how will it look like when the supply is exceeds the demand?
There are a few strategies for tackling the problem of sustainable solutions in house design. All of these approaches can be dedicated to one of the three steps in the 'Trias Energetica'. The following strategies are of interest within this section:

1. Conservation and Recycling of Energy (§ 02.01.01)
2. Passive Solar Design (02.01.02)
   (a) Heating (§ 02.01.02.02)
   (b) Cooling (§ 02.01.02.03)
   (c) Daylight (§ 02.01.02.04)
3. Active Solar Design (§ 02.01.03)
4. Production of Remaining (Residual) Energy (§ 02.01.04)

These approaches are very different in their individual nature and they have to fit to the personal values and priorities of the home-owner or investor. The main priority in the action of designing is given to the drastic reduction of non-renewable energy consumption of the building while at the same time an improvement of comfort is requested, too.

Nevertheless, the goal is clear: the energy producing house. The designer should focus on the proper use of his/her tools. The following approach represents a refined and logical solution for this purpose. A four-step-strategy in coherent order illustrates the interventions/tools, which are available during the design process. The figure ‘Pyramid of Interventions’ illustrates this idea.

Basically the triangle is representing the field of interventions, which are available during planning processes to reach the goal of a sustainable design for an energy+ house. Starting at the bottom of the pyramid the designer has four subcategories within the variety of possible treatments and tools. Each field has its own specific characteristics and its own approaches and strategies. The emphasis within the pyramid is illustrated by the captured areas of each of the four fields, i.e. rather big field should get the correspondingly attention.

‘Conversation and Recycling of Energy’ is the fist step on the path to an energy+ building. The conservation, thus, not using energy is a logical beginning and it comes along with the optimal use of energy (recycling). The next reasonable step is ‘Passive Solar Design’ shows opportunities to gain free energy passively. It is followed by the active use of sun’s energy and in the last step, on top of the pyramid are the interventions for the ‘Production of the Remaining Energy Demand’ located. They are used in the last step to cover peak loads of the demand by means of conventional and non-solar based techniques.
Conservation and Recycling of Energy

Introduction

First of all, the First Law of Thermodynamics tells us that energy can be neither created nor destroyed. When talking about ‘Conservation of Energy’ than is meant the efficient use of energy. Here the Second Law of Thermodynamics comes in, which says that the quality of energy is degraded every time energy is used in any process. This ‘energy quality’ has been named exergy. The amount of energy in the universe remains constant (First Law), but exergy is constantly used up (Second Law).

Under the head of the International Energy Agency (IEA), ‘LowEx’ - the international research programme for Low Exergy Systems for heating and Cooling of Buildings was initiated. The aim of the programme is promotion of the rational use of energy [Ala-Juusela, 2004].

Thus, when addressing the issue ‘saving energy’ it is meant the efficient use of ‘energy quality’ (exergy) and this also includes the recycling or reuse of already used qualities.

One of the first and most simple strategies is the limitation of energy. Logically, energy that is not needed is the most ecological energy. Thus, the focus should be on the preservation and reuse. The highly insulated, tight envelope of a building and heat recovering will play a major role in order to achieve this goal. In a next step the remaining energy needed will be generated by using a maximum of ‘free’ energy, i.e. passive solar gains, daylight, and active solar thermal systems etc. But first more details on conversation and recycling of energy.

The authors of the book ‘Sustainable Solar Housing’ [Hastings & Wall, 2007a] state that the conservation of energy includes an all over consideration of the following principles:

1. Reducing transmission and infiltration losses;
2. Reducing ventilation losses;
3. Reducing energy needed to heat domestic hot water; and
4. Reducing energy use of running technical systems (fans, pumps, controllers and other electrical devices).

The following picture illustrates the proportion of losses regarding these four principles and gives in consequence an indication on the potential for each of them.

By adding all losses from a building and categorizing it into the four types of losses it is clear that transmission and ventilation amount more than two third of the overall losses. It has to be noticed that this analysis is independent from the energy use of a building (§ 01.04). Thus, ‘energy use’ versus ‘energy losses’. It is remarkable that the losses
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connected to the use of electrical power are negligible small. 47 % of the energy is lost by transmission through the envelope of a building and 30% ventilation by air-exchange.

1. Reducing transmission and infiltration losses

As mentioned before, one part of the lever arm in minimizing the building’s demand on energy is the reduction of transmission and infiltration losses. The following interventions are commonly known in the professions of the designers. To picture the full spectrum, transmission losses can be drastically reduced by:

• improving the building’s insulation;
• using active insulation (compensation envelope heat losses by passive solar gains);
• interrupting thermal bridges across constructions; and
• making the building form more compact (reduction of the envelope heat losses, A/V ratio).

Thoughts on improved insulation and the interruption of thermal bridges are the first interventions which come to the designer’s mind. The active insulation is, so far, not popular in the construction sector and the compact building form is usually restricted to the architect’s or client’s perception of beauty or the urban planning.

Basically, the quality of building insulation is expressed in the U-value, which represents the conductivity of a material or component (façade unit). This means in consequence, the higher the conductivity of a façade element the higher the heat loss. Today, lots of variations of façade systems -based on several material applications and layering techniques- are on the market. Thus, simply said, in order to improve a building’s insulation properties, one has to apply a façade system with a smaller U-value (conductivity). Some examples will be discussed in a later chapter of this thesis.

Active or Transparent Insulation Material (TIM) can help to compensate heat losses by using passive solar energy. In addition to its insulation capabilities TIM gains energy through solar radiance. The material of the TIM is conditioned to transport the direct and diffuse sun light to the interior wall. The heat is stored in the wall and will be emitted to the room with a delay. The annual energy gain per square meter of transparent insulation amounts up to 30-120 kWh [IDEA, 2007].

Today’s standard in building practice is to prevent thermal bridges in the envelope. Besides a waste of energy they can cause condensation problems. The appearance of condensed water will cause possible mould development and the deterioration of air quality in a later stage. Several techniques and products are on the market, for instance thermal break profiles for windows or structural thermal breaks for balconies, can prevent negative effects.
A high compactness of a building contributes also to a reduction of transmission losses. Some planners argue that the surface-to-volume ratio (A/V-ratio) is playing a significant role in the energy consumption. In consideration of the A/V-ratio minimalistic facades and roofs without dormer or bay should be used. The reduction of A/V-ratio by 0.1/m benefits the heating-energy demand with 10 kWh/m²a and decreases the costs for construction in addition [Erhorn et al., 2001].

2. Reducing ventilation losses

After the insulation of a building (walls, windows, roof and foundation-slab) is optimized and transmission losses are minimized the losses by ventilation represent the biggest fraction in undesirable energy losses.

Essential for a high-performance house is an air-tight envelop. High performing air tightness can hardly be realized on common market price level, especially for light constructions made from timber. Besides the reason to reduce the energy consumption of a building a proper building tightness can avoid moisture condensation problems, can avoid uncomfortable drafts by cold air leaking in from the outdoors, and makes sure that the home’s air quality can be controlled. Hence the air exchange rate needs to be examined closer.

Professional energy auditors use a so called ‘Blower Door Test’ to help to determine a building’s air-tightness. During this test a negative pressure will be produced inside the house. With the help of instruments like a smoke pencil air leaks can be detected and the over all air-tightness of the building can be measured by monometers and hoses, and finally quantified.

Crucial for a long-life consideration is the durability of the components. For example, since a contemporary building façade lasts in average 20 years taped joints must be composed with adhesives that will maintain their bond over this period. Thus, like for every other product, the component’s durability has to be compatible to its functional lifetime.

Simon and Simon [2004] state in their book frequent leakage areas: hollow core brickwork, hollow core slabs, obtuse wall junctions, window junctions, window shutters, drills for the power supply, and places with change in materials etc.
In order to reduce the amount of energy consumed for ventilation a first step is to ensure that no spaces are excessively ventilated. Yet a planner should not exaggerate his/her actions. A minimum ventilation rate is requested and prescribed by the determination of human and hygienic requirements. Thus, the air exchange rate cannot be dramatically reduced and has to meet certain standards. After sealing the building’s envelope the compliance with required ventilation standards can probably not be fulfilled without extra measures.

This leads to the topic of controlled ventilation by means of mechanical systems. In many designers’ opinion a mechanical ventilation system is inevitable to achieve a high performance. Instead of releasing used air to the environment, heat recovery systems are installed to recycle the energy, which is stored in form of heat, in the indoor air. The recycling of this air will reduce the heat losses by ventilation by preheating the inlet air. Of course, the question of the payback of the additional investment will arise. Optimized components, i.e. reduced fan power, tuned timing of air flow, and minimized duct length (short is beautiful), will benefit economical considerations.
3. Reducing energy needed to heat domestic hot water

One fifth of the energy losses are caused by wasting hot water. The major part of the losses can be prevented by recycling the energy, which is stored in the waste water.

Planners use standardized figures, prescribed by the building codes, to dimension a building’s hot water services. Basis for this dimensioning is as assumed standard consumption. This standardized consumption is a question of the occupants’ behaviour and it varies from country to country. Obviously, a key step is to specify and use devices that have a minimal hot water demand. These devices have compared to other building part a relatively short life-span (see ‘sharing layer’ § 01.05). This in consequence opens the opportunity to install a more efficient component when a replacement is needed.

The strategy of a reduction of DHW-losses includes, as already mentioned, energy recovery (e.g. tube in tube shower application). Drain-water heat recovery (DHR) devices, for instance, recover heat energy from drain-water. This energy can be used to preheat cold water going to showers, water heaters or other devices. The savings in water heating energy depends on properties of the system itself, on the specific installation, and hot water consumption patterns.

Measurements show that savings of 30 to 50% for the energy needed on heating shower water seems to be reasonable. Paybacks range from 2.5 to 7 years, depending on how often the system is used [DOE, 2005]. Such heat recovery systems tend to require an unacceptable amount of maintenance states Hastings and Wall [2007a]. The producers of such systems on the other hand are selling their products as maintenance-free.
4. Reducing energy use of running technical systems and household appliances

The term running technical systems refers in the first place to the mechanical systems of the buildings services. The planner can directly influence the performance of a system by choosing the right components and settings. It can be assumed that the designer’s choices is orientating on the best available technologies.

What the planner can not influence is the equipment of the occupants’ home with household appliances. They actually show a big potential in minimizing the annual electricity bill. By applying Best Available Technology (BAT) in the housing sector a large saving potential can be utilized. The technical potential from highly efficient electric appliances is very large and requires little or no change of the users’ habits or comfort level [Eichhammer, 2000]. The ‘MURE’ report by Eichhammer [2000] demonstrates the potential impact of those technologies (in this case mechanical systems are included) on the energy consumption. Taking Germany as an example, it turns out that (depending on the used scenario) saving potentials of 12, 15 or 34% can be generated for the electricity consumption. In the United Kingdom, the highest potential was just 25% [Fenna, 2000].

The energy consumption of electric appliances has been raising steadily since 1970 through a combination of increased ownership and different user patterns. The introductions of minimum standards across the EU have lead to a reduction in consumption, notably cold appliances (freezer, fridge). A decrease by 20-50% of energy consumption can be expected [Fenna, 2000] as a consequence of technical progress and energy labelling.

Another study by Hiller [Hiller 2003] confirms a saving potential for house appliances of circa 55% when applying BAT. For an extended tabulation.

5. Other approaches

It has to be mentioned that there is a big variety of other concepts in application. Approaches like the zoning concept, for instance, which is not so popular, are also used to conserve energy. The zoning of a building is the arrangement of rooms with different heating levels next to each other. In this concept an optimization of the heat flow/use within a building can be achieved by planning the rooms hierarchically. Following the principle of an onion skin the room with the biggest heat demand is located in the centre. Thus, the heat losses can ‘flow’ to the adjacent rooms with a smaller heat demand (‘recycling of heat losses’). The disadvantage of this principle is a probably increased temperature in the ‘core’ during the summer months and less usable passive energy.

Generally, non heated rooms should be located in the north of the building; low heated rooms like the bedrooms and the kitchen located to the north, northeast; normal heated rooms to the south. [Simon and Simon, 2004] [Weber 2001]
02.01.02 Passive Solar Design

02.01.02.01 Introduction (Passive Solar Design)

Sunlight can provide ample heat, light, and can induce summertime ventilation into the well designed home. Passive solar design can reduce heating and cooling energy bills, increase spatial vitality, and improve comfort. Flexible passive solar design principles typically facilitate energy benefits with low maintenance risks over the life of the building. It integrates a combination of building features to reduce or even eliminate the need for mechanical cooling and heating and daytime artificial lighting.

Thus, passive solar design comprises:
- Heating (§ 02.01.02.02);
- Cooling (§ 02.01.02.03);
- Daylight (§ 02.01.02.04).

The most important characteristic of passive solar design is that it is holistic. That means that it relies on the integration of building’s architecture, materials selection, and mechanical systems to reduce heating and cooling loads.

Passive solar design implicates a consideration of local climate conditions, such as temperature, solar radiation, and wind. Thus, meteorology is one major factor, which affects the passive energy generation. It basically concerns maximising sun’s solar radiation use. The intensity of solar radiation on earth’s surface is narrowly 1.0 kW/m². Due to certain obstacles (atmosphere, clouds etc.) the average solar radiation is decreased to 200 W/m² [Simon & Simon, 2004].

Passive solar design, of course, influences a building’s architecture. An adapted concept usually consist of: building with rectangular floor plans (elongated on an east-west axis); a glazed south-facing wall; a thermal storage media exposed to the solar radiation; overhangs or shading devices which sufficiently shade the south-facing windows from the summer sun; and windows on the east and west walls; and preferably none on the north walls [WBDG].

Not only the architectural design is affected also the urban planning. Energy-conserving planning and passive solar design begins with the optimized site selection. This optimisation starts already on district level, respectively in the urban planning design stage. The thesis work of Sabine Gabriel [Simon and Simon, 2004] could proof for instance that with little an effort in rearranging the master plan of a district a large optimisation can be realized. Several design guides help in optimizing urban design. [Simon and Simon, 2004, page 226ff.]

Passive solar design is cost-effective at today’s energy prices, but it requires the thoughtful integration of building design with the natural features and topography of the building lot. Guidelines recommend that the building’s southern exposure must be clear of large obstacles that block the sunlight (e.g. tall buildings, tall trees). Although a true southern exposure is optimal to maximize solar contribution it is neither mandatory nor always possible. Provided that the building faces south within a maximum deviation of 20-30 degrees (sources differ a little) the passive solar gains can be used to its maximum. The deviation of the building’s orientation to the south has minor influence on passive gains; according to DOE [2005] south-facing glazing will still receive about 90 percent of the optimal winter solar heat gain.

The design guide of Wortmann [Wortmann et al., 2002] originates in a computer simulation that a south façade’s deviation of maximal 45 degrees from south orientation is possible without large negative impacts.
The picture illustrates that a 45 degrees deviation will result in 5% higher energy consumption. Compared to the case of northern exposure (180 degrees) with an increased consumption of 22% a maximum deviation of 45 degrees is reasonable.
02.01.02.02  Heating (Passive Solar Design)

Passive solar heating is just one strategy in a selection of design approaches. In particular it makes use of the building components to collect, store, and distribute solar heat gains to reduce the demand for space heating. It does not require the use of mechanical equipment because the heat flows by natural means (radiation, convection, and conduction) and the thermal storage is in the building structure itself. This strategy is in strong relation to day lighting and window properties.

Passive solar heating design starts, like every passive measure, with the first thoughts during the initial phase of a project (see § 01.06). The whole building approach evaluates it in the context of building envelope design, day lighting, and heating and cooling systems. Window design, for instance, and especially glazing choices is a critical factor for determining the effectiveness of passive solar heating. Compared to active solar systems (§ 02.01.03) passive solar measures cause no or relatively low additional initial building costs because this principle is basically just a smart application of already existing measures. [WBDG]

The principle of passive heating generally could be used first with the application of glazing in houses. It was firstly used by the Romans, which applied window glazing in their houses in 400 BC for decoration purposes. Since circa 600 AD window glazing is used to keep the sun’s heat inside the building.

Principally, net passive solar gains occur when the solar input exceeds the heat losses of the window. The solar gains have to be higher than the losses by transmission and air leakage (see picture below).

Hastings and Wall [2007a] give an exemplary calculation for the net passive solar gains of a modern conventional window (U-value 1.0 W/m²K). It turned out that on a sunny day with an average solar radiation of 300 W/m² a positive solar gain can be achieved while on an overcast day (radiation 75 W/m²) the balance will be negative. This calculation therefore shows that even with today’s standard windows a positive balance can be achieved. But the critical issue is not the balance; the question is whether the gains occur when they are useable.

Two crucial factors, namely (a) meteorology and (b) glazing, affecting the ‘income’ of passive solar heating in a high-performance house are worse a closer look.
(a) When talking about meteorology it basically is meant the possible useable radiation impact from the sun, which of course differs during the seasons and depends on weather situations. One major objective behind the use of the passive solar approach is the minimization of the heating season length to the mid winter months (when days are shortest and solar radiation weakest). Solar gains can be used most efficient in spring when the heat demand still exists and the days are longer and the sun stronger. This effect is illustrated in the graphic bellow, which shows the difference of a high performance house compared to a standard house.

![Diagram showing energy demand and solar gains for standard and high performance houses](image)

While the standard house has to cover the energy demand form October till May the high performance house can decrease this period to November till March. Again, the biggest potentials can be used in spring (March till May), when the solar impact from the sun (expressed by gains of solar collector) reaches adequate values for passive solar gains.

These boundary conditions, described by the meteorological circumstances, can not be influenced by the planner. But the following issue can be determined by the planner.

(b) Glazing: The window selection is a crucial factor, too. Heating with solar energy is simple when considering a window’s heat balance. The natural properties of glass let sunlight through but trap long-wave heat radiation (greenhouse effect). The challenge is to properly size the south-facing glass and specify its other properties to balance heat gain and heat loss without overheating.

Glass with a high performance reduces the amount of solar energy that penetrates into the house by means of low emissivity coatings and typically three layers of glazing. The energy performance of windows depends on factors like passive solar gains (g-value), thermal insulations (U-value) and air leakage. Window Energy Rating Systems (WER) can help to get an objective rating on window qualities [BFRC-British Fenestration Rating Council].
Commonly used is a heat insulating glazing with a heat flow rate of $U=1.1 \text{ W/m}^2\text{ K}$ in a standard housing has a glass transmittance or 60% (g-value=0.6°). For High performance glass ($U=0.5 \text{ W/m}^2\text{ K}$), the g-value can be easily 0.4. Good glazing provides has a transmittance of 50% and higher [Hastings and Wall, 2007a].

The glass industry developed products for the market with a multiple improvement in insulation quality (during last decade: 5x improved insulation quality of windows, 10 x decreases in heating demand). The following picture gives an overview on available glazing-products.

![Glazing products comparison](image1)

Ultimately, the optimum choice of window and glazing systems will depend on many factors including the building type, the local climate, utility rates, and building orientation.

The extent to which direct solar gains reduce heating peak load is confirmed by monitoring. From the collected data, two observations can be made: 1. The extent that heating peak load decreases with increasing solar radiation; 2. as the ambient temperature decreases measured heating peak loads are furthest from the theoretical demand. This effects are visualized in the following graph.

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The g-value indicates how much direct + indirect energy is delivered by the window relative to the total radiation striking the glass.
By the use of solar gains the heating peak load of a building’s heating systems can be decreased. This in consequence means that every planning mistake has a critical impact on the micro-heating system caused by a smaller capacity in the compensation of errors.

Conclusion: Solar gains through windows make small but useful contributions. This is caused by the shortening of the heating season. The window area should not be over-dimensioned (max 50% of the south façade) and highly insulated with good frames ($U_{\text{window}} = 0.8-1.0 \text{ W/m}^2\text{K}$). In this point literature differ a little. Erhorn et al. [2001] recommend a maximum window area of 70% in the south facing façade and 15% in the east and west. Generous window areas can be important for daylight, view out and value of the real estate. With a good window construction and effective exterior sun shading, passive solar gains can modestly decrease auxiliary heating demand in winter without causing overheating in summer [Hastings & Wall, 2007a].

Design advice
The apparent concern for an overall reduction of energy consumption has caused a re-examination of alternative technologies and systems. Published research has shown that a return to alternative energy sources, techniques and systems can be used to satisfy a major portion of the cooling needs in buildings. Followed by the energy crisis in the 1970s a very active area of research, named natural and passive cooling, has been developed. These cooling strategies manage cooling needs without the extensive requirement of additional energy or the use of other major mechanical systems.

Before the development of mechanical cooling systems the use of cooling techniques was not based on the understanding of the physical processes involved, but rather on conceptual experience. Mostly simple applications like air movement through open spaces, external and internal shading, the use of materials etc. were used. People kept their homes cool by using natural methods like: breezes flowing through windows, water evaporating from springs and fountains as well as large amounts of stone and earth absorbing daytime heat. These ideas were developed and used over thousands of years as integral parts of building design. Today they are called ‘passive cooling’. Ironically, passive cooling is considered as an ‘alternative’ to mechanical cooling that requires complicated refrigeration systems. By employing passive cooling techniques into modern buildings, mechanical cooling can be eliminated or at least reduced in size and cost.

Passive cooling is based on the interaction of the building and its surroundings. Strictly speaking, passive cooling is an approach without causing additional energy expenses. Before adopting a passive cooling strategy, one must be aware of the local climate. In general, the strategy for reducing cooling energy in the home is as follows:

(a) prevention of exterior and interior heat gain;
(b) heat gain modulation; and
(c) heat dissipation.

Examples in extended application of air conditioning systems in office buildings illustrate the necessity of a closer look to ‘alternatives’. Offices usually have a big internal heat load. Nevertheless, providing employees a comfortable environment, technique in form of air conditioning systems is extensively applied. A comparison of the annual specific energy consumption for cooling in large air-conditioned office buildings all over Europe shows a variation in the energy consumption of those systems of about 15 to 110 kWh/m². Since the whole building design is considered under the issue of sustainability it cannot be seen as the best solution.

Once have to keep in mind that the goal of air convincing is to provide comfort for the occupants of the house, not to maintain a particular temperature programmed into the system. If a breeze is passing through a room, the human perception of the temperature will be lower than measured by the thermostat because the movement of air allows the human body to lose heat more effectively. Some passive cooling techniques use indeed this effect; not removing the cooling load of the building itself, but rather extend the tolerance limits of humans for thermal comfort in a given space.

In fact, the literature [Santamouris and Asimakopolous, 1996] distinguish ‘passive cooling’ and ‘natural cooling’. Passive cooling refers to techniques which are used to prevent or modulate heat gains. Natural cooling refers to the use of natural heat sinks for excess heat dissipation from interior spaces.

The authors of ‘Passive Cooling of Buildings” [Santamouris & Asimakopolous 1996] reveal: “By combining passive and natural cooling techniques, it is possible to prevent overheating problems, decrease cooling loads and improve comfort conditions in buildings.”
(a) Heat gain prevention

The prevention of heat gains involves the following design techniques:
- microclimate and site design
- solar control
- building form and layout
- thermal insulation
- behavioural and occupancy patterns and
- internal gain control.

In first place a consequent prevention of the external and the internal heat load should be targeted. This in consequence will minimize the remaining cooling demand. Several of the above mentioned issues are also applied as heating techniques. The smartest major cooling strategy is to use the one that already is used in buildings to provide savings in heating energy. By making sure that a house is well-insulated, not only the minimization of heat losses to the outdoors in winter, but also a reduction of unwanted heat gains in summer can be ensured. A good sealed building will have a reduced infiltration of cold air in winter and exfiltration of conditioned air in summer. Though ventilation is important for occupants comfort, it should come from a well-planned ventilation of fans, open doors, and windows rather than the uncontrollable leakage of air through cracks and gaps.

Shading is one of the simplest and most effective methods of blocking heat from entering the building. There are many different methods available to provide shading both inside and outside the house. In general, exterior shading (see picture on the right) is more effective than interior because the heat is blocked before it enters the building. Interior shading, however, has the advantages of being easily controlled by the occupants of the house while also not being exposed to wind and rain. A combination of both indoor and outdoor shading maximizes both heat reduction and controllability.

Exterior shading starts with landscaping. It is an effective and pleasant means of providing shading for a building and will block out the hot summer sun, encourage warming sun to enter the house in winter, deflect cold winter winds, and channel breezes for cooling in summer. Thus, a proper landscaping around the house can improve the microclimate. Even trees which do not directly shade the building are valuable because they reduce the temperature of the air surrounding the building site. Estimation says that a full size tree evaporates 1,460 kg of water on a sunny day, which is equivalent to 870 MJ of cooling capacity. Due to the phase change during water evaporation areas with high vegetation may exhibit noticeably lower air temperatures (by 2 to 3 degrees). Also open pools, waters and fountains etc. contribute to a better microclimate illustrated by the popularity in the historical development of a southern climate’s architecture. [Santamouris and Asimakopolous, 1996]
Other devices that fulfill the purpose of shading are roof overhangs; awnings; exterior shade screens; shutters and shades; and not to forget a diversity in interior shadings.

Regarding the internal gain control the topic of selected energy-efficient appliances plays a big role. Not all of the heat in the building is caused by the sun; much of it comes from the occupants and the appliances they use. In fact the behavioural response of people in their buildings can have a rather big effect on the monthly energy bill. For instance in South Europe people adapt to their environment in withdrawing into cooler indoor spaces during the day. Since the focus is on the Netherlands this issue represents only a minor option. A rather big potential are find in the use of productive household appliances. By using BAT (best available technologies; see § Fehler! Verweisquelle konnte nicht gefunden werden.) for household appliances the unintentional production of heat is minimized.

Regarding the occupancy pattern, there a plenty of more interventions and action which can be adapt to the target of saving energy.

(b) Heat gain modulation

When talking about heat gain modulation the use of the building's thermal mass is meant. In region with high daily temperature-fluctuations this strategy can perform best. The absorbed heat by a building's mass during the day can be partly released during the night hours. Passive cooling techniques can be used during the night, since the outdoor conditions are more favourable. Thus, high fluctuations in temperature can be extenuated.

Modulation means, for instance, that an unoccupied building can also be pre-cooled by ventilation. The cold is stored during the night and will be transferred during the early hours of the following day. This method can reduce the energy consumption for cooling by close to 20% [Santamouris and Asimakopolous, 1996].
(c) Heat dissipation

One open issue still have to be discussed: How to remove the heat from the building after the application of means by prevention of modulation? Following natural heat sinks are used for this purpose:
- ventilation;
- ground cooling;
- evaporative cooling; and
- radiative cooling are the applied strategies.

Natural or forced ventilation is one of the primary means of reducing the cooling load in buildings. Besides for the cooling effect the ventilation is (even more) necessary in all indoor spaces in order to introduce the required levels of fresh air and to control odours and indoor pollutants. Ventilation, or the movement of air, has two goals: (1) to remove heat from the house and (2) to provide air movement within the house to cool its occupants.

The forced ventilation is based on mechanical devices like fans. Though mechanical ventilation measures are not strictly passive, they are a much less energy-intensive method of achieving a cool home than air conditioning.

Natural ventilation is relying upon summer breezes to generate air movement within the house. Due to the variability of wind speed and direction, though, it can be pretty unreliable. However, a careful selection of windows and their positioning can help enhance the natural ventilation possibilities in a building.

[Two techniques using the stack effect and natural ventilation; source: Mohanty, 2005]

Ground cooling is a concept that gained popularity for a while in the late 1970s and has since a couple of year its revival. It consists of pipes buried in the ground (deeper than 1.50 m), where temperatures are lower. Air is drawn into the house through the underground tubes, which has the effect of pre-cooling (preconditioning) the air before entering the building. The deeper the tubes in the ground the higher the difference in temperature and the higher the efficiency.

Concerning the physical concept, this strategy is using the mass of the soil. In fact the building integrates the mass of the ground beneath to increase its own mass.

One major problem with this system, which appeared in the past, is an increase of humidity while the air is cooled down. This can cause an uncomfortable situation of the occupants. A solution for this problem is a dehumidification of the air before entering the house. This of course will cause an extra consumption of energy. Other problems could appear, like the entry of insects or vermin and the increase of possible exposure to radon. In combination with air-conditioning system the preconditioning via ground heat exchanger works best.

Advantages: low energy cost; environmental friendly; cooling in summer and pre-heating in winter; with application of filter hygienically unobjectionable.
Disadvantages: high initial building costs; additional space demand; performance varies depending on soil conditions and weather conditions; regular filter exchange necessary. [Technologien der Passiven Kühlung www.energytech.at]

Evaporative cooling concepts have been known and successfully implanted for centuries. Evaporation occurs whenever the vapour pressure of water is lesser than the water vapour in the surrounding atmosphere. The phase change of water from liquid to vapour state is accompanied by the release of large quantity of sensible heat from the air that lowers that temperature of air while its moisture content increases. The provision of shading and the supply of cool, dry air will enhance the process of evaporative cooling. Passive direct systems include the use of vegetation for transpiration and evaporation, as well as the use of fountains, pools and ponds where the evaporation of water results in lower temperature in the surroundings.

Technical solutions (building services) were developed which use the effect of evaporation but their disadvantage is an undesirable increase of the moisture content during the cooling process. Consequently, it cannot be used in regions with high humidity levels. In this case the indirect concept is a solution where air is cooled by passing through a heat exchanger. Furthermore, the techniques of roof spray and roof pond are based on this physical background but there are a number of problems (high costs, maintenance, available water, limited applicability) associated with these systems.

Considering radiative cooling the roof is the most important passive radiative cooling system of a building. During a clear night the roof temperature can be a few degrees cooler than the ambient temperature due to the radiative emittance to the sky. Roofs, using this technique, give a measured cooling potential of 0.014 kWh/m² [Santamouris and Asimakopolous, 1996]. The following picture illustrates exemplary one technique based on radiative cooling.

![Radiative cooling; source: Mohanty, 2005](image)

To complete the picture of cooling strategies, non passive based cooling techniques uns mechanical services; this includes:
- Vapour compression systems;
- Gas compression systems; and
- Thermoelectric systems.

To give an indication on the potential of several techniques Santamouris and Asimakopolous [1996] have made investigations on a 80m² one-storey dwelling located in Athens, Greece. They came to following conclusions:
- Night ventilation techniques are effective during the months with lower night outdoor air temperature (June and August). The maximum depression of the peak indoor temperature does not exceed 1 degree Celsius.
- Ground cooling techniques with an earth-to-air heat exchanger have to be buried at a depth between 3.5 and 5 meter, and can cause a peak indoor temperature reduction
of 2 to 5 degrees Celsius. The diameter and air velocity affect the indoor air temperature significantly.

- A direct evaporative cooler can reduce the max peak indoor air temperature by 4 to 6 degrees Celsius.

Natural and passive cooling techniques exhibit a high potential in reducing the energy consumption for cooling in buildings. They have been applied successfully in the past, are being partly revitalized, enhanced with new research findings and applied with current technology and advanced system-design. A combination of these techniques can prevent overheating problems, decrease the cooling load and improve indoor thermal comfort conditions. In particular, 20% energy conservation in buildings is possible. For example, by means of using proper shading a significant reduction of external loads and by using energy efficient indoor appliances a reduction of internal loads can be achieved. Natural ventilation will contribute additionally to energy saving.

**02.01.02.04 Daylight (Passive Solar Design)**

The planned use of natural light becomes a more important strategy for improving energy efficiency and is the last of the three strategies discussed in the context of passive solar design. Sophisticated daylight strategies can reduce a building’s energy consumption (especially electricity) and improve the quality of the light inside the house. The art of proper day-lighting design is not so much how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects. Besides the adding of windows or skylight it involves a balancing of heat gain and loss, glare control, and variations in daylight availability. It is a concept which also involves the use of shading devices.

Basically, a window can be defined as a hole in the insulated envelope of a building, which lets heat escape and light enter. The planner’s decision on window size and position is dominated by the occupant’s requirements. A well lighted, bright space without glare makes a good impression and is always desired. In opposition, dark corners, a strong decrease of brightness over the room depth or glare usually cause negative impressions. The designer’s would, hence, normally decide on planning of very large windows. But even good windows lose up to five times more heat than a highly insulated wall. Thus, there is the challenge of finding the right window properties based on the day-lighting issue and the heat conserving efforts.

The following parameters influence human’s perception of light in a room:

- Window proportion;
- Window position;
- Cross-section of the window opening in the wall;
- Treatment of room surfaces; and
- Glare protection.
The mentioned parameters are discussed in the report ‘Gutes Tageslicht in Passivenhäusern’ [Junghans and Hastings, 2002]. The following information on the influence of windows’ properties is extracted from this paper:

- **window size**
  - A window size much beyond a window-to-façade ratio of 50 per cent, is not justified by unproved day-lighting.
  - Window areas up to a 50 per cent ratio increase the absolute amount of light and reduce the luminance contrast and the resulting glare.

- **window proportions and position**
  - Tall windows are stated with: The higher the window, the deeper the daylight projection into the room.
  - Horizontal windows are associated with a good light penetration into the room depth (in any case, east-, west-facing windows).
  - A combination of high and low windows is unfavourable for the human impression.
  - Corner windows cause asymmetric lightening.
  - Windows located on two walls yield to good day-lighting and the probability of more glare.

- **window frame**
  - The insulation properties are worse than today’s high-performance glazing.
  - Slim window frame constructions improve day-lighting and thermal performance.
  - Insetting the window frame behind the exterior insulation is a good solution to minimize heat losses.

- **window-opening cross-section**
  - To avoid thermal bridges the preferred position of the window is towards the exterior of the wall opening.
  - By flaring of deep window cross-section into the room, the impression of the window size is much larger than it is in reality.
  - The illuminated flared surface reduces the contrast glare between wall and window and leads to an improved visual comfort.

- **room surfaces**
  - Surfaces (wall cladding, materials and colours) are having as much impact on the light quality as the window properties itself.
  - The wall colour to either side of the window is extremely important. The wall on the back side of the room away from the window has a small influence on the room luminance.
  - The floor colour has also a strong influence. A good compromise is a floor colour slightly darker than the walls. The ceiling has a smaller influence than floor and walls. These cognitions are illustrated in the following figure.
It can be concluded that the ceiling has a minor influence on light quality than walls and floors; the higher the surface reflection the higher the illumination.

Besides the window there are obviously more ways to allow natural light into the building. However as a generalisation, daylight systems can be categorised into five main types:

- Windows;
- Skylights;
- Saw-tooth skylights;
- Roof monitors; and
- Atriums.

As a general rule of thumb, the daylight penetration into the room is only sufficient of a distance 2.5 times the window height.

To overcome dark space, of course, additional windows can be added.

Although it gives excellent daylight levels, it is difficult to control. Therefore, adjustable shading devices are recommended. Caused by their location, skylights gain and lose more heat than other daylight systems.
South-facing window sections need additional shading devices like all other window section located south. An orientation of the ‘teeth’ towards the north will cause an equal defuse lighting.

- roof monitor:

- atrium:

The atrium is a core lighting technique used in modern multi-storey buildings. The outside perimeter is lit with windows and the centre receives diffuse light from the atrium.

- light pipes (www.solatube.com), sun ducts, fibre optic illuminators, light chimneys
<table>
<thead>
<tr>
<th>Design advice:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Window size:</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Window sill height: (bottom)</strong></td>
</tr>
<tr>
<td><strong>Window head height: (top)</strong></td>
</tr>
<tr>
<td><strong>Window position:</strong></td>
</tr>
<tr>
<td><strong>Windows in two facades:</strong></td>
</tr>
<tr>
<td><strong>Window frame:</strong></td>
</tr>
<tr>
<td><strong>Room surfaces:</strong></td>
</tr>
<tr>
<td><strong>Glare/privacy control:</strong></td>
</tr>
</tbody>
</table>
Active solar design involves capturing the sun’s energy through the use of solar thermal panels or photovoltaic (PV) cells. It represents the third step in the pyramid of interventions. Here, renewable sources help to cover the remaining energy demand of a household in a sustainable way. Like the passive solar approaches, it basically utilizes the sun’s energy for the building’s demands and is defined by moving parts, which means that this approach depends on mechanical devices (like pumps, fans, vent dampers and electrical controls to regulate flow). This definition, however, covers only the thermal collector systems for hot water production. The term active-solar system within this paragraph is, as mentioned, also referring to photovoltaic panels, which generate electric power.

An active solar heating system captures heat and can cover a significant part of the remaining energy demand of high performance house. Active solar heating relies strongly on three components: a solar collector to absorb the solar energy, a solar storage system, and a heat transfer system to disperse the heat to the appropriate places in the house.

As already described in a former section, since the space heating demand of high performance houses is very low the annual energy demand for domestic hot water (DHW) becomes relatively important. Typical industrial manufactured solar hot water systems cover 50% and more of the hot water demand, depending on size, design and climate [Furbo et al., 2003].

Combisystems cover both, space heating and DHW. Here, the planner’s key issue lies in estimating the space heating contribution realistically while considering a given shorter heating period for a high performance house. But these systems are rather complex since they consist of several components. Therefore, the cost of solar combisystems is generally higher than the cost of solar domestic hot water systems.

A general problem in northern and middle Europe is that the energy demand of a building is largest during the winter, when very little solar energy is available, and smallest in summer, when the solar energy supply is largest. For a DHW system, this is not a big problem, since the hot water demand is rather constant throughout the year, whereas the heating demand of a building is strongly depending on the seasons. The following figure illustrates this dependency.

[Energy supply from two solar collectors of 15 and 10 m² for a general Swedish household; source: Furbo et al., 2003]
On the contrary, the daily variations in heating demand for space heating are very small whereas the hot water demand varies significantly. This seasonal mismatch (area 2 in the figure) of energy demand and supply causes difficulties in optimising such systems. In order to profit from as much irradiation as possible, the solar based systems are often overestimated. This in return can result in overheating and stagnation in the summer time (area 1 in the figure). A combisystem covers usually between 10 and 30% of the space heating demand, but can be increased by a building’s higher insulation quality (area 3 in the figure). By using seasonal storage in smaller or bigger scale, the mismatch in offer and demand can be to some extent compensated. This is however very expensive, causing large heat losses, and is unreasonable for an ordinary household. [Furbo et al., 2003]

Nevertheless, different systems are available; different producers offer a diversity of products with properties, specifications and prices. The question is which of these systems can cover economically sustainable the annual demand for space heating and DHW?

Within the WAELS-project [see § 01.03] researchers try to find an answer on this question. In the work-packages ‘WP B’ and ‘WP C’ solutions for heat generation and heat storage are worked out.

As revealed in § 01.04 ‘Future Developments in the Netherlands’ 65% of a residential building’s energy demand is needed for space heating and domestic hot water. The rest (25%) is needed for electrical devices (pumps, fans, lighting, household appliances). This part of the energy demand can be covered by photovoltaic panels (PV). Like the thermal collector systems, PV-system’s performances are depending on solar radiation intensity at their location. Due to certain obstacles (atmosphere, clouds etc.) the average solar radiation is decreased. The following picture gives an indication on the annual global irradiation received by PV modules in the Benelux.

In the Netherlands the average annual global irradiation is about 1180 kWh/m²a. Regarding the annual electricity consumption (in average 3402 kWh) the mismatch between demand and offer will be not as extreme as for space heating. However, of course, there are variations in the seasonal electricity production (see picture below).
The question is whether the produced electrical power can be used or not (or maybe stored). By connecting the building to the electricity grid this problem is shifted to the national level. Now, the electricity supplier has to level the peaks caused by the local electricity production on the building’s roof. A solution to overcome these problems is the mounting of the collectors with a higher tilt. From the picture above can be seen that the distribution of radiation for a collector with 90° tilt is more even than for a collector with a tilt of 45°. Even the problem of overheating during the summer can be decreased when mounting the thermal collectors vertically. In consequence the annual energy yield from the collectors will be lower. In central Europe the annual solar irradiation on a façade is about 30% less than the irradiation on a south-facing roof with a 45° slope. Thus, larger collector areas are needed to produce the same amount of energy. [Furbo et al., 2003]

Again, the question is which approach is more economical, having a system with a big expensive storage capacity or a system with less buffer ability and less efficiency?
Not only the collector’s slope, also the deviation from the optimal south-orientation has an influence on the performance. The Fraunhofer Institute Germany came to the conclusion that for an optimal efficiency of thermal collectors and PV-panels, the pitch of the south facing roof should have between 35 to 45 degrees. A bigger slope of the roof allows higher efficiency in winter term. The following table gives an overview on the mean solar radiation energy on non-shaded surfaces during heating period (Germany).

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Energy (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>270</td>
</tr>
<tr>
<td>South-West</td>
<td>225</td>
</tr>
<tr>
<td>West</td>
<td>155</td>
</tr>
<tr>
<td>North-West</td>
<td>105</td>
</tr>
<tr>
<td>North</td>
<td>100</td>
</tr>
<tr>
<td>North-East</td>
<td>105</td>
</tr>
<tr>
<td>East</td>
<td>155</td>
</tr>
<tr>
<td>South-East</td>
<td>225</td>
</tr>
<tr>
<td>Horizontal</td>
<td>225</td>
</tr>
</tbody>
</table>

[Mean solar radiation gains on non-shaded surfaces during the heating season in mean German climate conditions, Source: Erhorn et al. (2001) Fertighäuser im Wandel, page 3]

The data between north and south orientation differs by factor 2.7. It can be concluded that a collector orientation towards north, east or west can hardly be economically sensible.
**02.01.04 Producing Remaining Energy**

The term ‘remaining energy’ refers to the energy still needed after conservation measures and interventions in active and passive design. This step represents last one in the pyramid of interventions and is used to cover peak loads of the demand by means of conventional and non-solar based techniques. This strategy uses, for instance, combustion systems or heat pumps.

**Combustion Systems**
- Fossil fuel combustion systems
- Biomass combustion systems
- Combined heat and power systems

**Heat Pumps**
- Ambient air heat source
- Ground/surface water heat source
- Exhaust air heat source

Like in the case of active solar systems there is a big variety offered by the industry. Since the production of the remaining energy represents the last step in the ‘pyramid of interventions and there is an almost vast offer of these systems, this issue is not treated to the outmost extend. This means that only a small view on this topic will be given within this research. A more detailed description of technological background is given in § Fehler! Verweisquelle konnte nicht gefunden werden. ‘Fehler! Verweisquelle konnte nicht gefunden werden.’.

Besides technical question, which properties must such a system have to be economically sustainable? Robert Hastings [Hastings & Wall, 2007a] explores this subject. He says that it is important for the selection of heat production systems that the energy supply source has minimal fixed costs. This turns out as a key factor for the efficiency. An example for a cost calculation in heating a high-performance house with gas is presented in Hastings 2007.

**Design advice:**

Important characteristics of the equipment supplying the remaining energy for high performance housing include:
- Simplicity:
- Fast reacting:
- Well insulated:
- Less is more: Low parasitic power: electricity consumed by fans supplying combustion air and expelling flue gas and pumps or fans for circulating the produced heat
- Low base costs:

The most economical solution requires the connection of one type of energy carrier. A better system performance and a higher efficiency can be gained if the heat is delivered at a lower temperature.

**Conclusions to strategies:**

Ecologically, low energy elements and designs respectively require higher qualities. These higher standards in quality cost more than designs where decisions were made based on a short-term perspective. Thus, while treating the subject of sustainable buildings aspects of additional added costs on high-performance design must be respected.
One question arises: how to find the best strategies in developing the product? Having the choice between different strategies obviously implies that there must be some contradictions within these strategies. Therefore, priorities have to be determined before starting with the design of a product. Useful tools like multi-criteria decision-making (MCDM) and total quality assessment (TQA) help to motivate decisions. A closer look to assessment tools will be made in the following chapter. Finally and that is probably the most important issue the product must be marketable. Having a perfect product that does not attract customers is surely not the designer’s intention. Thus, the product designer has to be aware of these approaches, of their efficiency, and of the arguments that influence a buyer’s decision.
02.02 Ecology

Obviously, if a building is to be promoted as ecological, the whole lifespan of the construction must be considered. A building can hardly be entitled with a sustainable image while the reduction of energy consumption is only shifted to the production processes of the used materials. The shifts of environmental burdens in the construction sector can be properly judged in an integrated investigation. For example the approach of a life cycle assessment (LCA, § 02.02.02) can help with the examination. Multi-criteria decision tools can be applied to the housing sector, which systematically weigh negative and positive interventions.

Generally, the building’s used recourses are not visible on the annual energy bill. Besides the ‘direct’ energy consumption of a building caused by occupants’ use, resources are also needed for the production, erection and for the recycling of the house. These different stages in a building’s life cycle represent important parts considering the energy issue, too. It gets even more important the more energy saving measures are incorporated into the building.

Since one focus in this thesis is sustainability [see § 01.05], the whole life cycle of a product and its impact on the environment has to be measured and evaluated as well. As already discussed before, a decision made during the design phase of a building is most decisive for the overall environmental performance. The early integration of environmental issues prevents one from having only minor improvement potentials in later life cycle phases (like construction, use phase, and demolition).

Typically, reductions in operating energy occur at the expense of increased embodied energy, embodied emissions, and life cycle material flows. Will this still cover the aim of sustainable development? Moreover, as operating energy becomes less significant, the operating demand load for water and materials becomes relatively more important. [IEA Annex 31, 2005a]

Generally spoken, sustainability is addressing economic, ecology and social aspects. In this section a short overview will be given on selected methods in assessing the sustainability of buildings:

1. Cumulative Energy Demand (CED)
2. Life-Cycle Analysis (LCA)
3. Architecture Towards Sustainability (ATS)
02.02.01  Cumulative Energy Demand (CED)

Since large improvements in insulation materials and the reduction of energy needed for heating are taking place in the building sector, the proportion of energy consumed during the production and construction process becomes a more important factor. This will even play a bigger role in the sector of very low energy and energy-plus houses.

The entire primary energy demand over the whole life cycle of a product or service is expressed in the cumulative energy demand. It is the sum of energy used in producing the product and its components, as well as during operation over the lifespan. Thus, the CED is a good indicator to assess the ecological balance of a building regarding its embodied direct and indirect energy.

The idea behind cumulative energy is the opportunity of a fair comparison of products and services. Based on the amount of energy is used, the environmental impact of the product can be rated. For the comparability among all forms of energy they are converted into the basic unit of primary energy.

The VDI [1997] gives the following statement: “the data on the cumulative energy demand … form an important base in order to point out the priorities of energy saving potentials in their complex relationship between design, production, use and disposal”.

Cumulative energy analysis can be a good ‘entry point’ into life cycle thinking and since this method implicates energy in form of direct uses as well as indirect uses (grey energy), its full capacity can be used in combination with other methods [Frischknecht and Jungbluth, 2004a].

The following parameters are considered in the CED:

• the amount of materials, which are used;
• the energy used in the processing of the materials;
• the service life of the materials;
• the energy required over the lifetime of the materials through the recycling of parts, components or materials; and
• Emissions related to energy conversions during production, use and disposal.

CED-assessment tools are based on large databases, which contain major information’s to the mentioned parameters.

The building specific aspects [accordingly to Hastings and Wall, 2007a] for the Cumulative Energy Demand approach are described below. The CED can be applied at different scales for a building project:

• The production and recycling phase can be assessed for a given building material. Product-specific values, which are taken form the database, are helpful in choosing materials.
• Functional elements (for example, 1 m² exterior wall with specific characteristics such as a defined thermal conductivity) can be assessed by CED and can support the planner in her/his decisions. Not only the average demands for the production, also secondary aspects such as transport or expanses during construction are considered. The lifetime and maintenance for the elements are inputs for this assessment.
• The whole building assessment requires a careful selection for the criteria to be used. Are functional units (per square metre living area) or lifestyle aspects (per dwelling, per person) more relevant? The results typically include the energy demand for construction and demolition, the energy demand during use for heating and domestic hot water (DHW), and the energy demand for maintenance.
• Urban planning can also make use of the CED and can assess both the buildings and their infrastructure.
In conclusion it can be said that the method of cumulative energy is used to get a general view on the energy related environmental impacts in a life cycle of a product. Since it is only based on embodied energy, it cannot give a full picture of all environmental impacts of goods and services. Thus, this method is not the one and only ecological strategy in evaluating products and actions.

02.02.02 Life-Cycle Analysis (LCA)

Another strategy in evaluating ecological impacts is the Life Cycle Analysis (LCA). In applying the LCA in the building and construction sector, a life cycle perspective can be taken into account. Life Cycle Assessment supports planners by providing information on different environmental aspects, like primary energy consumption, global warming, resource consumption, summer smog etc. Even shifts of environmental burdens can be prevented when addressing environmental issues ‘from cradle to grave’.

In order to improve and respect the overall performance over the life cycle planners, architects, and building owners should not select a product or system by its initial life cycle impacts only. Sometimes, necessary higher initial burdens can reduce use phase impacts significantly [Brunner et al. 2006].

The International Organisation for Standardisation published international standards on LCA [(ISO), 1997-2000], which standardizes the framework within the series ISO 14040. The method distinguishes four main steps for a life cycle assessment, namely:
1. Definition of the goal and scope;
2. Inventory analysis;
3. impact assessment; and
4. Interpretation of the results.

[Source: www.dantes.info (Demonstrate and Assess New Tools for Environmental Sustainability)]
Intermediate Report - Literature Review

These steps are executed in an iterative process. Changes in the first phase may be necessary after results are known from the last phase.

The LCA requires a definition of the scope, the life cycle itself, system boundaries, as well as a certain required data quality. Essential for an inventory of building processes, building materials and energy-supplying processes are common system boundaries to ensure the consistency of the data base. Inventory tables consist of a huge number of data of used resources from nature (as oil, ore or land use) and emissions to nature (to air, water and soil).

An impact-orientated classification of the inventory data has to be done (step (3)). There are different methods in weighting, which yield to different LCA-based tools to evaluate the ecological performance of buildings. A distinction can be made between passive tools (guidelines, catalogues, labels etc.) and active tools (software based tools). A list is presented in IEA Annex 31, 2005c and further information in RMIT, 2001.

However, a strict application of LCA methods in the building sector is very difficult due to the complexity of processes, inputs, and the data sources. Hence, a more general/simplified approach is used.

The functional unit for the LCA of a building may be residents, apartments, m² usable or m² heated floor area. Depending on the scale of comparison, the units ‘resident’ or ‘apartment’ are useful for urban planning; the unit ‘m² heated floor area’ prioritizes the differences in operational energy use, in contrast.

Accordingly Hastings and Wall (2007a), the life-cycle for long-life products (such as a building) incorporates assumptions about the functional service lifetime, use and maintenance scenarios, repair and replacement of components, major refurbishment or renovation, and demolition and recycling scenarios.

A building specific LCA involves an inventory of the following components [IEA Annex 31, 2005a]:

- a base data on energy and raw material processing;
- building products and systems, construction processes, utility and waste disposal;
- and
- building elements (components of a constructed building).

The classifications of tools by position in the decision making process shows the potential of LCA in the construction sector.

- They provide information on the ecological performance of building concepts,
- allow a quantitative comparison among different solutions, and
- simplify the identification of problematic steps in life cycle.
02.02.03 Architecture Towards Sustainability (ATS)

ATS is the last tool, which is discussed within ecology-content. Sustainable architecture is more than energy efficient or zero-emission architecture. It must adapt to and respect its environment in the broader context of ‘milieu’ [Hastings and Wall, 2007a].

A successful solution must address the principles, taken from the 1992 Rio Declaration [UNEP, 1992]:

- Shared but differentiated responsibilities;
- Intra- and intergenerational equity;
- Integration of the components of sustainable development;
- Precaution and acknowledgement of scientific uncertainty; and
- Participation and good governance.

In applying these principles to the planning process of a building, the designer is forced to be aware of the impact of his/her actions in consequence. Those are exceeding the boundaries of the project on various scales of the public space; i.e. by undertaking personally to the client, the planner also makes an undertaking to the society.

As a consequence thereof, individual and collective well-being has to be respected as well as the heritage, which is handed from generation to generation. The architecture must operate at individual levels (functionalism) and community levels (mixed functions).

Due to the fact that we cannot anticipate the individual and collective spatial needs of future generations any better today than previous generations did earlier, the sustainable architecture should be adaptable and designed to meet the needs of future occupants (see § 01.05). Many inherited buildings from prior generations incorporate natural materials, day-lighting, passive cooling techniques and a rational use of passive sources of energy. These principles have to be improved partly, new developed and applied in today’s practice.

The idea of improving the public’s awareness of environmental, social, economical and political problems belongs also to the scope of ATS.
Exemplary, the following principles of ATS, based on the objectives of the Building Research Establishment’s Environmental Assessment Method (BREEAM), can be stated [Hui, 2002]:

- demolish and rebuild only when it is not economical or practicable to reuse, adapt or extend an existing structure;
- reduce the need for transport during demolition, refurbishment and construction and tightly control all processes to reduce noise, dust, vibration, pollution and waste;
- make the most of the site, e.g. by studying its history and purpose, local micro-climates and the prevailing winds and weather patterns, solar orientation, provision of public transport and the form of surrounding buildings;
- design the building to minimize the cost of ownership and its impact on the environment over its life span by making it easily maintainable and by incorporating techniques and technologies for conserving energy and water and reducing emissions to land, water and air;
- wherever feasible, use the construction techniques which are indigenous to the area, learning from local traditions in materials and design;
- put the function of the building and the comfort of its occupants well before any statement it is intended to make about the owner or its designer. That is, make it secure, flexible and adaptable (to meet future requirements) and able to facilitate and promote communications between staff;
- build to the appropriate quality and to last. Longevity depends much on form, finishes and the method of assembly employed as on the material used.
- avoid using materials from non renewable sources or which cannot be reused or recycled, especially in structures which have a short life;

After all, assessing the probable (economical, political, social, and environmental) impact of a development is a complex enterprise. The diversity of issues dealt with makes it difficult to establish a weighting system for both on individual and community level. During the design paradoxes will arise and can only be solved through a system of compromise and collaboration that no longer targets attaining a maximum for any one criterion but an optimum for all criteria.

General Conclusion:
The broad variety of perspectives in the typical building process, and the predominance of non-environmental criteria in decision-making, present a major barrier to the development of green buildings. As well, the design process for buildings is culturally specific: every building is a unique construction within its particular surroundings and context, and should be conceived as such. [IEA Annex 31, 2005a].
02.03 Marketing & Economics

Of what avail is a proper designed product when it cannot be sold? Within the strategic approach for the development of a sophisticated product like a high performance house economical and marketing issues have to be addressed. The marketability is actually the key strategy for the success of a product. The following question has to be answered: What is buyer's motivation to acquire this product?

The topic of sustainable housing is currently finding its place in the housing market. Sustainable living is anticipated as healthy living and this again is strongly interrelated with high comfort in living. As a result of global developments, public awareness, and policy decisions the housing industry is realizing that sustainability is an important market with lots of potentials.

For the development of a consistent marketing strategy an observation of current trends in the housing sector is inevitable. Some trends have been already elaborated in the § 01.04. The International Energy Agency has observed several marketing trends for sustainable housing [IEA, 2006]:

- Moving from national to international business;
- Moving from ‘product’ to ‘concept’;
- Shorter product life cycle (products are rapidly replaced);
- Immediate response to market changes;
- Branding; and
- Changing consumer groups (elderly people).

Besides the current dynamic in this market, cost issues are still the major selling point. When considering costs in sustainable buildings not only the initial exploitation costs also the decreased utilities and common charges (energy and water) have to be seen. Also Aspects with a indirect financial profit can be addressed in the marketing. Advantages in sustainability and environment, a higher comfort, higher efficiency, a bigger flexibility in space, the increased durability of the building are selling arguments as well [SBR, 2002].

The proportions of costs within the building sector are pretty complex and in consequence the distribution of costs and responsibilities within the design and production process of the product ‘building’ as well. Among others is this complexity caused by a big variety of standards and participating parties. Furthermore, these parties have different interests. ‘Soft aspects’ in consequence (like the ecological quality) are playing a minor role in the design and represent obstacles in terms of measurability and comparability with the financial performance.

The United Nations [UNEP, 2007] have located further barriers to energy efficiency in the construction sector.

- One of the main barriers to a wider adoption of sustainable design and construction solutions is the perception of additional costs without apparent benefits (this affects in first place project developers and real estate investors). Advanced cost analysis, based on sustainable approaches, contradicts this assumption and demonstrates that with a little additional financial effort significant improvements can be achieved in many cases.
- The conflict between builders’ interests (minimizing investment cost and maximizing profits) and operational actors (which want to minimize the running costs) appears to be another reason for the implementation of sustainable measures in the residential sector.
• The lack of information/knowledge about energy efficiency is another obstacle. Individuals often do not know housing standard like for instance Passive Houses.
• The human behaviour represents an additional uncertainty. It is important that occupants are willing to live within these concepts and want to save energy.

The consortium for the promotion of passive houses in Europe [PEP, 2006] has identified the following barriers for the Netherlands:

Technical/construction barriers:
• Main barrier is the brick cavity wall tradition (Lower U-values result in thicker walls; to avoid extreme thick walls other finishing materials and construction may be preferable)
• Limited knowledge of thermal bridges and air tightness
• Availability of appropriate window casing
• Ventilation: maintenance contract necessary for balanced ventilation systems, otherwise problems regarding indoor air quality and poor electrical performance of fans
• Lack of small heat pumps

Market related barriers:
• The Dutch housing market can be characterized as a push-market
• The occupants/sellers of houses buy what they can buy, without much interest and knowledge of (passive) houses
• Market-barrier: brick cavity wall tradition; besides the technical solutions, market-related aspect: Dutch consumer is used to the brick cavity wall and associates this construction method with quality

Building regulations related barriers:
• Different housing standards have to compete with each other

After the analysis of the product’s barriers interventions can be taken and new strategies developed to steer in the opposite direction. The following reasons could, for instance, favour consumers for this product:
• Direct savings from lower energy costs
• These saving will be greater as non-renewable energy prices rise; and
• There are non-energy benefits like:
  • better air quality;
  • higher thermal comfort levels;
  • convenience
  • a better house with a higher value; and
  • taking responsibility for the environment.

The above mentioned advantageous factors will increase the business potential for the industry. For a success of the product a company has to answer one essential question: Who are the buyers of the new product when introduced to the market? In the introduction stage of a product consumers either have a special interest in the product or they want something new, so-called ‘innovators’. When these people have ‘tested out’ the product, given it credibility and in consequence a positive image, the ‘followers’ enter the market [IEA, 2006]. Thus, first prove than break through.
A so called SWOT analysis (strength, weakness, opportunities, threats) can help to find the potentials of the new product ‘sustainable house’. An analysis regarding the marketing of passive houses is exemplary made by Anliker (Anliker AG, Emmenbruecke, Switzerland) and summarised in the table below:

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal factors about the organisation and the product</td>
<td>Internal factors about the organisation and the product</td>
</tr>
<tr>
<td>1. Biggest company of its type within the field</td>
<td>1. 7% higher construction costs</td>
</tr>
<tr>
<td>2. appropriate business philosophy: high standard in housing and low maintenance costs</td>
<td>2. Little experience with passive housing construction</td>
</tr>
<tr>
<td>3. A willingness and drive to be innovate and take market opportunities</td>
<td>3. Lack of credibility in passive housing</td>
</tr>
<tr>
<td>4. Good architecture, quality and design</td>
<td></td>
</tr>
<tr>
<td>5. Whole firm behind this project</td>
<td></td>
</tr>
<tr>
<td>6. Good reputation in the market, well known for service</td>
<td></td>
</tr>
<tr>
<td>7. Good public relations</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>External factors which affect the company's and product's possibilities in the market</td>
<td>External factors which affect the company's and product's possibilities in the market</td>
</tr>
<tr>
<td>1. An untapped market with significant growth potential for passive houses</td>
<td>1. Private funding and banks strongly influence the market and take little interest in being an active part in the development of the private housing market</td>
</tr>
<tr>
<td>2. Increasing awareness of environmental issues in the targeted market niche</td>
<td>2. House buyers still concentrate on the initial costs and do not tend to concern themselves with running cost; maintenance costs are much less considered (these are much lower with passive houses)</td>
</tr>
<tr>
<td>3. Building The Passive Standard is an investment in the future</td>
<td></td>
</tr>
<tr>
<td>4. Reduction of fossil fuels</td>
<td></td>
</tr>
<tr>
<td>5. Subsidies by the authorities</td>
<td></td>
</tr>
<tr>
<td>6. The media has environmental concerns high on its agenda; free press coverage is possible</td>
<td></td>
</tr>
</tbody>
</table>

[SWOT analysis for ‘Anliker’ regarding the marketing of passive houses; source: IEA, 2006, page 24]

In the marketing guide of the IEA [IEA, 2006] some basic do’s and don'ts are described in the marketing of sustainable housing:

Do’s:
- Ride on the wave of increasing public awareness of environmental issues
- Join other players in the marketplace – commercial / interest groups / local, regional, national, and international authorities – and develop win-win alliances
- Think strategically (long term)
- Define your target group, accept the fact that you cannot sell to them all
- Know your target group preferences
- Clearly define how you differentiate yourself from others
- Focus on added value.

Don’t:
- Have a one-sided focus on ‘additional investment cost resulting in annual energy savings’
- Start immediately with communication without having done a strategic analysis.
02.03.01 Economic instruments and incentives

Regulations and standards are usually taken as guidance within the building sector. This includes energy systems and their operation. Besides the framework of regulations decisions in the construction sector (as in the other sector on the free market) are pretty much based on economic considerations. This implicates a dominant short time perspective in the building sector. Investments with a longer refund period are therefore less attractive.

Opportunities to take countermeasures these ‘rules’ of the market can be find in economic instruments and incentives, which encourage stakeholders to adopt more energy efficient approaches in design, construction, and the operation of buildings. Basically, the purpose of these measures is to change the market conditions in a way that a product gets more attractive. Instruments like reduced tax rates or improved loan conditions are often more efficient than regulations and standards [UNEP, 2007].

Economic instruments, which can be applied, are [UNEP, 2007]:
- Rating systems (market-based programmes, government-owned regulatory programmes)
- Tariffs (’The user pays’ method; consumer based monitoring with liberalized markets and dynamic tariffs)
- Energy Audit Programme (systematic procedure that obtains an adequate knowledge of the existing energy consumption profile of the site)
- Europe – promotional initiative (e.g. The GreenLight Programme, [www.eu-greenlight.org])
- Flexible instruments (energy audits, ‘green mortgage’ and tax incentive systems, environmental permits etc).

02.03.02 Economics of High-Performance Houses

A basic question appears during the in the first phase of a building project, whether additional investment costs for a house with a high performance are worth and what is the investor’s or owner’s perspective on the payback? The higher initial costs of construction are easily paid back within the building’s lifetime says Hastings and Wall [2007a]. The payback period even looks shorter when having the recent escalation in energy prices in mind.

Interventions, which improve the energy efficiency of a building, can be assessed by the economic savings which they cause and the return on investment in consequence by comparing it to the standard home without improvements.

Some studies are based on the indicator ‘payback period for the investment’ but sometimes it turns out that this period is even not within the expected lifetime of a product. For reasons of sustainability it might be more favourable to use for the evaluation the measure ‘cost of a saved kWh’. In the book of Hastings and Wall [2007a] some exemplary calculations are made on this basis.

Hastings and Wall recapitulate:
- The optimum insulation layer of a house is 23 cm.
- The roof insulation layer is by far the most economic measure and has its optimum thickness at 24 cm.
- Windows are on of the valuable and high costly measures and they cost about 30 to 35 per cent more than standard windows. They are worth additional costs (circa additional 60 €) and have an essential role in the performance of a house.
- Combined heat pump systems are nearly 50 per cent more expensive than direct heating. A combi-system with a high efficiency is irrelevantly more expensive than a direct heating system.
- Taking the time to train and motivate the craftsmen and tradesman is a good investment.
The ‘Milieu Centraal’ [Utrecht, the Netherlands] has summarized a list of interventions, its cost and payback period:

Summary
A high-performance house needs some additional investment. High quality components are essential to achieve a high efficiency. A smaller heating system, reduced operational costs, and improved comfort pay back additional investments. Due to the reduction in energy consumption the home buyers are protected from highly volatile energy prices of the market.

Win-win story for all groups of people involved:
- Customer gets a comfortable sustainable and, hence, affordable home;
- Producers will discover new markets;
- National economy which profits from locale investments instead of exporting capital to energy producing countries.
- Future generations will profit from larger remaining non-renewable resources.

02.03.03 Quality Issue

The quality issue is in the marketing of a ‘high performance house’ a strong selling factor. People anticipate sustainable living with high comfort and best quality in living. Thus, the product has to fulfill this expectation of its buyers to prevent a loss of credibility before the breakthrough on the market. If the product proofs to meet the requirements there will be a good chance to its success.

To ensure these high standards in quality, quality insurance system should cover the design and production process. Wherever decision processes are involved compromises may cumulate in a way that the final-product does not match the good intentions one had at the beginning. Somebody has to have the big overview and someone should have always the target in mind.

Producing a highly sophisticated product like a high performance building requires a good quality management in form of control instances. From the very first design stage till completion, an integrated workmanship between all building parties is necessary to ensure a certain level of quality.

The implementation of new technologies should not end with the design phase. The prefabrication (preferably off-site) and the assembling on site have to include the knowledge and the technique as well as their related connections. The exact execution has to be solidified by checks.

Typical factors in the building sector, which diminish the quality of the product ‘building’, are [Simon and Simon, 2004]:
- the plurality of building regulations;
- the unknowingness of building parties;
- the tangle of languages on site;
- not existing control instances; and
- a missing interdisciplinary communication.
**House standards**

One approach to ensure a certain quality level is the predefinition of a certain standard for houses. As already mentioned before, a definition of sophisticated, new housing standards is representing a strong selling point and supports the consumer’s credit into the product. Two standards embody already these ideas and have proofed its credibility on the market. One is the ‘Passive House Standard’ developed in Darmstadt, Germany around 1990 and the other one is the ‘Minergie-P Standard’ primarily used in Switzerland. Both result in ultra-low energy buildings. Since the implementation of these standards about 6000 houses were built within Europe.

Today’s definition of a low-energy house can be divided into two specific approaches: the concept of 50% and the concept of 0%. The percentage presents the amount of energy that these buildings use in comparison with a standard building according to current building regulations.

The 50% building, which cannot be seen as a sufficient solution, is a traditional house with an increased level of thermal insulation, high performance windows, and heat recovery. As a rule of thumb, houses with an at least 50 percent better performance when compared to standard building requirements can be addressed as sustainable. With this definition, many different products and groups of products can be defined as sustainable and create a new market segment [IEA, 2006].

The concept of 0%, covered by Zero Energy and Passive House standards, produces as much energy as it consumes over a full year. This requirement legitimises the term ‘passive’. This approach represents one of the most challenging solutions in terms of environmentally responsible construction. It requires state-of-the-art technologies and renewable energy systems. Zero Energy buildings are usually connected to the utility grids, in order to bridge fluctuations in the demand.

With this standard the occupants’ comfort can be maintained without active heating and cooling systems. The house heats and cools itself and is therefore ‘passive’. For European passive construction is a maximum annual heating demand of 15 kWh/m² required. Furthermore, the combined primary energy consumption of living area may not exceed 120 kWh/m²a. A passive house is cost-effective when the combined capitalized costs (construction, including design, equipment, operating costs for 30 years) do not exceed those of an average new home [UNEP, 2007].

### Characteristics of a passive house [UNEP 2007]:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact form and good insulation</td>
<td>U-value ≤ 0.15 W/m²K</td>
</tr>
<tr>
<td>Orientation and shade considerations</td>
<td>Passive use of solar energy</td>
</tr>
<tr>
<td>Energy-efficient window glazing and frames</td>
<td>U-value ≤ 0.80 W/m²K, g-value ≥ 0.5</td>
</tr>
<tr>
<td>Building envelope airtight</td>
<td>Air leakage ≤ 0.61/h</td>
</tr>
<tr>
<td>Passive preheating of fresh air</td>
<td>Through underground ducts</td>
</tr>
<tr>
<td>Highly efficient heat recovery</td>
<td>Heat recovery rate 80%</td>
</tr>
<tr>
<td>Hot water supply using renewable sources</td>
<td>Solar collector and heat pumps</td>
</tr>
<tr>
<td>Energy-efficient household appliances</td>
<td></td>
</tr>
</tbody>
</table>

### Characteristics of a passive house [PEP, 2006]:
Another marketing product is the Minergie House. Minergie is a Swiss quality label for new and refurbished buildings. This label is a registered trademark and enjoys complete protection. The required building quality is quantified by specific energy indicators. In this way, a reliable assessment can be assured. Only the final energy demand is relevant. The Swiss Minergie Standard has a market share of about 30% of new construction works [IEA, 2006]. The Minergie House has requirements similar to the Passive House Standard.
02.04 Multi-Criteria Decisions-Making (MCDM)

Considering the complexity of planning and the design process the building sector is special. Design processes for buildings are culturally specific. Descriptions, which are universally valid, are impossible to create. Every building is a unique construction with its particular surroundings and context; it is a one-of-a-kind object. Each country has its own professional standards and its own ‘codes of conduct’. Disciplines involved in the decision making processes cannot be covered by standard hierarchies or standard organizing structures. They have to be adapted to every individual project and the importance of perspectives will change. For example, in one design the emphasis will be on aesthetic issues and money plays a minor role and in the next project this can be oppositional. To achieve the best result in form of the best over all performance, synergistic solutions are necessary. Multi-criteria decision-making (MCDM) methods can help to find these solutions.

MCDM is a systematic approach to solve problems with a wide range of attributes. These complex issues (criteria) may have different units of measurement and may be conflict each other. The aim is to organize conflicting and complex information in a way that facilitates the decision making and furthermore reinforce the consciousness of planer’s decision.

How to use MCDM?

The highly iterative nature of planning is complicating the establishment of a decision making framework. Several phases of a building design -particularly during the early stages of design- tend to be cyclical in nature. Any of such a design cycle might benefit from an MCDM approach, both for structuring the design work and as part of the evaluation process. The amount of information and the degree of detail defines the depth of the MCDM model during the design phases. This progression, from general to detailed, defines the role of the supporting decision-tools. It is recommended to use a trimmed-down or simplified version of the method during the early phases of design (preliminary design) and use a fuller, more comprehensive version in a later project phase. [Hastings and Wall, 2007a] [IEA Annex 31, 2005b]

To illustrate the complexity in this field; a construction element has to integrate major functions like:
- Functionality
- Technical aspects
- Legal conditions
- Finances
- Aesthetic
- Environment.

The application of MCMD can be separated into seven main steps [Balcomb et al. 2002]:
1. Select main design criteria and sub-criteria;
2. Develop measurement scales for the sub-criteria;
3. Weight the main criteria and sub-criteria;
4. Generate alternatives;
5. Predict performances;
6. Aggregate scores;
7. Present and discuss results, and make decisions.
The functional description of these individual operations is not addressed in this paper with reference to [Balcomb et al. 2002]. So far, in the last step, a star diagram is recommended to present the overall performance of the alternatives. It shows all the individual performance measures on its axis. These scores can be weighted to its importance and finally evaluated in a summed performance. The outcome of this analysis is the design criteria score.

![Star diagram](source: Balcomb et al. 2002)

![Score chart](source: Balcomb et al. 2002)
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Since 1995 building regulations in the Netherlands require an energy-performance based calculation for the planning permission. This calculation is expressed in one value, the energy performance coefficient (EPC). Dutch building regulations, i.e. EPC, were and will be intensified and for the objective evaluation of these measures references in form of standardized dwellings are needed. SenterNovem has set up six reference dwellings based on current requirements (2006) in the construction sector. The reference dwellings function as theoretical template for qualitative and quantitative technical questions in construction and comfort etc in the early design phase.

The six reference dwellings are available in two variants, (1) with a balanced ventilation-system including heat recovery and (2) with a self-regulating ventilation and mechanical suction system.

The following reference dwellings are distinguished, including the share (in %) to new build dwellings in the Netherlands:

- Terraced House (middle dwelling) 36,5%
- Terraced House (edge dwelling) 13,5%
- Semi-detached dwelling 13,0%
The ‘terraced house (middle dwelling)’ represents the biggest share to the market of new constructed dwelling in the Netherlands. Thus, if someone wants to implement interventions/measures efficiently s/he should start with this reference dwelling.
Terrace House (middle dwelling)

The terraced house covers circa 50% of the dwelling-production in the Netherlands. 20% of this production is placed in the rental-market and 80% on the selling-market. The average dwelling has 125 m² living space (with three bedrooms, one kitchen, one bathroom and one living room). The roof is either pitched, saddle or flat.

Dwelling properties

- Inner distance wall to wall: 5.1 m
- Depth of the dwelling: 8.9 m
- Storey height: 2.6 m
- Net (usable) space: 124.3 m²
- Gross space (outer boundaries): 156.9 m²

Architectural properties

- Rc-value façade: 3.0 m²K/W
- Rc-value roof: 4.0 m²K/W
- Rc-value slab: 3.0 m²K/W
- U-value windows: 1.8 W/m²K
- U-value entrance door: 2.0 W/m²K
- External sun-shading: yes

Depending on the variant (1 or 2): with solar collectors for DHW (2.8 m²) or heat recovery systems with a performance of 95%; the annual energy consumption is between 359 MJ/m² and 340 MJ/m².