Constructing energy efficient dwellings in the Netherlands

The effect of energy efficiency measures through the lifecycle of a dwelling

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Abstract

Energy efficient building is an important trend in the Dutch effort to reduce the nation's energy use. Households are responsible for about one third of the total natural gas consumption in the Netherlands during their lifetime. The results of this research show that about 20% of all energy reductions between 1996 and 2008 were due to energy efficiency measures in newly-build dwelling projects. The remaining 80% could therefore roughly be attributed to retrofitting. Also, a survey amongst newly-build dwelling projects finished in 2008, demonstrated that the current EPC norm of 0.8 is easily met or even better. About 12.2% of these dwellings perform better with an average energy use which is 16% lower than the norm.

Another aspect, besides this energy use during the users' phase, is the energy involved within the actual construction of the dwellings. Worldwide the building construction industry consumes about 40% of the materials entering the global economy and generates 40-50% of the global output of greenhouse gases and the agents of acid rain. For this phase, the results showed that depending on the lifetime of a dwelling (ranging between 30 and 100 years), the relative construction energy in relation to the total energy use (over this lifetime) of the average dwelling was between 30% and 10%.

Finally, also the demolition phase of dwellings in the Netherlands was investigated in the search for energy saving possibilities. In general about 96% of all demolition debris is actually recycled. Unfortunately the bulk of these materials are downcycled into low quality applications like the foundation of roads. Still, the results indicate that about 0.13% of the total embodied energy of the average dwelling in 2008 was saved due to recycling.

Table of Contents

1 Introduction

In the Netherlands as well as internationally, a lot has been written about the construction of energy efficient buildings. Many methods, technologies and policy measures have been discussed to the extend that one could say that in this field a lot is possible to save substantial amounts of energy. Households are responsible for about one third[1] (see *Figure 1*) of the Dutch natural gas consumption. Therefore it is clear that the potential to develop energy neutral of even energy producing dwellings, in order to safe fossil fuels and reduce greenhouse gases, is very high. Besides the actual energy use of dwellings during their lifetime, another aspect is also important: the energy involved within the actual construction. Namely, in many countries the construction industry is a large user of energy and natural resources. *The building construction industry consumes about 40% of the materials entering the global economy and generates 40-50% of the global output of greenhouse gases and the agents of acid rain.*[2] From a life cycle perspective, this is also in close relation with the demolition phase at the end of a dwellings' lifespan. With this background in mind, the relevance of this research lies within the question whether or not we are on the right track or alternative action should be taken.

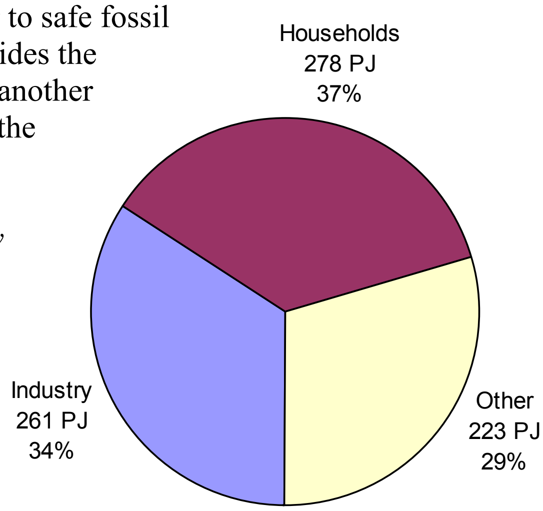

Figure 1
Distribution of total final natural gas usage in the Netherlands in 2007

Since 1992, the Dutch government has laid down minimal technical building regulations in the Building Decree (Dutch: Bouwbesluit). These uniform and performance based regulations are imposed on the national level and are characterized by a lot of standards. These standards can be used to checked whether a structure (in this case a dwelling) complies with the (general) requirements: safety (e.g. fire safety, mechanical strength, etc.), health (e.g. sound insulation, ventilation, etc.), usefulness (e.g. communal store for domestic waste, accessibility for disabled people, etc.), energy-saving (e.g. energy performance, thermal insulation etc.). Especially the energy-saving article has a high relevance considering the topic of this thesis and explains in detail government regulation on the using phase of a dwelling.

Interestingly enough, a sixth article concerning environmental safety is also mentioned in the building decree. This article should discuss building regulations concerning the building phase of constructions (e.g. material choice, building methods, etc.), but has not been filled in. Therefore official regulation on this issue does not yet exist.

Although so-called 'sustainable building projects' with high energy savings targets emerge, the question remains what their real effect on our primary energy consumptions will be. Are these (maybe relative small) projects combined not only a drop in a vast ocean? In other words: Do these (theoretical) technologies and measures find their way to common practice by construction companies, contractors, etc.?

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[1] Statistics Netherlands – www.cbs.nl
[2] CIWMB (California Integrated Waste Management Board), Designing with vision: a technical manual for materials choices in sustainable construction; 2000

This master thesis will focus on these questions from a life cycle perspective and therefore analyse the energy consumption and material use during each phase of a (future) building's lifecycle. Namely: constructing, using and finally demolishing. During the construction phase the focus will be set on energy savings due to material choice and construction techniques. The user phase will be characterized by energy savings due to the structure of the final dwelling during its lifetime. Finally the demolition phase will be analysed based on energy saving measures due to more energy efficient demolition techniques and the separation of materials for secondary use.

This research will touch both sides of the energy and resources track of this masters program, generally because material and energy efficiency are vital in the dwelling life cycle analysis. During construction and demolition, material efficiency will be the issue and during the usage of the dwelling, energy efficiency due to the dwelling structure and applied energy saving techniques.

2 Problem definition

The relevance of this research lies within the potential energy, material and greenhouse emission savings which can be achieved within the construction of dwellings in the Netherlands. It will also evaluate to what extend technological innovations are actually implemented and what their relative importance is. Besides this, it will also provide indicators to measure the energy or material efficiency of these buildings. These indicators could prove useful for policy makers, trying to design construction regulations in order to match sustainability goals.

The problems described lead to the following main question:

How do sustainable construction practices in the Netherlands affect energy efficiency of new dwelling projects during their life cycle?

Since a life cycle approach has been chosen, the sub questions will be divided into the three phases of the lifecycle of a typical Dutch dwelling project. Therefore:

- *To what extent is the selection of materials during construction affecting the energy efficiency of dwelling projects and what are the impacts?*
- *To what extent are energy efficiency measures implemented during construction, taken into account the usage phase of a dwelling and what is their impact?*
- *To what extent are residue materials during the demolition phase of dwellings in 2008, reused or recycled into new buildings and what is the energetic impact?*

3 Theory

The theory chapter is divided into several parts. Paragraph *3.1* describes the development on sustainable building policies within the Netherlands and the EU. The paragraphs *3.2* and *3.3* describe (in depth) some energy performance indicators and their usefulness for this research (based on the research sub question on energy efficiency during the usage phase). Paragraph *3.4* describes a number of other LCA based sustainable building measurements. Paragraph *3.5* describes the life cycle Analysis of some major energy consuming building materials (based on the research sub question on energy efficiency during the construction phase). Finally paragraph *3.6* covers the demolition phase and the major results in this sector (based on the research sub question on energy efficiency during the demolition phase).

3.1 Policy development and regulation

This chapter describes the developments of policy measures and regulations in the Netherlands, as well as the more recent development of EU interference within this context.

3.1.1 The Netherlands

The first notion of sustainable building policies in the Netherlands, surfaced during the 70s in reaction to a growing interest in energy savings. Among other things this was due to the report of the Club of Rome in 1972[3] and the oil crisis in 1973/1974. These developments resulted in the PREGO-scheme in 1980. A policy measure which stimulated energy saving pilot projects within dwellings and commercial and industrial buildings. For existing buildings, in 1978 the national insulation scheme was set up to deliver insulation to 2.5 million dwellings.

An influential catalyst in the process to more sustainable policies was the release of the Brundtland report[4] in 1987. The definition “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." of its main concept (sustainable development), inspired the Dutch government in 1989 to publish the National Environmental policy plan (Dutch: Nationaal Milieubeleidsplan). This plan comprised three important targets: the closure of the building materials chain (by reuse), quality improvement of buildings focussed on health and energy savings during the usage phase of the dwelling. Until this point, the focus had primarily been set on the energy savings, instead of the first two targets.
In the same year the Environmental Building Counsel (Dutch: Milieuberaad Bouw) was founded as a body to mediate between the national government and building industry actors. Their goal was to find a structured approach to environmental issues within the building sector. The reuse of building material demolition debris (60% reuse in 1990 to 90% in 2000), a plan to increase the use of wood with 20% and the first approaches to lifecycle analysis for buildings (in 1995) are only a few examples of the merits of this counsel.
On request of the Dutch Lower House, in 1996 the program Sustainable and Energy-saving Example Projects (in Dutch: programma Voorbeeldprojecten Duurzaam en Energiezuinig Bouwen) was started. During these years and in reaction to this program, fifty sustainable pilot projects where selected. Examples are Morrapark in Drachten, Ecodus in Delft, Ecolonia in Alphen aan de Rijn and Nieuwland in Amersfoort. For these last two projects, the DCBA method was used as a measurement of the extent of sustainable building. These projects had

[3] Club of Rome, Limits to Growth, 1972
[4] World Commission on Environment and Development (WCED), Our common future, 1987

to show what the technical possibilities of that time were and what technologies could become common practise within a few years.

In 1992/1993 the new Residential Act (Dutch: Woningwet) does, apart from building requirements formulated in the just established Building Decree (Dutch: Bouwbesluit), not allow any other building prescriptions (e.g. by municipal governments).
Two years later in 1995, a Sustainable Building Action Plan (Dutch: Plan van Aanpak duurzaam bouwen) was developed to make ‘a jump of scale’ in sustainable building. This trend had to become a standard and central theme during all phases in the construction process: during planning, designing, implementing and managing.

One of the consequences of this plan was the implementation of the Energy Performance Coefficient (Dutch: Energie Prestatie Coëfficiënt) in the Building Decree[5]. This first EPC was set on 1.4 for dwellings in 1995. The actual equation to calculate this coefficient is more thoroughly described in the next paragraph on *The Energy Performance Coefficient*. Nevertheless, EPC can be described as the maximum theoretical energy usage of a building (taken into account its size and surfaces), converted to a single number. It should be noted that these theoretical energy consumptions are not only based on shape and size, but also assumptions on the (typical) behaviour concerning energy usage of the residents and outside temperature conditions. During the years the Energy Performance Coefficient was lowered a number of times: to 1.2 in 1998, to 1.0 in 2000 and to 0.8 in 2006[6]. This gradual decrease in dwelling energy usage was also suggested in the third Energy Paper (Dutch: Derde Energie Nota), in which a decrease of the total energy consumption in the Netherlands was intended.

After the first Sustainable Building Action Plan, a second one, which focussed more on commercial and industrial buildings, was introduced in 1997. As a large administrator and commissioner of these buildings, The Dutch Government Building Department (Dutch: Rijksgebouwendienst, RGD) was appointed to show examples of sustainable commercial and industrial building projects. It also initiated a number of sustainable index programs like GreenCalc and the Environmental Index (Dutch: Milieu-index) to grade sustainable building projects. With these methods sustainable building became more measureable for (market)parties and allowed then to incorporate it into the decision and planning process of new projects more easily.

Now a few methods existed to measure the sustainability of projects to a certain degree, it became essential to convert these examples of sustainable building projects into common practise. Developers and contractors wanted practical, unambiguous and proven measures with national uniformity which could be implemented without much difficulty. The answer to this call appeared as the National Sustainable Building Packages (Dutch: Nationale Pakketten Duurzaam Bouwen, see *3.4.7*). For (newly build) dwellings one was developed in 1996 and for dwelling management one in 1997. In these packages a distinction was made between standard cost-neutral measures and variable measures which were not universal or not realisable without additional costs. The latest updates of these packages where published in 2005 and will be discussed further on.

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[5] Article 5,3 from the Building Decree (Dutch: Bouwbesluit) - 2003
[6] National Normalization Institute (NEN), EPC’s over the years; http://www2.nen.nl/cmsprod/groups/public/documents/bestand/201135.pdf

The beginning of the 21st century was marked with a policy program on sustainable building, issued in 2000[7]. The goal was to bring gained experiences over the last 10 years into common practise. This policy program was evaluated in 2002 with the 'policy letter on sustainable building'[8]. This letter focused on three themes: energy, materials and health, but also on the demands of consumers or building users and project development within existing and new districts.

Also during these years it became clear that a number of sustainable initiatives did not had enough support. For example a radiation (maximum radiation from building materials) and water performance norm were never added to the Dutch Building Decree. This decree has, besides the first four paragraphs on safety, health, usefulness and energy-saving, also a fifth 'environmental' paragraph which is still not filled-in. Energy-savings became the primary goal, especially because the Kyoto protocol was now officially put in motion. It was ratified by Russia in 2005, so the minimum amount of 55 subscribed countries was reached.
In order to reach a greenhouse gas reduction of 6% before 2012, a number of policy instruments were developed. An Energy performance advise (EPA) for private owners of dwellings and corporate parties was realised to stimulated them to invest into (subsidized) energy-saving measures. This subsidization scheme (Dutch: Energiepremieregeling) was finally ended in 2003 because it became clear that a lot of the measures were already economically feasible.

In the meantime around 2004, it became clear that an energy transition action plan would be needed to actually reach the goals described in the Kyoto protocol. Therefore in 2006 a long-term plan until 2050 was developed[9]. It stated ambitions like the more efficient use of energy (with yearly savings of 1.5 – 2%), the substantial use of green resources and renewable energy, reduction of CO_2 emissions by 50% (compared by 1990) and strengthening the position of the Dutch business community.

Unfortunately, these kind of long-term plans were not very popular among market parties. Their short-term day-to-day worries and incomprehension of the high investment costs made them held back on sustainable building measures. 'Quality' became the new central theme with other key concepts like People, Planet, Profit / prosperity (the triple-P approach). Especially the more social 'people' concept was new in this context. Urban restructuring of neighbourhoods became vital to create a good living environment, but also to achieve further energy reductions in these existing dwellings. In line with these developments, industrial, flexible and detachable (IDF[10]) construction methods appeared. This concept opened a new phase in which more flexible dwellings could emerge to respond to future changes in demand. In return, the amount of prematurely demolished dwellings can become lower with less waste and the use of less resources. Also the quality and working conditions can improve because of the prefabricated industrial parts. Finally, these prefabricated parts will be easier to dismantle during the demolishing process, so consequently larger quantities can be reused.

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7 VROM, Beleidsprogramma duurzaam bouwen 2000-2004;Verankering in beleid en praktijk, 2000
8 VROM, Duurzaam Bouwen; Brief staatssecretaris over de speerpunten van het rijksbeleid de komende jaren: energiebesparing, verantwoord materiaalgebruik en verbetering binnenklimaat Kamerstuk 2001-2002, 24280, nr. 22, Tweede Kamer
9 Ministry of Economical affairs, Meer met Energie : kansen voor Nederland, June 2006
10 SEV Realisatie, De kunst van rekbaar vastgoed, Bouwen in een tijd vol verandering; 2006

3.1.2 The European Union

During the last months of 2006 and the beginning of 2007 a confluence of events occurs which would put energy-saving policies firmly back on the agenda. These events can be summed up as the movie 'An Inconvenient Truth' by Al Gore, the publication of the 'Stern Review of the Economics of Climate Change'[11] (in which the sense of urgency is confirmed), claims by the Intergovernmental Panel on Climate Change (IPCC) which indicate that human activities are the most important cause of climate change (thus supporting Al Gore's claims) and Russia, turning off the gas supply to the Ukraine and thereby cutting off the rest of western Europe as well. This made European countries realise their dependency on fossil fuels and a political willingness to discuss energy-saving and renewable energy opportunities emerged.

One of the specific outcomes of these events, which generally led to more ambitious international policies on sustainable development, was the implementation of the Energy Performance Building Directive (EPBD) in the Netherlands. The EPBD is actually the European EPC directive, and was already published on the 4th of January 2003.

Early 2007, the Dutch government came with ambitious plans on energy and energy savings, namely:

- A 30% reduction of greenhouse gasses in 2020 (compared to 1990)
- Yearly energy savings from 1 to 2 %
- The renewable energy share in the Netherlands from 2.7% in 2007 to 20% in 2020

In terms of sustainable building this meant:

- The renovation of 500,000 buildings before 2011 to make them more energy efficient[12]
- A new subsidy scheme to stimulate investments in renewable energy (SDE)
- The increase of the Energy Performance Coefficient from 0.8 to 0.6 in 2011 and 0.4 in 2015

Besides these targets, it was also decided to bring the EPBD into force in the Netherlands on the 1st of January 2008 to comply with this new EU directive, thereby abandoning the current Dutch energy performance norms. This means the replacement of NEN 5128 (norms for dwellings) and NEN 2916 (norms for commercial and industrial buildings).

The EPBD is composed of over 30 European norms, which together determine the energy performance of a building. Generally, the difference between the current Dutch norms and the new EPBD, is not very large. This is mainly because a lot of input was given by the Netherlands during the development of these EU norms. In order to bring this new legislation into force, the Dutch normalisation institute (NEN[13]) has chosen to develop one Dutch Energy Performance Norm which incorporates the EU EPBD (NEN 7120).

One of the major changes in respect to the Dutch norm system, is the fact that the EU system also demands an Energy Performance Certificate for existing buildings. This also demonstrates one of the new norms' major strengths. Namely, a general foundation on energy performance calculations for all buildings (new and existing). Another improvement of NEN 7120 is the fact that new technologies (like water saving measures) are also included in the calculations. Taken into account the importance of reference climate figures in establishing

[11] Stern, Stern Review of the Economics of Climate Change, 2006

[12] Formulated in the covenant 'More with Less', by the Ministry for Housing, Regional Development and the Environment, the Ministry of Economical affairs and several other (market) parties involved; www.meermetminder.nl

[13] Website NEN, EPBD page; http://www2.nen.nl/nen/servlet/dispatcher.Dispatcher?id=195705

the EPC of a building (see *3.2*) and the climate change of late (with softer winters and warmer summers[14]), the update of these figures is also an important improvement.

The timetable for further development on this EU directive within Dutch legislation is as follows:

- December 2009: publication final version NEN 7120
- 1st January 2011: NEN 7120 officially added to the Dutch Building decree, simultaneously with the decrease from 0.8 to 0.6 of the EPC (according to current standards).

3.1.3 Policy summary

Finally, all the discussed policy measures can summarized into the following table.

Table 1 Summary of all policy measures discussed in 3.1.1 and 3.1.2.

Initiative	**Year**
Publication of 'Limits to Growth by the Club of Rome	1972
The oil crisis	1973/1974
National insulation scheme	1978
PREGO-scheme (which stimulated energy saving pilot projects on buildings)	1980
Publication of the Brundtland report	1987
The Dutch National Environmental policy plan	1989
The founding of the Environmental Building Counsel	1989
New Residential Act (minimum building prescriptions are established	1992/1993
Development of the Sustainable Building Action Plan	1995
Implementation of the Energy Performance Coefficient in the Building Decree (it was set on 1.4 for new dwellings).	1995
The Sustainable and Energy-saving Example projects program	1996
The National Sustainable Building Packages (on new dwellings) were developed	1996
Development of the second Sustainable Building Action Plan	1997
The maximum EPC of new dwellings was decreased to 1.2	1998
The maximum EPC of new dwellings was decreased to 1.0	2000
Publication of the policy program on sustainable building	2000
The Kyoto protocol is put into motion officially, after being ratified by Russia	2005
The maximum EPC of new dwellings was decreased to 0.8	2006
The publication of a long-term (until 2050) action plan by the Dutch government	2006
Publication of the Stern Review of the Economics of Climate Change	2006
The movie 'An inconvenient Truth' by All Gore	2007
The Energy Performance Building Directive (EPBD) implemented by the Dutch government	2008

[14] Dutch Normalisation Institute NEN, Concept version NEN 7120:2009

3.2 *The Energy label – Energy Index*

In the Netherlands the outcome of the new EU Energy Performance Building Directive came in the form of an Energy Label scheme based on the Energy Index. From the 1st of January 2008, an energy label (which is maximally valid for ten years) is obligatory delivered with the construction, selling or rent of a dwelling. In October 2009, a new improved energy label will be presented (and put into force on the 1st of January) and the Regulation on Energy Performance of buildings published.

Since all new dwellings already must comply with the minimum (strict) energy performance requirements (EPC) described in the Dutch Building Decree, the Energy label will not add anything to these dwellings. Therefore newly-build dwelling owners may submit the EPC calculation of their dwelling as well, which may be up to ten years old.

The energy label gives information on the expected building related energy use, based on a standardised behaviour of its occupants. This involves all the characteristics discussed in *3.3.2* (on the Energy Performance Coefficient). The characteristics of the dwelling are finally converted into a single value: the Energy Index.

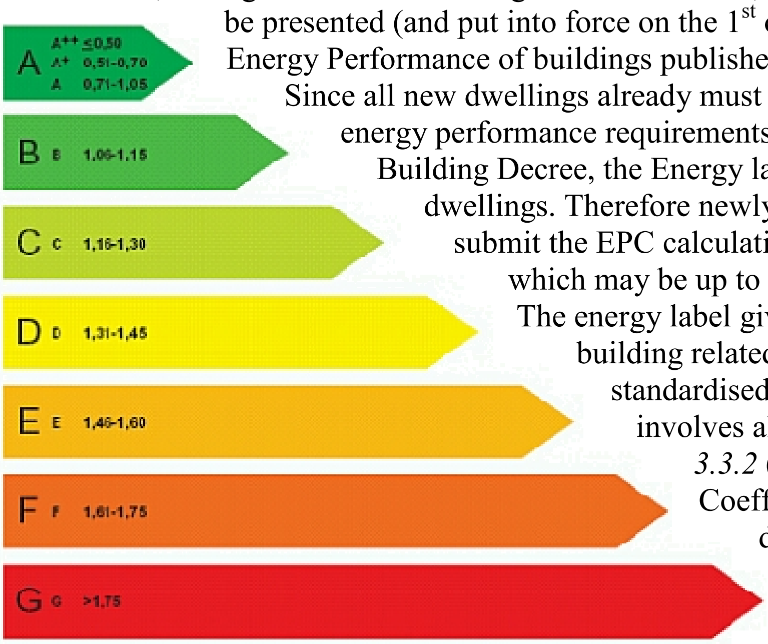

Figure 2 The Energy Label class distribution of the Energy Index
Source: www.energielabel.nl

Based on this index, the dwelling is labelled according to the classes displayed in *Figure* 2 ('A' being very energy-conserving and 'G' being very energy-consuming).

The equation of the Energy Index[15] value (EI) differs from the EPC calculation and can be displayed as follows:

$$EI = \frac{Q_{tot} \times A_{schil}}{56 * A_{schil}^2 + 0,06 \times Q_{tot} \times A_g} \times 0,13 \qquad \textbf{(1)}$$

The variables Q_{tot} (in MJ), A_g (in m^2) and A_{schil} can respectively be compared with $Q_{pres;tot}$ (the typical primary energy use per year), A_g (the used living surface) and $A_{verlies}$ (the heat loss surface) of the EPC calculation (see *Equation 2*). The figures within the calculation are correction factors with several units.

Since 2007 Senternovem (an agency of the Ministry of Economical Affairs), keeps track of the Energy label scheme in the Netherlands. In 2008 a total of 725,400 dwellings came with an Energy label, this is about 10.2 percent of the total amount of dwellings in the Netherlands that year (7,106,564)[1].

[15] German Federal Ministry of Transport, Building and Urban Affairs, Monitoring and evaluation of energy certification in practice with focus on central European states ANNEX I - Country Reviews (Draft, approved for Phase I); 8th September 2008

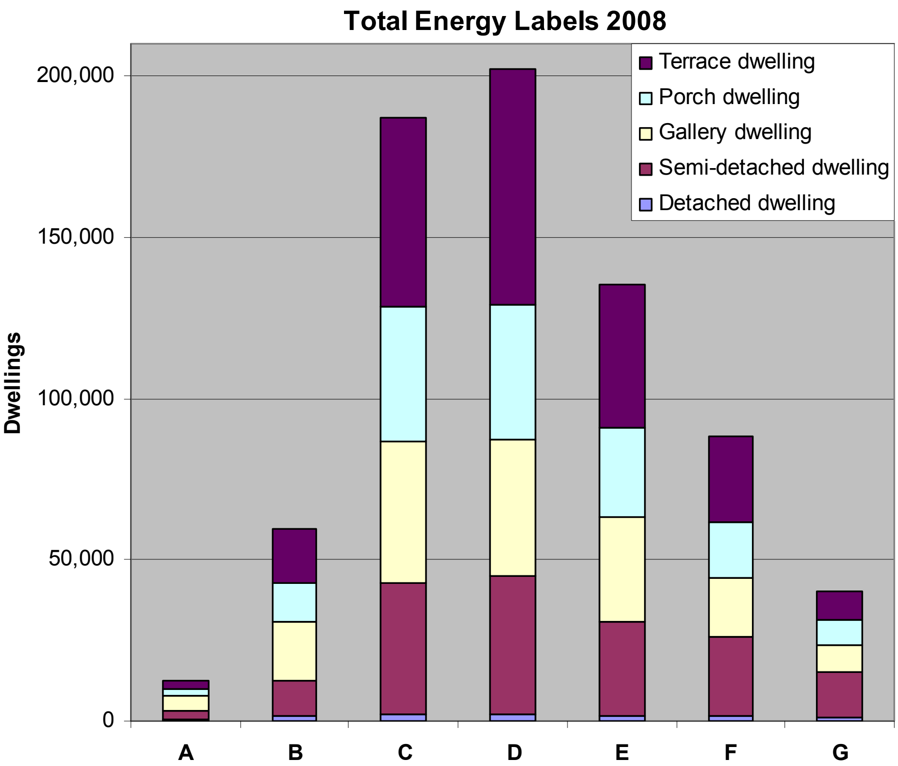

Figure 4 The distribution of types of dwellings per energy label class
Source: Senternovem database; http://senternovem.databank.nl/; 08-2009

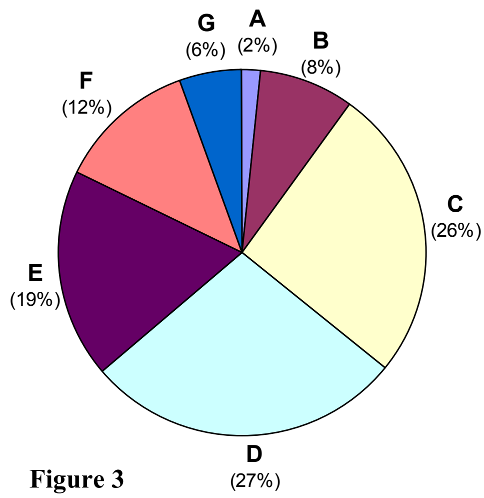

Figure 3

The distribution of types of dwellings per energy label class
Source: Senternovem database; http://senternovem.databank.nl/; 08-2009

Derived from this data[16] *Figure 3* displays the distribution of the different energy labels in the Netherlands. *Figure 4* also shows the distribution of the types of dwellings per energy label, showing nothing particular conspicuous.

3.3 The Energy Performance Coefficient

This paragraph will give some in-depth information about the energy performance coefficient, mainly because it will be used to answer the second sub question of this thesis "*To what extent are energy efficiency measures implemented during construction, taken into account the usage phase of a dwelling and what is their impact?*". Therefore the exact calculation of the coefficient will be explained (at least the part which is significant for this research) and the relation between the EPC and actual energy performance (including assumptions) will be discussed.

[16] Senternovem database; http://senternovem.databank.nl/; 08-2009

3.3.1 EPC in depth

The basics about the Energy Performance Coefficient have been discussed in *3.1* in the *Theory* section. This paragraph will cover the actual equation in which this norm is formulated and discuss the details involved.
The Energy Performance Coefficient equation[17] can be displayed as follows:

$$EPC = \frac{Q_{pres;tot}}{330 \times A_g + 65 \times A_{verlies}} \times \frac{1}{cEPC} \qquad \textbf{(2)}$$

Within this equation A_g is the used living surface and $A_{verlies}$ the heat loss surface (both in m^2) of the dwelling.

$Q_{pres;tot}$ is the typical (maximum) primary energy use per year (expressed in Mega Joules), derived from characteristic human behaviour and a normalised outdoor climate and finally combined with the actual energy related characteristics of the dwelling (see *3.2.2*)
This characteristic human behaviour involves assumptions on the presence of inhabitants, heating and ventilation (cooling) preferences, the use of tapping water and lighting usage.

It should also be noted that other energy intensive household appliances like refrigerators, radios, televisions, computers etc. or activities like cooking, washing etc. are not taken into account since they are not directly related to the energetic quality of the building itself.

Finally the cEPC value of 1.12 is used as a constant correction factor, added to the EPC calculation on the 1st of January 2006 when NEN 5128:2004 (on dwellings) and NEN 2916:2004 (on commercial and industrial buildings) came into force. The changes of the new EPC calculation within this revised norm in 2006, caused a small deviation compared to the 'old' final EPC's. In order to stay connected to the EPC's calculated before 2006, the cEPC correction factor addition was made.

3.3.2 User phase energy savings options in relation to the EPC

The assumptions within the EPC calculation on energy consuming activities and the outdoor climate (see *3.3.1*) are combined with the actual energy related characteristics of the dwelling. These characteristics are categorized below with present day technology examples and summarized into three basic factors[18]: *Orientation*, *Constructional shell* and *Installation concept*. All these factors are represented by the EPC value of a dwelling and will be discussed next.

3.3.2.1 Orientation

The way in which a dwelling is oriented in relation to the sun can have a tremendous impact on energy savings. Especially when passive heating (the use of solar heat) is applied to heat the dwelling (e.g. during winter), heating energy is saved. A good dwelling design makes optimal use of the low sun level energy during winter but keeps out the high level sun energy during summer (see *Figure 5* [19]).

[17] Senternovem, Woningen met EPC ≤ 0,8 berekend met de herziening van NEN 5128; 2006
[18] Senternovem, Handboek Handhaving EPN, based on NEN 5128:2004 and NEN 2916:2004
[19] http://www.bouwwereld.nl/1010768/Een-project-uitgebreid/Zomercomfort-integreren-in-ontwerp.htm

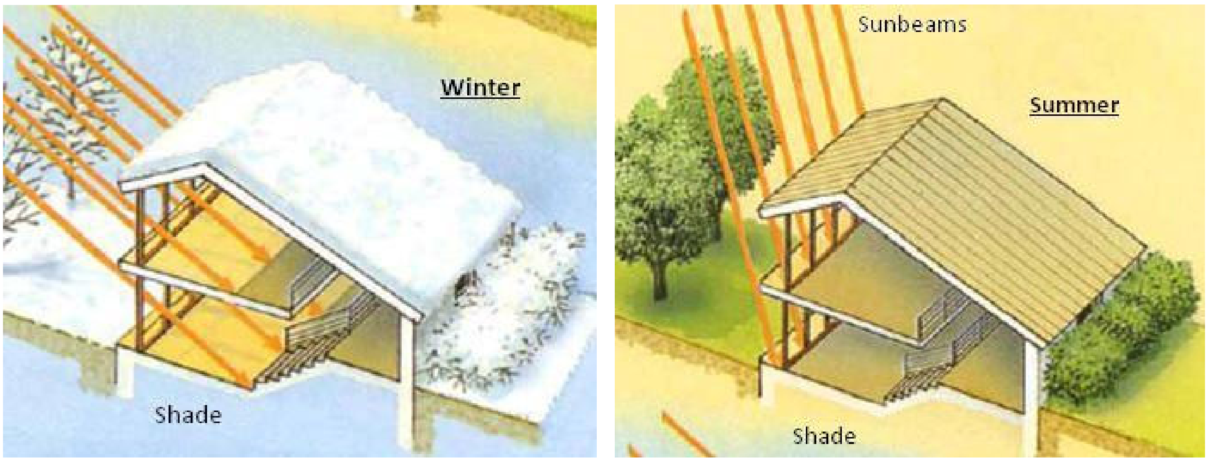

Figure 5

Solar level orientation of dwellings during winter and summer time
Source: http://www.bouwwereld.nl/1010768/Een-project-uitgebreid/Zomercomfort-integreren-in-ontwerp.htm

This way of constructing dwellings (solar-oriented), implies the use of relatively a lot of glass on the southern side in respect to the northern side of the dwelling. Other factors which play a major role in utilizing solar heat are:

- Building mass (whether or not the dwelling easily absorbs or looses heat, basically: insulation)
- Size and orientation of the windows
- The solar-radiation entry and insulation value of the glass (how much radiation / warmth is let through the glass)
- The presence of atriums
- Shading

<u>Summer comfort</u>
A drawback of solar-oriented building is naturally the chance of overheating the dwelling during summer and therefore the need for cooling. In practise, examples are known in which indoor temperatures (during hot periods) could rise to more than 50ºC during the day and still be 30ºC during the night. This problem can be lessened through the use of passive cooling measures like outside sun blinds and eaves, building mass and (if applicable) the use of a bypass in the heat recovery system (See: *3.3.2.3*). This concept of summer comfort is also taken into account in the Energy Performance Coefficient calculation. An expected cooling energy factor (based on a fictional low efficiency cooling installation) is added if inside temperatures during summer are too high. Therefore, excess heat during summer should be prevented to maintain a low EPC.
It is clear the purpose is therefore to cleverly design dwellings, to prevent a cooling installation is necessary. If constructional measures are still not sufficient, a cooling installation can be implemented to prevent the low efficiency cooling energy factor which will increase the overall EPC dramatically. This will occasionally be the case within balance ventilation systems. The cooling systems can be categorised al follows:

- Compression cooling machines

Within this type of cooling device, a electrical driven compressor brings a cooling agent to high pressure, thus increasing its temperature and phase (from fluid to gas). Next it is led to a condenser where the cooling agent condenses to a liquid again. Finally an expansion valve induces a reduction of pressure takes place and the cooling agent evaporates within the evaporator. Within this process, heat is extracted from the cooling water (indirect expansion cooling) or air (direct expansion cooling). This heat is subsequently emitted outside.

- Absorption cooling machines

These devices work according to a total different concept in comparison to their compression counterparts. Instead of mechanical compression is uses thermal compression, with the advantage that it does not contain any moving parts and thus produces less noise. On the other hand the efficiency of this installation is quite low and is, from this perspective, only advantageous if there is residual heat from other sources (like external heat delivery). The generation efficiency of these machines is therefore largely dependant of the quality of this residual heat.

- Seasonal storage

This type of cooling is largely described within the *heat pump* heading in the *installation concept* part of this paragraph below. It involves the opposite process described there, namely the use of stored water below the ground which has been cooled down during winter. Pumps and a heat exchanger are used to pump up this water from the soil and in such a way cooling the dwelling.

3.3.2.2 Constructional shell

All dwellings are under the influence of heat loss. This takes place through three different aspects of the dwelling:

- Outer walls, floors and roofs

The thermal resistance values of the outer walls, the ground floor and the roof are important factors in calculating the thermal insulation of the dwelling. The heat resistances of the different layers and the transition resistances (caused by thin layers of stationary air between the material layers) of these parts are added up to a single heat resistance value of the dwelling, called the R_c (m^2K/W). The higher the heat resistances, the lower the transmission losses through these parts.

- Transparent parts of the outer walls (windows)

These parts include windows, doors and fixed panels. Their thermal insulation value determines the extent to which heat can be transferred through. The EPC calculation takes more factors into account: the heat transmission coefficient (based on the thermal insulation value), the solar-radiation entry factor (see 3.3.2.1), angle of inclination in respect to a horizontal surface, the presence of outdoor sun blinds and shading. It should also be noted that the window frames can have a very high impact on the overall heat transmission coefficient of the window.

- Cold bridges and infiltration

Apart from the insulation (heat resistance) values of the different constructional parts of the dwellings' shell, the presence of cold bridges also has some influence in the total heat resistance of the dwelling. All existing connections within and between outer walls, roofs and floors can be described as cold bridges. Thereby also the infiltration factors plays an important role. These can be described as the characteristic amounts of air which 'leak' through the outer shell materials.

3.3.2.3 Installation concept

An efficient installation concept can have a large impact on energy savings and is basically an optimal combination of ventilation and heating (equipment) in relation to a good constructional shell. This also determines which combinations of energy saving techniques are possible. For example, the implementation of the balance ventilation system and its related energy saving performance, requires high insulation values of the constructional shell to prevent heat leakage. Next to heating and ventilation, solar panels and lighting are also factors in the energy performance calculation.

- Equipment for heating and warm tapping water

Installation equipment on heating and tapping water is the major consumer of building related energy use and should fit within the constructional shell properties of the dwelling. The most important factor of the heating equipment is off course the efficiency, which can be divided into two categories: generation efficiency and system efficiency. Generation efficiency is the actual efficiency of the apparatus and is determined by its type. System efficiency is a measure of the energy loss which occurs in the distribution process of the generated heat and is determined by the delivery efficiency (the effectiveness of the radiators and floor/wall-heating), circulation efficiency and distribution efficiency (the last two losses are only an issue within collective installations). Within the tapping water equipment (mostly the same installation), also the length of the piping system is an important factor.
The installations which can be incorporated into the EPC calculation can be described as follows:

- *Boiler (individual or collective heat supply)*

  There are three types of boilers: conventional, improved and high efficiency. Newly build dwelling are practically always equipped with the high efficiency variant (around 90 percent).
- *Combined heat and power installation (individual or collective heat / power supply)*

  A CHP installation is actually a small scale Combined Cycle (CC) power plant for one dwelling or a small block, which generates electricity and heat through the combustion of natural gas in a small Stirling engine. Since its efficiency is based on the production of both energy carriers, it is almost solely used during the heating season.
- *External heat delivery (collective heat supply)*

  This system (also known as district heating) uses residual 'waste' heat out of power plants (e.g. CC), waste burning installations, industries, biomass power plants, etc. in order to heat dwellings at a higher overall efficiency.
- *Heat pump (individual or collective heat supply)*

  A heat pump brings heat from a lower to a higher temperature level and needs therefore a (natural) source with a certain temperature level. Examples are outdoor air, surface water, ground water (aquifer) or soil. But also residual heat from waste water or ventilation air could be used. From these sources, heat is extracted during the heating season (winter), while a reverse (cooling) process can take place during summer. In the Netherlands, heat pumps are not commonly used yet. Still, the development of these systems is well underway.
- *Solar boiler*

  The principal of the solar boiler lies within a solar collector which is put on a roof, where a fluid runs through. The fluid is heated up by the sun and used for heating the house or tapping water. The system also contains a buffer vessel to (if necessary) store the heat and a regular boiler to heat up the fluid if there is not enough sunlight. The solar boiler can only be added into a low temperature heating system and has a yearly efficiency of around 0 to 40 %. If necessary, the system can also be combined with a heat pump.

It should be noted that the boiler and heat pump installation can be delivered with a low temperature heating system as well. Often the water supply temperature to the central heating is still about 90ºC, with a return temperature of about 70ºC (high temperature system). This system supplies water of about 55ºC with a return temperature of about 40ºC and is therefore more energy efficient.

The EPC calculation also takes into account additional (electrical) energy required to power the (described) installation combinations and which does not go to the actual heating. Examples are the pumps for circulating the central heating water and electronics in the boiler. The yearly energy usage of the pilot flame is also fixed in the EPC on 2500 MJ per year[18] (or about 70 m^3 of natural gas).

- Ventilation

The present Dutch building decree prescribes requirements in relation to the minimum ventilation characteristics of a dwelling. The different existing ventilation systems can therefore be described as follows:

- *Natural inflow – natural outflow*
  Taken into account the regulations for newly-built dwellings in the Dutch building decree, this kind of system only exists within older dwellings.
- *Natural inflow – mechanical outflow*
  Almost all newly-built houses are built with a natural inflow and a mechanical outflow of air. This is mainly because otherwise the necessary (constant) amount of ventilation can not be guaranteed (as within a natural in- and outflow system). Within this system the ventilation air is let into the dwelling through a grid in the outer wall. Through the kitchen, bathroom and toilet, the air is finally extracted from the dwelling with an outflow ventilator.
- *Mechanical inflow – natural outflow*
  This kind of almost never exists and will therefore not be further described.
- *Mechanical inflow – mechanical outflow*
  Within this (balance ventilation) system, the ventilation air is sucked into the dwelling with a ventilator (through self-regulating grids for constant ventilation supply) and supplied to the bedrooms, living room etc. Through the kitchen, bathroom and toilet it is finally extracted from the dwelling with an outflow ventilator. Often these two vents are combined into one unit, usually combined with a heat recovery system. This system can therefore deliver high heating energy savings.

- Solar panels

PV cells (often the multi crystalline silicon version) convert solar energy into electricity in order to power a dwelling. In general two types of PV-systems can be determined: grid-linked (connected to the power grid to which surplus electricity is delivered) and autonomous (standalone units with batteries to store surplus electricity). PV cells generate a direct current while the electricity grid operates with an alternating current. To remove this difference, a converter is placed to convert the direct current into an alternating current.
The solar panels' performance is influenced by the following factors:

- The yearly amounts of absorbed sunlight, which is dependent of the orientation and angle of inclination of the panel.
- The type of PV-system. A cold (ventilated) PV-system has a higher performance in comparison to a heated up system.
- The type of PV-cell (its efficiency)
- The surface area of the solar panels
- Shading of the PV cells (which can drastically reduce its performance)

The maximum contribution of a photovoltaic system within an EPC-calculation, equals the amount of building related electricity demand. If PV systems deliver more electricity, this will not be taken into account. Still, this energy can be used to power the remaining electricity related equipment and activities (mentioned above). Therefore this shortcoming can have an distorting effect on the EPC in comparison to the real energy performance of the dwelling.

- Lighting

For dwellings (instead of commercial and industrial buildings) a fixed determination method, based on the surface area of the dwelling, is used to estimate electricity usage on lighting. This is mainly because for dwellings the electricity usage on lighting can not be influenced through energy saving techniques, it is too user specific. Therefore these energy saving techniques on lighting can not be added to the energy performance calculation (described in NEN 5128[20]).

3.3.3 Relation EPC and real energy performance

As has been described in *3.3.1*, the EPC calculation is based on a few assumptions on human behaviour and outdoor temperature. Therefore there is a difference between the theoretical and the actual energy performance of Dutch dwellings. In 2004 (under the authority of Senternovem) IVAM conducted a research[21] on 580 newly-build dwellings, build in 2000 and 2001. The goal of this research was to gain insight on the effect of the EPC on the natural gas usage (heat demand) of the dwelling, or whether there are other factors involved. *Figure 6* shows that this might be the case, since the spread of the energy use per EPC class is quite large. Some dwellings with an EPC of 0.8 are even consuming more energy, compared to (part of the) EPC 1.2 dwellings.

[20] Dutch Normalisation Institute NEN, www.nen.nl
[21] J. Uitzinger (IVAM), Analyse EPC en Energieverbruik bij woningen, 2004

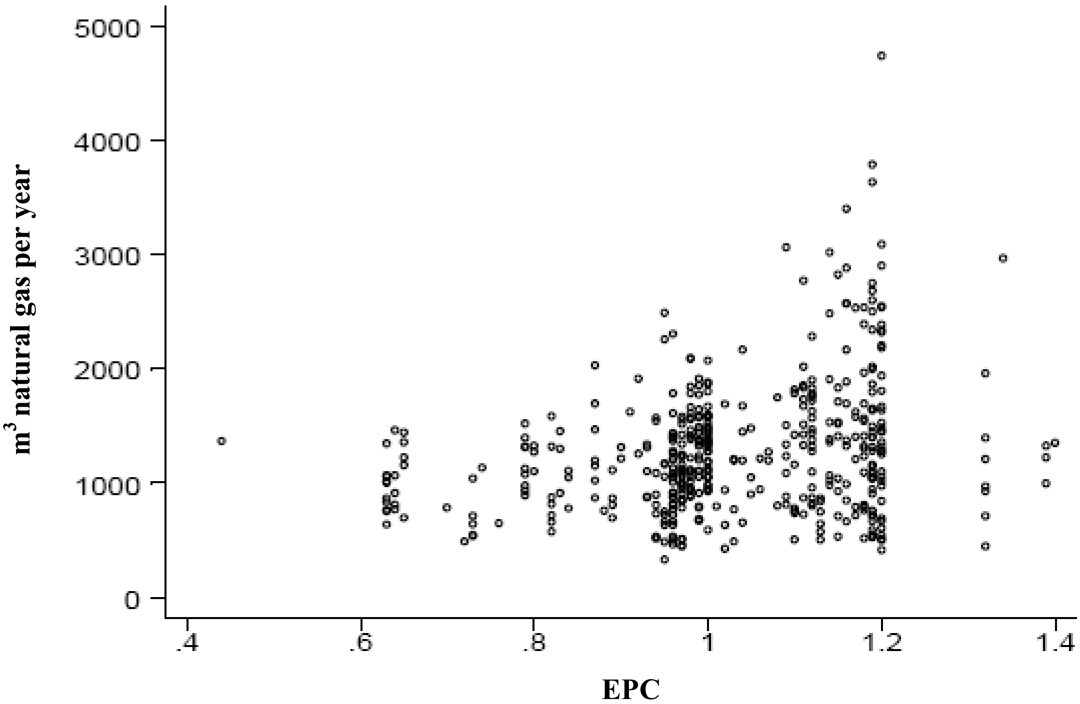

Figure 6 Average spread of the natural gas use per EPC class
Source: J. Uitzinger (IVAM), Analyse EPC en Energieverbruik bij woningen, 2004

The total actual natural gas usage (per year) had a range of about 2300 m^3 of which about 1600 m^3 was building related and about 700 m^3 user behaviour related.
The actual energy savings due to an improved EPC seem to decrease while the EPC decreases. This is shown in *Figure 7*, which shows the relative energy savings with an EPC improvement of 0.1 to the addressed EPC.

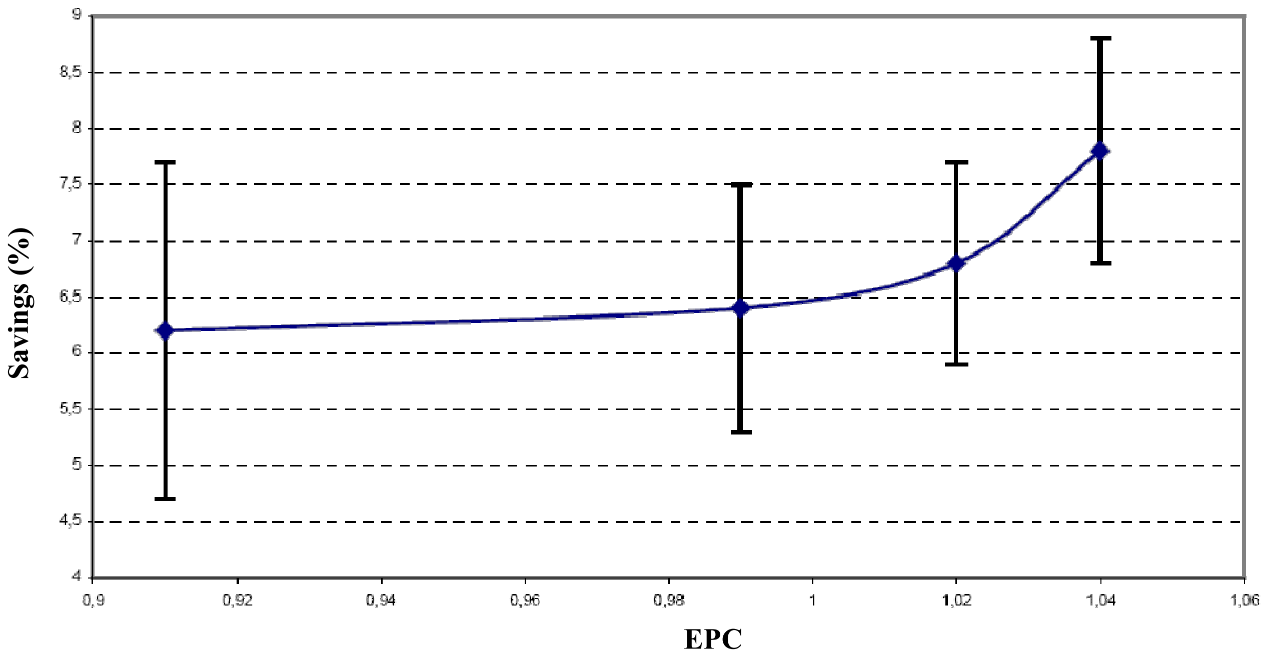

Figure 7 An EPC improvement of 1.0 to 0.9 would normally mean a theoretical improvement of 10%. But based on this table an improvement of 1.0 to 0.9 would result in a different (energy saving) percentage, namely about 6.1%. An improvement of 0.1 to the EPC value at the x-axis, gives this new relative saving.

This observation could actually show, it is harder to obtain actual energy savings when the building at hand is already energy efficient to some degree. An explanation of this issue could be the following. The research also showed, that among dwellings with different EPC values, the users' behaviour related energy use does not vary much. This also means, the users' behaviour related energy use is relatively higher in low EPC dwellings in comparison to high EPC dwellings. This is also shown in *Figure 7*, in which the uncertainty ratio is larger in the low EPC dwellings.

3.3.3.1 Energy saving options: actual impacts

The model developed in the IVAM research[21] also showed installation concept factors (see *3.3.2.3*) which had a significant correlation with the actual energy usage of a dwelling. These factors were:

- The used living surface and heat loss surface of the dwelling.
- The type of heat delivery. Within dwellings with external heat delivery, high savings were reached because of the efficiency gain compared to normal indoor boilers.
- The heat resistance (RC-value) of the dwelling.
- The use of a solar boiler, which mend a natural gas saving of about 200 m^3/yr per dwelling.

It should be noted that the effect of heat pumps and heat recovery systems was not significantly found because both systems were not commonly used within all types of buildings investigated. In combination with the analytical approach chosen, no correlation was found. But therefore, from this research it can not be concluded that both systems do not have an effect on the energy usage.

The same model also showed some important users' behaviour factors which influenced the actual energy consumption of the researched dwellings. Strong correlations were found with the number of inhabitants, the heating temperature (determines 18% of the total heat demand) and how often people shower (determines 7% of the total heat demand).

3.4 LCA based sustainable building measurements

Besides the Energy Performance Coefficient, a number of LCA based sustainable building measurements has also been developed over the years. Since energy efficiency measures based on the usage phase of dwellings have already been covered by the Energy Performance Coefficient (see *3.3*), the paragraphs *3.5* and *3.6* will focus on the construction and demolition phase. The (possible) methods to measure the energy efficiency of theses phases, will shortly be described in this paragraph.

3.4.1 GreenCalc

GreenCalc is a tool which expresses the sustainability of a building in a single value: the environmental index. Based on the total life cycle of a building, involving the life cycle of building materials, the energy performance and the water-user efficiency, this value is estimated. It also encompasses a environmental costs method which actually converts environmental cost into monetary costs and a 'mobility module' which grades the traffic performance on a neighbourhood level. Finally this tool is able to generate a number of other indices as well. For example: the Energy Index (see *3.2*) and the EPC (see *3.3*).

3.4.2 Green Declaration

A green declaration is necessary as a qualification in order to receive Green Financing (a Dutch subsidy scheme) from the Ministry for Housing, Regional Development and the Environment. The Green Declaration is then valid for ten years, while the projects are randomly checked. In practice, only about five percent of the applications qualify for this certificate. The assessment indicators (or checklist) are based on the criteria formulated in the National Sustainable Building Packages (see *3.4.7*).

3.4.3 GPR Building

The GPR method[22] is an independent sustainable building instrument, developed by the local authorities of the city of Tilburg (the Netherlands) and the consultancy firm W/E advisors. This software tool indicates the performance of energy saving measures and certain material choices for existing buildings. It gives ratings in five themes: energy, materials, waste, water and health. A building is considered sustainable if all these theme's are graded with at least seven points. Finally this tool is (also) able to generate a number of other indices as well. For example: the Energy Index (see *3.2*) and the EPC (see *3.3*).

3.4.4 Eco-Quantum

Eco-Quantum is an assessment method which calculates the environmental damage of dwellings during their total life cycle. Starting point are the environmental data on building parts and installations, based on the LCA-method. This environmental data is delivered by the building material suppliers in the form of MRPI-tables (see *3.4.8*). The method gives ratings on environmental effects (e.g. primary resources, emissions, energy and waste) within the themes water, material- and energy-flows.

3.4.5 BREEAM (BRE Environmental Assessment Method)

This assessment method has been developed by the Centre for Sustainable Construction of the British Building Research Establishment (BRE) and is used to determine the environmental performance of a building. Based on a standardised 'sustainable' building which is used as a benchmark, existing dwellings and newly designed ones are rated qualitatively. The categories which are used to determine the (newly build) buildings' environmental performance, are: management, health, energy, transport, water, materials, land use & ecology, waste management and pollution. The final mark of these dwellings are pass, good, very good or excellent. LEED (another assessment method) can be seen as the American equivalent of BREEAM).

3.4.6 DCBA

The DCBA-method is a classification model, developed in 1993, for different sustainable building measurements. These measurements are divided into four ambition levels. D: the business as usual situation. C: corrections on the business as usual situation. B: restrict environmental damage to the minimum. A: Autonomous, the most favourable environmental situation. This method can be put into action during the whole building process.

3.4.7 National Sustainable Building Packages

As has been described in *3.1.1*, these packages (Dutch: Nationale Pakketten Duurzaam Bouwen) were developed to offer practical, unambiguous and proven measures with national uniformity which could be implemented without much difficulty. They were first developed

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[22] Formerly this abbreviation stood for 'Municipal Practice Guidelines' (Dutch: Gemeentelijke Praktijk Richtlijn). The term is now used to indicate this method.

in 1996 and updates were published until 2005. Since energy efficiency measures based on the usage phase of dwellings have already been covered by the Energy Performance Coefficient (see *3.3*), only the material related measures of these building packages have been summed up in appendix *9.4* (in Dutch). As can be seen in *9.4*, the measures are variable or fixed. Since most measures are variable and (in general) arbitrary, it is quite hard to judge to what extend a measurement has been implemented. Thereby, it is hardly ever clear what the quantitative (energetic) impact of a certain measurement actually is.

3.4.8 MRPI

The Environmentally Relevant Product Information label (Dutch: Milieu Relevante Product Informatie), is a label which has been developed by construction industry suppliers in order to deliver uniform product information which can easily be compared. The label gives checked (quantitative) information on the environmental aspects of a building material, product or component through a life cycle analysis. Measured examples are production energy requirements, the amounts of raw materials used, generated waste and air/water/surface emissions. The data provided within the MRPI tables has also been implemented into the Eco-Quantum assessment method (see 3.4.4).

The MRPI label has been developed in reaction to the raising interest in the environmental effects of (building) products. The Dutch government plans to integrate the environmental performance of building materials into new legislation. Still, in respect to the LCA-method no binding standard has been developed yet. MRPI seeks to limit the degrees of freedom in order to present itself as an optional standard, also on an European level.

3.5 Life cycle Analysis of major energy consuming building materials

In the Netherlands, building materials are basically used in four kinds of construction methods. The naming of these methods is directly related to the methods in which these building materials, in combination with labour, are put into action. They determine in which way the frame of newly-build dwellings is realized. The foundation, façade and the roof are therefore independent of the construction method used (in this definition, the ground floor is not a part of the frame).

The four construction methods in the Netherlands will are described below.

(Traditional) stacking
- Bricks, blocks or elements are laid (with mortar) or glued together on site

Casting
- Fluid concrete is cast into wooden, aluminium or steel framings on site

Prefab
- Prefabricated concrete walls and floors are assembled on site

Wood frame
- All supporting and non-supporting elements above the foundation are constructed with standardized and prefabricated building timber and plate materials.

It should also be noted that the sustainability of the major energy consuming building materials (described in this paragraph) composed of sand-lime, concrete, steel and ceramics, stretches further than clean (energy efficient) production processes and integrated chain management. The flexibility of a construction is mainly determined by its supporting construction. The higher the (constructive) flexibility, the higher the technical and functional life time of a building. Some examples are the possibility to add extra staircases and additional floors later, or the segmentation between constructive and non-constructive parts. In this way, through an innovative design, the (potential) long technical life time of a building can also become a long economical life time. Therefore the environmental burden will decrease relatively as well.

3.5.1 Concrete

The raw materials for concrete are generally natural materials which are extracted locally: sand, aggregate gravel, water and a binding agent (cement). These raw materials (with the exception of sand) will shortly be discussed in combination with their recycling and energy saving opportunities.

3.5.1.1 Aggregate gravel

In theory, concrete is 100% recyclable. At the end of its life cycle, a concrete construction can be demolished while the (concrete) waste is used to replace (part of) the aggregate gravel. Unfortunately there is no concluding data about the (energetic) environmental gains. This largely depends on the transport distances and quality of the granules. A study[23] from 2003 found that the selective collection of clean concrete debris, could prove useful. Still it should be noted that the extent of this development will largely depend on the market prices of primary and secondary resources (in contrast with fly ash and blast furnace slag discussed in *3.5.1.3*).
The Sustainable Purchasing scheme[24] from the Dutch government, acknowledges the use of concrete granules as a sustainable application. This program aims at stimulating the marked of (frontrunner) sustainable products trough government spending. Specifically, this means for example that the Dutch Government Building Department nowadays prescribes the use of (at least) 20% concrete granules in their building tenders.

The availability of these recycling granules, largely depends on debris from building demolition and waste from renovations and newly-build constructions. It is expected that the amounts of stony materials (debris) will increase from about 25 Mton/year in 2005 to 30 Mton/year in 2025, which then consists of 22 Mton concrete debris[25]. *Figure 8* shows the supply and delivery of granules debris streams in 2005 from a draft report[26] by the Ministry of Waterways and Public Works. This figure shows that a lot of this debris is actually down cycled into the foundation and raising of roads (see *3.6*).
In combination with the knowledge of an increasing supply over the next 20 years, this development could stagnate. In order to prevent a build-up of concrete granules, they should be inserted back into their chain. This development could also prevent down cycling.

[23] PRC Bouwcentrum B.V., Stofstroom- en levenscyclus analyse van grondstoffen voor de funderings-, ophoog- en betontoeslagmarkt; 2003
[24] www.vrom.nl/duurzaaminkopen
[25] DWW, Scenario studie BSA-granulaten – aanbod en afzet van 2005 tot 2025 (DWW-2006-058); 2006
[26] Ministry of Waterways and Public Works, Social Cost-benefit Analysis (Dutch: Maatschappelijke Kosten Baten Analyse); draft version 2009

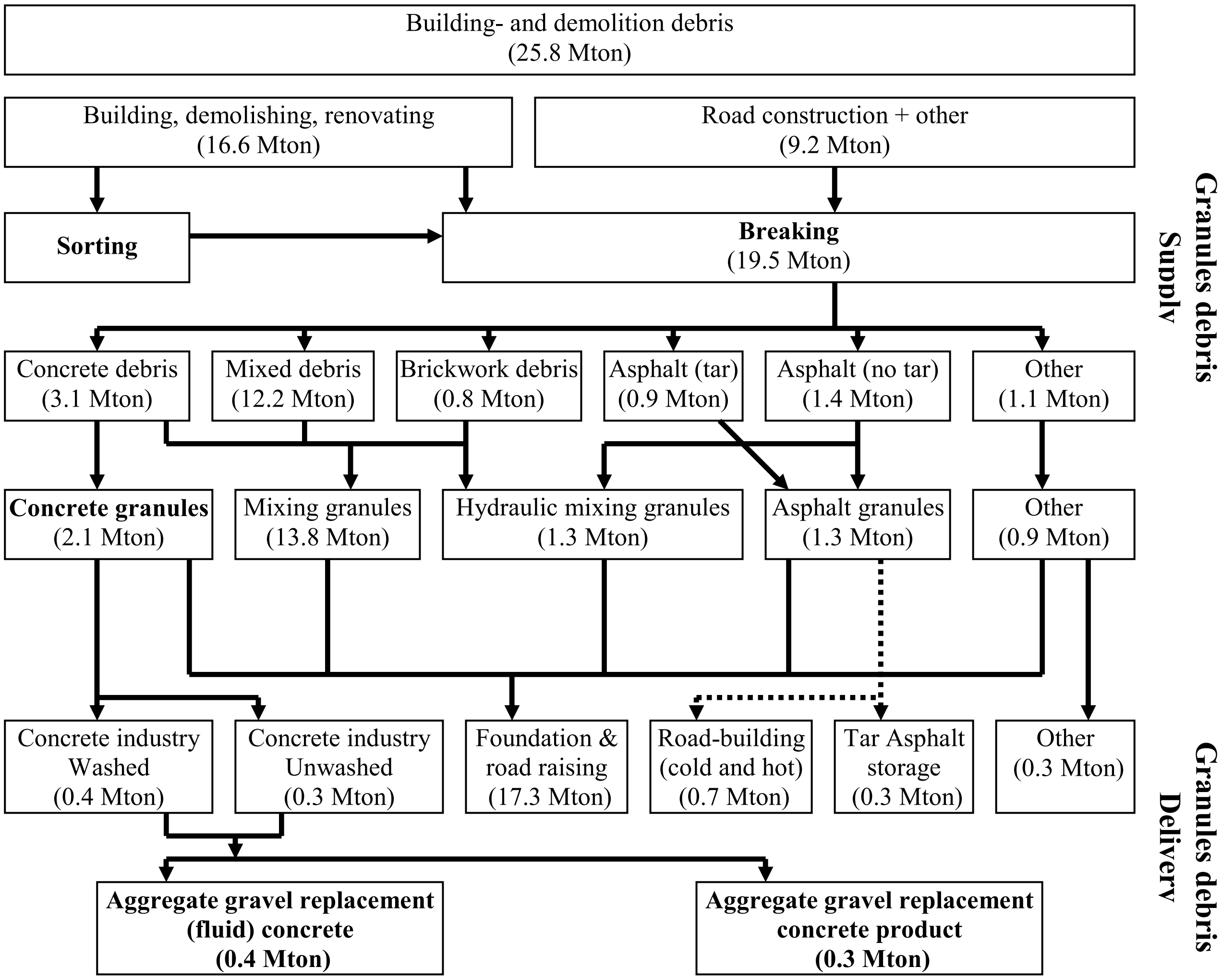

Figure 8 Supply and delivery flows of granules debris in 2005
Source: Ministry of Waterways and Public Works, Social Cost-benefit Analysis, draft version 2009

3.5.1.2 Water

During the production process, water is used in order to mix the concrete. Besides (clean) tapping water, industrial wastewater (e.g. in the form of washing/cleaning water) can also be used for this process. In order to do so, the amount of floating particles in the water should be limited. Therefore it is preferable to keep these different categories of waste water, separated. The use of (secondary) waste water is already widely used in practise, which in return limits the environmental pollution.

3.5.1.3 Cement

The three most important types of cement in the Netherlands are Portland cement, Blast-furnace cement and Portland fly ash cement. These last two types of cement are based on secondary raw materials and described next.
Fly ash is generated within power plants in which coal is pulverized into coal powder, which is subsequently combusted at a temperature between 1300-1700°C. The remaining ash particles of this process are used to produce cement. This (Portland) fly ash cement generates only 70% of the regular CO_2 emissions involved in the production of traditional Portland cement.
Blast-furnace cement consists mainly of *Blast-furnace slag* and is obtained by the quenching (with water) of molten slag. In this way the European Steel industry produces more than 16

Mton granulated slag per year, which is a high-quality replacement of raw resources like sand-lime stone. Due to the use of less sand-lime stone, less CO_2 is emitted with a factor three or four.

3.5.1.4 MRPI Life Cycle Analysis on Energy

Concrete is often used in cast and prefabricated building techniques and is delivered as a semi manufactured product on the construction site, for further processing. Since concrete is being used for different applications within the construction of a dwelling, three MRPI tables[27] with different concrete applications were developed in 2006. Namely:

- Supporting walls
- (Ground) floors
- Foundations

It should also be noted that maintenance or replacement of concrete is not necessary during the users' phase of the building.

Table 2 MRPI tables for concrete foundations, floors and walls: production energy
Source: Gietbouwcentrum, (www.gietbouwcentrum.nl); 2006

Concrete Production	Energy
C 20/25 (MJ / m³) *(only production)*	
no granules recycling	1000
20% granules recycling	1000
50% granules recycling	990
100% granules recycling	960
C 28/35 (MJ / m³) *(only production)*	
no granules recycling	1200
20% granules recycling	1100
50% granules recycling	1100
100% granules recycling	1100
(Concrete) steel (MJ / kg) *(including production, transport, installing, demolishing and waste processing)*	16

Table 2 displays the (average) energy costs involved with the production of (fluid) concrete in the Netherlands[28] (used for the construction of dwellings and from cradle), before it is cast into the final products. It shows two types of concrete with different strength classes: C 20/25 and C 28/35 (with densities varying between 2140-2340 kg/m^3). Besides the concrete, necessary for these applications, (concrete) steel is also used to reinforce these products. The energy related to the production of this (concrete) steel, is therefore also depicted in *Table 2*. The mentioned products above are not distinguished in this table, nor in *Table* 3 because their energy characteristics do not differ.

[27] Gietbouwcentrum, MRPI tables for concrete foundations, floors and walls (www.gietbouwcentrum.nl); 2006
[28] Produced by members of the (Dutch) association of Concrete producers (Dutch: De Vereniging van Ondernemingen van Betonmortel fabrikanten in Nederland, VOBN), which represents (with 140 factories) the major concrete factories in the Netherlands (http://www.gietbouwcentrum.nl/vobn).

The (next) MRPI Table 3 distinguishes the remaining (life cycle) stages which follow after production.

Table 3 MRPI tables for concrete foundations, floors and walls: involved energy in processing
Source: Gietbouwcentrum, (www.gietbouwcentrum.nl); 2006

Concrete processing	Energy (MJ / m^3)
Transportation to the construction site	100
Processing / installing the concrete on the construction site	48
Demolishing the concrete at the end of the buildings' life cycle	460
Concrete debris processing (recycling)	200

As has been mentioned before, (concrete) steel is also used to enforce the final products. Therefore, besides the concrete per m^3, the energy costs of a complete standardized product is depicted in *Table* 4.

Table 4 MRPI tables for concrete foundations, floors and walls: production energy for application products
Source: Gietbouwcentrum, (www.gietbouwcentrum.nl); 2006

Concrete application	Energy (MJ / unit)
Supporting walls (per m^2) *Composed of 0.25 m^3 concrete and 1.2 kg steel*	500
(Ground) floors (per m^2) *Composed of 0.18 m^3 concrete and 6.25 kg steel*	440
Foundations (per stretching meter of 400x500mm) *Composed of 0.20 m^3 concrete and 10 kg steel*	520

3.5.2 Ceramic bricks

The most important resource for ceramic bricks is clay, which is often extracted from river floodplains. The location where the clay is extracted, determines the type of product. In the Netherlands many sorts of clay are processed. E.g. loess, sea clay, types of (old) river clay etc. According to a research[29] from 2009, clay from the Dutch river floodplains can be considered as a (locally available) renewable product. This because of the yearly sedimentation of new clay particles. This (constant) supply is about one centimetre per year and is lower than the amounts which are yearly extracted. Still, one could argue that the renewability of this resource is questionable since it is entirely dependent on the extraction rate (which should not exceed 1 cm per year).

This clay is stored in large depots and then transported to the clay preparation where it is processed through multiple pre- treatment machines. Here the clay is kneaded and mixed into clay with the same (homogenous) composition. Water and steam is used to adjust (and thereby improve) the pliability of the clay.
During this preparation process, (most often) colouring substances are also added to the mixture in order to colour the final product.

The mixed clay mass is then mechanically pressed into moulds in the brick press, producing the bricks. The shaped bricks are put through a drying process in which residual heat from the baking process is used (if necessary with ancillary gas heaters).

[29] J. van der Meulen et al, Sediment management and the renewability of floodplain clay for structural ceramics; 2009

The final stage is the baking process in which the (dried) bricks are baked at a temperature between 1050 and 1250°C (depending of base clay mass and the chosen brick type). Within all brick factories in the Netherlands, the main type fuel of this process is natural gas. Only very occasionally, oil is used. Possible rejected products are pulverised and put back into the process by mixing it with new clay. After the baking process, the bricks are put through a cooling route.

3.5.2.1 Brick reusing

Many ceramic materials like roof tiles, paving bricks, glazed stoneware pipes and tiles can be reused completely[30]. Paving bricks are almost always reused and these 'secondary bricks' even have an increased economic value. This is mainly because old looking paving bricks are favoured in traditional cities.
With normal bricks used for buildings, this is a different story. Although modern mortar increases the quality of brickwork in general, it cannot be removed easily. Therefore these bricks are often pulverized into granules (see *3.6*) and cannot be reused but are 'downcycled' (the granules are generally used as road foundation).

3.5.2.2 MRPI Life Cycle Analysis on Energy

The MRPI table of bricks has been issued on behalf of the Royal Association of Dutch Brick manufacturers, in 1998 and 2008.[31] The values in *Table 5* are therefore representative for all kinds of bricks produced by members of this organisation (which are almost all brick factories in the Netherlands). The table also makes a distinction between normal and paving bricks. The latter needs generally a longer baking time and is therefore more energy intensive compared to normal bricks used for buildings. The two types of bricks therefore also have different densities[32]. Normal bricks vary between 1700-1900 kg/m^3 and paving bricks have a density of about 2100 kg/m^3.

Besides the production energy, also the processing of the bricks at the end of their life cycle, is depicted.
Life stages which were <u>not</u> depicted are:
- Transportation to the construction site
- Laying the bricks on site
- Demolishing the brick walls at the end of the buildings' life cycle

Table 5 MRPI tables for (paving) bricks: production energy
Source: Koninklijk Verbond van Nederlandse Baksteenfabrikanten (KNB); 1998 and 2008

Energy (MJ / kg)	Normal bricks	Paving bricks
Production in 1998 (from cradle to finished product at the factory)	2.81	3.4
Production in 2008 (from cradle to finished product at the factory)	2.59	3.04
Recycling the bricks at the end of their life cycle in 2008	0.12	0.12

[30] Based on an interview with Arie Mooiman from the Association of Ceramic Organisations (www.vko-keramiek.nl).
[31] Koninklijk Verbond van Nederlandse Baksteenfabrikanten (KNB), MRPI tables for (paving) bricks; 1998 and 2008
[32] http://www.ekbouwadvies.nl/tabellen/baksteen.asp

Table 5 also shows a drop in energy use at the normal brick production of 7,8 % over ten years (between 1998 and 2008). This reduction was realized due to the recycling of (baking) heat into the drying process (see *3.5.2*).

3.5.3 Sand-lime bricks

Sand-lime stone is a building product which is made from sand, lime and water. Sand is often acquired from sandpits in the vicinity of the factory and lime is imported from Germany and Belgium. These resources are mixed in the right proportions with small amounts of water and led into a reactor where it is slaked. Then the mixture is led to the presses, where the shaping into sand-lime bricks, blocks or elements takes place. After this, the products are transported to a autoclave where under high pressure and with hot steam of 200°C a petrifaction process takes place and the sand-lime stone is hardened.

At this point, the sand-lime stones can be used as supporting and non-supporting elements in building constructions. Nevertheless, the elements, blocks or bricks still need to be held together in a structure. For this purpose glue mortar has been developed specifically. Glue mortars are powdery binding agents which have to be prepared with water, before they can be applied. These kind of mortars petrify about 28 times faster then normal mortars. The final sand-lime constructions meet all quality demands concerning strength, resilience and fire resistance.

3.5.3.1 MRPI Life Cycle Analysis on Energy

The MRPI table of sand-lime stone has been issued on behalf of the Dutch sand-lime stone platform, in 1999.[33] The values in *Table 6* are therefore representative for all kinds of sand-lime stones produced by members of this organisation (which are almost all sand-limestone factories in the Netherlands).

Table 6 MRPI table for sand-lime stone: production energy
Source: Vereniging Nederlands Kalkzandsteenplatform (VNK); 1999

	Energy (MJ / kg)
Production in 1999 (from cradle to grave)	0.91

The life stages of sand-lime bricks which are included in the MRPI *Table 6* value (from cradle to grave) are:

- The extraction of resources
- Transportation to the production locations
- The (industrial) production of the sand-lime elements
- Transportation to the construction site
- The absorption of CO_2 during the usage phase
- Waste processing

The life stages which are <u>not</u> included are:

- Applying the sand-lime elements at the construction site
- Maintenance
- The actual demolition of the building at the end of its life cycle

[33] Vereniging Nederlands Kalkzandsteenplatform (VNK), MRPI table for sand-lime stone; 1999

The density of normal sand-lime elements lies around 1750 kg/m^3. Through the addition of basalt, this density is increased to around 2300 kg/m^3. The final product is now called a sand-lime mass element, which is also suitable for supporting high-rise buildings.

3.5.4 Steel

Steel is a high quality material from iron ore, due to low amounts of coal. During the production process of steel, 'waste' materials like blast-furnace slag and gas is reused. The first for road hardening and cement production (see *3.5.1.3*), the latter for the production of electricity[34].

3.5.4.1 Steel recycling

When a building is demolished, the scrap can be recycled completely into all common steel qualities. With steel 'down cycling' is not an issue since it keeps its quality and remains fitted for high-grade application. Even the zinc from galvanized steel can be separated before it is recycled.

Table 7 MRPI table for steel products: scrap disposal statistics
Source: Bouwen met Staal; 2003

Type of steel	% Recycling	% Reusing	% dumping
For heavy applications	51	49	0
For middleweight applications	87	12	1
For light applications	87	12	1
Within inside walls	87	12	1
Within roof and façade coating	70	29	1

As is shown in *Table 7*[35], almost 100% of all steel is recycled. The table also shows that besides recycling, large quantities of steel are also reused, especially within heavy applications and roof and façade coating. *Figure 9* gives some examples of the types of steel which are described in *Table 7*.

[34] Branche organisation for Steel products in the Netherlands (www.bouwenmetstaal.nl).
[35] Bouwen met Staal, MRPI table for steel products; 2003

Roof and façade coating

Middleweight applications

Heavy applications

Light applications

Inside walls

Figure 9 Examples of the types of steel which are described in the (Bouwen met staal) MRPI table
Source: Bouwen met Staal; 2003

3.5.4.2 MRPI Life Cycle Analysis on Energy

The MRPI table of sand-lime stone has been issued on behalf of 'Building with Steel', an association of Dutch steel manufacturers, in 2003.[35] The values in *Table 8* are therefore representative for all steel produced in Western Europe, which is applied on the Dutch market.

Table 8 MRPI table for steel products: production energy
Source: Bouwen met Staal; 2003

Steel Production	Energy (MJ / kg)
Heavy applications (e.g. beams, columns, plates)	7.3
Middleweight applications (e.g. supporting beams, sheet pile walls)	14
Light applications (e.g. window-/doorframes, profiles - **Galvanized**)	14
Inside walls	17
Roof and façade coating (**Strip steel coating** and **Galvanized**)	11

The life stages of steel which are included in the MRPI *Table 8* are:

- The extraction of resources
- Transportation to the production locations
- The (industrial) production of steel elements
- Transportation to the construction site
- Applying the steel elements at the construction site
- The removal of steel elements at the end of the buildings' life cycle
- Waste processing

The life stages which are <u>not</u> included are: Maintenance and Replacements.

3.6 The demolition phase

This paragraph covers the end of a dwellings' lifecycle: its demolition. In order to get an impression to what extent these secondary materials are recycled or reused, a (draft) report[36] on Dutch building and demolition debris in 2006-2007 will be studied primarily.
As had been partly stated in *3.1.1*, the Netherlands have a long history of waste control legislation. Over the period 1985-2000, this led to an increase in waste reuse from 50 to 77%[36]. Waste dumping also decreased during this period from 35 to around 9%. An illustrative example of this issue is the fact that dumping residue debris is prohibited in the Netherlands. Therefore nowadays about 96% of all building and demolition debris is processed and reused.

The building- and demolition waste sector, therefore became a professional sector with a couple of specialities. First there are the debris breaking companies, which mainly break the stony debris (the largest fraction) from buildings into smaller particles (granules), in order to apply these in the production of concrete (see *3.5.1.1*) or road construction. The second group are the sorting companies, which sort the remaining materials (a small fraction) with the exception of economically valuable materials like metal parts or paving bricks (see *3.5.2.1*). These materials are directly sold by the demolition companies. According to these groups of waste processing companies, the next paragraphs will be structured and describe trends in demolition debris quantities. These values also match with the diagram of *Figure 8* in *3.5.1.1* (the bold groups), which describes the origins of concrete granules used in the production of concrete.

3.6.1 Debris breakers

Debris breakers in the Netherlands form a recognizable group with about 150 companies. The majority of these companies is organized in two branch associations: the association for recycling, breaking and sorting (BRBS) and the association for mobile recycling (BMR). In 2007, about 19.5 Mtons of stony debris was processed by debris breakers in the Netherlands. Of this amount, about 12.5 Mtons (64%) came from the building industry.

Table 9 Types of stony materials which were processed by breakers from 2005-2007
Source: Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009

Type of debris (breaker supply in Mtons)	**2005**	**2006**	**2007**
Concrete	3.1	1.7	2.0
Brickwork	0.8	0.4	0.3
Mixed	12.8	15.2	15.5
Mixed from sorting companies	0.3	0.2	0.2
Non-tar containing asphalt	1.4	0.5	0.4
Tar containing asphalt	0.9	1.0	1.0
Remaining materials (like slag and cinder)	0.2	0.1	0.1
Total	19.5	19.2	19.7

[36] Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009

Table 10 Final products of breakers between 2005-2007
Source: Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009

Type of debris (breaker final product in Mtons)	2005	2006	2007
Mixing granules	13.8	16.1	16.4
Concrete granules	2.1	0.9	0.9
Brickwork granules	0.03	0.1	0.0
Hydraulic mixing granules	1.3	0.8	0.8
Asphalt granules	1.3	0.7	0.7
Remaining products	0.8	0.5	0.7
Non useful products	0.03	0.1	0.1
Total	**19.4**	**19.2**	**19.7**

Table 9 depicts all types of stony materials which were processed by breakers from 2005-2007. The amounts of concrete granules has clearly decreased over the years, while the amounts of mixed debris has increased. This could indicate the fact that more and more concrete debris is processed as mixed debris. This point is also backed up by the fact that the number of product certificates for mixing granules (mainly used for road foundation) has also increased in comparison to the number of concrete granules certificates (used for the production of concrete)[36]. Clearly, the breaker companies only separate the concrete debris only if there is demand for concrete granules (in the production of concrete). *Table 10* illustrates the expectations according to *Table* 9, which shows indeed the trends described.

Table 11 Final use of the products of breakers between 2005-2007
Source: Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009

Type of debris (breaker product market in %)	2005	2006	2007
Foundation and heightening (excl. asphalt)	89.2	85.5	84.4
Breaker asphalt (mortars)	1.4	0.9	1.0
Asphalt industry (hot utilization)	1.9	3.1	2.6
Tar containing asphalt for thermal cleaning	2.4	5.9	7.5
Concrete industry (washed for own plants)	1.8	0.8	0.7
Concrete industry (unwashed for third party)	1.5	1.3	1.1
Breaker sieve sand	0.6	0.9	0.6
Sorting companies	0.4	0.2	0.2
Dumping	0.1	0.0	0.0
Special dumping (because of asbestos)	0.0	0.0	0.0
Export	0.4	1.0	1.2
Metal market (reinforced concrete)	0.3	0.3	0.2
Total	**100%**	**100%**	**100%**

Table 11 finally shows the market expectations described above, with indeed a large percentage for the foundation and heightening (of roads) industry.

3.6.2 Sorters

Sorter companies are often part of a large waste processing company, in which the sorting of building and demolition debris is only part of a larger process. In 2007, about 2.7 Mtons of (waste) materials were processed by sorting companies in the Netherlands. Of this amount, about 2.10 Mtons (78%) came from the building industry.
It should be noted that the values only apply to mechanical sorting. The incoming material stream is always pre-sorted first, to separate fractions which can easily be removed. This involves primarily wood and metals. The values assumed in the monitoring rapport[36] were therefore based on monitoring values from 2004-2005. Namely 0.73 Mtons of wood and 0.37 Mtons of metal every year.

Table 12 Final products leaving the sorting companies 2005-2007
Source: Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009

Final products sorting companies (in Mtons and %)	**2005** Mton	%	**2006** Mton	%	**2007** Mton	%
Wood (A+B quality)	0.52	**21.7**	0.35	**16.7**	0.39	**14.7**
Wood (C quality)	0.02	**0.8**	0.02	**1.0**	0.02	**0.7**
Metals	0.09	**3.8**	0.06	**2.9**	0.07	**2.6**
Paper and Cardboard	0.00	**0.0**	0.01	**0.7**	0.02	**0.7**
Synthetic materials	0.00	**0.0**	0.01	**0.4**	0.01	**0.5**
Secondary fuels	0.08	**3.3**	0.03	**1.4**	0.03	**1.3**
Debris (to breakers)	0.47	**19.6**	0.67	**32.2**	0.95	**35.5**
Unwashed sieve sand	0.42	**17.5**	0.31	**14.9**	0.32	**12.0**
Washed sieve sand	0.00	**0.0**	0.00	**0.0**	0.00	**0.0**
Plaster. cellular concrete	-	**-**	0.02	**1.0**	0.02	**0.7**
Plaster. cellular concrete export	-	**-**	0.01	**0.6**	0.01	**0.6**
Mono streams	0.02	**0.8**	0.01	**0.7**	0.02	**0.8**
Roofing material	0.00	**0.0**	0.01	**0.3**	0.02	**0.7**
Transport to further sorting NL	0.06	**2.5**	0.12	**5.5**	0.09	**3.3**
Export for removal	0.07	**2.9**	0.00	**0.0**	0.00	**0.0**
Export to further sorting	0.32	**13.3**	0.08	**3.8**	0.23	**8.6**
Dumping	0.25	**10.4**	0.24	**11.3**	0.23	**8.7**
Waste incineration	0.06	**2.5**	0.14	**6.7**	0.23	**8.7**
Total	**2.4**	**100%**	**2.1**	**100%**	**2.7**	**100%**

Table 12 displays the final products leaving the sorting companies. The amounts of debris to the breaking companies has increased relatively, while the amounts of wood (A+B quality)[37] seems to have decreased. Nevertheless it should be noted that the uncertainty of the results in *Table 12* is quite large because of the few respondents to the monitoring report inquiry (with regard to the sorting companies). The bandwidth of this uncertainty is even higher compared to the just described trends.

[37] The different qualities of wood are as follows: A-wood is clean and untreated, B-wood has been treated with glue, paint etc., C-wood has also been impregnated in order to make the product more durable.

4 Methodology

To answer the research questions for new dwelling projects in the Netherlands, a representative number of large building projects from different building companies which were finished in 2008, will be used as case-studies. In this research, 2008 represents the present day situation where the main research question focuses on. This year was chosen because statistical information can easily be acquired and about 70-75 percent of the finished dwellings of that year will have been build with the new 0.8 EPC value (issued in 2006). For example, this last point would have been true for only 20-25% in 2007 (see *Table 14*). Within the first two phases (construction and using), the same projects will be involved. The third and final phase will have a more general focus, which will be explained further on.
During each phase a benchmark will be used to measure the difference with the 'business as usual' situation. Where possible this benchmark will be the regulatory norm imposed by the government and formulated in the Dutch Building Decree. At this moment, the decree only enforces norms which are focussed on the energy efficiency of the future building and not the construction/demolition process itself. Therefore a business as usual scenario will be set as a benchmark for these stages.

The case-study information will be acquired through the use of a survey, send to all 172 members of the Association for developers and buildings contractors[38] (which represents a large part of all dwelling developers in the Netherlands). This survey (see *Appendix 9.3*) will request information on low energy intensive projects and energy related material choices involved in these projects. Finally, the respondents will be requested for in-depth information on their low energy intensive dwelling projects.

The above described actors will be contacted and interviewed to acquire the information described in these mentioned phases. The central question during these interviews will be the extent to which material or energy efficiency measures are implemented during the discussed phase of the building project (derived from the main question) and what their effects are. Where governmental legislation is at issue, for example at the energy performance coefficient stated in the Dutch Building Decree[5], statistical information will, where possible, also be retrieved in larger quantities.

4.1 Construction phase

The focus in this phase will be primarily on the material choice during the dwelling projects' construction phase discussed in the case studies. Data will as much as possible be used quantitatively to calculate actual energy savings on materials, compared to a benchmark situation. The embodied energy of the dwellings' construction will be assessed in two ways:

- By comparing the total energy intensiveness of the materials used.
- By the use of secondary (recycled) materials and their impact on the total embodied energy of dwellings in the Netherlands.

The first will be discussed in this paragraph (on the construction phase), the latter in paragraph *4.3* (the demolition phase). This choice has been made since, from a life cycle perspective, there is a direct relation between the 'waste' materials in the demolition phase and the used recycled materials during construction.

[38] Dutch: Vereniging voor ontwikkelaars en bouwondernemers; www.nvb-bouw.nl

In the theory chapter, the energy life cycle of some major energy consuming building materials were discussed (see *3.5*). These materials (concrete, bricks, sand-lime stone and steel) will be used as base materials from which the total material related energy of a dwelling will be calculated (in combination with some other materials involved). Since a dwelling is mainly composed of these materials, it is assumed they together form an important part of the total embodied energy of a typical dwelling.

4.1.1 Building materials benchmark

In order to calculate energy savings with the use of less energy intensive or reused/recycled materials, a comparison has to be made with a present situation benchmark. For this, a list of typical building materials and their quantities will be used based on a research[39] from 2006. In this research a reference (terraced) dwelling with a pitched roof is described with a living space of about 117 m^2. Since this research has been published in 2006, the minimum EPC of that time is used (0.8). The material inventory of this 'average' dwelling is displayed in paragraph 9.1 of the appendix.

4.1.2 Comparison with actual dwellings

The second question from the case-study surveys (see appendix *9.3*) asks which dwelling projects are considered sustainable. Therefore, the dwellings which were considered to be sustainable, will be compared with the benchmark dwelling according to the total embodied energy of their materials. This will be limited to the materials mentioned in *3.5* because it could otherwise become a too time consuming question for the enquired contractors.

In order to make a correct comparison with the reference dwelling, the amounts of materials and embodied energy per m^2 will be discussed. Also, the comparison will only be made with pitched roofed terraced dwellings (which are the characteristics of the reference dwelling as well).

4.2 Dwelling usage phase

This phase focuses on the energy intensiveness during the (future) usage of the finished dwelling. The major indicator in measuring to what extent energy efficiency measures are implemented during construction, taken into account this phase of the dwellings' life cycle (see *chapter 2*), is the Energy Performance Coefficient (EPC). The reasons why this measurement was chosen and for example not the Energy Label (discussed in *3.2*), can be described as follows:

- Data on distributed Energy Labels is only available from 2007 onward (see *3.2*). An impact assessment as described in *4.2.2*, would therefore not have been possible.
- The Energy label is introduced specifically for already existing dwellings[15] and this research focuses primarily on newly-build dwellings.
- In general, an index label (like EPC) was chosen in order to get a more complete overview of newly-build dwellings. Also, in comparison to a more installation and constructional concept approach (in which more in-depth surveys would have been necessary), the index label approach seemed more feasible to acquire enough cooperation of contractors.

[39] A. Meijer, Improvement of the life cycle assessment methodology for dwellings, 2006; Table 2.6

In order to answer the first second sub-question of this research (see *chapter 2*), the chosen approach is two-fold and discussed next.

4.2.1 Impact case-study dwellings

As has been stated above, in the Netherlands normative legislation which aims at energy use of a dwelling exists, but only aims at the energy efficiency during the users' phase. The means to achieve this norm (the EPC, see *3.3*) during the construction phase, are not prescribed. During this phase the normative minimal energy performance coefficient (which is 0.8 since January 2006[40]) will be used as the benchmark to compare with actual energy performance coefficients of the case-study projects. The actual energy savings compared to this norm will then be calculated using *Equation 2* (see *3.3* and displayed again below).

$$EPC = \frac{Q_{achieve\ ,tot}}{330 \times A_{use\ ,surf} + 65 \times A_{loss}} \times \frac{1}{cEPC}$$

In other words: how much (expected) energy is saved due to the difference of the project EPC, compared to the norm of 0.8? The $Q_{pres;tot}$ will be the compared variable as the typical (building related) primary energy use per year. In order to calculate this, A_g (the used living surface in m^2) and $A_{verlies}$ (the heat loss surface in m^2) of the case-study projects are necessary values. Since the research involves dwellings for which the permit was given in 2006 or later, the cEPC correction factor will also be used in the calculation (see *3.3.1*).

Since the expected energy use of these dwellings (derived from the EPC formula) is primarily based on theoretical assumptions, a conversion to actual (expected) energy usages will be made. To make proper assumptions on this issue, a study which compares EPC's and actual energy usages of dwellings, shall be used and is already described in *3.3.3.1*.
In order to finally make the comparison and calculate the potential of these dwellings, values are compared with the average nowadays energy use of a Dutch dwelling.

4.2.2 Impact assessment EPC regulation

Besides the impact of the case-study projects on nowadays dwellings. An small-scale impact assessment shall be made on the effect of the EPC regulations since 1995 on the average (building related) energy usage of Dutch dwellings. The steps that need to be taken are described below.

4.2.2.1 Determination of the average EPC in 1995

An average EPC shall be estimated of all existing dwellings in 1995 (one year before the start of the EPC legislation). The calculation shall be based on *Equation 2* without the cEPC addition (because it is based on the old equation, see 3.3.1). In order to do so, the following data was acquired:

The average A_g (the used living surface in m^2) of Dutch households in 1995
This value is calculated based on the assumption that the average living surface of newly-build dwellings from 1940 until 2006 has increased with about 0.4 m^2/year for apartments and

[40] Ministerie van VROM - www.vrom.nl

0.75 m^2/year for remaining (single family) dwellings (in Dutch: grondgebonden)[41]. This assumption was combined with:

- *The (average) reference living surfaces* of today's (2006) newly-build dwellings (detached: 169.5 m^2, two semi-detached: 147.5 m^2, corner: 124.3 m^3, terraced: 124.3 m^3 and apartment: 86.9 m^2).[42]
- *The distribution of these types of dwellings in the Netherlands in 1995* is based on the earliest values found from 1998. Namely 15,0% for detached, 11,9% for two semi-detached, 13,6% for corner, 28,7% for terraced and 30,8% for apartments. It should be noted that these values did not show much variance from 1998-2002 (years of which data was available).[1] Therefore it is assumed they stay more or less constant over the years.
- *The composition of dwellings in 1995 based on their year of construction* was also acquired (see
- *Table* 13)[1]. It should be noted that since (especially in the early years) large ranges are used (e.g. 1945-1969). In these cases the 'average' year was chosen to represent its living surface (e.g. 1957 in 1945-1969).

Table 13 The composition of the Dutch dwelling supply in 1995 by year of construction
Source: Statistics Netherlands, 2009 – www.cbs.nl

Date of building	< 1945	1945-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	Total
# Dwellings 1995 (mln)	1.478	1.838	0.724	0.539	0.609	0.571	0.434	6.192

The average $A_{verlies}$ (the heat loss surface in m^2) of Dutch households in 1995
This value is calculated based on the reference living surfaces of the types of dwellings. In order to do this, the data described above is combined with:

- *The ratio between living surface and heat loss surface (A_g / $A_{verlies}$)*, which is based on the same (average) reference data as described above. Namely 0.47 for detached, 0.55 for two semi-detached, 0.54 for corner, 0.79 for terraced and 0.97 for apartments.[42] It is assumed that this ratio is a general value attached to the type of building, which does therefore not change (much) over time.

The average $Q_{pres;tot}$ (the typical building related primary energy use) of Dutch households in 1995
In order to acquire this value, the typical natural gas usage of Dutch dwellings is chosen as the main factor. Almost all building related energy usage is (directly or indirectly) related to this value.
In respect to the orientation (see *3.3.2.1*), the only exception is the use of compression cooling machines (on which no data was available). Still it is assumed the use of cooling devices on an average scale within the Netherlands in 1995 was quite low.
In respect to the construction shell (see *3.3.2.2*), all factors are heating related.
In respect to the installation concept (see *3.3.2.3*), almost all installations related to heating are natural gas driven. Still there are exceptions in the form of e.g. electrical boilers and electrical driven heat pump systems, but it is assumed they had a minor impact in 1995. Other installation based exceptions are the use of solar panels, ventilation systems and lighting. Since the use of solar panels started rising not until the year 2000[1] and most common

[41] D. Bodewes (STEC Group), Een meter per jaar; column 2007 (http://www.stec.nl/index.php?option=com_content&task=view&id=81&Itemid=46)
[42] Senternovem (by order of the Dutch ministry of VROM), Referentiewoningen nieuwbouw; December 2006

ventilation systems in 1995 where based on the natural in- and outflow of air (see *3.3.2.3*), these values are also assumed to be not significant. Overall, the electricity use on lighting and natural gas usage values from 1995 will be acquired as follows:

- *The (average) electricity use on lighting* in the EPC calculation is based on a fixed value per m^2 (56.4 MJ / m^2 / year)[43]. This value will therefore also be used here, in combination with the average A_g (living surface) of dwellings in 1995 (acquired above).
- *The typical natural gas usage values of Dutch dwellings* from 1995 until 2008 are derived from the Senternovem database[16] and a publication of Senternovem[44], based on the same source. Since these values are not corrected for the temperature differences over the years, they did not give a correct impression of the actual energy usage. In order to correct them, the number of degree-days[45] of each year has been acquired, weighted[46] and compared to the average number of degree-days between 1984 until 2006.

4.2.2.2 The effect of newly-build EPC dwellings from 1995 on the average EPC

From 1996, the effect of the new EPC dwellings has been included in the average EPC of Dutch households. The model assumes that over the years, all newly-build dwellings comply with the EPC norm of their time. Namely, 1.4 in 1995, 1.2 in 1998, 1.0 in 2000 and 0.8 in 2006 (see *3.1.1*). Since there is no real (significant) data on dwellings which perform better than the EPC norm of their time, this effect has not been incorporated. In this research, this effect is actually measured for dwellings constructed in 2008 (see *4.2.1*). In order to calculate the impact of EPC-dwellings (since 1995) on the average EPC (determined for 1995), the EPC phases above are combined with the following data:

- *The completion time of a dwelling* (the time between the application of a building permit until the actual delivery of the dwelling) between 1995 and 2008 is displayed in *Table 14* below[1]. Displayed per year, is the percentage of finished dwellings (of that year), of which the building permit was issued x months ago.

[43] This value is derived from the Senternovem website (http://www.senternovem.nl/epn/tools_en_aandachtspunten/woningbouw/stap_3_vaststellen_installatietechnische_uitgangspunten.asp) and an EPC example calculation from http://www.energielabel-voor-mijn-huis.nl/info.aspx

[44] Senternovem (by order of the Dutch ministry of VROM), Cijfers en Tabellen 2007

[45] The number of degree-days per year are estimated by selecting all days with an average day-temperature lower than 18 degrees. The difference between this temperature (the heating boundary) and the actual temperature of all these days is then summed up.

[46] The gas usage is higher during the colder months in comparison to the warmer months. Therefore the degree-days are weighted according to their month: with 1.1 for November until February, 1 for March until October and 0.8 for April until September.

Table 14 The percentage of finished dwellings per year, of which the building permit was issued x months ago. *Source*: Statistics Netherlands, 2009 – www.cbs.nl

Period	< 7 months (%)	7 - 10 months (%)	10 - 13 months (%)	13 - 16 months (%)	16 - 19 months (%)	19 - 22 months (%)	22 - 25 months (%)	25 - 37 months (%)	> 37 months (%)
1995	11	13	21	24	14	8	3	4	1
1996	10	11	18	20	17	10	8	6	1
1997	10	10	17	21	15	10	6	7	2
1998	9	9	17	18	17	9	7	11	3
1999	6	7	13	19	16	13	9	13	3
2000	8	6	11	14	18	13	10	14	5
2001	9	5	7	11	16	16	13	17	6
2002	11	5	8	12	10	12	10	26	6
2003	11	5	8	12	11	10	11	21	12
2004	11	5	8	11	13	13	11	20	9
2005	10	5	9	11	12	9	12	23	8
2006	8	4	9	13	13	12	12	18	10
2007	8	4	6	10	13	14	12	23	9
2008	8	4	7	11	12	11	12	28	9

- *The number of finished dwellings by the quarter from 1995 until 2008* is necessary to determine the amounts of finished dwellings per licence year (which determines which EPC it carries). These values are displayed in paragraph 9.5 of the appendix.
- *The number of issued permits (per dwelling) by the quarter from 1995 until 2008* is finally necessary to check whether the values calculated from *the completion time of a dwelling* and *the number of finished dwellings* were derived correctly. These values are (also) displayed in paragraph 9.5 of the appendix.

The calculations mentioned above result in a graph which shows the average EPC of Dutch dwellings change over time (due to the introduction of EPC dwellings), thus showing the effect of the EPC legislation on the average energy use of all dwellings in the Netherlands. Since the EPC is linearly related to the actual energy use of a dwelling (e.g. an average EPC drop from 1.0 to 0.8 implies a 20 percent decrease in energy use), the average living surface of a dwelling also plays an important role. Therefore the average energy use per square meter of Dutch dwellings, will also be calculated over the years.

4.2.2.3 Comparing the (theoretical) effect of newly-build EPC dwellings with actual data

The theoretical energy use variations (in MJ/m^2) due to EPC legislation (per dwelling), will be compared with actual data on natural gas use variations (in MJ/m^2) added to the fixed value (of 56.4 MJ/m^2) for lighting (see *4.2.2.1*). The data on average natural gas use in dwellings, will be acquired for 1995 until 2008, as has been described in *4.2.2.1*. Since this data on 1995 and 1996 has not been recorded by Senternovem[16], it was extrapolated using comparable data from the Dutch Department of Statistics[1].
Adequate data is only available on the natural gas usage of households (over the years) and it is the main factor determining building related energy use (see *4.2.2.1*). The fixed value for lightning was used again (as an assumption), because no useful data on (average) lighting usage in dwellings between 1995-2008 could be acquired.

Finally, it has been determined which part of the total energy savings of dwellings, are due to EPC legislation, which part is not and what could be the cause of this.

4.3 Demolition phase

Case-study example projects of the demolition phase can naturally not focus on the projects described in the construction and usage phases, simply because their lifetime has just begun and demolition is not an issue. Therefore the separation of materials in order to use as secondary materials for new building projects, will be investigated more broadly. The question to what extent materials are reused/recycled will also be vital during this phase.

In order to get specific quantitative answers to the questions above, first of all, the researched materials need to be selected. For this purpose, the materials discussed in *3.5* will be investigated.

Secondly, monitoring data on reused/recycled materials from the demolition sector (described in *3.6*) will be used in combination with the involved materials and their Gross Energy Requirements discussed in *3.5*. This, in order to get quantitative information on energy savings due to the use of recycled/reused materials obtained during the demolition phase.

5 Results and Analysis

This chapter will display and analyse the results of this thesis.

Regarding the survey discussed in the introduction of chapter 4, a total of 172 contractors were asked to participate in the survey. A (useful) response of 31 companies was acquired, 21 did not want to participate due to time limitations, 26 could not participate due to other reasons and 94 companies did not reply at all. The 31 useful responds represented 4079 newly-build dwellings, finished in 2008. Out of a total of 78882 finished newly-build dwellings in 2008[1], this research represents 5.17 % of this total. The representativeness of these total respondents will be further discussed in the discussion section of this research. The acquired projects, which were marked as being sustainable, were spread across the Netherlands as is shown in *Figure 10*.

Figure 10
The spread of researched projects in the Netherlands

5.1 On the dwelling construction phase

As had been mentioned in the introduction of chapter 4 (methods), the respondents of the survey were also asked to deliver information on the quantities of building materials (mentioned in *3.5*), which were used during construction of the concerning dwellings. Unfortunately, no contractor respondent was able to deliver this information on these four materials. Therefore, no comparison between ‘sustainable’ projects can be made from this perspective.

Still it is useful to get an impression of the relation between the total embodied energy of a typical Dutch dwelling versus the yearly energy costs (mentioned in *5.2*). For this purpose the reference dwelling material list[39], mentioned in 4.1.1 and displayed in the appendix paragraph 9.1, will be used. Based on this list and combined with the MRPI data in paragraph *3.5* and complementary data from Worrell (1994)[47] and Ecofys (2009)[48], the table in appendix paragraph 9.2 was constructed. This table also notes which specific complementary source data was used in combination with the material inventory table of the average dwelling[39] (see appendix 9.1).

While combining this list with the MRPI data, the following should be noted:

- For bricks and ceramics the same MRPI table (from *3.5.2.2*) will be used. This because no separate MRPI table of ceramics (roof tiles) was available and the production process is nearly the same. The MRPI table does not cover transportation to the building site and processing as all the other materials. Therefore these values from concrete will be adopted. Which is 2.71 + (148 / 2240) = 2.78 MJ/kg
- For concrete and mortar also the same MRPI table (from *3.5.1.4*) will be used because it is basically the same material, only processed differently on the construction site. Since the MRPI table used MJ/m^3 as unit, the average density of concrete will be used. Which is (2140 + 2340) / 2 = 2240 kg/m^3. Also the average will be chosen between the two types of concrete (C 28/35 and C 20/25) with no granules, which is (1000 + 1200) / 2 = 1100 MJ/kg.

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[47] E. Worrell et al, New gross energy-requirement figures for materials production; 1994

[48] Ecofys, Methodology for the free allocation of emission allowances in the EU ETS post 2012 - Sector report for the gypsum industry; November 2009

- For steel, an average will be made between heavy and middleweight applications (from the MRPI table in *3.5.4.2*). Which is (7.3 + 14) / 2 = 10.7 MJ/kg
- For steel (enamelled), the 'Roof and façade coating' type of steel will be used from the MRPI table of *3.5.4.2*).
- For steel (galvanized), the 'light applications' type of steel will be used from the MRPI table of *3.5.4.2*).
- Finally is should be noted that the complete lifecycle of all materials is covered using the MRPI tables.

As has been stated before, the table in appendix paragraph 9.2 shows the total embodied energy of a typical Dutch (terraced or in Dutch: rijtjeshuis) dwelling with a pitched roof and a living space of about 117 m^2. The total mass of the materials mentioned in the embodied energy table in paragraph 9.2 of the appendix, is 235,799 kg. Compared to the total mass of the average dwelling materials inventory list (which is 237,465 kg), 99.3% of the total mass is covered. Since the embodied energy of the remaining materials could be averagely high (due to e.g. special plastics), it is (safely) assumed that about 90% of the total embodied energy of a Dutch dwelling (which is 481,7 GJ in appendix paragraph 9.2) is covered. Therefore, the more realistic embodied energy will be set on 481,7 GJ / 0.90 = **535 GJ**.
Now this total embodied energy can be compared with the typical building related energy use during its lifetime. For this purpose, the EPC calculation will be used (*Equation 2*) and filled in with the living space (A_g) of 117 m^2 and an EPC of 0,8 (which is the norm nowadays). The Heat loss surface ($A_{verlies}$) will be calculated using the $A_g/A_{verlies}$ ration described in the reference dwelling document by Senternovem[42]. Therefore: $A_{verlies} = 117 / 0.79 = 148\ m^2$.
Filling in these values in order to calculate $Q_{pres;tot}$ (in GJ / year) gives:

$Q_{pres;tot} = 0.8 \times (330 \times 117 + 65 \times 148) \times 1.12 = 43.2$ GJ/year

This means that it takes an average dwelling a good twelve years (535 / 43.2) to match its yearly building related energy use with the initial energy requirements from the construction phase. The GreenCalc database (see *3.4.1*) uses an average dwelling lifetime of 75 years. With this assumption in mind, it would mean that over the total lifetime of a dwelling, the contribution of the construction phase energy is about 16.5% (535MJ / (75yrs x 43.2MJ/yr)). Off course this largely depends on the actual lifetime of the dwelling. It is for example quite common that an apartment block is demolished within 35-40 years, meaning a doubling of the mentioned construction phase ratio.

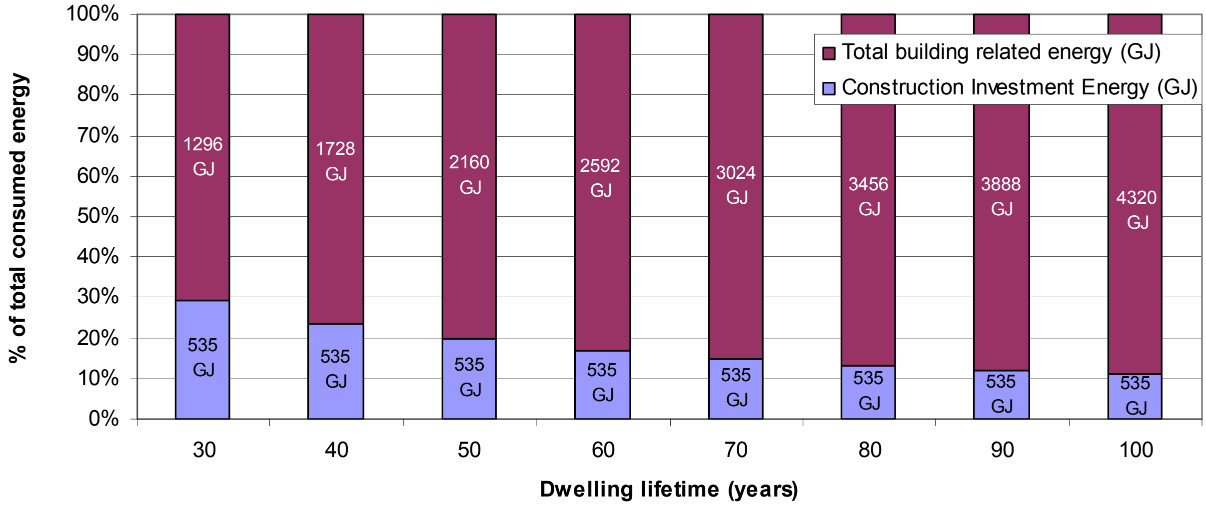


Figure 11 The total consumed energy of an average dwelling, depending of its lifetime.

Figure 11 makes it clear that the lifetime of a building is an important factor in the sustainability debate. Especially when looking at the construction/demolition phase versus the user phase energy distribution of the total dwellings' lifetime.

5.2 On the dwelling usage phase

In order to answer the second research question of this thesis, this section will bring the methods described in *4.2.1* and *4.2.2* into practice. For this purpose, the impact of the case-study dwellings and the EPC regulation in general will be discussed.

5.2.1 Impact case-study dwellings

Out of the total of 4079 newly-build dwellings discussed above, 497 were marked as being sustainable with EPC's lower than 0.8. These dwellings are described in *Table* 15

Table 15 The 497 case-study dwellings which were marked as being sustainable, with EPC's lower than 0.8.

Project ID	Dwelling Type	Number of dwellings	(average) EPC	Used living surface (m2)	Heat loss surface (m2)
#01	Terraced	50	0.45	168	*212*
#02	Terraced/Semi-detached/Detached	150	0.67	*132*	*208*
#03	Corner	8	0.75	110	300
#04	Terraced	16	0.70	110	200
#05	Semi-detached	20	0.75	150	350
#06	Apartments	21	0.69	100	200
#07	Terraced	6	0.77	120	*180*
#08	Terraced	30	0.72	*124*	*157*
#09	Terraced	28	0.72	*124*	*157*
#10	Apartments	32	0.72	80	*85*
#11	Terraced	39	0.72	*124*	*157*
#12	Terraced/corner	36	0.70	113	183
#13	Semi-detached	5	0.70	110	*200*
#14	Semi-detached	35	0.70	150	*273*
#15	Apartments	21	0.70	95	*101*
	Total	**497**	**dwellings**		

Red marked (italic) values were assumed and/or derived, based on reference dwellings [42]

Next, the total typical primary energy use per year ($Q_{pres;tot}$) of each project can be calculated using *Equation 2* and compared with the EPC 0.8 benchmark situation (as described in *4.2.1*). resulting in *Table* 16.

Table 16 The total typical primary energy use per year of each case-study dwelling project

Project ID	EPC 0,8 Total $Q_{pres;tot}$ (MJ / yr)	Average (EPC 0,8) $Q_{pres;tot}$ (MJ / m^2)	Actual EPC Total $Q_{pres;tot}$ (MJ / yr)	Average (actual) $Q_{pres;tot}$ (MJ / m^2)	Total savings per project (MJ / yr)
#01	3,101,234	369	1,744,444	208	1,356,790
#02	7,672,048	387	6,425,340	324	1,246,708
#03	399,974	455	374,976	426	24,998
#04	706,765	402	618,419	351	88,346
#05	1,294,720	432	1,213,800	405	80,920
#06	865,536	412	746,525	355	119,011
#07	275,821	383	265,477	369	10,343
#08	1,376,726	369	1,239,054	332	137,673
#09	1,284,945	369	1,156,450	332	128,494
#10	919,773	358	827,795	322	91,977
#11	1,789,744	369	1,610,770	332	178,974
#12	1,586,511	390	1,388,197	341	198,314
#13	220,854	402	193,247	351	27,607
#14	2,108,153	402	1,844,634	351	263,519
#15	713,387	358	624,214	313	89,173
Total	**24,316,192**		**20,273,343**		**4,042,848**

As can been seen in this table, the last column adds up all savings compared to the EPC 0.8 benchmark. This total of roughly 4.0 TJ is not a lot of energy. But taken into account that 12.2% (497 / 4079) of the newly-build dwellings in this survey were performing better that the EPC regulation (with an average EPC of 0.67), there is a high potential.
The average $Q_{pres;tot}$ per m^2 (per year) should also be noted, as this (standardised) value (which is averagely 324 MJ/m^2/yr) will also be compared with the results of the Impact assessment of the EPC regulation (see *5.2.2*).

5.2.2 Impact assessment EPC regulation

The multiple steps that were needed to come to the analysis, are categorized step-by-step below.

5.2.2.1 Determination of the average EPC in 1995

The average EPC in 1995 has been estimated based on the average A_g (used living surface in m^2), the average $A_{verlies}$ (heat loss surface in m^2) and $Q_{pres;tot}$ (typical building related energy use in MJ). These values were used in combination with *Equation 2*, in order to acquire the average EPC.

The average A_g (the used living surface in m^2) of Dutch households in 1995
Based on the *(average) reference living surfaces* of today's (2006) dwellings[42] and the assumption that the surfaces increased linearly over the years (see *4.2.2.1*), the table in paragraph 9.6 of the appendix has been acquired. In combination with *The distribution of types of dwellings in the Netherlands in 1995* and *The composition of dwellings in 1995 based on their year of construction*[1], an average A_g of 95 m^2 in 1995 has been acquired.

The average $A_{verlies}$ (the heat loss surface in m^2) of Dutch households in 1995
Based on the *ratios between living surface and heat loss surface (A_g / $A_{verlies}$)* of each type of dwelling and the data described in the *average A_g* section above, an average $A_{verlies}$ of 148 m^2 in 1995 has been acquired.

The average $Q_{pres;tot}$ (the typical building related primary energy use) of Dutch households in 1995
The yearly primary energy use related to *(average) electricity use on lighting* has been calculated by multiplying the fixed constant of 56.4 MJ/m^2/yr (primary energy) with the average A_g, resulting in an average yearly energy use of 5383 MJ per dwelling (see *4.2.2.1* for argumentation).
The *typical natural gas usage value of Dutch dwellings* in 1995 [44] has been corrected and weighted for temperature differences over the years. This has resulted in an average yearly gas usage of 67,177 MJ per dwelling.
Combining the two values results in the total average $Q_{pres;tot}$ of 72,560 MJ/yr per dwelling in 1995.
A_g, $A_{verlies}$ and $Q_{pres;tot}$ can now be filled into *Equation 2* (without the 1 / cEPC addition, see *4.2.2.1*) with the following average EPC of dwellings in 1995:

$$EPC = \frac{Q_{pres;tot}}{330 \times A_g + 65 \times A_{verlies}} = \frac{72560}{330 \times 95 + 65 \times 148} = 1.76 \qquad \textbf{(3)}$$

5.2.2.2 The effect of newly-build EPC dwellings from 1995 on the average EPC
Since the steps and necessary tables have already been discussed in the Methods chapter (see *4.2.2.2*), the results will be shown and discussed below straight away.

Figure 12

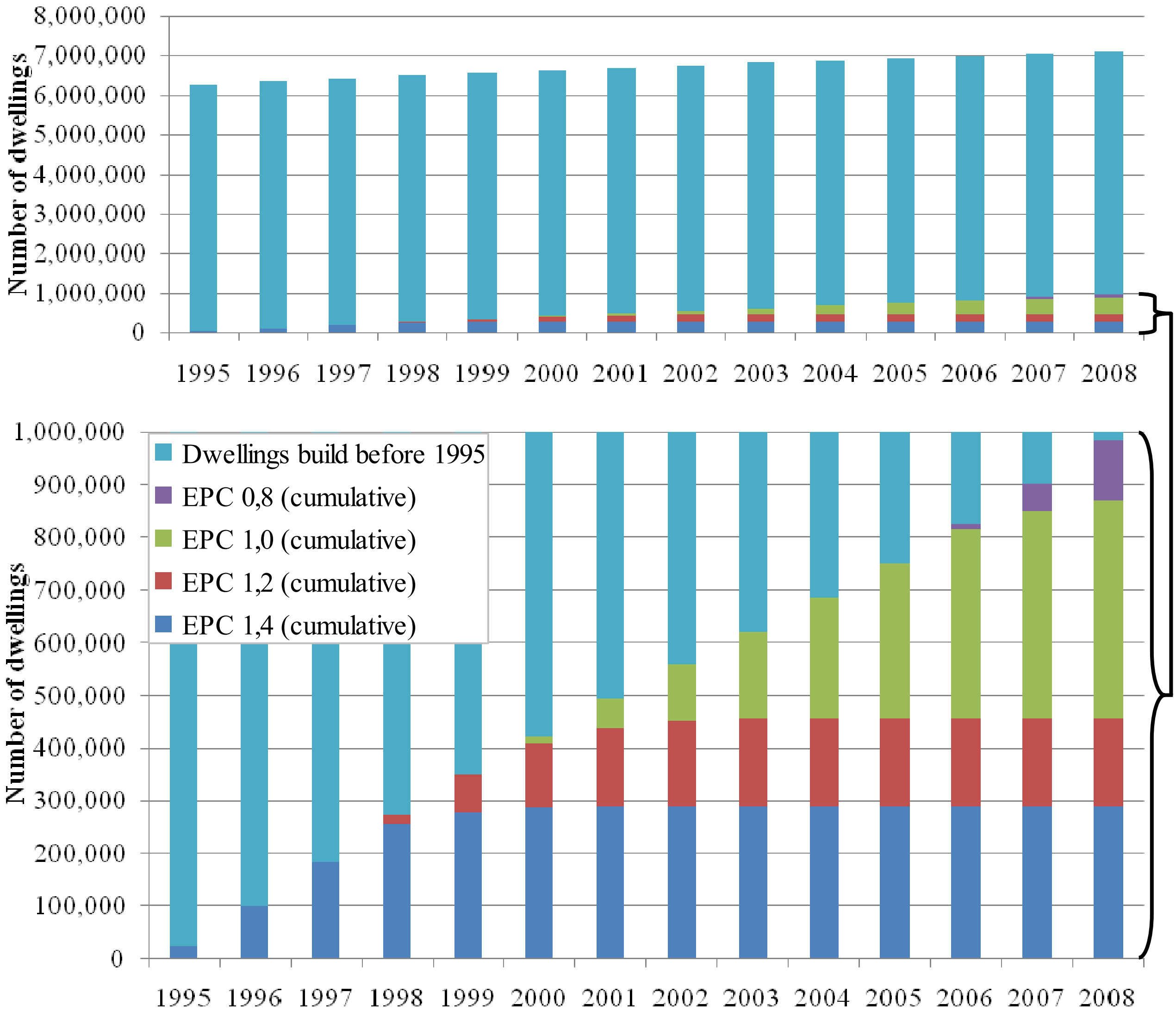


Table 17

Year	**EPC 1.4 Dwellings** *(introduced in 1995)*	**EPC 1.2 Dwellings** *(introduced in 1998)*	**EPC 1.0 Dwellings** *(introduced in 2000)*	**EPC 0.8 Dwellings** *(introduced in 2006)*	**Dwellings build before 1995**
1995	0.38%				99.62%
1996	1.55%				98.45%
1997	2.85%				97.15%
1998	3.90%	0.27%			95.83%
1999	4.21%	1.11%			94.69%
2000	4.30%	1.85%	0.16%		93.68%
2001	4.30%	2.22%	0.83%		92.65%
2002	4.27%	2.40%	1.60%		91.72%
2003	4.24%	2.44%	2.43%		90.90%
2004	4.21%	2.42%	3.37%		90.00%
2005	4.18%	2.40%	4.30%		89.12%
2006	4.15%	2.38%	5.16%	0.14%	88.17%
2007	4.11%	2.36%	5.62%	0.76%	87.15%
2008	4.06%	2.34%	5.84%	1.61%	86.16%

The table and graph above show the entry of EPC dwellings into the total stock of dwellings in the Netherlands

First, *Figure 12* and show the entry of EPC dwellings into the total stock of dwellings in the Netherlands absolute as well as relatively. Their EPC's start affecting the average EPC (see *Equation 3*) of Dutch dwellings from 1995 on. *Figure 12* also shows that the total stock of dwellings increases over the years.

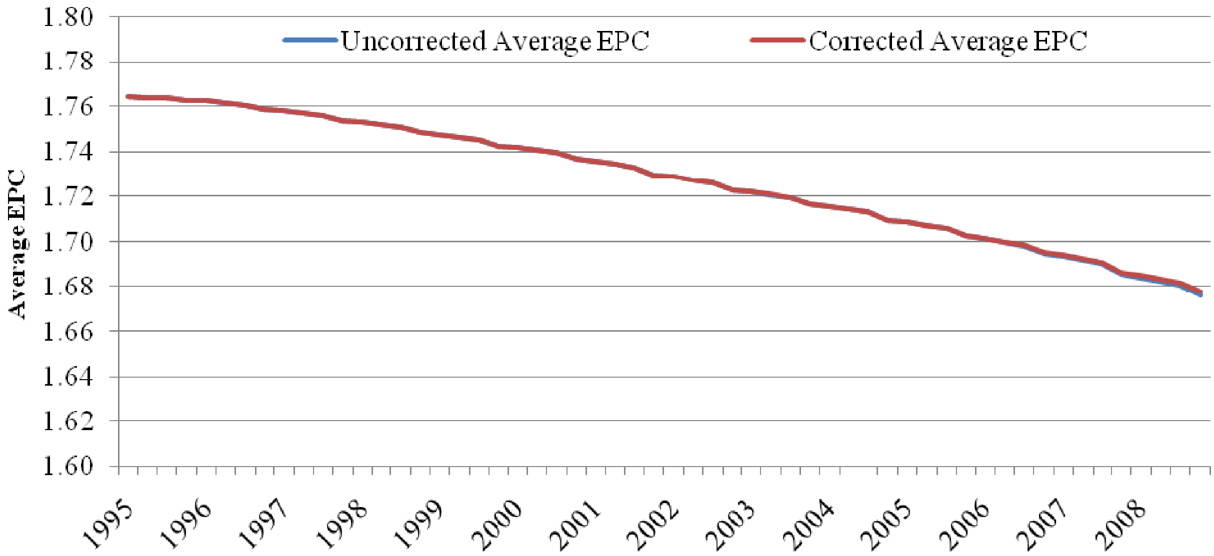


Figure 13

Figure 13 (Uncorrected graph) shows the (theoretical) decrease of the average EPC in the Netherlands, due to the introduction of EPC dwellings in 1995. Generally, it drops from 1.76 in 1995 to 1.68 in 2008, which is a decrease of 4.99 % within 13 years.

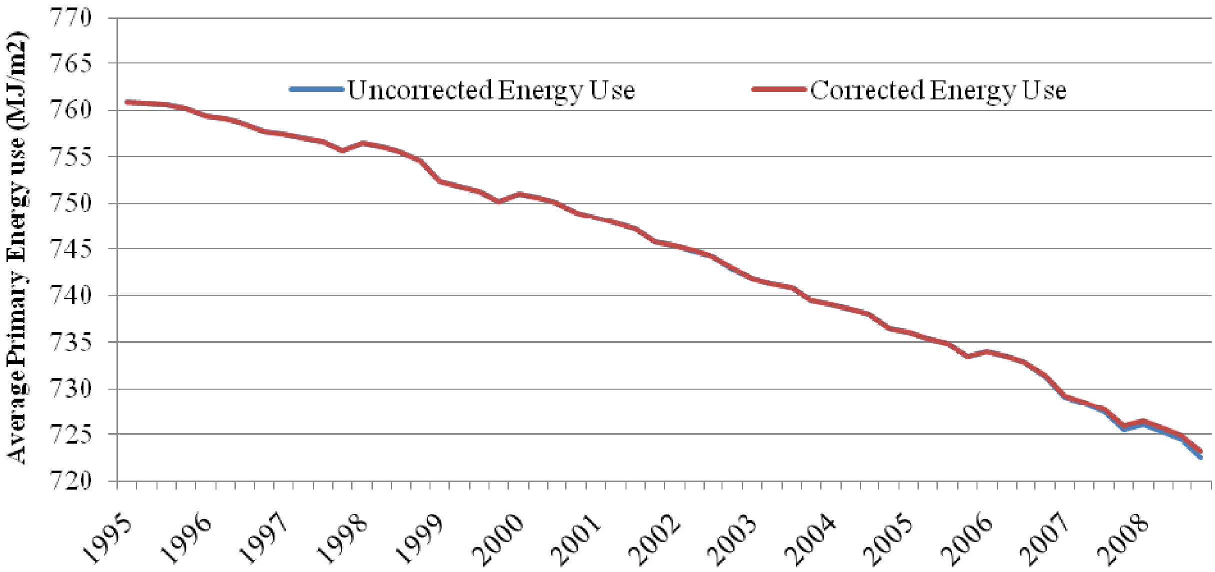


Figure 14

Figure 14 (Uncorrected graph) shows the (theoretical) decrease of the average energy use per square meter, based on the average EPC and the (slowly increasing) average living surface of Dutch dwellings. Generally, it drops from 761 MJ/m^2 in 1995 to 723 MJ/m^2 in 2008, which is an actual decrease of 5.03 % within 13 years (a difference of just 0.04% in 13 years, compared to the average EPC graph).

Correction based on relation EPC vs. actual energy performance

As has been described in 3.3.3, the actual energy performance of EPC buildings cannot completely be compared to their EPC. Based on *Figure 7* in 3.3.3, the biggest savings are made when the EPC's of high EPC dwellings are decreased, while (relatively) only small gains are made within the low EPC dwelling improvements. Despite the small range given in this figure (from 0.91 – 1.04) and the large uncertainties (see the increasing variance displayed in *Figure 7*), the values between 0.8 and 1.7 (with steps of 0.1) have been inter- and extrapolated. In *Table 18* these values are displayed including the mentioned assumptions.

Relative energy savings (%) with an EPC decrease of 0.1 to this →	EPC	
6	0.8	♦
6.2	0.9	♦
6.2	*0.91*	▲
6.4	*0.99*	▲
6.4	**1**	■
6.8	*1.02*	▲
7.8	*1.04*	▲
10.8	1.1	♦
15.8	1.2	♦
20.8	1.3	♦
25,8	1.4	♦
30,8	1.5	♦
35,8	1.6	♦
40,8	1.7	♦

Table 18

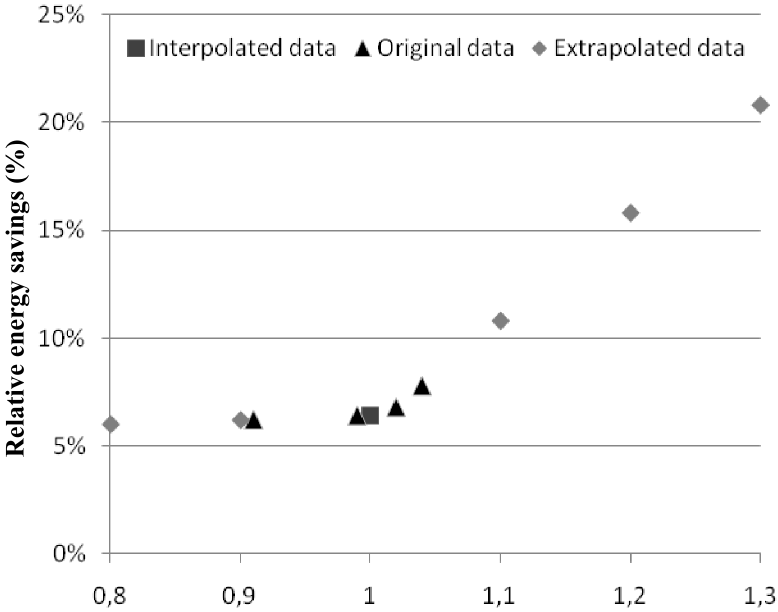


Figure 15

The table and graph above show the relative energy savings (excluding EPC 1.7) with an EPC decrease of 0.1 to the addressed EPC. The inter- and extrapolated values were assumed using the original values.
Source: Derived from J. Uitzinger (IVAM), Analyse EPC en Energieverbruik bij woningen, 2004 (original values)

The (partly inter- and extrapolated) *Table 18* above, shows the relative energy savings with an EPC improvement of 0.1 to the addressed EPC. It is used to calculate new 'relative' EPC's (instead of 1.4 in 1995; 1.2 in 1998; 1.0 in 2000 and 0.8 in 2006 with the same baseline of 1.76). *Figure 15* displays the original and inter- and extrapolated values of this table in a graph. EPC 1.7 has been excluded in order to get a readable reproduction of the graph.

Table 19 The calculation of the corrected EPC's, based on Table 18. The grey coloured values are not used in the corrected EPC. Instead, their normal EPC change counterparts are used.
Source: Derived from J. Uitzinger (IVAM), Analyse EPC en Energieverbruik bij woningen, 2004 (original values)

Year of EPC change	EPC	Normal EPC change (%)	Corrected EPC change (%)	Corrected EPC
	Baseline 1.76			*Baseline 1.76*
1995	1.40	-20.5%	*-80.5%*	1.40
1998	1.20	-14.3%	*-33.3%*	1.20
2000	1.00	-16.7%	-16.5%	1.00
2006	0.80	-20.0%	-11.8%	0.88

Table 19 shows the normal relative improvements (based on a standard baseline of 1.76) per one EPC value above and their relative improvement counterparts based on the correction *Figure 7*. These corrected and normal EPC change percentages were calculated as follows:

<u>For example</u>: an improvement of 1.2 to 1.0 would normally mean a theoretical improvement of (0.2/1.2) 16.7% (see Table 19, Normal EPC change column).
But based on Table 18, an improvement of 1.2 to 1.0 would result in a different percentage. This value is calculated by multiplying the relative savings from 1.2 to 1.1 (10.8% decrease and therefore a multiply factor of 89.2%) and from 1.1 to 1.0 (6.4% decrease); resulting in a (more realistic) net decrease of 16.5% (instead of the theoretical 16.7%).

From these values, the new corrected EPC's were derived. It should be noted that it is assumed that the corrected EPC values cannot exceed the normal ones. In other words: the actual energy reductions due to an EPC decrease, cannot exceed the theoretical energy reduction. E.g. an EPC decrease from 1.0 to 0.8 cannot realise an energy reduction of more than 20%. Therefore, the (grey coloured) values -80.5% and -30.3% will not be used to calculate the corrected EPC. Instead, the normal EPC change values (-20.5% and -14.3% will be used).

Starting with the average EPC 1.76 of dwellings in 1995, using this method, new (corrected) EPC's have been determined for 2000 and 2006. In 2000 the new EPC change value from -16.7% to -16.5% resulted in no real significant EPC change (still 1.00). In 2006 the new EPC change value from -20.0% to -11.8% resulted in a new EPC value of 0.88.

Based on this new (relative) EPC, the corrected graphs in *Figure 13* and *Figure 14* were constructed. Both showed almost no significant differences compared to their uncorrected counterparts. The corrected average EPC now decreases 4.91 % and the corrected average energy use (per m^2) 4.94 % within 13 years (compared to respectively 4.99% and 5.03% with the uncorrected version).

5.2.2.3 Comparing the (theoretical) effect of newly-build EPC dwellings with actual data

The data on average natural gas usage has been acquired as has been described in *4.2.2.3*. *Figure 16* compares the (theoretical *corrected*) energy use variations due to EPC legislation (per m^2) with this actual data on natural gas use variations.

The actual data on natural gas use variations is less stable in comparison to the EPC impact curve. However, a general (linear) trend can be estimated (see the dotted line in *Figure 16*). As can be seen, both curves have the same starting point and start to move apart from 1995 on.

The **Uncorrected** EPC related energy use decreases with 2.78 MJ/m^2/yr and the Actual energy use decreases with 13.63 MJ/m^2/yr averagely. This difference (basically shown in the blue area) between building related energy savings due to newly build EPC dwellings and the overall savings represents about 80%. *Calculation*: (13.63 – 2.78) / 13.63

The **Corrected** EPC related energy use decreases with 2.76 MJ/m^2/yr and the Actual energy use decreases with (the same) 13.63 MJ/m^2/yr averagely. This difference (basically shown in the blue area) between building related energy savings due to newly build EPC dwellings and the overall savings represents (again) about 80%. *Calculation*: (13.63 – 2.76) / 13.63

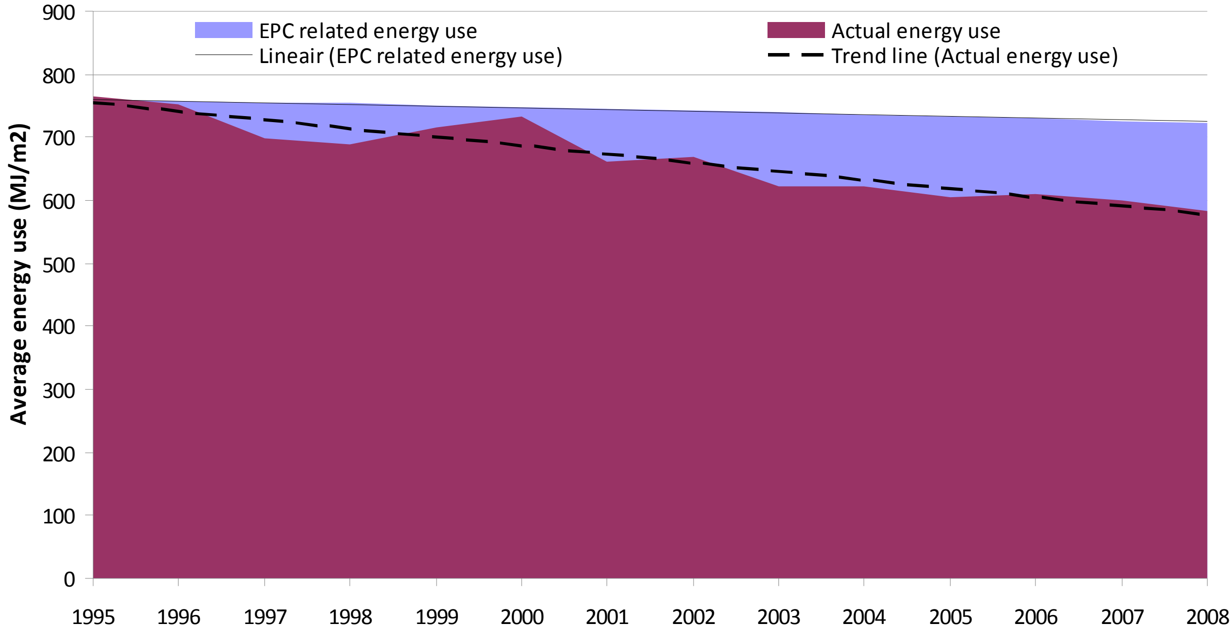


Figure 16 Comparison between the (theoretical) **corrected** energy use variations due to EPC legislation (per m^2) with this actual data on natural gas use variations.

This means that over the last thirteen years until now, 20% (100%-80%) of the average building related energy savings of dwellings (described in 3.3.2) are due to newly-build EPC dwellings.
The main explanation for the remaining 80% should be the energy saving measures on existing dwellings in the Netherlands (retrofitting), possibly in combination with a changed user behaviour over the years (for which no likely significant theory is available). An important factor affecting this, are the insulation measures within Dutch dwellings. As has been stated in *3.1.1*, in 1978 the Dutch government started a national insulation scheme, stimulating the use of roof-, floor- and wall-insulation and double layered glass windows. The effects of this scheme, still echo through existing dwellings of the last ten years. This can be seen in *Figure 17*, which shows the percentage of Dutch dwellings with the mentioned forms of insulation, increasing over the years 2000 until 2007.

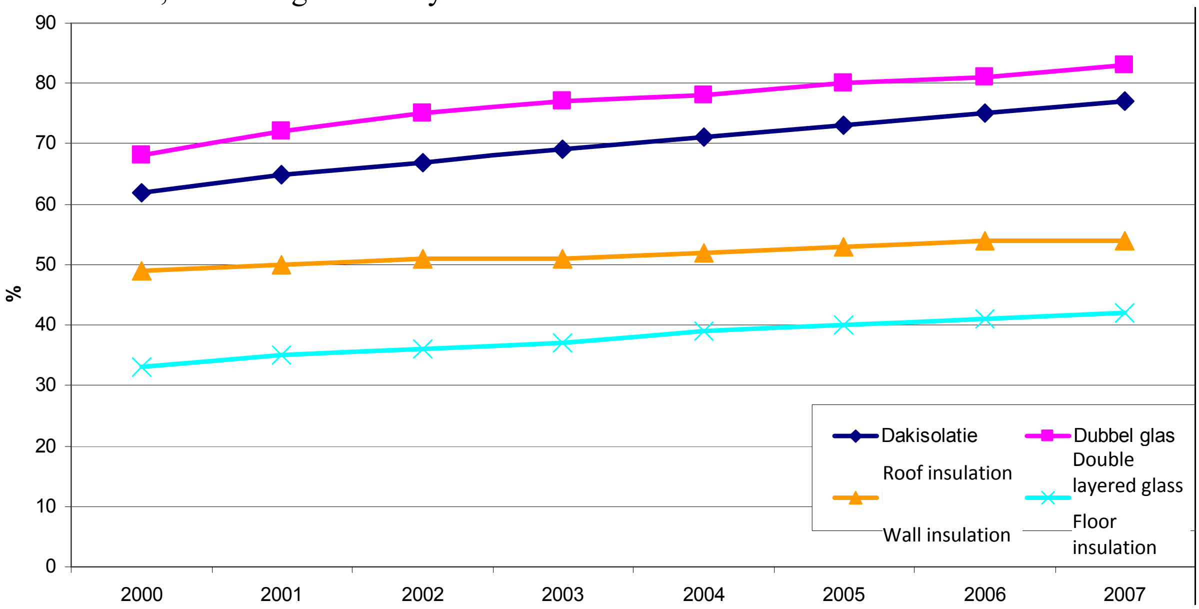


Figure 17 The percentage of Dutch dwellings with four forms of insulation, over the years 2000 until 2007. *Source:* Senternovem database; http://senternovem.databank.nl/; 08-2009

5.3 On the dwelling demolition phase

The introduction of paragraph *3.6* states that about 96% of all building and demolition debris is processed and reused. In the same paragraph, two kinds of companies are described which process this 96% of all debris: breakers (16.4 Mtons / 81%) and sorters (2.7 Mtons mechanically and 1.1 Mtons by hand / 19%).
The central question in this paragraph will firstly be to what extend the waste debris is separated during the demolition process of dwellings in the Netherlands. Secondly, how these streams are reused/recycled and what the energetic consequences of these processes are. Both questions will be answered with the latest values[36] on demolition monitoring from 2007.

Table 10 answers the first question on the extend of separation of materials, since 83% (or 16.4 Mtons) of the breakers' final products are mixed granules (which contain all kinds of stony materials). The more specific materials are processed and separated by the sorter companies. Table 12 in *3.6.2* shows that a relative large amount goes to the breakers as well (35.5%). Still in general, most specific materials are separated into separated streams.

Most debris processed by the *breaking* companies (*Table* 11), is actually down cycled and almost completely used in the road construction sector: for foundation and heightening of roads (84.4%) and in the asphalt itself. The only exceptions are the (washed and unwashed) concrete granules which are used for the production of concrete (see also *3.5.1.1*).
The debris processed by the *sorting* companies (*Table 12*) is mostly composed of materials which were not very energy intensive while looking at the total embodied energy of a dwelling (see *3.5*). Still, since these materials are partly reused/recycled, the energetic impact can be calculated.
Therefore, the materials from *Table* 11 (breakers) and *Table 12 (sorters)* from which the energetic impact will be calculated, are:

- Mixing granules (used to replace gravel for the foundation and heightening of roads)
- Concrete granules (used as a resource in the production of concrete)
- Wood (which is often recycled into chipboard)
- Metals (for which steel will be assumed as the main contributor)
- Unwashed sieve sand

Since no (energetic) information is available on the other material streams (e.g. the caloric value of the 'waste incineration' streams), their energetic impact will not be calculated in this research. Still, the chosen materials above are mainly present in building en demolition debris.

Now, two important building materials will shortly be discussed because of their energetic impact in the dwellings' lifecycle when they are recycled.

Finally, *Table* 20 displays the total amounts of energy per material, which are yearly saved due to building and demolition debris recycling.
Since in 2008 about 20000 dwellings where demolished[1], the total of 14.4 TJ adds up to averagely 0.72 GJ per demolished dwelling. This is roughly 0.13% of the total embodied energy of the average dwelling (*see 5.1*; *calculation*: 0.72/535).

Table 20 The total energy savings through the reuse of demolition waste streams.
Sources: E. Worrell et al, New gross energy-requirement figures for materials production; 1994 (GER column) and Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009 (Amounts Replaced column).

Reused/recycled material	GER of replaced material (GJ/tonne)	Amount of replaced material (tonnes)	Total saved energy per stream (GJ)
Mixing granules	0.3 (broken gravel)	16400	4920
Concrete granules	0.031* (concrete recycling)	900	28
Wood	19.5 (chipboard)	410	7995
Metals	19.9 (steel slabs)	70	1393
Unwashed sieve sand	0.1 (sand & gravel)	320	32

* This value has been derived from the average difference in concrete production energy between no granules recycling and 100% granules recycling (see Table 2), of the two different kinds of concrete (C20/25 and C28/35). *Calculation*: (((1000-960)+(1200-1100)) / 2) / ((2140+2340)/2) = 0.031

6 Discussion

This chapter will discuss the found answers to the research questions, their (un)certainty and finally some recommendations for further research. It is structured using the research questions.

1. To what extent is the selection of materials during construction affecting the energy efficiency of new dwelling projects in 2008 and what are the impacts?

Unfortunately, this question could only be answered partly (only 4.1.1). Namely, the relative importance of the construction phase in relation to the yearly building related energy consumption of the average dwelling. As had been mentioned before, the respondents of the survey were asked to deliver information on the quantities of building materials (mentioned in *3.5*), which were used during construction of dwellings in 2008. Unfortunately, no contractor respondent was able to deliver even a bit of information on this subject. Therefore, no comparison between sustainable (EPC < 0.8) and 'normal' projects can be made from this perspective. Information on the amounts of energy intensive building materials in sustainable dwellings compared to less energy intensive materials in normal dwellings and the total energetic impact in relation to the dwellings' lifetime, could therefore not be acquired.
The reason why many contractors were unable to deliver the necessary information, was often the lack of time. Projects which were finished in 2008 were "already archived" and detailed information could therefore not easily be extracted.

The relative importance of the construction phase in relation to the yearly building related energy consumption of the average dwelling in the Netherlands was calculated using the Gross Energy Requirements of 99.3% (mass-percentage) of building materials involved within a typical Dutch dwelling. The source[39] and level of detail of this list indicates that it is probably very adequate for this research. Besides the material list, the GER data on the materials is probably variably accurate since it is composed of the MRPI table data (with publication years ranging between 1998 and 2008) and supplemented with GER data from a research[47] published in 1994. Beside the novelty of this data, there is also some uncertainty due to the fact whether or not all lifecycle stages of the building materials are involved in the GER's. Still, in general it can be said that the final graph (see *Figure 12*) gives some clear insight into the building related energetic relation between the construction phase and the user phase.

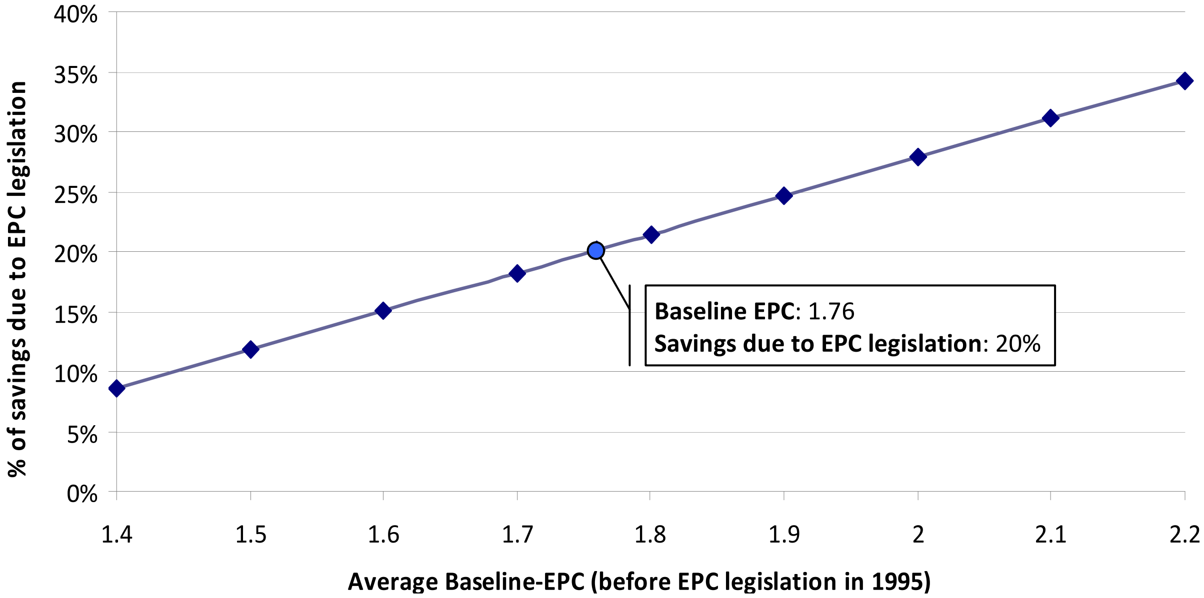
2. To what extent are energy efficiency measures implemented during the construction of new dwellings in 2008, taken into account the usage phase of a dwelling and what is their impact?

Also on this research question, some remarks can be made about the survey and the effort it took to acquire EPC information on dwellings finished in 2008 in the Netherlands. Since the Dutch legislation on the EPC norm requires the registration of newly build dwellings at the municipal governments, these were first contacted to deliver the requested information. Unfortunately the administration on newly build projects was quite bad. Therefore no real summary on the EPC's of newly-build dwellings was available at any city. Since the requested information was not available at the municipalities, contractors were chosen as the new information source. This information on the EPC's of newly-build dwellings has given some insight into the best available (EPC) practices of these projects and their relative energetic impact (see 4.2.1).

About this part of the research question, actually one remark should be made: EPC information on only 5.17% of all newly-build dwellings in 2008 was acquired. Since this is not much, one could question the authority of the results in 5.2.1 and argue that particularly *well performing (in EPC terms) contractors replied on the survey. These particular results could therefore be biased to some extend.*

The second part of this research question comprises an impact assessment of the EPC regulation, introduced in 1996. This assessment was performed by measuring the theoretical impact of EPC dwellings which were build from 1996 onward. For this purpose, an average EPC was established by combining the expected average used living/heat loss surface and the average building related primary energy use of Dutch households in 1995.

On this 'virtual' average EPC dwelling supply in 1995, the new EPC dwellings were added from that year on, which therefore also changed the average EPC (with the related energy use). The sensitivity of this model will now be tested by the sensitivity analysis shown in *Figure 18*. It depicts the relation between the mentioned baseline EPC (which represents the average 'virtual' EPC before 1996) and the final analysis result (see *5.2.2.3*), namely which percentage of all building related energy savings between 1996 and 2008 was due to the EPC legislation (which is 20% in the final analysis). Just as with the final analysis, the corrected model has been used in the sensitivity analysis.



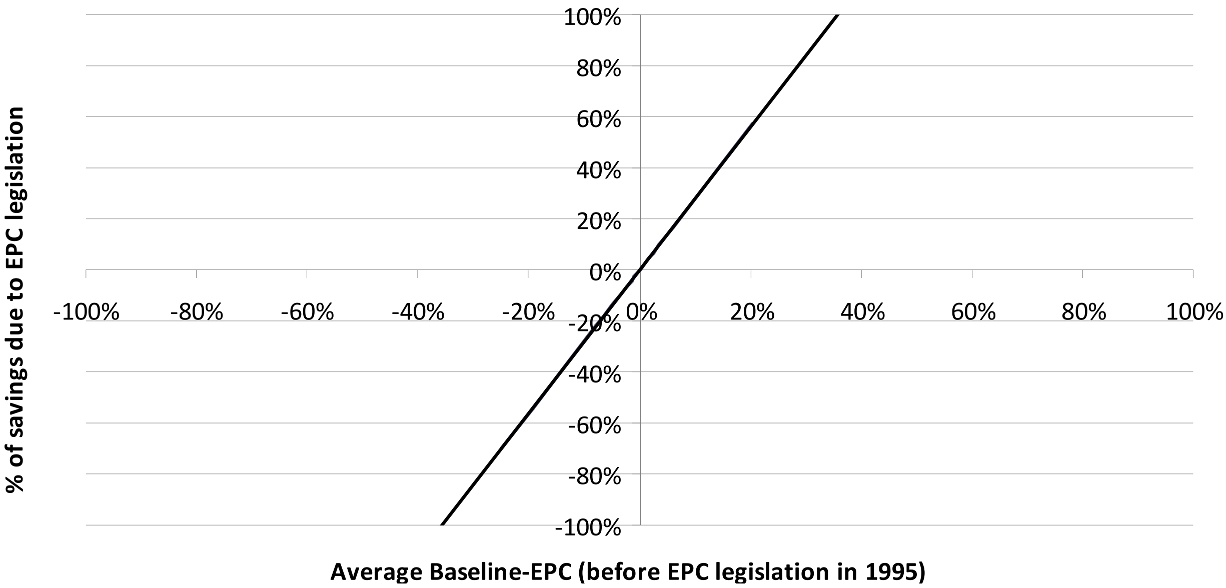


Figure 18 Sensitivity analysis on the relation between the established average baseline EPC and the percentage of savings due to the EPC legislation between 1996 - 2008.

As is shown in *Figure 18*, the *% of savings due to EPC legislation* ranges between about 9% and 35%, while the *average baseline-EPC* ranges between 1.4 and 2.2. Since the first EPC established in 1996 was set on 1.4, it is unlikely that this was the actual average (baseline) EPC of that time, therefore it has been set as the minimum in this analysis. Based on this minimum, also the maximum of EPC 2.2 has been set.
In general it can be said that the final *percentage of savings due to EPC legislation* is moderately sensitive to an error of the *average baseline-EPC*. This is especially visible in the second graph in *Figure 18*, which is quite steep. Still, given the small expected error range, the results are still fairly accurate.

3. To what extent are residue materials during the demolition phase of dwellings in 2008, reused or recycled into new buildings and what is the energetic impact?

As has been stated in 4.3, the case-study projects derived from the survey could not be used in this phase. Alternatively, building and demolition materials monitoring data[36] from 2008 has been used. In order to get an impression of the energetic impact of recycling, these waste material streams which are recycled, are combined with the Gross Energy Requirement data of the materials they replace.
Again, just as has been mentioned in the discussion of research question 2, these GER values are somewhat dated (with only one from a 2006 MRPI table and four others from 1994; Worrell[47]) and therefore deliver some uncertainty to the final results. Also, the replacement of certain materials does not necessarily give a full account of the avoided energy use when recycled materials are used. This is mainly because the total production process energy of certain final products could increase when secondary materials are used as raw materials. However, the goal of this research question is to give an estimation on the impact of building and construction debris recycling in the Netherlands. Therefore, the given results certainly give a clear indication of this impact.

7 Conclusions

This chapter will shortly discuss and summarize the found answers to the research questions formulated in chapter 2 and is structured on the same way.

1. *To what extent is the selection of materials during construction affecting the energy efficiency of new dwelling projects in 2008 and what are the impacts?*

Unfortunately, the survey did not result in a response on the quantities of building materials used in new dwelling projects in 2008. No contractor responds delivered this information. Therefore, no comparison between 'sustainable' projects can be made from this perspective.

Still, the relation between the total embodied energy of a typical Dutch dwelling versus the yearly energy costs (derived from the results of *5.2*) was analysed to get an impression of the (energetic) importance of the construction phase. For this purpose a reference dwelling material list was used. Based on this list, the table in appendix paragraph 9.2 was constructed. This table combined with the mentioned yearly energy cost of the same type of dwelling and living surface, resulted in the following figure (which is also displayed in *5.1*).

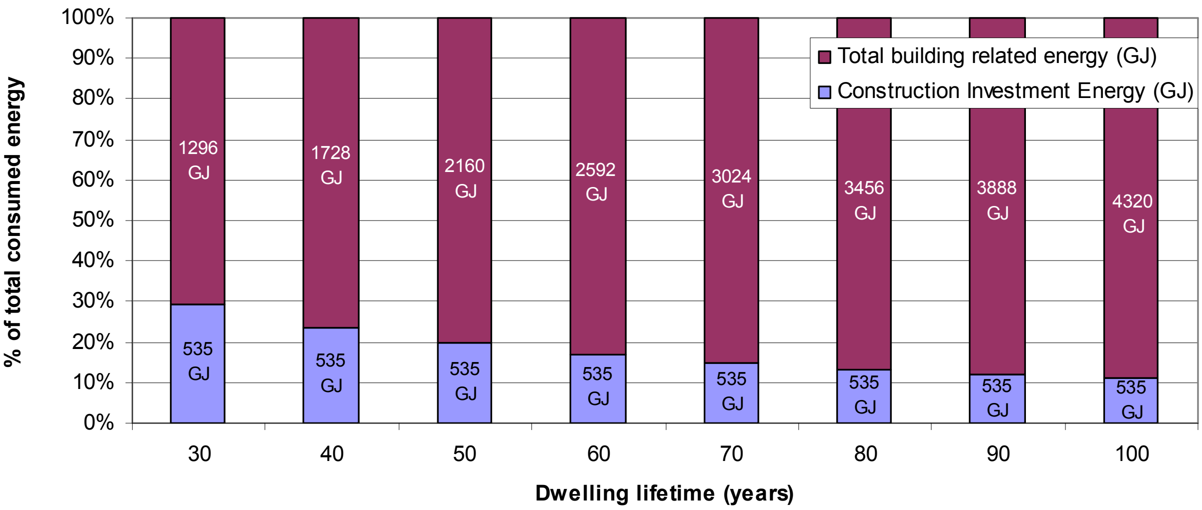


Figure 11 The total consumed energy of an average dwelling, depending of its lifetime.

It shows that the relative importance of materials used in the construction phase, drops from about 30% to 10% while the dwelling lifetime period varies between 30 and 100 years. Therefore it can be concluded that the construction phase plays a moderately important role in the energy debate.

2. *To what extent are energy efficiency measures implemented during the construction of new dwellings in 2008, taken into account the usage phase of a dwelling and what is their impact?*

Generally it can be said that due to the EPC regulation in the Netherlands, contractors were forced to implement numerous energy efficiency measures during construction in order to reduce the building related energy use. All these measures were thoroughly discussed in 3.3. Still the question remained what the actual energetic impact of these measures was on the total energy use of dwellings in the Netherlands between 1996 and 2008. This was researched using an impact assessment with the following final result (with some relevant timeline remarks added from *3.1.3*).

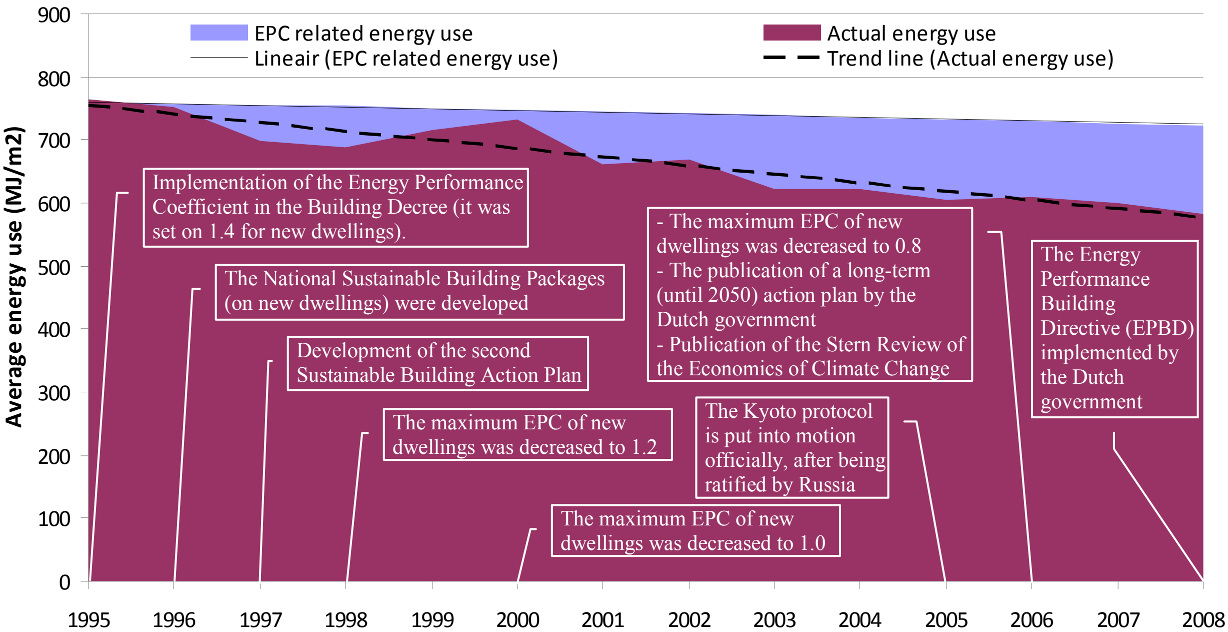


Figure 16 Comparison between the (theoretical) **corrected** energy use variations due to EPC legislation (per m^2) with this actual data on natural gas use variations.

By comparing the speed of decrease of the two displayed graphs, it can be concluded that over the last thirteen years, 20% of the average building related energy savings of dwellings, were due to the newly-build EPC dwellings. This also means that with some certainty it can be said that 80% of these savings were due to energy saving measures on existing dwellings in the Netherlands (retrofitting). This explanation can (probably not likely) be combined with a changed user behaviour over the years (for which no likely significant theory is available).

This conclusion leads to the question whether the Dutch government should focus more on energy saving measures on existing dwellings. This because, in spite of the EPC regulation of the last 13 years, it seems as if it only had a minor impact on the total savings.

Besides these general conclusions, also a sample of 5.17% of all newly-build dwellings in 2008 was taken. Out of these 4079 dwellings, 497 had an EPC lower than 0.8 (averagely 0.67) with one average project EPC of 0.45 (see *5.1*). When we compare this value to the average EPC in 2008 of about 1.68 (see *5.2.2.2*), this shows that still a lot is possible in respect to building related energy saving measures within newly-build and existing dwellings.
But again: looking at the conclusions of the previous indentation (on the importance of retrofitting), the Dutch government should focus more on the existing dwellings in order to lower the average EPC of dwellings even faster.

3. *To what extent are residue materials during the demolition phase of dwellings in 2008, reused or recycled into new buildings and what is the energetic impact?*

In general it can be said, that about 96% of all building en demolition debris is reused or recycled. The bulk of these materials (about 81%) is stony and processed by breaker companies and broken into granules. These are mostly used as a substitute product for gravel in the raising of roads. The remaining 19% of the building en demolition debris is sorted and finally reused, incinerated or dumped.
The total energetic impact of five important demolition materials has been calculated in order to get insight on this impact. The results of this calculation has been displayed in the table below (which is also displayed in 5.3).
Since in 2008 about 20000 dwellings where demolished[1], the total of 14.4 TJ adds up to averagely 0.72 GJ per demolished dwelling. This is roughly 0.13% of the total embodied energy of the average dwelling (*see 5.1*; *calculation*: 0.72/535).

Table 21 The total energy savings through the reuse of demolition waste streams.
Sources: E. Worrell et al, New gross energy-requirement figures for materials production; 1994 (GER column) and Senternovem, Monitoringrapportage Bouw en Sloopafval 2006-2007; 2009 (Amounts Replaced column).

Reused/recycled material	**GER of replaced material (GJ/tonne)**	**Amount of replaced material (tonnes)**	**Total saved energy per steam (GJ)**
Mixing granules	0.3 (broken gravel)	16400	4920
Concrete granules	0.031* (concrete recycling)	900	28
Wood	19.5 (chipboard)	410	7995
Metals	19.9 (steel slabs)	70	1393
Unwashed sieve sand	0.1 (sand & gravel)	320	32

* This values has been derived from the average difference in concrete production energy between no granules recycling and 100% granules recycling (see Table 2), of the two different kinds of concrete (C20/25 and C28/35). *Calculation*: (((1000-960)+(1200-1100)) / 2) / ((2140+2340)/2) = 0.031

8 Recommendations

The recommendations for further research in this chapter will also be structured using the three research sub-questions formulated in chapter 2.

Regarding the first research sub-question (on the construction phase), further research should focus on the question formulated in 4.1.2, which could not be answered because of a lack of data. Namely, a comparison between the total embodied material energy of energy efficient dwellings and the typical dwelling discussed in 4.1.1. This will become an increasingly important topic because the construction phase of dwellings will become more and more important (in energy terms) while dwellings become more energy efficient. This is clearly shown in *Figure 11* (see *5.1*).

Regarding the second research sub-question (on the usage phase), an important conclusion has been drawn in this research. Since probably about 80% of the energy savings between 1996 and 2008 were due to retrofitting, further research on this issue should focus on the effects of this trend and the potential energy savings which can be achieved on existing dwellings.

Regarding the third research sub-question (on the demolition phase), further research should focus on the potential energy savings which can be gained when developers of new dwelling projects and building material producers, already take the demolition phase into account. This could also prove important in respect to innovations which increase the lifetime of newly-build dwellings.

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Appendices

9.1 Average dwelling material list

	Crawl space (kg)	First floor (kg)	Second floor (kg)	Outdoor (kg)	Soil (kg)	Total (kg)
Acrylic paint		15	31			46
Acrylonitrile-butadiene-styrene		1.1	7.6			8.7
Alkyd paint		13	9.5	22		44.5
Aluminium		13	120	17		150
Anodising layer		0.042	0.09	0.13		0.262
Bitumen				83		83
Brass		12	32			44
Bricks		1400	1700	3100		6200
Cardboard		52	96			148
Cast iron			15			15
Ceramics		420	840	100		1360
Chipboard		470				470
Chloroprene			1.1			1.1
Concrete	17000	17000	37000	13000	7800	91800
Copper	4.4	9.5	82			95.9
Copper, primary		11	16			27
Electronics			8.4			8.4
Enamel		2.3	3.1			5.4
Ethylene propylene dipolymer		1.1	2			3.1
Expanded polystyrene	81	81	77	74		313
Glass		220	240	450		910
Glass wool			0.68			0.68
Glue		39	46			85
Glue, sand-lime bricks		280	340	44		664
Glue, water-based			2.9			2.9
Gypsum		2200	2400			4600
Gypsum plaster		330	510	66		906
Hardboard		200	130			330
Lead		12	2.9	15		29.9
Meranti		130	190	200		520
Meranti, FSC		6.8	7.5	14		28.3
Mortar		1400	1900	1900		5200
Multiply		180	490	460		1130
Multiply, FSC				240		240
Paper		180	230			410
Pinewood		210	380	270		860
Pinewood, FSC			10	87		97
Pinewood, FSC, impregnated				2000		2000
Plastic coating		80				80
Polyamide		0.43	1.5			1.93
Polybutylene		6.5	9.9			16.4
Polyester		2.8	7.8			10.6

Polyester concrete		70	70			140
Polyethylene, high density		17	30			47
Polyethylene, low density			52	47		99
Polypropylene			2.7			2.7
Polysulfide		15	20	26		61
Polyurethane foam, blown with air			11			11
Polyurethane foam, blown with pentane		7.5	34	9.9		51.4
Polyvinyl chloride	18	31	38	13	22	122
Rock wool		51	65	120		236
Sand					61000	61000
Sand mortar	2400	4200	6100			12700
Sand-lime bricks		17000	21000	2900		40900
Stainless steel		0.3	52	4.9		57.2
Steel	480	350	710	94	230	1864
Steel, enamelled		320	630			950
Steel, galvanized		49	160			209
Zinc				67		67
Zinc coating		0.49	0.65			1.14
Totals						**237,465**

9.2 *Total embodied energy of the average dwelling*

	Total (kg)	Source	Source name	Energy content (MJ/kg)	Embodied energy (MJ)
Acrylonitrile-butadiene-styrene	8.7	Worrell	ABS	79.9	695
Aluminium	150	Worrell	Aluminium	187.1	28,065
Brass	44	Worrell	Copper	82.8	3,643
Bricks	6200	MRPI	Bricks	2.78	17,236
Cardboard	148	Worrell	Corrugated board	13.2	1,954
Ceramics	1360	Worrell	Bricks	2.78	3,781
Chipboard	470	Worrell	Chipboard	19.5	9,165
Concrete	91800	MRPI	Concrete	0.85	78,030
Copper	95.9	Worrell	Copper	82.8	7,941
Copper, primary	27	Worrell	Copper	82.8	2,236
Expanded polystyrene	313	Worrell	Polystyrene	82.7	25,885
Glass	910	Worrell	Glass (container)	8.1	7,371
Gypsum	4600	Ecofys	Gypsum blocks, plasterboards and coving	1.49	6,854
Gypsum plaster	906	Ecofys	Gypsum plaster	0.85	770
Hardboard	330	Worrell	Chipboard	19.5	6,435
Meranti	520	Worrell	Tropical hardwood	36.3	18,876
Meranti, FSC	28.3	Worrell	Tropical hardwood	36.3	1,027
Mortar	5200	MRPI	Concrete	0.85	4,420
Multiply	1130	Worrell	Plywood	37.4	42,262
Multiply, FSC	240	Worrell	Plywood	37.4	8,976
Paper	410	Worrell	Packaging paper	20.4	8,364
Pinewood	860	Worrell	European softwood	32.6	28,036
Pinewood, FSC	97	Worrell	European softwood	32.6	3,162
Pinewood, FSC, impregnated	2000	Worrell	European softwood	32.6	65,200
Polyethylene, high density	47	Worrell	Polyethylene (LDPE)	67.8	3,187
Polyethylene, low density	99	Worrell	Polyethylene (LDPE)	67.8	6,712
Polypropylene	2.7	Worrell	Polypropylene	63.2	171
Polyvinyl chloride	122	Worrell	Polyvinylchloride	52.4	6,393
Sand	61000	Worrell	Sand & gravel	0.1	6,100
Sand mortar	12700	Worrell	Sand & gravel	0.1	1,270
Sand-lime bricks	40900	MRPI	sand-lime bricks	0.91	37,219
Stainless steel	57.2	MRPI	Steel, Middleweight applications	14	801
Steel	1864	MRPI	Steel, Middleweight applications	14	26,096
Steel, enamelled	950	MRPI	Steel, Roof and façade coating	11	10,450
Steel, galvanized	209	MRPI	Steel, Light applications	14	2,926
Totals	**237,465 kg**				**481,708 MJ**

9.3 Members NVB-bouw survey (Dutch)

Utrecht, 30 maart 2009

Onderzoek Universiteit Utrecht

Duurzaamheid in de bouw

Geachte heer/mevrouw,

Binnen onderzoek van de universiteit Utrecht, ben ik bezig met een onderzoek naar duurzaam bouwen. Meer specifiek wil ik onderzoeken in hoeverre energiezuinige woningbouwprojecten van de grond komen en in hoeverre zij substantieel bijdragen aan energiebesparing in Nederland. Hiervoor wil ik kijken naar zowel de bouwfase (materiaalkeuze & bouwtechniek) als de gebruiksfase (energieprestatie woningen). Uw onderneming, [ONDERNEMING], is als lid van de Vereniging voor ontwikkelaars en bouwondernemers benaderd voor dit onderzoek. Met name door het profiel van deze vereniging –maatschappelijke inspiratie en oog voor commercie- verwacht ik binnen haar leden een belangrijk deel van duurzame woningbouwprojecten te vinden.

Er is geprobeerd om de vragenlijst zo kort en gestructureerd mogelijk te maken. Mochten enkele vragen nu niet of moeilijk te beantwoorden zijn, schroom dan niet om de (deels) ingevulde enquête toch terug te sturen (eventueel met een korte toelichting bij de niet ingevulde vragen). Uiteraard zullen de resultaten van het onderzoek ook naar uw organisatie worden gecommuniceerd. De geleverde data zal tenslotte anoniem en als statistische data worden verwerkt in het uiteindelijke rapport.

Bij voorbaat hartelijk dank voor uw tijd!

Met vriendelijke groet,

Gerhard Schoonvelde

Master student Sustainable Development – Energy and Resources
Supervisor: Prof. Dr. E. Worrell - Universiteit Utrecht
Email: G.J.Schoonvelde@students.uu.nl

Vragen

1. Wat is het totaal aantal woningen die uw onderneming in 2008 opleverde?
   ...

2. Heeft uw onderneming in 2008 bouwprojecten gerealiseerd die kunnen worden geclassificeerd als 'duurzaam'? Zo ja, kunt u een opsomming geven van deze projecten in de desbetreffende gemeenten? …

Project	Gemeente

3. Welke nieuwbouwwoningen die in 2008 werden opgeleverd, hadden een energieprestatie coëfficiënt (EPC) die <u>lager</u> was dan 0,8? Zie onderstaande tabel voor invulling:

Project	Type woningen	Aantal woningen	EPC per woning	Gebruiks-oppervlakte (m^2) per woning	Verlies-oppervlakte (m^2) per woning	Jaar van vergunnings aanvraag
Voorbeeld	*Rijtjeswoning*	*35*	*0,75*	*173*	*347*	*2007*

4. Zouden wij u mogen benaderen wat betreft een aantal extra vragen over de materiaalkeuze en bouwmethoden die uw bedrijf toepast (al dan niet binnen de beschreven duurzame projecten)? Zo ja, graag uw naam, telefoonnummer en/of emailadres.

Naam:
Telefoon:
Email:

9.4 National Sustainable Building Package (2005 update)

Described below are the material related measurements from the latest update of the National Sustainable Building Packages from 2005 (in Dutch).

Spec. nr	Description	Fixed	Variable
S032	Maak het ontwerp geschikt voor het gebruik van actieve zonne-energie	V	
S050	Optimaliseer het ontwerp op leidinglengtes	V	
S051	Pas geprefabriceerde producten toe		v
S053	Voer ramen uit in hardglas		v
S054	Beperk de hoeveelheid en onderhoudsfrequentie van het schilderwerk		v
S056	Maak verbindingen bereikbaar en demontabel		v
S061	Bescherm opgaand werk door gevelontwerp		v
S062	Stem dakvorm en maatvoering van hellende daken af op het gebruik van standaard hulpstukken		v
S063	Pas, indien verkrijgbaar, duurzaam geproduceerd hout toe		v
S064	Stem de duurzaamheidsklasse van hout af op de toepassing	V	
S066	Gebruik voor gipstoepassingen binnen: rogips of natuurgips	V	
S069	Verduurzaam stalen bouwproducten uitsluitend wanneer dit aantoonbaar noodzakelijk is	V	
S071	Pas alleen PVC toe waarvan de kringloop gesloten wordt	V	
S072	Hergebruik bouwcomponenten		v
S073	Gebruik voor beton waar dit technisch mogelijk is, klinkerarme cementsoorten	V	
S074	Indien gebruik wordt gemaakt van beton, gebruik dan waar mogelijk betongranulaat als grindvervanger.	V	
S076	Gebruik ontkistingsmiddelen op plantaardige basis of biologisch afbreekbare middelen op minerale basis; gebruik deze producten zuinig		v
S077	Gebruik voor metselwerk een schelpkalk(basterd)mortel of een cementmortel met een gering portlandklinkergehalte		v
S081	Pas voor totale houtverduurzaming milieubewuste methoden toe	V	
S086	Gebruik zo laagwaardig mogelijk materiaal als bodemafsluiting		v
S098	Gebruik waar mogelijk halfverharding		v
S112	Gebruik waar mogelijk houten funderingspalen		v
S116	Pas een prefab begane grondvloer toe		v
S117	Pas als niet-woningscheidende verdiepingsvloer betonnen prefab systeemvloeren met een laag eigen gewicht of houten vloeren toe		v
S117	Indien het casco bouwsysteem dit toelaat: pas als niet-woningscheidende verdiepingsvloer betonnen prefab systeemvloeren met een laag eigen gewicht en conform 074 of houten vloeren toe		v
S118	Pas, indien bereikbaarheid van leidingen gewenst is, een flexibel vloersysteem toe		v
S132	Gebruik voor buitenafwerking gevel: metselwerk of hout (conform S063/S064/S072)		v
S146	Stem de uitvoering van niet-dragende wanden af op eisen ten aanzien van veranderbaarheid en toekomstig hergebruik		v
S154	Indien prefab dooselementen worden toegepast: gebruik vernieuwbare grondstof of reststof als isolatiemateriaal		v
S170	Pas montagekozijnen toe		v
S177	Gebruik raamdorpels bestaande uit keramische elementen, staalplaat, natuursteen, gegoten composietsteen of prefab beton (conform S074)		
S193	Gebruik als binnendeur hardboard met honingraatvulling van karton, massief spaanplaat (conform S067), multiplex of hout (conform S063/S064)		v
S208	Maak puibekleding van vernieuwbare grondstof of recyclebaar materiaal	V	
S239	Gebruik dorpels van natuursteen, keramische tegels of gegoten composietsteen bij natte ruimten		v
S248	Gebruik als naaddichting: PE-rolband of EPDM-rubber; gebruik als kierdichting bij raam- en		v

	deuraansluitingen: EPDM- of EPT-rubber; achter timmerlatten: PE-band		
S257	Gebruik voor pleisterwerk binnen: gips (conform S066) of kalk		v
S267	Indien een dekvloer wordt toegepast, vervaardig deze dan van gips (anhydrietvloer)		v
S278	Gebruik als beplating voor wand- /plafondsysteem: gipsvezelplaat of gipskartonplaat		v
S353	Stem maatvoering af op handelsmaten		v
S354	Beperk het gebruik van eenmalig verpakkingsmateriaal		v
S369	Streef naar 'schuim- en kitarme' detaillering		v
S371	Scheid bouwplaatsafval in zoveel mogelijk relevante fracties		v
S389	Baseer het bouwplan op een gesloten grondbalans		v
S395	Maak tuinafscherming/privacyschermen door middel van beplanting, gevlochten scherm of hout, duurzaamheidsklasse 3/4; gebruik perkoenpaaltjes van niet-verduurzaamd hout, duurzaamheidsklasse 4		v
S396	Pas natuurvriendelijke oevers toe		v
S413	Bied de bewoner gebruiksflexibiliteit voor de toekomst		v
S444	Gebruik als bedekking voor platte daken dakbedekkingssystemen met een lange levensduur		v
S471	Gebruik indien mogelijk vernieuwbare grondstoffen		v
S485	Gebruik houten buitendeur (conform S063/S064/S072)		v
S493	Gebruik, indien gietbouw wordt toegepast, bouwstaalnetten op maat	V	
S501	Gebruik bij voorkeur producten waarvan de kringloop gesloten wordt		v
S637	Realiseer scheiding van drager en inbouw		v
S672	Bied de bewoner (toekomstige) uitbreidingsmogelijkheden van de woning		v

9.5 *The number of finished dwellings and issued permits*

Licenses issued	*Finished dwellings*	*Period*
23856	15387	**1995 1st quarter**
25244	20340	**1995 2nd quarter**
21638	20918	**1995 3rd quarter**
27667	37191	**1995 4th quarter**
23370	10576	**1996 1st quarter**
23236	19851	**1996 2nd quarter**
23181	22148	**1996 3rd quarter**
31329	36359	**1996 4th quarter**
20060	11909	**1997 1st quarter**
24786	21586	**1997 2nd quarter**
26330	20137	**1997 3rd quarter**
30325	38683	**1997 4th quarter**
21242	16301	**1998 1st quarter**
19198	19552	**1998 2nd quarter**
19435	18359	**1998 3rd quarter**
27798	36304	**1998 4th quarter**
17063	11864	**1999 1st quarter**
21534	18407	**1999 2nd quarter**
22513	15915	**1999 3rd quarter**
23091	32439	**1999 4th quarter**
20509	10835	**2000 1st quarter**
20841	14377	**2000 2nd quarter**
18303	14892	**2000 3rd quarter**
18910	30546	**2000 4th quarter**
15119	11133	**2001 1st quarter**
13451	15193	**2001 2nd quarter**
17549	15931	**2001 3rd quarter**
16207	30701	**2001 4th quarter**
12281	8961	**2002 1st quarter**
14805	14989	**2002 2nd quarter**
15291	13390	**2002 3rd quarter**
24806	29364	**2002 4th quarter**
17106	7480	**2003 1st quarter**
16463	11972	**2003 2nd quarter**
15586	10889	**2003 3rd quarter**
23299	29288	**2003 4th quarter**
14085	8824	**2004 1st quarter**
16579	12213	**2004 2nd quarter**
14590	10569	**2004 3rd quarter**
30926	33708	**2004 4th quarter**
17139	9500	**2005 1st quarter**
19448	13811	**2005 2nd quarter**
17899	12885	**2005 3rd quarter**
28787	30820	**2005 4th quarter**
23621	12417	**2006 1st quarter**
25536	13646	**2006 2nd quarter**
21702	15281	**2006 3rd quarter**
25588	31038	**2006 4th quarter**
18251	10395	**2007 1st quarter**

19153	14463	**2007 2nd quarter**
22405	17066	**2007 3rd quarter**
28109	38269	**2007 4th quarter**
16766	12715	**2008 1st quarter**
18808	15381	**2008 2nd quarter**
22425	16798	**2008 3rd quarter**
29199	33988	**2008 4th quarter**

9.6 The average used living surface in m^2 of Dutch households

Year ↓ / Living surface newly-build dwellings →	Terraced	Corner	Semi-detached	Detached	Apartments
2008	125.8	125.8	149.2	171.0	87.7
2007	125.1	125.1	148.5	170.3	87.3
2006	124.3	124.3	147.7	169.5	86.9
2005	123.6	123.6	147.0	168.8	86.5
2004	122.8	122.8	146.2	168.0	86.1
2003	122.1	122.1	145.5	167.3	85.7
2002	121.3	121.3	144.7	166.5	85.3
2001	120.6	120.6	144.0	165.8	84.9
2000	119.8	119.8	143.2	165.0	84.5
1999	119.1	119.1	142.5	164.3	84.1
1998	118.3	118.3	141.7	163.5	83.7
1997	117.6	117.6	141.0	162.8	83.3
1996	116.8	116.8	140.2	162.0	82.9
1995	116.1	116.1	139.5	161.3	82.5
1994	115.3	115.3	138.7	160.5	82.1
1993	114.6	114.6	138.0	159.8	81.7
1992	113.8	113.8	137.2	159.0	81.3
1991	113.1	113.1	136.5	158.3	80.9
1990	112.3	112.3	135.7	157.5	80.5
1989	111.6	111.6	135.0	156.8	80.1
1988	110.8	110.8	134.2	156.0	79.7
1987	110.1	110.1	133.5	155.3	79.3
1986	109.3	109.3	132.7	154.5	78.9
1985	108.6	108.6	132.0	153.8	78.5
1984	107.8	107.8	131.2	153.0	78.1
1983	107.1	107.1	130.5	152.3	77.7
1982	106.3	106.3	129.7	151.5	77.3
1981	105.6	105.6	129.0	150.8	76.9
1980	104.8	104.8	128.2	150.0	76.5
1979	104.1	104.1	127.5	149.3	76.1
1978	103.3	103.3	126.7	148.5	75.7
1977	102.6	102.6	126.0	147.8	75.3
1976	101.8	101.8	125.2	147.0	74.9
1975	101.1	101.1	124.5	146.3	74.5
1974	100.3	100.3	123.7	145.5	74.1
1973	99.6	99.6	123.0	144.8	73.7
1972	98.8	98.8	122.2	144.0	73.3
1971	98.1	98.1	121.5	143.3	72.9
1970	97.3	97.3	120.7	142.5	72.5
1969	96.6	96.6	120.0	141.8	72.1
1968	95.8	95.8	119.2	141.0	71.7
1967	95.1	95.1	118.5	140.3	71.3
1966	94.3	94.3	117.7	139.5	70.9
1965	93.6	93.6	117.0	138.8	70.5
1964	92.8	92.8	116.2	138.0	70.1
1963	92.1	92.1	115.5	137.3	69.7
1962	91.3	91.3	114.7	136.5	69.3

1961	90.6	90.6	114.0	135.8	68.9
1960	89.8	89.8	113.2	135.0	68.5
1959	89.1	89.1	112.5	134.3	68.1
1958	88.3	88.3	111.7	133.5	67.7
1957	87.6	87.6	111.0	132.8	67.3
1956	86.8	86.8	110.2	132.0	66.9
1955	86.1	86.1	109.5	131.3	66.5
1954	85.3	85.3	108.7	130.5	66.1
1953	84.6	84.6	108.0	129.8	65.7
1952	83.8	83.8	107.2	129.0	65.3
1951	83.1	83.1	106.5	128.3	64.9
1950	82.3	82.3	105.7	127.5	64.5
1949	81.6	81.6	105.0	126.8	64.1
1948	80.8	80.8	104.2	126.0	63.7
1947	80.1	80.1	103.5	125.3	63.3
1946	79.3	79.3	102.7	124.5	62.9
1945	78.6	78.6	102.0	123.8	62.5
1944	77.8	77.8	101.2	123.0	62.1
1943	77.1	77.1	100.5	122.3	61.7
1942	76.3	76.3	99.7	121.5	61.3
1941	75.6	75.6	99.0	120.8	60.9
1940	74.8	74.8	98.2	120.0	60.5