3 Actual and theoretical gas consumption in Dutch dwellings: What causes the differences?

Explanatory note

The results of chapter 2 show that the discrepancies between theoretical and actual gas consumptions were quite significant and have a substantial impact on the energy savings targets set by the government. Therefore, the next logical step was to find out why the discrepancies occur. The third chapter investigates the same dataset used in the second chapter, this time with the intention of gaining insight into the causes of the discrepancies discovered. National socioeconomic data were added to the studied sample and a regression analysis was carried out. Due to the low predictive power of the included variables, a sensitivity analysis of the theoretical gas usage was performed on the basis of the average row house taken from the WOON dataset. Sensitivity analysis was performed on six assumptions made in the theoretical calculation to show how an incremental difference in one of the assumptions affects the final theoretical gas consumption and whether this could explain the performance gap.

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Abstract

Energy labels in buildings are awarded based on theoretical gas and electricity consumption based on dwelling's physical characteristics. Prior to this research, a large-scale study was conducted in The Netherlands comparing theoretical energy use with data on actual energy use revealing substantial discrepancies (Majcen et al., 2012). This study uses identical energy label data, supplemented with additional data sources in order to reveal how different parameters influence theoretical and actual consumptions gas and electricity. Analysis is conducted through descriptive statistics and regression analysis. Regression analysis explained far less of the variation in the actual consumption than in the theoretical and has shown that variables such as floor area, ownership type, salary and the value of the house, which predicted a high degree of change in actual gas consumption, were insignificant (ownership, salary, value) or had a minor impact on theoretical consumption (floor area). Since some possibly fundamental

variables were unavailable for regression analysis, we also conducted a sensitivity study of theoretical gas consumption. It showed that average indoor temperature, ventilation rate and accuracy of U-value have a large influence on the theoretical gas consumption; whereas the number of occupants and internal heat load have a rather limited impact.

§ 3.1 Introduction

Buildings account for approximately 40% of the EU's total energy consumption. One way of achieving a significant reduction in energy demand of the residential sector is to inform tenants and homeowners of the energy consumption of their dwelling. The European Performance of Buildings Directive was passed in 2002, setting up an EU framework for energy performance certification. The directive introduced mandatory energy performance certification (labelling) for all residential buildings at the time of construction, sale or rental. The Netherlands' energy label is based on the 'Decree on Energy Performance of Buildings' (BEG) and the 'Regulation on Energy Performance of Buildings' (REG) national requirements which came into force in 2008 (Beerepoot, 2007). The Dutch energy label certificate allocates each home into a category, ranging from 'A++' to 'G', and states its expected (theoretical) energy consumption.

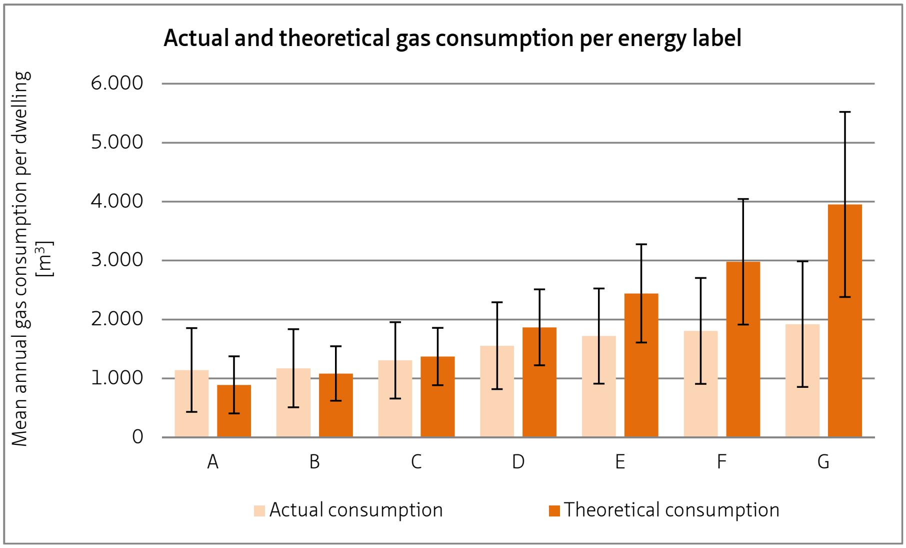

FIGURE 1 Actual and theoretical gas consumption in dwellings across label categories with ± 1 standard deviation (Majcen et al., 2012)

The motivation for the present study was a previous paper by Majcen et al. (2012), which compared the theoretical energy consumption stated on nearly 200,000 energy label certificates issued in the Netherlands with the actual consumption of those dwellings. The results showed that in energy-inefficient dwellings (labelled F or G), predicted gas consumption (gas is the chief energy source for heating in the Netherlands) was much higher than the actual rates of consumption, while energy-efficient dwellings (labelled A or B) consumed slightly more than predicted. For label C dwellings, actual and theoretical gas consumption match relatively well (Figure 1).

While it is clear that the calculation method implemented to certify dwellings is simplified and therefore deviates from actual dwelling consumption on the level of individual dwelling due to assuming zero variation in climate and occupant characteristics, the average actual consumptions of a certain label category should coincide with the theoretical consumptions declared on the certificate. If it is not the case, it disables an estimation of actual energy savings when improving the label of the dwelling (Majcen et al., 2012), which is the final aim of such an energy label.

Actual vs. theoretical heating energy consumption

Results similar to those shown in Figure 1 were obtained in numerous studies across Europe, including those by Guerra Santin and Itard (2012), Tigchelaar et al. (2011), Cayre et al. (2011) and Hens (2010) about the overestimation of heating energy consumption in energy-inefficient dwellings and Haas and Biermayr (2000), Branco et al. (2004) and Marchio and Rabl (1991) concerning the underestimation in energy-efficient dwellings. These examples and the study by Majcen et al. (2012) seem to show that the theoretical consumption, which is calculated using various design and policy-based calculation tools, often fails to represent the actual energy consumption of residential buildings accurately. A study in Norway (Pettersen, 1994) showed that total heating energy consumption cannot be predicted more precisely than approximately 35-40%, which corresponds with the case-study by Majcen et al. (2012) and others previously mentioned cases of discrepancies. The causes for these discrepancies are complex. One of them is the variation in presence patterns and comfort. Under many calculation methods, in particular those used for certification, this variation is deliberately ignored in order to produce a standardised measure of the thermal properties of the dwelling. Nevertheless, in many countries, including the Netherlands, the theoretically estimated consumption shown on the label certificate is the basis on which the energy savings of potential renovation measures are calculated. This calls for a theoretical consumption that corresponds to a dwellings' actual consumption better than demonstrated in Figure 1. To arrive at a more accurate theoretical consumption, Gaceo et al. (2009) calculated energy consumption by what he called 'specific user' profiles. Unlike the 'average user' profiles that are usually used for energy performance calculations, using the specific profiles resulted in a much more accurate estimate of energy consumption. However, the effects of occupant behaviour are complex and depend on environmental factors such as climate (Pettersen, 1994) and the characteristics of the building (Guerra Santin, 2010). For example, households with a programmable thermostat are more likely to keep the heating on for longer than households with a manual thermostat (Guerra Santin, 2010). It is therefore not only occupant preferences, but also the characteristics of the dwelling that can explain the variation in the accuracy of predictions across the range of label categories (Figure 1). Furthermore, evidence shows that occupants tend to increase their comfort demands when the efficiency increases, which in the literature is referred to as the 'rebound effect'. An overview of studies regarding the rebound effect in residential heating was conducted by Greening et al. (2000) and according to Haas and Biermayr (2000), the rebound effect can amount to 20-30% of the energy savings gained through a retrofit. A study conducted in the UK by Milne and Boardman (2000) estimates that at an indoor temperature of 16.5°C, 30% of the benefits gained through energy-efficiency improvements are offset because the residents are likely to want to raise the temperature of the dwelling further, meaning that the full energy saving will only be gained while implementing saving measures at an average indoor temperature of 20°C.

Furthermore, the results presented by Majcen et al. (2012) raise questions about the methods in place for predicting theoretical levels of consumption. Even now, there is little information available regarding the reliability of energy performance certificates, how they relate to the state of the building and the accuracy of the calculation methods. No validation of the calculation methods used in the Netherlands or elsewhere in Europe has been found in literature.

Inaccurate estimates of spending on energy can also hamper the process of estimating the potential savings, which seems to be a problem across the EU. In Ireland, a 20% reduction target was set for 2002, relative to the old regulations in place from 1997, but a reduction of only 10% was achieved, according to Rogan and Gallachóir (2011). Majcen et al. (2012), examined the discrepancies between the actual and theoretical energy consumption with respect to the national targets set for energy and CO_2 reduction in the residential sector in the Netherlands. It was established that most policy targets for energy and CO_2 emissions can be achieved by extrapolating the theoretical consumptions of the dwelling stock, but if actual consumptions are used, almost none of the reduction targets for the next 20 years are achievable.

This study aims to gain a better understanding of the major discrepancies between theoretical and actual gas consumptions by looking at the influence of building and household characteristics on theoretical and actual gas consumption rates. A regression analysis explores the predictors of theoretical and actual rates of gas consumption and the differences between them. We then seek to gauge the impact of the quality of the input and of the assumptions made in the calculation method by analysing the sensitivity of the calculation model. The results will give us a better insight into actual household energy consumption and the sensitivity of the calculation models, and will therefore help us to improve labelling certificates.

The paper is structured as follows. Section 3.2 provides a brief overview of the Energy Labelling Framework in the Netherlands. Section 3.3 presents the sample data, the research methods and the regression analysis. The results and methods of the sensitivity analysis are given in Section 3.4. Finally, a discussion follows in Section 3.5 and our conclusions are presented in Section 3.6.

§ 3.2 The method used to calculate the energy label and the data used

§ 3.2.1 Calculation method

The Dutch energy label provides the following information on the dwelling for the consumer: the label category (A++ to G), the floor area, the type of dwelling, the consumption of gas [m^3], electricity [kWh], heat [GJ] and the total primary energy consumption [MJ]. The label categories are determined using the energy index, which is calculated on the basis of total primary energy usage, summing up the primary energy required for heating, hot water, pumps/ventilators and lighting, and subtracting any energy gains from PV cells and/or cogeneration as shown in equation 1 (ISSO, 2009). Any energy needed for cooling is not included in this calculation method.

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

EQUATION 1

If no additional heat is consumed (from district heating for example), the total primary energy consumption can also be expressed as described in equation 2. The primary energy consumption is calculated according to the type of fuel used by the installations in the dwelling (Equation 3 and Equation 4). Since primary energy is a form of energy that is found in nature and has not been subject 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 (north sea gas). The efficiency of the electricity network is considered to be 0.39. On the Dutch label certificate, the theoretical gas and electricity consumption from equation 2 are presented.

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

EQUATION 2

$$Q_{total\ gas} = Q_{gas-\ space\ heating} + Q_{gas-tap\ watwer}$$

EQUATION 3

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

EQUATION 4

The energy used for heating ($Q_{space\ heating}$, Equation 5) depends on the demand for space heating, the efficiency of the distribution system and the efficiency of the heating installation equipment. The efficiency of the distribution system ($\eta_{dist,system}$) ranges up to 1 for a dwelling where the temperature setting is optimal, there is individual metering and there is insulation on the ducts. The efficiency of the installation system ($\eta_{installation}$) may be higher than 1 in case of heat pumps, however. The potential contribution of a solar boiler (using a table of standard gains per m^2 of collectors) is accounted for. The energy needed for the pilot flame is assumed to be 2,500MJ. The space heating energy does not depend on the number of occupants.

$$Q_{space\ heating} = \frac{\frac{Q_{space\ heat\ demand}}{\eta_{dist.\ system}} - Q_{solar\ boiler}}{\eta_{installation}} + Q_{pilot\ flame}$$

EQUATION 5

The demand for space heating (Equation 6) is a sum of losses through transmission and ventilation, taking into account solar and internal heat gains. The equations below are simplified for a system without heat recovery and with natural ventilation. Transmission rates ($Q_{transmission\ loss}$) are calculated on the basis of an annual heating period of 212 days and a constant average indoor temperature of 18°C. The useful floor area consists of the heated rooms (bedrooms, living room, kitchen), plus some areas that are occasionally heated (halls, toilet, washing room, storage). Basements, attics and garages are generally not included. Heat losses through ventilation

($Q_{ventilation\ loss}$) are calculated using standard ventilation coefficients (f_1, f_2), which depend on the ventilation type and the infiltration rates. Ventilation losses are relative to the type of dwelling ($q_{reference}$) since for each type of dwelling, characteristic lengths of frames, joints etc. are assumed (ISSO, 2009). Internal gains ($Q_{internal\ gain}$) are assumed to be 6W/m² of floor area during the heating season (212 days) and solar gains ($Q_{solar\ gain}$) are based on the g-value of the glass. The assumed gains for lighting are 6 kWh/m². Heat gains from the sun are taken into account during the heating season at a constant rate of 855MJ/m² on a south vertical surface, accounting for frames and dirt on the glass.

$$Q_{space\ heat\ demand} = Q_{transmission\ loss} + Q_{ventilation\ loss} - Q_{internal\ gain} - Q_{solar\ gain}$$

$$Q_{transmission\ loss} = (\sum_{k=1}^{K} a_k \cdot A_k \cdot U_k) \cdot (T_{indoor} - T_{outdoor}) \cdot t_{duration\ heating\ season}$$

$\mathrm{a_k}$ – weigh factor for each surface, 0 if it borders on heated space, 1 if unheated

$\mathrm{A_k}$ – area of each surface$[\mathrm{m^2}]$

$\mathrm{U_k}$ – U value of each surface $[\mathrm{W/m^2K}]$

$$Q_{ventilation\ loss} = c.f \cdot (T_{indoor} - T_{outdoor}) \cdot t_{duration\ heating\ season}) \cdot \rho_{air} \cdot c_{air} \cdot q_{v,i}$$

c. f – correction factor, set to 1 in EPA

ρ_{air} – air density 1,2 $[\mathrm{kg/m^3}]$

c_{air} – air heat capacity 1000 [J/kgK]

$$q_{v,i} = f_1 \cdot A_{floor} + f_2 \cdot q_{reference} \cdot \frac{A_{floor}}{A_{reference}}$$

$f_1 - 0{,}47\ in\ case\ of\ natural\ ventilation\ [dm^3/s \cdot m^2]$

$f_2 - 0{,}13\ in\ case\ of\ natural\ ventilation\ [dm^3/s \cdot m^2]$

$A_{reference} - 120 m^2 for\ a\ detached\ house$

$q_{reference} - 310\ dm^3$

$/s\ for\ a\ detached\ house\ with\ a\ pitch\ roof\ a\ with\ draft\ proofing$

EQUATION 6

The energy consumption for hot tap water (Qwater heating) takes into account the main hot water installation and the auxiliary kitchen boiler (which, if present, is assumed to have a standard consumption of 8164.1MJ/year). Again, the standard efficiency of the installation system is applied (see Equation 7). The equations given below relate to a condensing boiler. As stated in ISSO (2009), standard hot water consumption is determined on the basis of the national average.

$$Q_{water\ heating} = Q_{main\ boiler} + Q_{auxiliary\ kitchen\ boiler}$$

$$Q_{main\ boiler} = \frac{c_f \cdot TAP}{\eta_{boiler}} \cdot r_{tap} + Q_{standing\ still} + Q_{stand.circulation\ loss} \cdot \frac{A_{floor}}{100} \cdot (1 - \eta_{useful})$$

c_f – conversion factor [MJ · day/l · year]

TAP – quantity of water [l · day]

η_{boiler} – boiler efficiency – 0.9 in case of a condensing boiler

r_{tap} – correction factor for short piping – 0.9 if $< 5m$, *else* 1

$Q_{standing\ still}$ – 4220,2MJ in case of a condensing boiler

$Q_{stand.circulation\ loss}$ – 10000MJ if non insulated, 4000MJ if insulated

η_{useful} – used part of the loss (0.44)

$$TAP = c_{kitchen} + c_{basins} + N_{people}(c_{per\ person} + c_{shower} \cdot F_{saving\ head} \cdot D + c_{bath} \cdot B \cdot B_{yes/no}$$

$c_{kitchen}$ – 13,03 for a condensing boiler [l · day]

c_{basins} – 3,97 for a condensing boiler [l · day]

$c_{per\ person}$ – 7,1 for a condensing boiler [l · day]

c_{shower} – 20,8 for a condensing boiler [l · day]

$F_{saving\ head}$ – saving shower head, if present 0.9 else 1

D – number of showers /person/day – 0.61

c_{bath} – 41,5 in case of condensing boiler [l · day]

B – number of baths /person/day – 0.096

$B_{yes/no}$ – presence of bath, if present 1 else 0

EQUATION 7

The auxiliary energy needed for the kitchen boiler is also determined using standard values. The number of people in equation 7 is determined using the following table:

FLOOR AREA	NUMBER OF PEOPLE (EPA)
<50 m^2	1.4
≥50 m^2 and <75 m^2	2.2
≥75 m^2 and <100 m^2	2.8
≥100 m^2 and <150 m^2	3.0
>150 m^2	3.2

TABLE 1 Number of people in a dwelling according to EPA calculation

The energy index (EI, Equation 8) correlates directly with 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 not to disadvantage larger dwellings and dwellings with a greater proportion of their heat envelope adjoining unheated spaces (different building types) with constant insulation properties and efficiencies of the heating/ventilation/lighting system. Shape correction is also applied when considering infiltration losses within demand for space heating – the air permeability coefficient depends on the building shape factor.

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

EQUATION 8

§ 3.2.2 Assumptions in the calculation method and accuracy of the inspection data

Many assumptions are made in the theoretical calculations which could lead to inaccuracies in the estimates of theoretical gas consumption. The calculation of theoretical values assumes that the whole floor area of a dwelling is heated, which may in some cases result in a significant overestimation of the demand for heating. In newer dwellings the whole surface area is likely to be heated and the indoor temperature is likely to be more uniform than in older dwellings (Guerra Santin et al., 2009). In older dwellings, especially where only the living room is heated with an old-fashioned stove (powered by wood, oil or gas), the heated surface area may be lower leading to a much lower average indoor temperature than assumed in the calculation method.

Moreover, it is possible that the estimated insulation values for walls in new dwellings is closer to the actual values than those for old dwellings. Inspecting older dwellings is often difficult and instead of measuring U-values, a guess is made as to whether the cavity walls were insulated at the time of construction and what the quality of that insulation may be after many years. In some cases, therefore, it is possible that older buildings are better insulated than is assumed.Compared to insulation of the wall, distinguishing between U values of windows is relatively easy when deciding between single, double or triple glazing but equally complicated when it comes to determining the exact type of double glazing (for example in case of low emissivity coating or gas filled cavity). Differences may also occur due to different assumptions when it comes to rates of ventilation and infiltration. It may be that less air enters older dwellings through natural ventilation than is assumed, and this may also influence the accuracy of the estimated demand for heat. On the other hand, it is possible that air flows with mechanical ventilation are underestimated, explaining the underestimates for labels A and B.

In addition, behaviour also influences temperature preferences, heated floor area, ventilation preferences and the internal heat gains of a dwelling, but in the theoretical calculations these are all assumed to be constant or a function of floor area.

The behaviour assumptions in itself are not problematic, since they were introduced in order to make dwellings comparable within the dwelling stock. However, the fact that the energy consumption calculated under these assumption is nearly double than actual in label G and roughly a third lower in label A (Figure 1) suggests that the assumptions used might not fit every label category equally well. As stated previously, if a label certificate is to inform about the quantity of the dwellings' heating energy consumption, these discrepancies should not occur.

§ 3.2.3 Energy label dataset

The Energy Label database, the core database used for this report, was provided by NL Agency – a public sector organisation that serves the Netherlands Ministry of the Interior and Kingdom Relations. The database contains all the energy labels issued from beginning of January until December 2010, including information about the installation for space heating, the dwelling type, its theoretical energy consumption (gas and electricity), floor area, construction and renovation year, date of labelling and the coded address variable to enable matching with other data. One limitation of this study was the missing information about hot tap water installation and ventilation systems.

This dataset was linked to actual energy use data for the year 2009, which was provided by CBS (Statistics Netherlands). CBS collects this data from the energy companies; however, it is important to note that the annual data is sometimes an extrapolation of monthly values. Unfortunately, not much is known about the reliability of this data, but our assumption was that the data yields reasonably accurate averages. The combined dataset was cleaned up (doubled addresses and incomplete cases were deleted), leaving 247,174 cases. The CBS expressed its doubts about the quality of the data obtained for the actual energy of collective installations due to the fact that 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 omitted since these are very specific cases. Cases where electricity consumption was null 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 in fact do use gas. Such cases were deleted, with only those dwellings that use electricity as power source for heating being kept in the database. Gas consumption was then redefined to 0 for those cases. On checking the theoretical energy use and the areas of the house, outliers were detected. Cases with a floor area of over 1000m^2 and primary energy use of more than 500,000 MJ were discarded. Finally, the actual gas consumption values for 2009 were corrected to the number of degree days used in the theoretical calculation. At the end of this process, the sample contained 193,856 cases.

The actual gas consumptions available from CBS corresponded to the climatic year of 2009. To be able to compare these values with the theoretical ones, the ratio between the actual degree days in the year 2009 and the degree days assumed in the theoretical calculation was calculated (factor f in Equation 9). The factor f was then applied to actual gas value.

$$f = \frac{DD_{theo}}{DD_{2009}} = \frac{2620}{2804} = 0.934$$

$D_{theo} = number\ of\ degree\ days\ in\ theoretical\ calculation\ (reference\ year\ De\ Bilt\ 1964 - 1965)$

$D_{2009} = number\ of\ degree\ days\ in\ 2009$

EQUATION 9 Equation 9

A possible limitation of the study is the differences between the end uses included in predicted and actual gas consumption. They both contain gas for hot tap water and space heating, but actual gas consumption also includes gas for cooking (see

Table 3 in Majcen et al., 2012). However, gas used for cooking is less than 3% of the total gas consumption.

The sample used represents slightly less than 0.3% of the total dwelling stock in the Netherlands (CBS Statline, 2012). An overview of the representativeness of the sample is available in a study from Majcen et al. (2012), which shows that the sample is representative for label categories, but less so for dwellings or ownership type. It is therefore important to note that while the results of this study are valid for this large sample of dwellings, some of the variables used might have a different predictive power when applied to the Dutch dwelling stock as a whole.

§ 3.2.4 Other datasets used in the paper

To account for the differences between theoretical and actual energy use as accurately as possible, more datasets were obtained from the CBS and matched with the basic database of 193,856 cases mentioned earlier. Up to date housing register (*Woonruimtereregister*), municipal records (*Gemeentelijke Basisadministratie*), employment database (*Social Statistisch Bestand Banen*), and the 'Woon' survey conducted by the Dutch government in 2009, were coupled with the energy label data.

For the regression analysis presented in the section 3.3, the energy label dataset was coupled with the first three mentioned databases, leaving a total of approximately 40,000 dwellings. In section 3.4, in which a sensitivity analysis was performed on the methodology, the Woon database was also incorporated. Consequently, the sample used for that purpose included around 700 terraced houses.

§ 3.3 Regression analysis

§ 3.3.1 Methodology

The goal of the regression analysis was to see how much variation can be explained and which variables have the best predictive power for theoretical and which for actual gas consumption. In addition to the variables used, many variables which could have been relevant to our analysis, such as the presence of hot water taps and ventilation systems, were not available. Variables that could relate indirectly to occupants' behaviour, are grouped under the category of 'household characteristics'. All other variables belong to the 'building characteristics' group (Table 2). Variables that describe occupant behaviour directly, such as indoor set temperature, the presence of thermostat, time spent at home, heating bedrooms, and so on, could have been very relevant but these are typically survey questions, and a survey large enough to give relevant regression results when coupling with our database was not available.

After preliminary analysis, the data was found to be suitable for parametric analysis. Forced entry regression analysis was conducted on actual and theoretical gas consumption per dwelling. Dummy variables were defined for the categorical variables in order to include them in the regression analysis (Table 2). If all dummy values of a categorical variable were insignificant, this variable was not retained in the regression analysis (in the cases of dwelling and installation type, only a few dummy values are insignificant, therefore these variables were retained). The variables which were found to be insignificant according to the criteria mentioned were omitted and forced entry regression was repeated without these variables. In Table 2, the dummy values that are not significant (sig. above 0.01) are highlighted.

Multicolinearity among the predictors was generally not an issue, with a slightly higher correlation detected between label category E, F and G and the vintage of the dwellings. However, these correlations were in the range of 0.2 – 0.25, which is still considered a weak correlation and did not disturb the regression analysis (Field, 2009).

§ 3.3.2 Results

The results for gas consumptions can be found in Table 2. A much higher degree of response variation of the theoretical gas consumption can be explained by the regression model (87.9%) than is the case for the actual gas consumption, for which only 50.5 % of response variation can be explained.

Floor area, label and vintage

Floor area is a good predictor of theoretical and actual gas consumption (Table 2). We can interpret these results as meaning that for every 10m^2 added to the size of the dwelling, theoretical gas consumption increases by 12.1m^3, but the actual increase is only about 6.7m^3. This means that in larger dwellings, the difference between theoretical and actual gas consumption is relatively larger than in small dwellings. It can be concluded that a larger floor area does not raise actual energy use as much as the estimates would lead us to believe. This could be due to occupant behaviour: in large houses, it is unlikely that all rooms will be heated evenly.

The age of the dwellings is a significant predictor of theoretical and actual consumption, predicting a similar increase in both. Each higher label is a stronger predictor in actual gas consumption, meaning that the label accounts for the thermal quality in the correct order. However, the beta values are smaller than those for the theoretical consumption, meaning that the label correlates with the theoretical consumption more strongly than with the actual.

Dwelling and installation type

Terraced houses located on corners and ground-floor flats surrounded by two others have higher gas consumption in both actual and theoretical terms, if a detached house is used as the reference dummy variable. Considering the geometry of these dwellings, this result was unexpected (detached houses have the least favourable shape in terms of heat conservation). This phenomenon is probably due to the fact that some of the variation is taken on by other predictors used in the analysis. For the other dwelling types, the variation was as expected according to their geometry. The predictive power of dwelling types was very similar for both actual and theoretical gas consumption, which suggests that dwelling type is not responsible for the large discrepancies seen in Figure 1.

Regarding the installation types used in the regression analysis, the reference dummy is an improved efficiency boiler. A negative beta power would be assumed for higher-efficiency condensing boilers, which is the case for the actual consumption, but strangely not for the theoretical consumption. However, regression analysis is only valid for the specific combination of predictors and does not necessarily mean that gas consumption will be higher for high-efficiency boilers than in improved-efficiency boilers. In general, the installation type seems to be a considerably worse predictor for actual gas consumption than for theoretical gas consumption. Since many dummy values are not significant predictors of actual gas consumption, the mean gas consumption at different installation types is also presented in Figure 2 below. It is notable that dwellings with central electrical heating and heat pumps consume gas in non-negligible quantities. Unfortunately, the gas installation systems for hot tap water were not included in the available data, which is a limitation for this study and could explain this discrepancy, together with the insignificant results in the regression analysis. However, a more detailed investigation of the dwellings with local electrical heating showed that all 98 of these dwellings have actual gas consumption, while only 37 dwellings have theoretical gas consumption. Heat pumps are a similar case: slightly less than half of the cases have theoretical gas consumption, while all the cases have actual gas consumption (hence the large standard deviation in Figure 2). Even though the information on hot tap water was missing in the database, this clearly indicates either flaws in the inspection phase or generically inaccurate actual gas consumption data. Due to the assumptions made by energy companies, a thermal renovation of the dwellings may not be reflected in the actual data (Majcen et al., 2012). The dwellings with other installation systems also show a large difference between the mean theoretical and actual gas consumption, which is difficult to analyse because the installations for hot tap water were unknown. It seems that the less efficient the installation system, the higher the overestimation, which is a similar trend to the one seen in Figure 1. Lower labels do indeed have a higher proportion of inefficient installation systems than more efficient labels (Table 2), although there was no significant correlation. It is also possible that the heating surface area is overestimated when a gas/oil stove is in use (with these systems, probably only one or two rooms are heated rather than the whole dwelling, as assumed in the theoretical calculation). This could explain some of the theoretical overestimation in labels E, F and G.

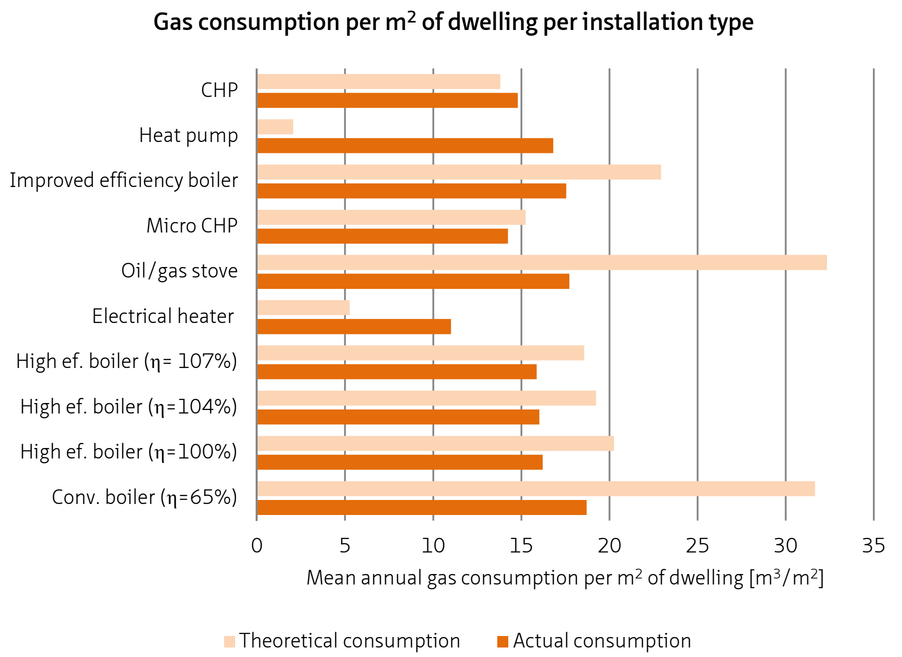

FIGURE 2 Mean annual gas consumptions per m^2 dwelling per installation type with ± 1 standard deviation (see Appendix for definitions of the installation types)

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Household characteristics

The beta values for the 'private rental' dummy are insignificant, but owner-occupied dwellings seem to have a slightly higher theoretical gas consumption than the social dwellings. On the other hand, actual gas consumption in owner-occupied dwellings is about 50m³ less than in social housing, which could be attributable to better insulation in owner-occupied dwellings or to different behaviour.

Interestingly, for a dwelling worth €100,000 or more, there will be 38 m³ more theoretical consumption, whereas actual consumption will be 97m³ higher. Results for salary per person in the household are similar – this predictor is insignificant for theoretical gas consumption, but an income that is €10,000 higher annually is associated with an increase in actual gas consumption of 8 m³. Salary is not a significant predictor for theoretical gas consumption.

Whereas one additional occupant means an increase of 45m³ in actual gas consumption, this variable fails to explain the variation in theoretical consumption, which is logical since the number of occupants is a function of floor area only, see Table 1.

Other household predictors were not significant.

	Independent Variables	GAS CONSUMPTION PER DWELLING [M³]						
		DUMMIES	THEORETICAL [R^2=87.9%]			ACTUAL [R^2=50.5%]		
			B	BETA	SIGN.	B	BETA	SIGN.
	Constant					-143.710		0.046
BUILDING CHARACTERISTICS	Floor Area	Ratio variable	12.100	0.438	0.000	6.670	0.313	0.000
	Vintage of building	Ratio variable	1.800	0.047	0.000	1.720	0.058	0.000
	Label [ref. dummy variable is A]	B	406.440	0.124	0.000	220.890	0.087	0.000
		C	719.630	0.322	0.000	366.470	0.212	0.000
		D	1146.12	0.489	0.000	539.500	0.299	0.000
		E	1672.40	0.617	0.000	655.940	0.314	0.000
		F	2237.10	0.632	0.000	735.060	0.270	0.000
		G	3146.00	0.565	0.000	802.000	0.187	0.000

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	Independent Variables	GAS CONSUMPTION PER DWELLING [M³]						
		DUMMIES	THEORETICAL [R^2=87.9%]			ACTUAL [R^2=50.5%]		
			B	BETA	SIGN.	B	BETA	SIGN.
	Constant					-143.710		0.046
BUILDING CHARACTERISTICS	Dwelling type dummy [ref. dummy variable is detached house]	Flat – corner – roof	227.800	0.036	0.000	48.330	0.010	0.031
		Flat – corner – ground floor	139.500	0.019	0.000	143.760	0.025	0.000
		Flat – corner – middle floor	-104.600	-0.017	0.000	-69.470	-0.014	0.002
		Terraced house – corner	388.400	0.166	0.000	288.700	0.160	0.000
		Terraced house – middle	64.380	0.030	0.000	16.490	0.010	0.290
		Flat – middle – roof	69.660	0.016	0.000	-101.040	-0.030	0.000
		Flat – middle – middle floor	-96.230	-0.031	0,000	-136.340	-0.057	0,000
		Flat – middle – ground floor	919.770	0.221	0,000	578.220	0.181	0,000
	Installation type dummy [ref. dummy variable is improved efficiency boiler (η=83%)]	Conv. boiler (η=65%)	-90.970	-0.013	0,000	-39.190	-0.007	0.061
		High efficiency boiler (η=100%)	36.340	0.009	0.000	-20.380	-0.006	0.120
		High efficiency boiler (η=104%)	28.800	0.003	0.060	-12.750	-0.002	0.593
		High efficiency boiler (η= 107%)	23.540	0.011	0.000	-22.450	-0.013	0.004
		Electrical heater	-1266.30	-0.038	0.000	-375.010	-0.015	0.000
		Oil/gas stove	-206.600	-0.038	0.000	-236.130	-0.056	0.000
		Micro CHP	317.500	0.005	0.008	185.780	0.004	0.320
		Heat pump	-1210.20	-0.048	0.000	150.890	0.008	0.031
		CHP	-18.000	0.000	0.832	22.410	0.001	0.865
HOUSEHOLD CHARACTERISTICS	Ownership type [ref. dummy variable is social housing]	Private rental	-2.060	0.000	0.905	18.930	0.003	0.480
		Owner-occupied	-5.540	-0.002	0.282	-48.610	-0.028	0.000
	Value (2009)	Ratio variable	0.000	0.040	0.000	0.001	0.125	0.000
	Number of people	Ratio variable	-1.380	-0.002	0.685	45.480	0.074	0.000
	Number working population per household	Ratio variable	-7.090	-0.006	0.009	-3.561	-0.004	0.400
	Salary per person	Ratio variable	0.000	-0.005	0.023	0.001	0.017	0.001
	Household type	Couple/elderly/ family	Insignificant variable					
	Household type	Ratio variable	Insignificant variable					
	Number of children in household.	Ratio variable	Insignificant variable					
	Days worked per person in household	Ratio variable	Insignificant variable					
	Overtime per person in household	Ratio variable	Insignificant variable					
	Salary per person in household	American Institute of Architects, 2002	Insignificant variable					

TABLE 2 Regression analysis of gas consumption (see Appendix for definitions). The orange values are insignificant on a 99% confidence interval scale.

§ 3.4 Sensitivity of the calculation method

In addition to the variables used for the regression analysis, parameters such as temperature preferences, time spent at home and other behavioural characteristics of the occupants could also affect the discrepancy seen in Figure 1. Moreover, it is said that the thermal qualities of the dwelling are often assessed inaccurately during the inspection and this could be another plausible explanation for the overestimation of the energy consumption of low-efficient dwellings (see section 3.1). However, no trustworthy data was available for matching with the large sample used in the regression analysis. The second part of this paper will seek to bridge this data gap by examining how changes in behaviour and assumptions related to the dwelling influence the theoretical gas consumption and whether more accurate assumptions could lead to a better match between actual and theoretical rates of gas consumption.

§ 3.4.1 Reference dwellings

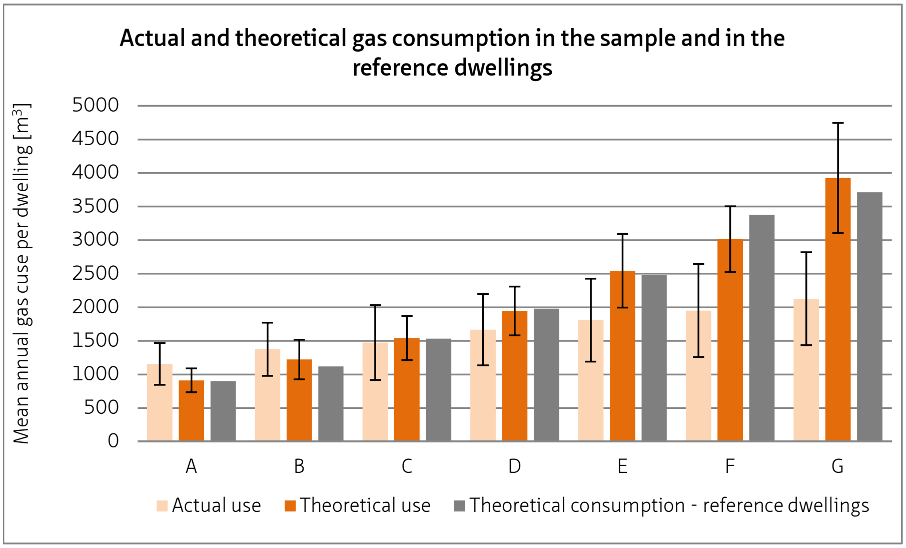

FIGURE 3 Actual and theoretical gas consumption in the sample of terraced houses together with the theoretical consumption of reference dwellings

The energy label database does not include complete information about the geometry of dwellings. In order to test how adjustments to the calculation assumptions could influence theoretical gas consumption rates, data such as the number of floors, floor area, shape of dwelling and roof type is needed; without this, the theoretical gas consumption cannot be calculated. To overcome this lack of data, the calculations were performed using reference dwellings that were representative of an average dwelling in each label category of the sample.

In order to reduce uncertainty due to the dwelling type, terraced houses (the most common type of dwelling in the Netherlands) were chosen as the subsample to be investigated in the sensitivity analysis. Because the Woon database was matched with the terraced houses from the original energy label database, the newly composed database consisted of 713 matched cases. Figure 3 shows the actual and theoretical consumption in this smaller sample, in order to ensure that this sample is representative of the trend described previously in Figure 1.

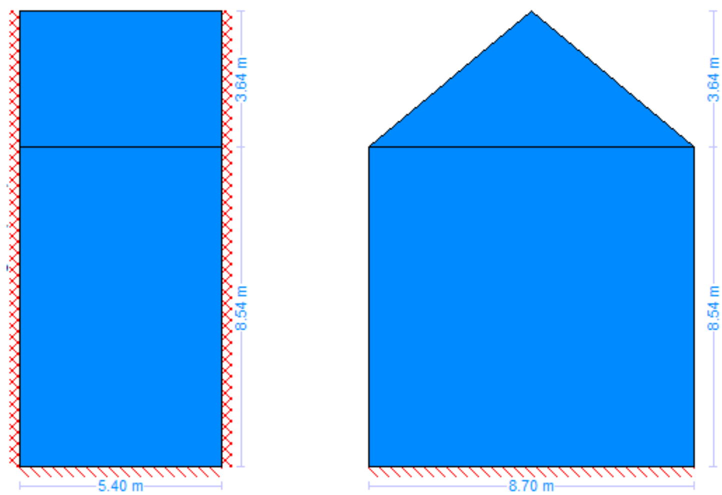

FIGURE 4 Side and front view of the reference terraced house

The Woon database provided the average number of rooms in the sample, which was used – together with the floor area, type and construction year – as the basis for the choice of the geometry of the reference dwelling (Novem, 2002). The reference geometry is shown in Figure 4. Both the front and back of the house are characterised by approximately $8m^2$ of window area. Both the side walls are shared with another heated house. The indoor floor area of the dwelling is $105m^2$. The chosen geometry was based on averages from these 713 dwellings and was used as a reference in all label categories. Although this might introduce a slight error – because in practice the geometry does correlate slightly with the energy label – the purpose was to test the sensitivity of the calculation method in different label categories due to the different thermal quality of the dwelling and not due to the varying geometry. We therefore deliberately selected a single reference geometry.

Appropriate envelope U-values were applied to the reference geometry in order to get 7 thermally representative reference dwellings, one for each label category (AgentschapNL, 2011). The installation and ventilation type in each of these dwellings was determined using the average of the available dataset (713 dwellings). The properties of the seven reference dwellings are summarised in Table 3. According to their theoretical consumption (Figure 3), reference dwellings are well representative of the sample. The assumed infiltration rate was 23.3 dm^3/s (ISSO, 2009) and the assumed ventilation flow rate was 49.4 dm^3/s (ISSO, 2009) for all the reference dwellings regardless of the label class.

	A	B	C	D	E	F	G
Installation system	HE boiler	HE boiler	HE boiler	HE boiler	HE boiler	IE boiler	IE boiler
Ventilation system	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Supply water temperature of heating system [°C]	>55	>55	>55	>55	>55	>55	>55
U value wall [W/m²K]	0.2	0.36	0.5	0.64	1.6	2.0	2.4
U value window [W/m²K]	1.8	2.9	5.2	5.2	5.2	5.2	5.2
U value floor/roof [W/m²K]	0.4	0.4	0.5	1.3	1.3	1.72/1.54	1.7

TABLE 3 Properties of the seven reference dwellings for each label

§ 3.4.2 Calculation method

The gas consumption (Q) of a dwelling is a function of many parameters such as the average indoor temperature (T) (averaged out over the heated floor area and time) number of occupants (N_{people}), internal load (Q_{int}), ventilation rate (F_{vent}), floor area (A) and insulation values (U). In the theoretical gas consumption calculation, these are set at nominal values (Table 4), which are shown in superscript '^{0}'.

The first four variables in Table 4 show the behavioural assumptions made in energy label calculations. As well as occupant behaviour, poor quality of inspection could also lead to an inaccurate estimation of theoretical gas consumption, which can result in an erroneous label and contribute to discrepancies between theoretical and actual consumption, because the dwelling should actually be in another category. A sensitivity test was therefore also conducted on the insulation quality of the dwelling and the heated floor area. In section 3.4.3.1, behavioural assumptions are addressed and section 3.4.3.2 relates to the sensitivity of the floor area and the quality of the insulation.

VARIABLE	ASSUMPTIONS IN EPA CALCULATION METHOD	RESULT OF INSPECTION
T^0	18°C	N/a (fixed in method)
N^0_{people}	3.2	N/a (fixed in method)
Q^0_{int}	6W/m²	N/a (fixed in method)
F^0_{vent}	Standard correction factor c.f=1	N/a (fixed in method)
A^0	All surface area is heated	105 m²
U^0	Default values vary throughout label categories (see Table 3)	Estimations from inspection or default values are used

TABLE 4 Assumptions in the EPA calculation method

According to our educated guess (see also section 0), inaccurate estimates concerning these six core parameters are very likely to be the cause of the discrepancies between the theoretical and actual rates of gas consumption. Since the software used for the energy label calculations (EPA-W by Vabi, 2011) is also used for a broad custom advice on dwelling energy consumption with which occupants are advised on how to reduce energy consumption in their particular situation, modifications could be made to the parameters from Table 4 and gas consumption was recalculated.

The new values for the parameters mentioned in Table 4 were fed into the calculation software which yielded altered gas consumption values.

$$\delta Q = Q(P^0 + \delta P) - Q(P^0)$$

EQUATION 10 Equation 10

Inversely, we also looked for the change in parameter which could explain the discrepancy and whether the gas consumption changes in a linear fashion with the altered parameter.

$$\Delta P(Q_{diff}) = \frac{\Delta Q_{diff}}{\frac{\delta Q}{\delta P}}$$

EQUATION 11 Equation 11

$$Q_{diff} = Q_{theoretical\ gas} - Q_{actual\ gas}$$

EQUATION 12 Equation 12

Each change in parameters ΔP was introduced back into the calculation software (Equation 11) to test whether the change in gas consumption was linear at that increment. Sometimes this was not the case and in such instances Equation 11 is not an accurate way to calculate ΔP, since the δQ is not a monotonous function of δP as described in Equation 10, but depends on other additional parameters. However, the purpose of the exercise was to begin to understand whether the flaws in estimations could realistically be the culprit for the discrepancies seen in Figure 1. In most cases, the calculation model behaved in a linear fashion where the solution ΔP which explained Q_{dif} was realistically possible. In cases where ΔP would have to be relatively large (for example with more than 5 occupants in a dwelling or a floor area larger than $100m^2$), gas consumption was not linear; however, such solutions are not likely to occur anyway.

§ 3.4.3 Results

§ 3.4.3.1 Behavioural parameters

Table 5 shows the sensitivity of the theoretical gas consumption model to the four behavioural parameters. The second column shows the difference between the theoretical and actual rates of gas consumption, as seen in Figure 3. The values in the δQ columns are highlighted whenever the difference exceeds the Q_{dif}. This means that the δP change in parameter would explain the difference Q_{dif}. The highlighted values in the columns $\Delta P(Q_{dif})$ signify that the gas consumption is a monotonous function and therefore the ΔP is valid.

For greater clarity, the theoretical rates of gas consumption at δP are also presented in Figure 5 together with the theoretical rate of consumption for the reference dwellings and the actual rate of gas consumption of the sample.

Indoor temperature

In the third and fourth columns, Table 5 shows the differences in theoretical gas consumption if the indoor temperature is raised or lowered from the assumed 18 degrees C by ±2°C. However, Table 5 shows that such increments can only explain the discrepancy (Q_{dif}) between the theoretical and actual rates of consumption in dwellings with labels B, C and D (highlighted). All the values in the fifth column are highlighted, because gas consumption is linear within the δT in all label categories.

On the basis of these results, indoor temperature would have to be 12.4°C in order to explain the discrepancy between theoretical and actual rates of gas consumption in dwellings with a G-label certificate. With an outdoor temperature of 5.64°C during the heating season, a heated area of 57.43m^2 would yield such an average indoor temperature (assuming very poor insulation). This is a realistic value if only the living room and some other smaller room (such as a kitchen or bedroom) are heated. On the other hand, an average indoor temperature of 20.7°C would explain the discrepancy for dwellings with an A-label certificate, which is realistic, considering these are very efficient houses with fewer temperature fluctuations and in which the occupants tend to adjust their comfort preferences upwards. However, it is likely that an inaccurate temperature estimate is not the only culprit for the difference and that a handful of factors are involved. On the basis of this table, one can say that the accuracy of temperature estimation has a major impact on the accuracy of the theoretical gas consumption.

Number of occupants

The difference in gas consumption remains fairly constant across label categories, which is because the demand for gas for space heating is independent of the number of occupants; only the demand for gas for hot tap water changes with this parameter. The demand for hot tap water is not related to the thermal properties of the dwelling (section 3.2, Equation 3). As such, theoretical gas consumption does not respond in a linear way to any change in the number of occupants (values in column $\delta N_{people}(Q_{dif})$ are not highlighted).

The inaccurate estimation assumption regarding the number of occupants is therefore unlikely to be the cause of the discrepancies. It could explain minor differences in middle-ranking labels, such as label C. In higher labels, the assumption about the number of occupants would have to be very inaccurate (over 10 occupants too many) in order to account for the overestimation. This conclusion, however, does not exclude the possibility that the algorithm for hot tap water gas demand is not representative of the actual state of the dwellings. Flaws in more complex assumptions such as the standard efficiency of boilers, average losses through piping, standard rates of hot water consumption and so on could also be the cause of inaccuracies when estimating theoretical gas consumption.

Internal heat gains

The third part of Table 5 is about internal heat gains, nominally set at 6 W/m^2. Internal heat gain influences the gas consumption for space heating, while the consumption of gas for hot tap water remains constant. The increment of 2 W/m^2 can only explain the difference in label C. If we derive the internal heat gain which would explain the difference, the value in G-label dwellings is very high, around 27 W/m^2, which again is unrealistic. Gas consumption is linear even for all positive increments in internal heat gain, but is not linear for negative increments. An inaccurate estimation of internal heat gains could therefore be responsible for moderate discrepancies.

Ventilation rate

In the energy label calculation, the correction factor for heat demand which occurs as a consequence of ventilation is set at 1. The ventilation is determined as a function of the ventilation system and infiltration rate, which is determined on the basis of nominal rates for the dwelling type and corrected for the floor area. In the sensitivity analysis, the factor was modified for increments of 0.5 upwards and downwards. Such a change in gas demand due to ventilation explains the discrepancies in labels B to D. For label A, a correction factor of 0.6 would explain the discrepancy. For label E and below, the correction factor would have to be negative to explain the difference, which is not possible (gas demand due to ventilation cannot be negative in the model).

LABEL	Q_{DIFF} [M^3 GAS]	INDOOR TEMPERATURE			NUMBER OF OCCUPANTS		
		δQ*		δT (Q_{DIF})* [°C]	δQ*		δN_{PEOPLE} (Q)(Q_{DIF})*
		δT = +2°C	δT= 2°C		δN_{PEOPLE} =+2	δN_{PEOPLE} =-2	
A	**-232.0**	175.3	-170.3	2.7	101.7	-154.2	5.1
B	-116.3	211.4	-208.6	1.1	101.7	-154.2	2.6
C	72.2	279.5	-278.7	-0.5	101.7	-153.6	-1.0
D	272.0	354.7	-354.6	-1.5	101.7	-153.6	-3.9
E	738.6	437.8	-437.6	-3.4	101.7	-153.6	-10.5
F	1081.3	583.8	-583.8	-3.7	101.7	-153.6	-15.4
G	1815.7	635.4	-644.0	-5.6	97.4	-157.9	-24.3

TABLE 5 (I) Sensitivity of gas consumption for behaviour parameters

LABEL	INTERNAL HEAT GAINS			VENTILATION RATE		
	δQ*		δQ_{INT} (Q_{DIF})* [W/M²]	δQ*		δQ_{VENT} (Q_{DIF})*[C.F**]
	δQ_{INT} = -2W/M²	$\delta Q_{INT}{}^{T}$ = +2W/M²		δQV_{EN} =0.5 C.F**	δQ_{VEN} =-0.5C.F**	
A	104.3	-112.2	-4.3	279.1	-265.1	0.4
B	111.2	-115.5	-2.1	282.3	-277.1	0.2
C	116.3	-117.7	1.2	284.2	-283.3	-0.1
D	117.9	-118.3	4.6	284.6	-329.5	-0.4
E	118.3	-118.6	12.5	284.8	-284.7	-1.3
F	140.7	-140.8	15.4	338.2	-338.2	-1.6
G	145.1	-136.6	27.5	395.1	-403.7	-2.2

* Highlighted values in the columns δQ mean that the difference in gas consumption meets the Q_{diff}, highlighted values in the columns δP (P=parameter) signify that the gas consumption responds linearly to this change of parameter.
** C.f stands for ventilation correction factor. The assumed ventilation rate (a function of dwelling type and door and window frame length) is multiplied with the ventilation factor. The factor is assumed to be 1 in energy label calculations.
The orange values are insignificant on a 95% confidence interval scale.

TABLE 5 (II) Sensitivity of gas consumption for behaviour parameters

Small changes in ventilation (10% less for label C or 20% more for label B) can already explain a large part of the discrepancies. This is an indication that the ventilation rate is very important in the theoretical calculation, and is a potential culprit if the assumptions are not matched by the reality. The validation of all the nominal rates and factors used could confirm or refute that.

§ 3.4.3.2 Floor area and insulation quality

The left-hand section of Table 6 shows how gas consumption changes when the heated floor area is increased or reduced by 20m². Such a reduction would only explain the discrepancy for label C. With a slightly larger inaccuracy in the estimation of floor area (approximately 30m²), the discrepancies can also be explained for labels B and D. For other labels, gas consumption no longer changes in a linear manner when the floor area changes; however, it would seem feasible that the actual heated floor area could be as little as half the assumed heated floor area, especially in thermally poor dwellings. On this basis, one can claim that the assumed heated floor area does indeed influence gas consumption to a significant extent. Furthermore, the heated floor area influences the average indoor temperature.

LABEL	U VALUE [W/M²K]	Q_{DIF}	FLOOR AREA			INSULATION VALUE			
			δQ*		δA (Q_{DIF})*	δQ*		δU (Q_{DIF})* [% ASSUMED U VALUE]	δU (Q_{DIF})* [W/M²K]
			δA=+20M²	δA=-20M²		δU =+20%	δU =-20%		
A	0.200	-232.0	91.6	-89.7	50.6	103.0	-103.0	45.0	0.09
B	0.360	-116.3	100.8	-99.0	23.1	104.9	-105.3	22.2	0.08
C	0.500	72.2	121.6	-119.1	-12.1	106.3	-106.3	-13.6	-0.07
D	0.640	272.0	191.8	-186.2	-29.2	106.6	-106.5	-51.1	-0.33
E	1.600	738.6	246.4	-240.6	-61.4	106.6	-106.6	-138.6	-0.89
F	2.000	1081.3	341.8	-333.9	-64.8	126.6	-126.6	-170.8**	-3.42**
G	2.400	1815.7	383.8	-375.2	-96.8	126.6	-126.6	-286.8**	-6.88**

* Highlighted values in the columns δQ mean that the difference in gas consumption meets the Q_{diff}, highlighted values in the columns δP (P=parameter) signify that the gas consumption responds linearly to this change of parameter.
The red values are insignificant on a 95% confidence interval scale.

TABLE 6 Sensitivity of gas consumption for floor area and insulation quality

Unlike all five parameters mentioned previously, the U-value was more complex to test since it was impossible to use the same increment in all label categories. We only changed the U-value of the dwellings' walls because we assumed that this was the most frequent cause of errors during the inspection process. Inspecting the windows, floor or roof insulation is usually much more straightforward. Since an increment of ΔU=0.1 W/m²K would be a very significant amount for label A and very few in label G, we used percentage increments of 20% of the initial U-value for that label category (see second column of Table 6). Such an increment only explains the difference for label C, however, when deriving the increment $\delta T(Q_{dif})$ [%] which would explain the difference (Q_{dif}), values from 45% (label A) to -287% (label G) were obtained. These values are then translated to absolute increments of U $\delta U(Q_{dif})$ [W/m²K]) by multiplying them by the initial U-values (second column). The necessary increment of U-value in label categories F and G yielded a negative U-value (they are marked with a double asterisk). For all other labels, an increment in U value can explain the discrepancy seen in relation to actual consumption.

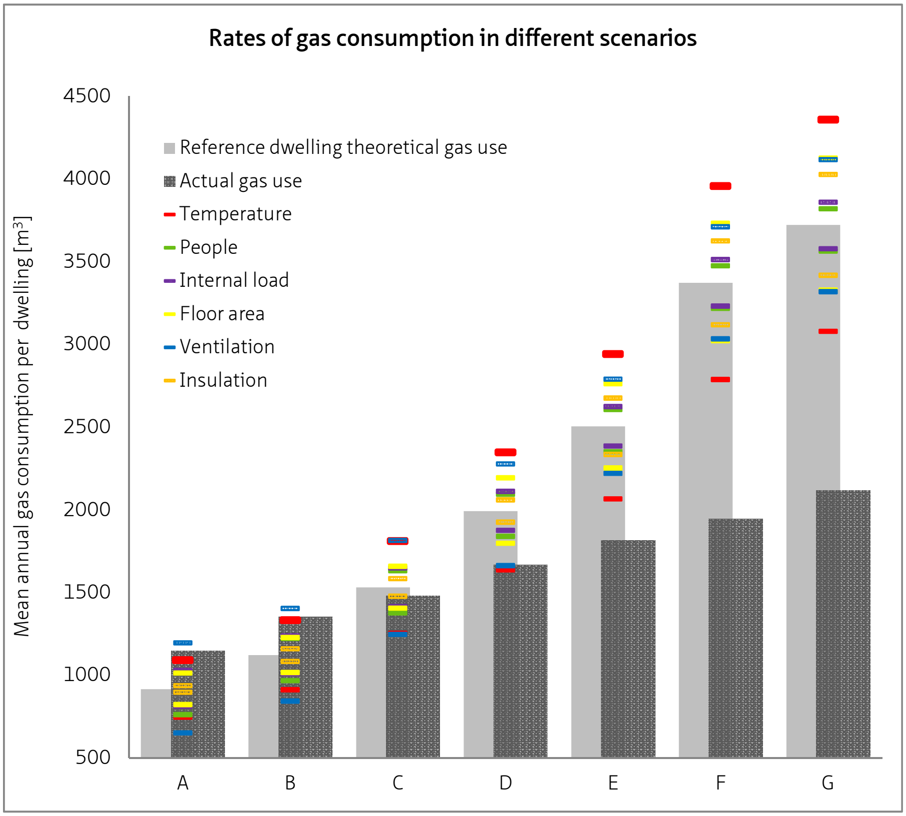

FIGURE 5 Rates of gas consumption when changing the values of the six assumptions considered in the sensitivity analysis

§ 3.4.3.3 Combined scenario

So far, the influence of each parameter on theoretical gas consumption has been investigated separately. However, it is likely that in reality several of the assumptions made are inaccurate. In this section a combined scenario involving all 6 parameters are modified as in Table 5 and Table 6 and applied to gas consumption simultaneously. Table 7 shows how the parameters changed under the two scenarios.

	δT	δN_{PEOPLE}	δQ_{INT}	δQ_{VEN}	δA	δU
Spending scenario	+2°C	+2	-2 W/m²	0.5 c.f	+20m²	+0.2%
Conserving scenario	-2°C	-2	+2 W/m²	-0.5 c.f	-20m²	-0.2%

TABLE 7 Parameters in the two combined scenarios

Figure 6 shows graphically the variation in gas consumption which arose due to the changed parameters. The actual gas consumption is somewhere within the two scenarios in all label categories. For labels A to E, the actual gas consumption falls fully within the variation range. For labels F and G, actual gas consumption can only be predicted if all the assumptions take extreme values. However, it is likely that if more extreme but still realistic assumptions (such as an average indoor temperature of 12.4°C) were made, actual energy use would have fallen within the range of the variations.

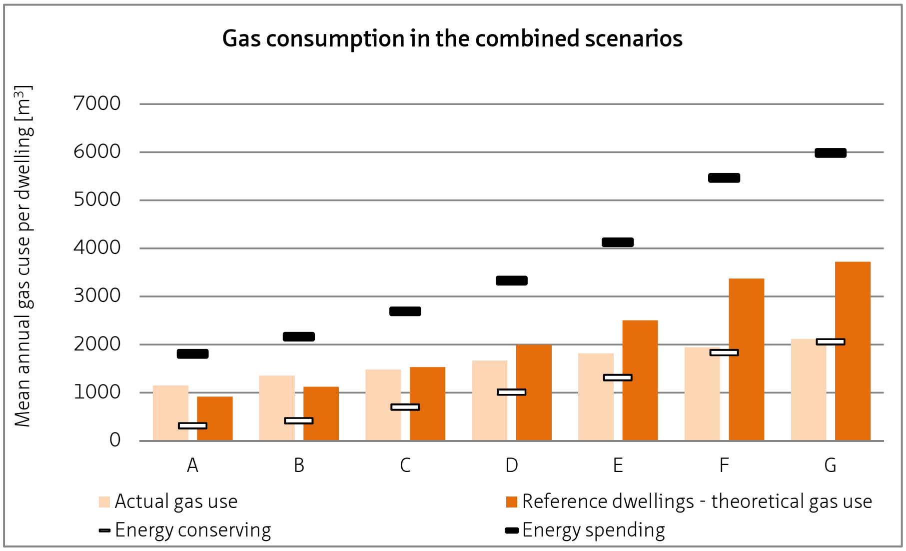

FIGURE 6 Rates of gas consumption in the combined scenarios

§ 3.5 Conclusions

Regression analysis using the make-up of the household and physical characteristics of the dwelling revealed that variables such as floor area, ownership type, salary and the value of the house, which predicted a high degree of change in actual gas consumption, were not significant (ownership, salary, value) or had a minor impact on theoretical consumption (floor area). This is most likely a consequence of occupant behaviour influencing actual gas use. Besides that, the installation system predictors showed that there was more overestimation in less energy-efficient systems, which can again be attributed to occupant preferences, or better yet, the relationship between the systems and the way the dwelling is heated. When a heat pump is present, there is usually under-floor heating so that the whole floor area is heated; meanwhile in older dwellings heated using a gas stove, the nature of the installation prevents the occupant from heating all the rooms. Moreover, there seem to be inspection faults in the current energy databases.

In the sensitivity analysis, average indoor temperature was found to have a large influence on the theoretical gas consumption together with the ventilation rate. The number of occupants together with internal heat load have a more limited impact on theoretical gas consumption. The accuracy of the U value estimation was also addressed, showing that slight deviations from the assumed U value can account for a large part of the discrepancy.

§ 3.6 Discussion and future work

The energy label calculation as the basis for the energy label is a simplified, static model, which does not take into account variations in occupant preferences. There are significant discrepancies between the actual and theoretical rates of gas consumption at the level of the Dutch housing stock and this has detrimental consequences for pay-back time calculations, estimates of potential savings and last but not least, people's confidence in the added value of certificates. This paper has sought to identify the source of these discrepancies.

The behaviour of the occupant undoubtedly has a major influence, even though it is sometimes difficult to quantify. Due to the fact that occupant preferences affect actual gas consumption, regression analysis explained much less of the variation in the actual consumption than in the theoretical. However, not all the variables that we wanted to examine were available for the regression analysis, so a sensitivity study was carried out on theoretical gas consumption to help to fill in the data gap. The variables examined in the analysis require further validation study in the future to find out whether assumptions regarding the factors and the reference dwellings used in the calculation (Equation 6) are actually representative of the Dutch dwelling stock. Moreover, the gas required for hot tap water, which is a variable influenced by the number of occupants, should be studied more thoroughly in the future since there are many assumptions involved which could reduce representativeness vis-à-vis the Dutch housing stock as a whole. The effect of the number of occupants on the number of rooms heated (and thus on the average indoor temperature) should also be studied. The fact that even slight changes in U-value resulted in a very different energy demand, again emphasises the importance of thorough inspections if label certificates are to represent the thermal quality of dwellings accurately.

In order to implement the best possible assumptions regarding the behaviour of occupants and the characteristics of installation systems, a thorough validation study would be needed, comparing all the assumptions used in the calculations with real values from a sample of dwellings representative of the Netherlands as a whole. It could be that different occupant profiles are required depending on the characteristics of the dwelling itself, whether in terms of thermal quality, installation system, dwelling type or some other quality it remains yet to be studied as well.

On the other hand, a perfect calculation method cannot reduce the inaccuracies that occur due to poor inspection of the dwelling; there should therefore be more emphasis on accuracy in the inspection phase.

At the same time, a question arises of whether the certificate in its current form is really the best possible option. The relevance of the theoretical rates of gas and electricity consumption on the label certificate is certainly open to question if the actual consumption rates deviate by more than 50% from the theoretical.

§ 3.7 References

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§ 3.8 Appendix : definitions and abbreviations

TYPE OF DWELLING	EXPLANATION
Terraced house – corner	The last house in a row of houses. Can also be a semi-detached house.
Terraced house – middle of terrace	A terraced house surrounded by another house on its left and right.
Flat – middle – roof	A flat surrounded by two other flats on its left, right and underneath side, with a roof exposed to the air.
Flat – corner – roof	A flat, surrounded by two other flats underneath and on one of the sides, with an external wall and a roof exposed to the air (corner of the building).
Flat – middle – middle floor	A flat, surrounded by other flats above, below and on both sides.
Flat – corner – middle floor	A flat, surrounded by two other flats above, below and on one side, with an external wall on the other side (corner of the building).
Flat – middle – ground floor	A ground-floor flat, surrounded by other flats above and on both sides.
Flat – corner – ground floor	A ground-floor flat, surrounded by two others above and on one side, with an external wall on the other side.
Detached house	A detached house.
TYPE OF INSTALLATION	**EXPLANATION**
Conventional boiler (η=65%)	Central heating, gas boiler, efficiency above 65%.
Improved efficiency boiler	Central heating, gas boiler, efficiency above 83%.
High efficiency boiler (η=100%)	Central heating, condensing gas boiler, efficiency above 100%.
High efficiency boiler (η=104%)	Central heating, condensing gas boiler, efficiency above 104%.
High efficiency boiler (η= 107%)	Central heating, condensing gas boiler, efficiency above 107%.
Electrical heater	Small electrical heaters, portable electrical radiators etc.
Oil/gas stove	Oil- or gas-burning stove, usually located in the living room.
Micro CHP	Single-family home cogeneration of heat and power (electricity).
Heat pump	Transfers thermal energy from outside air or water to the inside of the house.
CHP	Cogeneration of heat and power (electricity).

TABLE 8 Appendix: Definitions and abbreviations