2 Theoretical vs. actual energy consumption of labelled dwellings in The Netherlands: Discrepancies and policy implications

Explanatory note

This research studies the difference between actual and theoretical energy consumption in Dutch residential dwelling stock. The research utilised the energy label certificates issued in The Netherlands in 2010, containing dwellings' theoretical performance. This dataset was merged with actual energy data on the level of individual dwelling. Simple descriptive statistics were used to compare average theoretical and actual consumption of gas, electricity and primary energy and CO_2 emissions. It became clear that the discrepancies were significant and related strongly to the performance category, which meant that there could be a substantial impact on the energy savings targets set by the government. Therefore, the resulting averages of both theoretical and actual consumption were used in a scenario study, where they are extrapolated nationwide in order to be compared with the existing policy targets. Results showed that while the targets can be achieved using the theoretical consumptions as baselines they are out of reach if projected on the basis of actual consumptions.

Published as: Majcen, D., Itard, L., Visscher, H., 2013a. Actual and theoretical gas consumption in Dutch dwellings: What causes the differences? Energy Policy 61, 460–471.

Abstract

In Europe, the Energy Performance of Buildings Directive (EPBD) provides for compulsory energy performance certification (labelling) for all existing dwellings. In the Netherlands, a labelling scheme was introduced in 2008. Certificates contain the energy label of the dwelling and corresponding theoretical gas and electricity consumption, calculated based on the dwellings physical characteristics, its heating, ventilation and cooling systems and standard use characteristics. This paper reports on a large-scale study comparing labels and theoretical energy use with data on actual energy use. A database of around 200,000 labels was coupled with data from

Statistics Netherlands on actual gas and electricity consumption provided by energy companies. The study shows that dwellings with a low energy label actually consume much less energy than predicted by the label, but on the other hand, energy-efficient dwellings consume more than predicted. In practice, policy targets are set according to the theoretical rather than the actual consumptions of the building stock. In line with identified discrepancies, the study shows that whereas most energy reduction targets can be met according to the theoretical energy consumption of the dwelling stock, the future actual energy reduction potential is much lower and fails to meet most of the current energy reduction targets.

§ 2.1 Introduction

Buildings are responsible for approximately 40% of the EU's energy consumption and accounted for 30% of EU's CO_2 emissions in 2005 (SERPEC-CC Summary Report, 2009). In 2002, the European Performance of Buildings Directive was put in place with the aim of reducing the amount of energy consumed by the residential and utility sectors by informing renters and buyers of the energy consumption of the buildings in which they live and setting an EU framework for energy performance certification (EPBD 2002/91/EC). The general requirements of the 2002 EPBD for residential buildings included the development of a system of energy certification for new and existing buildings, regular inspections of heating and air-conditioning systems and the introduction of minimum energy-performance standards for new and extensively renovated existing buildings with a useable floor area of over 1000m^2. Mandatory energy certification for residential buildings, which is the focus of this paper, was introduced for all properties constructed, sold or rented.

All member states had implemented the directive by the end of 2009, some more effectively than others (Andaloro et al., 2010). This process seems to have been well studied within numerous EU projects and initiatives (BPIE, 2011, ASIEPI, 2009, IMPLEMENT, 2010, IDEAL, 2009). Moreover, a joint initiative undertaken by the EU member states and the European Commission, the Concerted Action EPBD, enables member states to share their information and experiences of adopting and implementing this European legislation at the national level (www.epbd-ca.eu). The two major shortcomings of the directive as concluded in the EU project IMPLEMENT, are the looseness of the regulations in the directive, which leave ample room for interpretation, and the fact that no sanctions are imposed in cases where the rules of the EPDB are ignored (for example, failure to issue an energy certificate when selling a house). Additionally, the European Project IDEAL-EPBD was specifically designed to investigate why energy performance certificates hardly seem to motivate homeowners to take measures to improve the energy performance of their dwelling; it produced several policy proposals to improve the impact of the EPDB. However, all these projects deal with implementation of the EPDB strategically and overlook the accuracy and outcomes of the calculation methods used. It seems certain that this varies throughout the EU, since the methodology of the energy performance certificates (EPC) is not defined by the directive and is in hands of individual member states, which have developed very different approaches and methodologies (EPBD Concerted Action). However, in 2004 the EC appointed the CEN (mandate M/343) to develop a series of standards. These include the following: EN 15217 (energy performance of buildings - ways of expressing the energy performance of buildings and energy certification); EN15603 (the energy-efficiency of buildings – overall energy use and the definition of the energy rating); EN ISO 13790 (energy performance of buildings – calculating the energy used for heating and cooling). However, the methodologies do not comply fully with the standards in all member states (Andaloro et al., 2010), including the Netherlands.

Clearly, the theoretical values are merely an estimation of the actual consumption, since they are based on standard values and do not take account of the lifestyle of the occupants. However, the labels also provide homeowners and tenants with information on possible energy-saving measures, and the pay-back time for these measures is directly related to the theoretical energy consumption. Future targets for reducing energy consumption and feasible energy reduction policies are formulated according to the theoretical potential for energy reduction. If the label is to become an efficient tool with which to reduce household energy consumption in line with the targets set, the theoretical decrease in energy consumption when improving the energy label of a particular dwelling should closely reflect the actual decrease in energy consumption.

This study aims to identify the results of the energy performance calculation which was implemented in line with the EPBD directive, comparing it with the actual energy consumption of Dutch dwellings. In order to assess a broader efficacy of the energy label methodology as a policy tool for achieving reductions in household energy consumption, actual and theoretical energy consumption were examined in respect to the targets set for reductions in energy consumption and CO_2 emissions for the residential sector in the EU and the Netherlands.

This paper is organized as follows. Section 2.2 provides background information on the topic, a review of existing studies and energy and CO_2 reduction targets. In section 2.3, the energy-efficiency of Dutch households is presented together with an overview of the Dutch energy label calculation for dwellings. The results are presented in section 2.4, followed by a scenario study in section 2.5 and finally, the discussion and conclusions in sections 2.6 and 2.7.

§ 2.2 State of the Art

§ 2.2.1 Existing studies on actual energy consumption

According to Perez et al. (2008), the lack of a complete databases containing the information on energy performance coefficients of buildings in the national dwelling stock together with building type, size etc., impedes the evaluation of the policies at the national and EU levels. Poor availability and accessibility of energy label databases for researchers is probably the main reason that this subject has remained under-researched. The small amount of literature that is available relating the label of the dwellings with their actual performance is mostly based on small samples, with the intention of quantifying the role of occupancy in explaining differences. Guerra Santin (2012) compared the actual and expected energy consumption for 248 Dutch dwellings built after 1996. The dwellings were categorised according to their EPC value (the Dutch energy performance coefficient for new buildings). The EPC (NEN 5128) calculation method is broadly similar to the energy index calculation method, which is the basis for the energy label (see section 2.3.2).

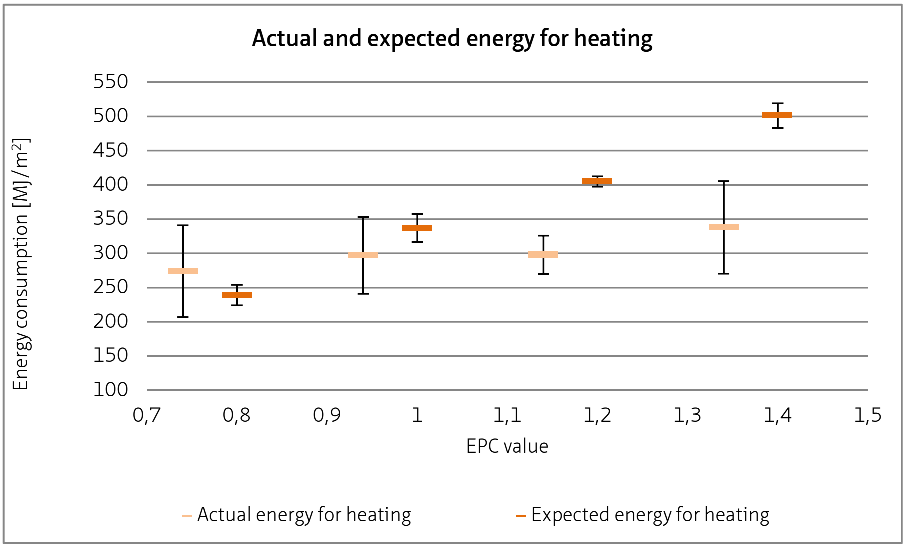

FIGURE 1 Mean and 95% confidence interval for the actual energy consumption (MJ/m^2) and expected energy for heating (MJ/m^2) per EPC value (Guerra Santin, 2012)

In energy-inefficient buildings with a high EPC, actual energy consumption for heating was almost half that expected, whereas in buildings with a low EPC (energy-efficient buildings), the actual and expected heating energy consumptions coincided much better. Due to the relatively small sample size, the differences between the actual heating energy of buildings with different EPC values were insignificant, although the mean actual consumption was consistently lower in buildings with a lower EPC (Figure 1).

In another study conducted in the Netherlands by Tigchelaar (2011), a 'heating factor' was calculated (the actual demand for heating is divided by the theoretical demand). The average heating factor in a sample of 4700 representative dwellings was found to be below one, meaning that the theoretical consumption was overestimated. Cayre et al. (2011) studied actual and theoretical energy consumption in 923 French dwellings and reached similar conclusions – the French EPC model overestimates the theoretical energy consumption in the sample, which was representative of the French dwelling stock as a whole. Hens (2010) arrived at similar findings when observing 20 low income, non-insulated dwellings in Belgium. There, the measured energy use was merely a fraction (on average approximately 50%) of the calculated consumption. These findings were extrapolated to a broader sample, showing that the difference between measured and calculated consumption is larger in non-insulated than in well-insulated homes. On the other hand, in 12 multi-family thermally retrofitted buildings in Austria, Haas and Biermayr (2000) found evidence that actual energy consumption significantly exceeded the expected. Similar results were obtained by Branco et al. (2004) in a multi-family complex in Switzerland and in a similar sample by Marchio en Rabl (1991) in France. On the basis of these results, it seems that the theoretical energy consumption tends to be overestimated when looking at average and less energy-efficient dwellings and underestimated when observing new or retrofitted buildings. The phenomenon of underestimated theoretical consumption can partly be explained by the 'rebound effect' (Berkhout et al., 2000), by which more efficient technologies (such as a low energy dwelling) cut energy bills but thereby encourage increased consumption. A typical example of rebound effect was found to be temperature control (Guerra Santin, 2010) - dwellings with a programmable thermostat turned out to consume more energy than households with a manual thermostat or manual valves on radiators. A similar phenomenon is described in previously mentioned study by Hens (2010), where the benefits of refraining from heating certain rooms in the dwelling are lower in well-insulated dwellings, since they are characterised by a more constant indoor temperature. Sorrell et al. (2009), provides an overview of the methods for calculating rebound effect and a summary of the studies available. Accordingly, he concludes that in OECD countries the mean value of the long-run direct rebound effect is likely to be below 30%. This means that up to 30% of the efficiency gained through the technical improvement of buildings and appliances result in increased consumption due to direct changes in user behaviour. In some cases, this can bring about increased comfort, but not always (for example, low energy bills may lead occupants to heat more rooms, which does not necessarily mean more comfort).

However, the size of the samples in the studies mentioned is relatively small, which sometimes leads to problems when assessing the statistical significance of the results. Moreover, the representativeness of the sample for the national dwelling stock is also not addressed at times. These factors are important when evaluating the accuracy of the energy label at a national level. Even in countries where energy label databases exist, few analyses of energy performance certificates are available.

§ 2.2.2 Energy and CO_2 reduction targets

As mentioned previously, buildings are an important sector in terms of the potential for reducing energy consumption and CO_2 emissions. The European Commission's Action Plan for Energy Efficiency, published in 2006, defines the full primary energy reduction potential of the residential buildings sector as around 27%. The EU's goal for overall primary energy is to reduce consumption by 20% by 2020 and, as stated in decision 406/2009/EC; a second goal is to reduce the total CO_2 emissions by 30% (including indirect emissions through the generation of electricity) by 2020 and by 50% by 2050. As part of this, the Netherlands has committed itself to reducing its total greenhouse gas emissions by 16% by 2020 (using 2005 as a baseline).

The SERPEC-CC report on the residential buildings and service sector was commissioned to identify the potential role of technology in reducing carbon emissions. It assumes the implementation of technologies which are available today or are likely to become economically viable in the near future, such as insulation, advanced heat supply technologies and more efficient electric appliances (lights, refrigerators, etc.). The reference level used was the standard practice and technology in 2005. The renewal of the buildings stock was assumed to occur at a pace of 1% per year and the renovation rate of buildings was assumed to occur at a maximum rate of 2.5% per year. Insulation measures and implementation of advanced heating systems were assumed to be implemented as part of a bigger project of buildings renovation, therefore the maximum implementation rate of these measures follows the rate of renovation. The future scenario, predicted for 2020, is comparable to a present-day energy-efficient house, which would now be labelled 'A' in the Netherlands. The study took account of technical measures rather than changes in behaviour (it assumed no rebound effect). It identified abatement costs, potential and reductions for the whole European Union within the built environment as 19% below 2005 emissions by 2020 and 29% by 2030. Reductions in the demand for heating are expected to result in a 61% decrease in CO_2 emissions by 2030, while electricity consumption is expected

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to increase by 5% due to the strong autonomous increase in electricity use. A similar study, which addressed member states separately, was also conducted within the European project IDEAL. On the basis of the results of the questionnaires relating to the building stock in the 10 participating countries, a preliminary estimate of the potential for energy savings was calculated. It was established that cost-effective energy savings of about 10% could be achieved by 2020 in most countries and 20% by 2030 – close to the goals set by the Netherlands.

As well as the laws and regulations concerning the energy performance of buildings at a national level in the Netherlands, several covenants have been made between the government and stakeholders, such as associations for the building sector, developers and housing associations. The Dutch federation of housing associations (Aedes) committed itself in the 'Covenant Energy Savings Housing Associations Sector' (*Convenant Energiebesparing Corporatiesector*, 2008) to save 20% on the consumption of natural gas (which is the main source of energy used to heat buildings in the Netherlands) in the existing social housing stock between 2008 and 2018. The social housing sector is set to achieve a 24PJ reduction in energy consumption between 2008 and 2020. The aim is to improve these dwellings to a B label or at least by 2 label classes. The so-called 'Spring Agreement' (*Lente-akkoord*, 2008) was signed by the Dutch government and other stakeholders, and states that all by 2015 newly constructed buildings will consume 50% less energy than in 2007. By 2020, all newly buildings should be 'energy-neutral'. However, at the time of writing of this paper it is still not clear what the exact definition of energy neutral building is, nor in The Netherlands nor in EU. However, rough guidelines are available in European Directive 2010/31/EU. Under the 'More with Less' (*Meer met Minder*, 2008) programme, the Dutch government and external stakeholders (corporations and external construction companies) are committed to achieving a reduction of 30% in the energy consumption (100PJ) of buildings by 2020.

§ 2.3 Household energy-efficiency and energy labels in the Netherlands

§ 2.3.1 Household energy-efficiency in the Netherlands

The energy-efficiency of the Dutch housing stock improved by 28% (Odyssee ECN, 2009) in the period between 1990 and 2008. The main reason for this significant improvement was the introduction of condensing boilers for heating and hot water.

Additionally, EPC regulations were introduced in 1995 and were also strengthened periodically, which significantly increased the efficiency of newly constructed dwellings, meaning that their energy consumption had halved by 2008 compared to 1990. However, Guerra Santin (2010) argues that the trend of decreasing energy consumption for heating in new dwellings failed to continue post-1998, despite the strengthening of the system of EPCs. Even though the efficiency measures implemented in the Netherlands place it at the forefront of the European residential sector (Odyssee ECN, 2009), there is no evidence for consistent reduction in total household consumption of natural gas since 1990 (consumption in 2008 was only 5% lower than in 1990) and the electricity consumption of households grew by 50% in the same period. This means that the total energy consumed by household grew by 11% (looking only at gas and electricity, the most important sources of energy in Dutch households). The reduction of consumption in the residential sector was also low due to the continued growth of the housing stock. Between 2008 and 2010, there was no significant decrease in either gas or electricity consumption (*De Nederlandse Energiebranche* website*, 2012*) at the household level (taking temperature correction into account).

Yücel and Pruyt (2011) claim that new construction can only achieve a limited reduction of energy consumption within the sector, since its rates are between 0.9 and 1.5% of the total building stock annually with a small fraction of demolition of about 0.2%. According to Yücel and Pruyt (2011), new construction will account for only a very marginal reduction in energy consumption by 2020, assuming the expected periodic strengthening of regulation and demolition and new construction rates. The renovation of the existing housing stock together with increased turnover is seen as the solution for a significant reduction in energy consumption.

The Energy Label strives to promote renovation work and the creation of more efficient buildings. However, research conducted in Denmark (Kjærbye, 2008) regarding the renovation of labelled dwellings showed that in most label categories there was no significant energy reduction within 4 years of owners purchasing the house (and receiving the label). Dwellings with label A were an exception, because there has been some energy reduction in the first two years after purchase. Unfortunately, no similar research was available for the Netherlands at the time of writing this paper. On the other hand, increased turnover has been observed for more energy-efficient buildings in the Netherlands (Brounen and Kok, 2010).

The data obtained through this study gives us an insight into the real potential for future energy savings through the energy label scheme, and thereby enables us to assess whether the scheme will help achieve the objectives set for reducing energy consumption and CO_2 emissions.

§ 2.3.2 Method of calculating the Dutch energy label for dwellings

The energy labelling of dwellings plays a crucial role in European and national policies that aim to reduce energy use. The energy label in the Netherlands is based on the 'Decree on Energy Performance of Buildings' (BEG) and the 'Regulation on Energy Performance of Buildings' (REG) which came fully into force in 2008. The method for calculating the energy label is described in ISSO 82.3. The first goal of labels is to provide occupants and homeowners with information on the thermal quality of their dwellings. To increase the practical significance of the label, the expected (theoretical) energy usage of the dwelling is also mentioned on all Dutch labels issued after January 2010, expressed in kWh electricity, m^3 gas and GJ heat (in dwellings with district heating).

An energy label awards each dwelling a grade, ranging from 'A++' to 'G' (Table 1). The categories are determined on the basis of the energy index, which is calculated on the basis of total primary energy demand (Q_{total}). Q_{total} sums up the primary energy consumed for heating, hot water, pumps/ventilators and lighting, subtracting the energy gains from PV cells and/or cogeneration (Equation 1).

$$Q_{total} = Q_{space\ heating} + Q_{water\ heating} + Q_{aux.energy} + Q_{lighting} - Q_{pv} - Q_{cogeneration}$$

EQUATION 1 Calculation of total energy consumption (Q_{total})

The energy index correlates directly to the total primary energy consumption, but is corrected for the floor area of the dwelling and the corresponding heat transmission areas (Equation 2) in order to not disadvantage larger dwellings and those with a greater proportion of envelope adjoining unheated spaces (different dwelling types). A correction is also applied for the shape of the dwelling when considering infiltration losses within space heating demand – the air permeability coefficient depends on building shape factor. Such a correction for compactness is also common in other European countries, although it has previously been argued that not correcting could promote more energy-efficient architectural designs (PREDAC WP4 report, 2003). On the other hand, striving exclusively for energy efficient design could compromise the functionality of the dwelling.

$$EI = \frac{Q_{total}}{155 \cdot A_{floor} + 106 \cdot A_{loss} + 9560}$$

EQUATION 2 Calculation of energy index (EI)

The total primary energy demand can also be expressed as described in equation 3. Since primary energy is an energy form found in nature, that has not been subjected to any conversion or transformation process, appropriate heating values need to be taken into account when calculating it. The assumed heating value for gas is 35.17MJ/m^3. The efficiency of the electricity network is considered to be 0.39.

$$Q_{total}[MJ] = Q_{total,gas}[m^3] \cdot 35.17 \left[\frac{MJ}{m^3}\right] + Q_{total\ el.}[kWh] \cdot 3.6 \left[\frac{MJ}{kWh}\right] : 0.39$$

EQUATION 3 Calculation of total primary energy

The level of carbon dioxide emitted depends on which fuel is used. As stated in ISSO 82.3, for 1MJ of energy derived from gas, 0.0506kg CO_2 is emitted into environment and for 1MJ of electricity, 0.0613kg CO_2 is emitted (taking into account the network efficiency and the fuel mix of electricity production).

LABEL	A++	A+	A	B	C	D	E	F	G
Index values	< 0,50	0,51- 0,70	0,71-1,05	1,06-1,30	1,31-1,60	1,61-2,00	2,01-2,40	2,41-2,90	> 2,9

TABLE 1 Dutch energy labels and the corresponding energy index values

The total primary energy consumption, and consequently the energy label allocated, are based on average occupancy and the average outdoor climate, and do not take account of the lifestyle or behaviour of the occupants. The energy index reflects the thermal quality of the building. Ventilation, internal heat production, energy use for lighting and heat losses during water circulation all depend directly on the useful floor area, which is defined as the area inside the heated zone, including rarely heated areas such as halls, toilets, washing rooms and storage spaces. The loft is also included if it is heated and the roof is insulated. Cellars, garages or other large storage areas are not included, since they are normally outside the thermal envelope. During the heating season, losses through ventilation and infiltration are taken into account as well at the standard indoor and outdoor temperatures. Heat loss through ventilation is calculated using a standard ventilation coefficient, which depends on the type of ventilation and is multiplied by the floor area of the dwelling. Heat loss through infiltration depends on the type of dwelling, since for each type of dwelling, characteristic lengths of frames, joints etc. are assumed (ISSO 82.3). A correction is made in the ventilation and infiltration calculations when a heat recovery system is present. Efficiencies are also defined for all kinds of heating and hot water installation systems. Heat gains from the sun are taken into account during the heating season at a flat rate of 855MJ/m^2 on a south-facing vertical surface, accounting for frames and dirt on the glass.

Possible energy gains through PV cells or micro co-generation plants are also taken into account. The demand for hot water is determined on the basis of the assumed number of occupants, which is determined as shown in Table 2. The heat demand calculations are based on a 2620 degree days (212 heating days, where the average outdoor temperature is assumed to be 5.64°C and indoor 18°C).

	CATEGORY	NUMBER OF PEOPLE/M², ASSUMPTION OF ENERGY LABEL METHOD
Dwelling floor area [m²]	<50	1.4
	≥50 and <75	2.2
	≥75 and <100	2.8
	≥100 and <150	3
	>150	3.2
Degree days [degree days]		2620
Internal heat production [W/m²]		6
Internal heat gains, south vertical [MJ/m²]		855

TABLE 2 Assumptions used in calculation

§ 2.4 Research methods and data

§ 2.4.1 Energy label database

This research used all the Dutch energy labels issued between January 2010 and December 2010 – a total of over 340,000 cases with 43 variables (regarding building location and technical characteristics, the properties of the label itself etc.). This data set was provided by AgentschapNL – a public sector organisation appointed by the Dutch Ministry of the Interior and Kingdom Relations.

This data was, on the basis of the addresses of the households, linked to actual energy use data, which was provided by the CBS (Statistics Netherlands), which collected this data from the energy companies. The combined data file was then cleaned up (deletion of double addresses on the basis of the label registration date, deletion of missing addresses on the basis of missing value) leaving 247,174 cases. The CBS expressed doubts about the quality of the data obtained for the energy consumption of collective installations (a single installation system providing heats for more dwellings) because this type of installation is arbitrarily assigned to buildings with a heat consumption that is too high to be considered realistic for an individual system. It was therefore decided to omit households with collective installation systems from the analysis. Dwellings which have multiple installation systems were also eliminated, since these are very specific cases. Cases where electricity consumption was nil were also removed. At this point, the gas values which were defined as missing were investigated. It turned out that most of them belonged to dwellings with heating installations, which do in fact use gas. Such cases were deleted, and only those which used electricity as a power source for heating were retained in the database. Gas use was then redefined to 0 for these cases. When checked the theoretical energy use and area of the house, outliers were detected. The cases with a floor space of over 1000m^2 and primary energy use of over 500,000 MJ were discarded. Finally, the actual gas consumption values for 2009 were corrected according to the number of degree days used in the theoretical calculation. After all this, the sample included 193,856 cases.

In this study, the following variables were used: energy index (transformed into energy label), theoretical electricity consumption, theoretical gas consumption and actual electricity, and gas consumption. Other variables, such as household floor area, dwelling type, construction and renovation year will be reported in a subsequent paper.

§ 2.4.2 Theoretical vs. actual energy consumption

The theoretical calculation method only takes account of energy for certain end uses and omits those uses which are determined by the occupants' lifestyle. On the other hand, actual gas and electricity consumption are derived from the actual energy bills for the dwellings in question and reflect consumption for all possible purposes. An overview of differences can be seen in Table 3. One important variable in electricity consumption is household appliances, which are not taken into account in the theoretical calculation, but are of course reflected in electricity bills (and therefore in our database). Appliances account for 32.4% of household electricity consumption (Milieucentraal, 2012). The difference between theoretical and actual gas consumption comes from gas used for cooking, which is only reflected in the actual value. On average, gas consumption represents 67.3% of total primary energy use, while electricity consumption represents 32.7% (Milieucentraal, 2012).

	THEORETICAL CONSUMPTION	ACTUAL CONSUMPTION	SHARE OF THE END USE IN THE TOTAL ACTUAL HOUSEHOLD CONSUMPTION OF THE NETHERLANDS
Electricity	Hot tap water	Hot water heating	14.7%
	Heating/Cooling	Heating/Cooling	17.6%
	Auxiliary energy (pump/ electronics/ventilation in heating installa-tion, ventilation system)	Auxiliary energy (pump/ electronics/ventilation in heating installa-tion, ventilation system)	n/a
	(Negative) PV/WKK production	(Negative) PV/WKK production	n/a
	Lighting	Lighting	14.7%
		Household appliances	32.4%
Gas	Heating	Heating	72.7%
	Hot tap water	Hot tap water	23.3%
		Cooking	3.9%

TABLE 3 Comparison of the end uses of gas and electricity in actual and theoretical household consumption

§ 2.4.3 Representativeness of the sample

Europe's buildings under the microscope (BPIE, 2011) highlights that only 11 out of 28 member states have (at the national level) a database of energy performance certificates, the Netherlands being one of those. The total Dutch dwelling stock included 7,104,000 dwellings in 2009 (CBS Statline, 2012). The sample we researched therefore represents slightly under 3% of the total dwelling stock.

The data for the whole Dutch dwelling stock was acquired from the *Energiecijfers* database, the CBS (Statistics Netherlands) Statline and the Energie NED (*De Nederlandse Energiebranche*) database. The representativeness of the sample needed to be assessed in order to have a clear idea of the extent to which the results within the sample could be extrapolated to the Dutch dwelling stock as a whole.

Since there were only a few cases in categories A++ and A+, all the A label dwellings were aggregated into one category. The distribution of labels thus became more normal and the results statistically more significant. As can be seen from Figure 2, more than half the dwellings in the energy label database belong to the categories C and D. As for the rest of the dwellings, only 1% belong to either one of the three most efficient categories (A, A+ or A++) and around 4% to G, which is the label of the most energy-inefficient dwellings. In the total Dutch housing stock, a slightly lower percentage of dwellings are labelled B and C than our sample included (Figure 2).

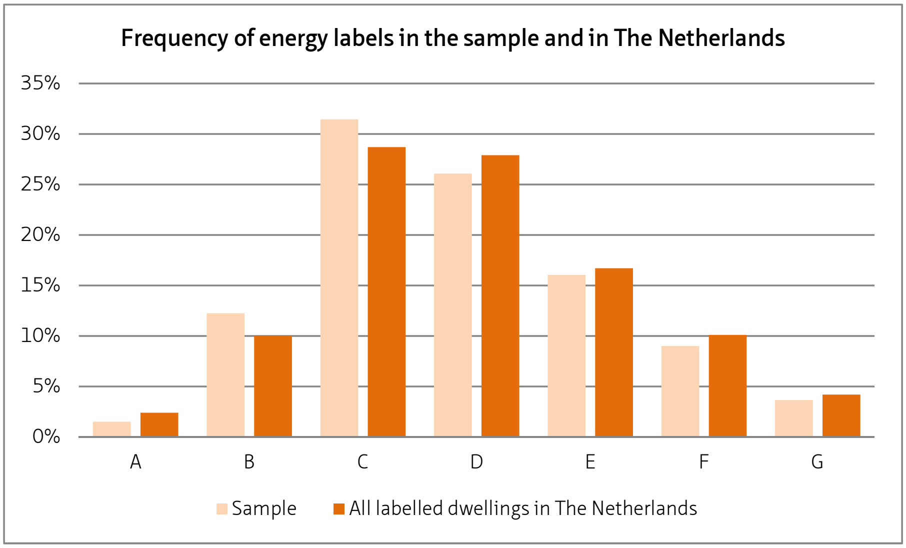

FIGURE 2 Shares of energy labels in the Dutch dwelling stock and in the sample

Almost half the dwellings in the sample were constructed in the 1970s, the 1980s, or the first half of the 1990s. Compared to the Dutch dwelling stock as a whole, one can see that the distribution in the dwelling stock is different to the sample (Figure 3).

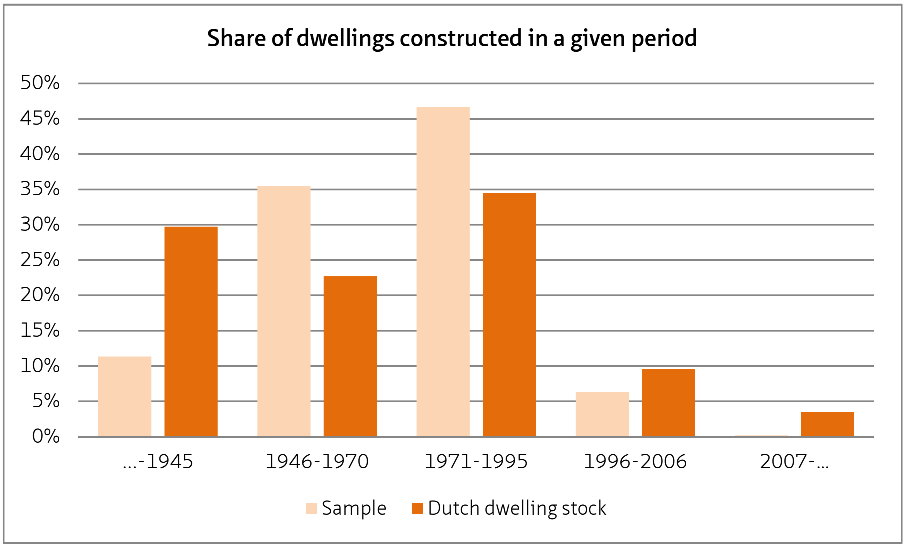

FIGURE 3 Share of the total Dutch dwelling stock and of the sample by period of construction/renovation

According to the *Energiecijfers* database, 62% of Dutch dwellings are terraced houses, 11% are detached (single family) houses and 27% are apartments. In our sample of dwellings, which was aggregated to the same four categories in Figure 4, this distribution was different. The discrepancies between the *Energiecijfers* database and our sample were the largest in the category of flats, which accounted for almost 36% of our sample but represented only just over 25% of the national housing stock in 2008, according to the *Energiecijfers* database. The below average number of detached dwellings in the sample is also reflected in the average size of a dwelling, which is over 10m^2 smaller in the sample than the national average (Meijer & Itard, 2008).

The distribution of dwelling types according to the CBS in year 2009 is also shown in Figure 4, and this differs slightly from our sample as well as from the *Energiecijfers* database (the total stock is considered here to be 6,993,000 dwellings).

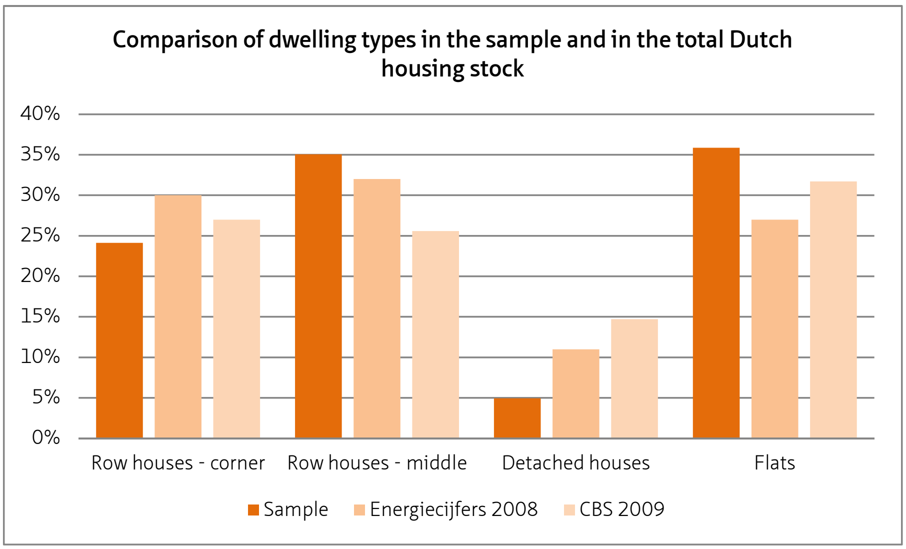

FIGURE 4 Representativeness of dwelling types of the Dutch housing stock in the sample, Energiecijfers 2008 and CBS 2009

In terms of ownership structure, the sample differs significantly from the national average (Energiecijfers database). Only slightly over 20% of the labelled dwellings are private owner occupied, while in the total housing stock this figure is 55%. Only one percent of dwellings in the sample were owner rental properties, whereas in the Netherlands as a whole, 12% of dwellings are owner rental properties. The third category is social housing, and this was over-represented in our sample (79% compared to 33% in the Netherlands as a whole), see Figure 5. The main reason for this was the absence of enforcement of the label scheme for owner occupants.

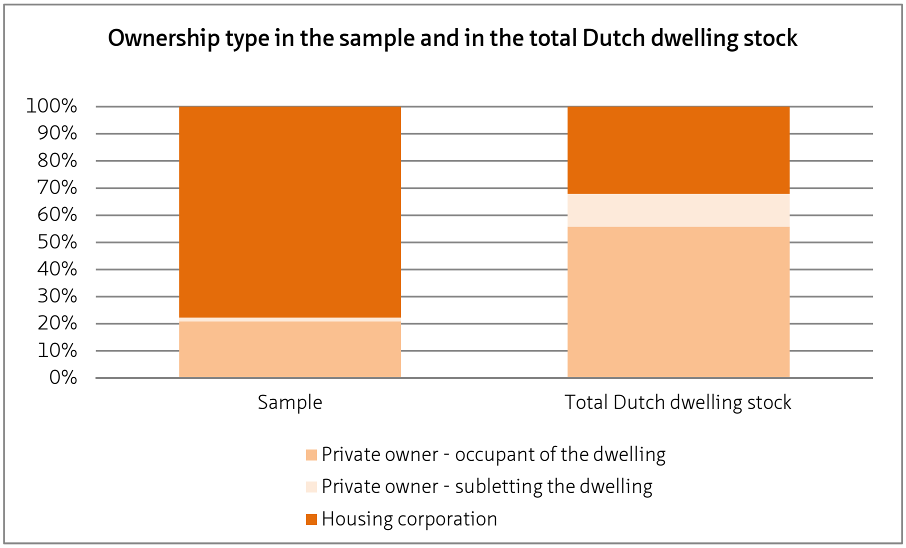

FIGURE 5 Ownership type distribution in the sample and in the Dutch housing stock as a whole

We can therefore conclude that our sample is well representative of all the labels issued in the residential Dutch dwelling stock. The construction years 1946-1995 are overrepresented. Flats and terraced houses are also overrepresented while detached houses are underrepresented. This is due to the fact that social housing is strongly overrepresented. The implications of this when interpreting the results are discussed in section 2.6.

§ 2.5 Results

§ 2.5.1 Actual vs. theoretical energy consumption

First of all, a comparison was made between the actual and theoretical primary energy consumption in the sample described above. The values appeared very similar, as can be seen from Figure 6. However, since it is known that theoretical consumption does not take into account end uses such as household appliances, which account for about 22% of total household energy consumption and the use of gas for cooking, which contributes 1.3% (calculated from the data in section 2.4.2), one might reasonably expect the theoretical consumption to be lower. Because gas and electricity are the two main energy sources for Dutch households and are also mentioned specifically on the energy label, they are examined separately in this study.

On average within the analysed sample, the theoretical primary energy use relating to gas consumption in a dwelling is on average much higher than the actual one, and the theoretical primary energy use relating to electricity consumption is significantly lower than the actual consumption of the same dwellings (Figure 6). In the case of electricity consumption, the fact that the amount of electricity used by appliances is not taken into account caused a part of the underestimation in theoretical consumption. However, judging from the values in Table 3, this is not the only cause (appliances account for an average of 32.4% of electricity consumption; if the overestimation in our sample was only due to appliances, these would contribute 64%). This may indicate that either the estimated electricity consumption of household appliances is inaccurate, or that electricity consumption for hot tap water and heating is higher than predicted. In contrast to electricity consumption, gas consumption was over-estimated. Since there is only one end uses for gas, with the exception of cooking, the difference in consumption reflects either a deviation from the assumed user behaviour or discrepancies in the assumptions used to estimate the demand for fuel for heating (air infiltration, U-values, floor area, transmission areas etc.) and the real values. However, this study does not aim to identify where these discrepancies come from, but rather their effect on the outcomes of energy policy targets in future.

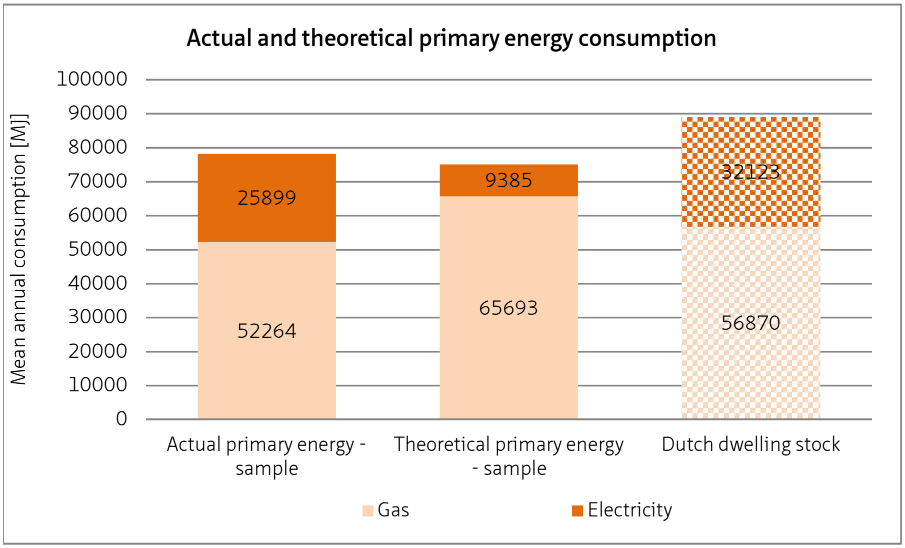

FIGURE 6 Actual and theoretical mean primary energy consumption per dwelling in the sample (N=193,856) and in the Dutch housing stock

In the Dutch housing stock as a whole (Figure 6), 3480 kWh of electricity (corresponding to 32123 MJ of primary energy) was consumed in a dwelling on average in 2010 according to *Energie Nederland*. This is around 700 kWh (6224 MJ of primary energy) more than the average in our sample. The same applies to gas: the average consumption in 2010 according to *Energie Nederland* was 1617m^3 (56870 MJ of primary energy), whereas consumption in our sample was 1487m^3 (52264 MJ of primary energy). This discrepancy is likely to have been caused by the smaller average size of the dwellings in our sample compared to the housing stock as a whole (see section 2.4.3).

§ 2.5.2 Energy consumption vs. energy label

The energy consumption for each label category is first presented separately for gas and electricity. Later, it is also presented together as total primary energy consumption.

§ 2.5.2.1 Gas

To understand how the energy label relates to the discrepancies described in the previous section, we examined gas and electricity consumption in various label categories. The plots in this report are presented with +/- 1 standard deviation. Because of the extremely large size of the sample, it is not relevant to plot the 95% confidence interval, which is always very small, meaning that the location of the mean value is known to a high degree of certainty and that all the differences were statistically significant on a 95% interval.

Figure 7 shows actual and theoretical gas use for each dwelling and Figure 8 shows the energy consumption per square metre of floor area of dwelling. Almost no difference can be discerned between either, except the difference in actual gas use between label A and label B. At the level of individual dwellings, the actual consumption was identical, but at the level of square metres of floor area, dwellings in category A use less gas than dwellings in category B. This may relate directly to the fact that dwellings in label category A were found to be considerably larger than all other dwellings (Figure 9). From these figures it is clear that although lower labels lead to increased actual gas consumption, there is a clear difference between the mean theoretical and mean actual gas consumption for each label.

For the most energy-efficient categories (A, A+ and A++) and for category B, Figure 7 and Figure 8 show that the theoretical calculation underestimated the actual annual gas consumption, in contrast to the rest of the categories for which the theoretical calculation largely overestimated the actual annual gas consumption. The theoretical and actual values only coincided for label C. It is worth noting that in label category G, actual gas consumption was only half theoretical consumption. Theoretical gas use predicts a much larger difference between an energy-efficient dwelling (A) and an energy-intensive dwelling (G) than we observed in our analysis of actual gas use. If the two consumptions are thought of as a linear function, they would differ significantly in the angle of their slope.

When standardizing the consumption per dwelling to consumption per square metre of floor space in the dwelling, we expected a better match between actual and theoretical levels of gas consumption because the dwellings could have different mean sizes in different categories. However, Figure 8 shows that this was not the case. The difference therefore does not arise because the dwellings are of different sizes, except for a small effect due to size among labels A and B (as is discernable from Figure 9). It is noticeable that the standard deviation of theoretical consumption decreases in Figure 8, meaning that the variation in terms of floor area is responsible for a large part of the variation in theoretical gas consumption at the level of individual dwellings (in Figure 7 the standard deviation is 40.7% of mean value for label G and in Figure 8 standard deviation is 20.8% for the same label).

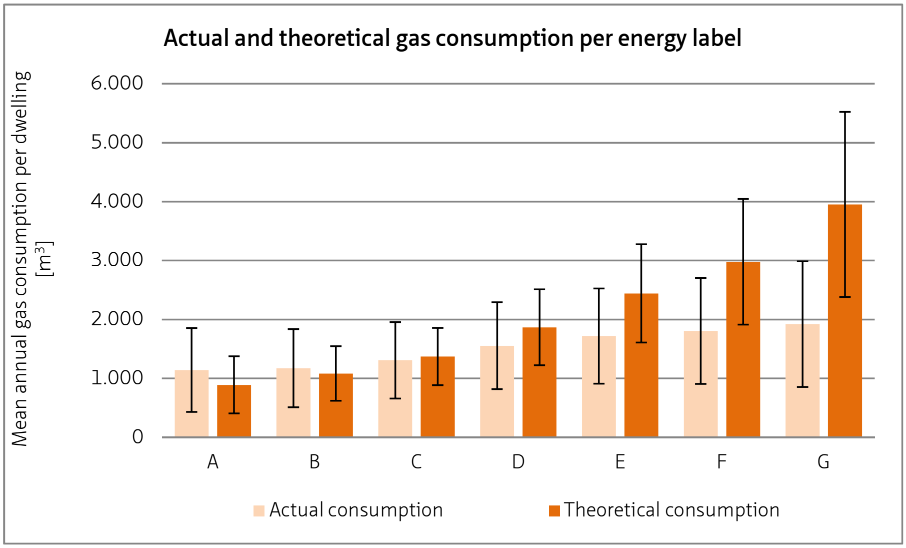

FIGURE 7 Actual and theoretical gas consumption per dwelling per label

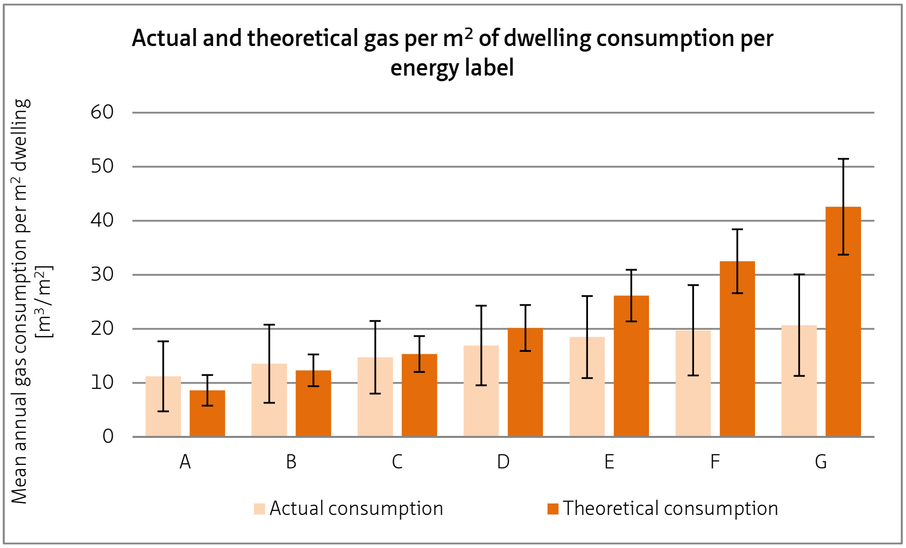

FIGURE 8 Actual and theoretical gas consumption per m^2 of dwelling area per label

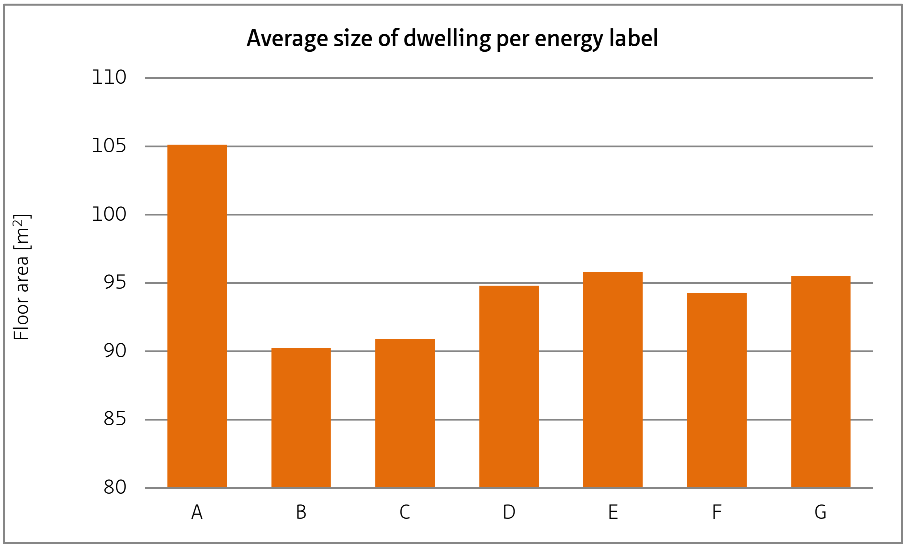

FIGURE 9 Average dwelling size (m^2 floor area) per label

§ 2.5.2.2 Electricity

In contrast to what we observed for gas consumption in the previous section, the theoretically calculated electricity consumption underestimated the actual consumption (Figure 6). Figure 10 shows that both actual and theoretical electricity consumption bear little relation to the label allocated. There is a very slight trend towards higher consumption in dwellings graded A, D and E which could be attributable to the electricity that is used for space and water heating or mechanical ventilation in certain more efficient dwellings (a larger proportion of heat pumps) and the larger floor areas. Figure 11, which shows electricity consumption per square metre of floor area, shows that the higher consumption for label A relates to larger floor areas. However, the curve still shows a slightly convex shape for the actual electricity consumption and a concave shape for the theoretical consumption, but ultimately the label does not appear to play a major role in the difference in electricity consumption. In fact, the differences between labels are very small compared to what was observed for gas consumption.

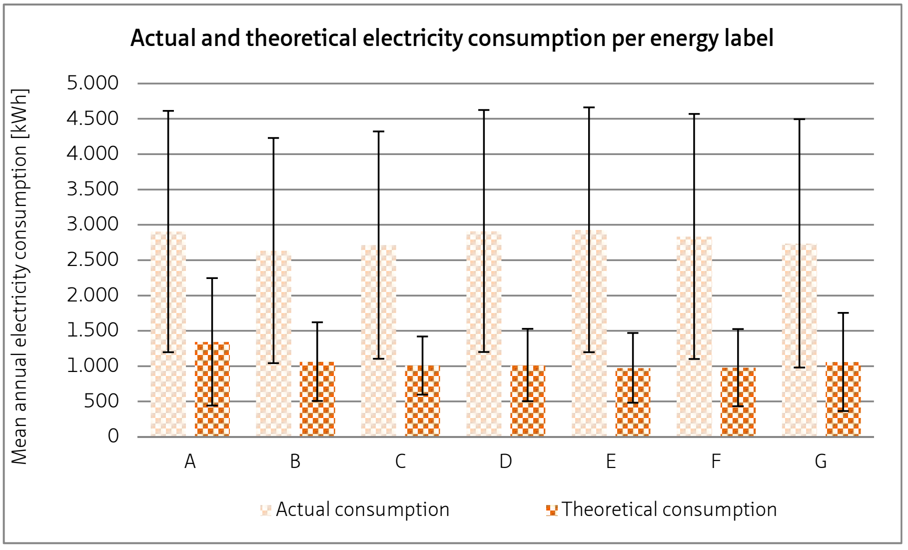

FIGURE 10 Actual and theoretical electricity consumption per label

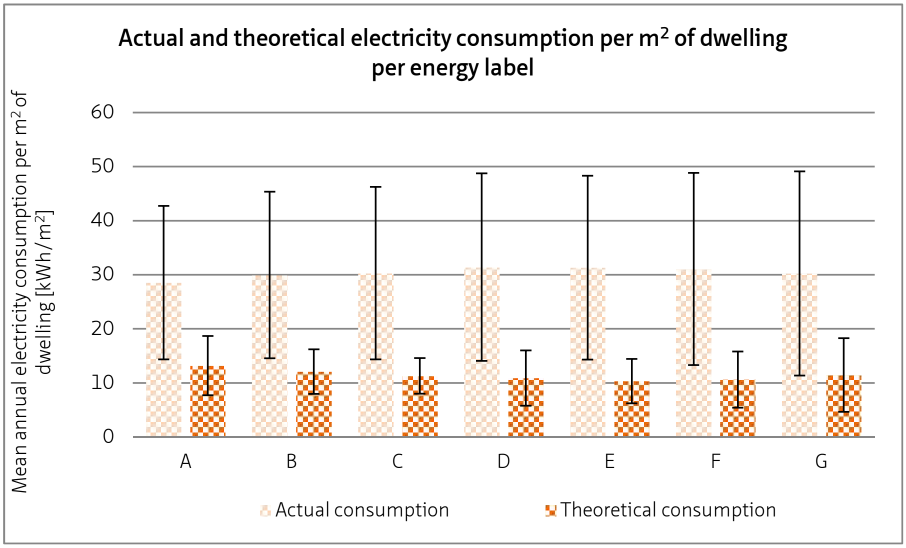

FIGURE 11 Actual and theoretical electricity consumption per m² of dwelling per label categories

§ 2.5.3 Total primary energy and CO_2 emissions per label category

An interesting insight into total primary energy consumption (Figure 12) can be gained by summing up the gas and electricity consumption data according to equation 3. From this figure, the occupants in dwellings with labels A – D can expect to consume more than the label certificate indicates. This will mainly be a consequence of higher gas consumption and will be offset by the fact that the household appliances are not a part of the label.

However, the difference in theoretical consumption is here again much greater between labels A and G than is the case in reality (looking at the actual values). This may have a very strong influence on the pay-back times and on the achievable savings. Dwellings with labels E, F or G seem to consume a similar amount of actual primary energy, even though the technical characteristics are much better in E than in G. The label may thus reflect the technical characteristics of a dwelling, but because actual primary energy consumption seems almost identical in each of the three categories, it might not be worth improving the technical specifications of houses labelled as G. From this figure it is clear that the savings which are expected to be achieved by improving the technical characteristics of a house, do not actually occur in practice. The theoretical primary energy consumption of a dwelling with an A label is 70% lower than that of a G label, but the actual primary energy consumption of an A label is only 28% lower than a G label.

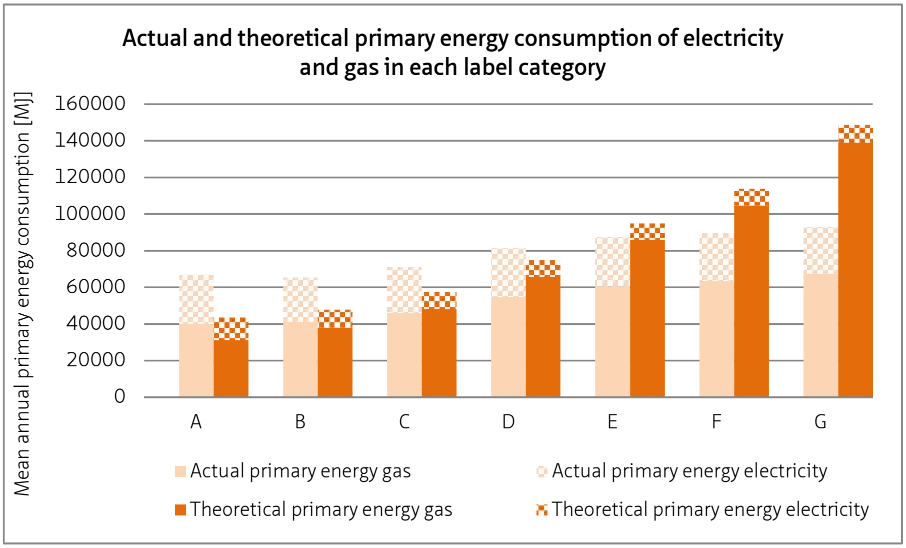

FIGURE 12 Actual and theoretical primary energy consumption per label

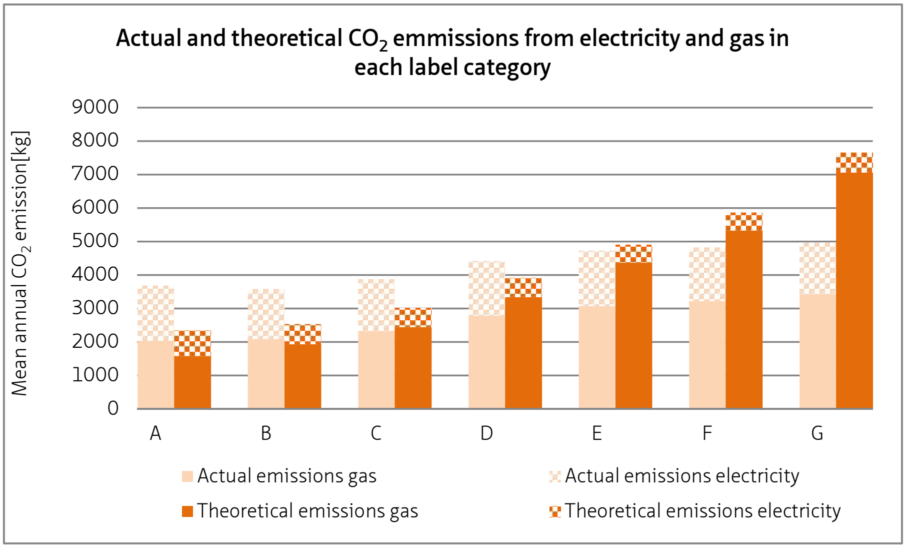

FIGURE 13 Actual and theoretical CO_2 emissions per label

Since European targets are not solely meant to reduce energy consumption but also CO_2 emissions, it is useful to look to what the energy label means in relation to CO_2 emissions. One megajoule of electricity produced in the Netherlands causes more CO_2 emissions than burning a megajoule of gas (0.0613kg vs. 0.0508kg of CO_2 per MJ). The

CO_2 emissions were calculated on the basis of this data. Theoretical CO_2 emissions are lower than actual emissions in labels except A – D. Interestingly, there is no significant decrease in CO_2 emissions for labels G, F and E and the label A is responsible for more CO_2 than label B. It is predicted that CO_2 emissions will decrease by 70% when moving from a G label to an A label, but in reality, looking at the actual consumption, this decrease is only 26%.

§ 2.6 Scenario study

An examination of Figure 12 and Figure 13 has cast doubt on the feasibility of the expected energy savings, as described in section 2.2.2, since these rely widely on theoretical estimates of consumption rather than on actual consumption data. As it was shown, actual and theoretical consumption differ considerably.

In order to determine what savings are actually possible by improving the energy label of dwellings already labelled, three different scenarios were tested. The analysis of consumption in the three scenarios is particularly interesting because this not only predicts the potential savings on the basis of the theoretical values but also on the basis of the actual consumption data from our sample. The average values for a particular label are extrapolated to the Dutch dwelling stock as a whole according to the distribution of labels all over Netherlands (Figure 2) and not only in the studied sample, thereby ensuring greater representativeness.

The first scenario equals the one proposed in the 'Covenant Energy Savings Housing Associations Sector', which aims to improve dwellings for at least by 2 label classes until the label B is achieved (so that dwellings with C labels are only improved by one label, dwellings labelled with B or A would not get improved, and all other dwellings are improved by 2 label classes) by the year 2018 (see section 2.2.2). In the covenant they assume that the entire housing stock that is labelled with C or lower will get refurbished by 2018. This implies a very high refurbishment rate and its feasibility is questionable. However, it is the target that Dutch housing associations have set and therefore it is tested in this paper. The second scenario assumes improving all labelled dwellings to label A, while the third assumes refurbishment to label B (dwellings currently labelled with A or B do not get improved). The first scenario is the least radical, while the second would require the most drastic refurbishment of the housing stock.

The differences in potential saving obtained through label calculation method (section 2.3.2) or by using the actual energy consumption data is clear (Table 4). According to the theoretical consumption, most of the targets would already be achievable with the implementation of the least stringent scenario – the only exception is the 100 PJ decrease in energy consumption as defined under the 'More with Less' Agreement (see section 2.2.2). However, this target can be achieved in the other two more radical scenarios.

However, the picture is completely different when the average actual consumption in each label category is used. The only target achievable with the first scenario is the 24PJ reduction in the energy consumption of social housing. There might be some bias here due to the fact that our sample contains both social and private dwellings (Figure 5), but in any case, social housing represents the majority (80%) of the sample. The 20% reduction in gas consumption throughout the whole dwelling stock, also proposed under the 'Covenant Energy Savings Housing Associations Sector', is also achievable with the implementation of scenario 2 or 3. All other targets regarding primary energy consumption reduction except the target of European project IDEAL, do not appear to be achievable (Table 4), regardless of the refurbishment scenario chosen. Interestingly, according to primary energy savings and CO_2 emission reductions, it seems better to aim for scenario 3 than scenario 2, since this scenario offers higher actual reductions of primary energy consumption and CO_2 emissions (but not gas consumption). This is a consequence of the phenomenon evident from Figure 10, which predicts a higher actual consumption of electricity for label A than for label B. The primary energy in one kWh of electricity is so high that it outweighs the impact of primary energy derived from gas consumption (which is indeed lower in dwellings with an A label).

		ACTUAL			THEORETICAL		
	AGREED SAVINGS	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 1	SCENARIO 2	SCENARIO 3
Convenant Energie-besparing Corporatiesector	-24PJ primary energy	70PJ	85PJ	96PJ	72PJ	146PJ	117PJ
	-20% gas use	16%	24%	22%	34%	54%	44%
Meer met minder	-100PJ primary energy	70PJ	85PJ	96PJ	72PJ	146PJ	117PJ
	-20-30% primary energy	12%	15%	17%	30%	43%	38%
SERPEC-CC	-19% primary energy	12%	15%	17%	30%	43%	38%
IDEAL	-10% primary energy	12%	15%	17%	30%	43%	38%
Dutch government	-16% CO_2	6%	9%	12%	21%	24%	27%
EC Action Plan for Energy Efficiency	-27% primary energy	12%	15%	17%	30%	43%	38%

TABLE 4 Energy and CO_2 savings in the three scenarios. he values in red are not achievable.

§ 2.7 Discussion

As mentioned in section 2.2.1, the strength of this study lies in the very large sample of households and energy certificates included (193,856). Figure 2 showed that the sample was representative in terms of the frequency of label categories, which was important since this study aimed to compare actual and theoretical energy consumption within label bands and extrapolate the predictions made within the energy label calculation to the whole Dutch dwelling stock (section 2.6). However, other characteristics of the sample, such as the type of dwellings or the ownership type showed poorer representativeness and we cannot exclude the possibility that this influenced some of the findings of this study to a certain extent. For instance, it may be the case that actual energy consumption in houses with poor label categories is higher in the (as yet) unlabelled housing stock than it is in our sample, which includes more social housing. This may therefore also influence the results of the scenario study (section 2.6).

Two additional points concerning the quality of the data used should also be noted. First, there are some concerns about the quality of the inspections on which the input data for the energy index calculations are based. A study carried out by the Inspection Service of Public Housing reported that in a sample of 120 labels issued in 2009, 60.8% of the inspected labels were incorrect, meaning that their energy index deviated more than 8% (Rapportage Gebruik en betrouwbaarheid energielabels bij woningen, 2009). In 2010 only 26.7% were incorrect, however the investigated sample contained only 30 houses (Betrouwbaarheid van energielabels bij woningen, 2010). In 2011, 16.7% of labels deviated more than 8% in their energy index in a sample of 48 dwellings (Derde onderzoek naar de betrouwbaarheid van energielabels bij woningen, 2011). There seems to be a trend of improvement, although the studied samples are very small. Most faults occur due to inaccurate input data and do not seem to correlate with the label of the dwelling. However, analyses of the data available in these studies show that the deviations are not symmetrical, in particular in label A, where the recalculated energy index is on average higher for 10% systematically, meaning that these dwellings were less efficient as demonstrated by their original certificate. In dwellings labelled with E and F the original index was higher than the recalculated one (2 and 1% respectively), meaning that the dwellings actually performed better. This is a small contribution to the performance gap detected in poor label classes but a significant one in dwellings with an A label.

Second, during the study some concerns arose concerning the quality of the actual energy data as given by energy companies to CBS. Because energy companies are required by law to check energy consumption at the meters only once every three years, it is possible that the consumption data used in the study are not the actual data for 2009, but contain some averages from the years 2006-2009. There is therefore also a possibility that thermal renovation of the dwellings at the end of this period (e.g. placing a heat pump) would then not be borne out by the actual data (measuring the old gas boiler). A sensitivity analysis on the sample showed that only slightly more than 300 cases may be concerned, and as such a small proportion of the total sample. In any case, these data were the best available, because the direct metering of energy use for such a large sample cannot be achieved.

Notwithstanding these limitations, we believe that for the first time this study provides useful information from a very large sample and gives an indication of the further research required and the effectiveness of energy-saving policies.

§ 2.8 Conclusion

It appears from this research that the energy label has some predictive power for the actual gas consumption. However, according to the labels, dwellings in a better label category should use on average significantly less gas than dwellings with poorer labels, which is not the case. The actual heating energy consumption is on average lower than theoretical consumption levels for most buildings (in our study for dwelling with labels C to G) as was observed previously by Guerra Santin and Itard (2012), Tigchelaar et al. (2011), Cayre et al. (2011) and Hens et al. (2010). Guerra Santin already pointed out that at a lower EPC value, the difference between the expected and actual consumption will be smaller. Our study has proved this, and showed that even in very energy-efficient buildings actual gas consumption can exceed the predicted levels (Figure 7). On the other hand, less energy-efficient dwellings are predicted to use more gas than they actually do: theoretical gas consumption seems to be around twice the actual levels. Unlike gas consumption, the discrepancies between theoretical and actual consumption for electricity are relatively constant for all the different categories (Figure 10) and part of the difference is probably caused by electricity consumption by household appliances. The fact that labelled dwellings vary in terms of gas consumption but not much when it comes to electricity consumption proves that the energy label can (on a large scale) only be efficient in reducing gas consumption, at least as long as gas remains the main source of heating energy. However, in Figure 13 one can see the importance of electricity in the carbon footprint of households – it accounts for more than one third of all CO_2 emissions, which is why efforts should be made in the future to reduce not just the demand for heating from households, but also the demand for electricity.

An important finding of this study is that the reduction in primary energy consumption, which is assumed to happen when improving a building from label G towards label A, turns out to be much lower in reality than expected. This could easily lead to inaccurate estimations of the payback times for measures taken to improve the energy-efficiency of dwellings and achieve the targets that have been set for primary energy as well as for reducing CO_2 emissions. From our calculations based on actual energy consumption, it seems that these targets may be unrealistic. Calculations were conducted in order to assess the broad feasibility of the energy (and CO_2) reduction targets set for the built environment, with the assumption that the Dutch housing stock as a whole was labelled and the average consumption values described in section 2.5 apply. It was discovered that even if the whole Dutch housing stock were refurbished and upgraded to an A label (which would in itself be an unrealistically ambitious undertaking), the actual primary energy savings would not meet most of the current targets (Table 4). However, if the theoretical levels of consumption are used, most of the targets seem (misleadingly) achievable. The targets for gas consumption and reduction in CO_2 emissions turned out to be similarly problematic. In the future, the actual energy consumption of houses should be taken into account when formulating targets. This way, measures developed to meet the targets will have a better chance of success.

The question remains of whether it makes sense to indicate the theoretical gas and electricity consumption on the label as has been done in the Netherlands since 2010. This may cause confusion instead of assisting the occupant, because it is not representative of actual values. A dwelling with a good label does not necessarily mean low energy usage. The label gives an approximate indication of the thermal quality of the dwelling but cannot predict the real energy consumption.

As a final remark, more research on the relationship between policy instruments and their effects is needed to validate the efficiency of these instruments and improve them. Simulation tools (such as the Dutch energy labelling method) are often used to support policy. However, these simulation tools do not always provide results that correspond to reality. This is not surprising because much is still unknown, especially in the field of statistically valid and standardized dwelling use and the relationships between dwelling use, dwelling type and occupant characteristics. However, the alternatives to simulation methods (as used in some countries), such as energy labels calculated on the basis of the actual energy consumption of the former occupant or based solely on insulation values, are not expected to produce more accurate results.

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