Comparison between regression models of actual and theoretical heating energy use

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Abstract
Dwellings represent a big potential for future energy savings. An European Performance of Buildings Directive (EPBD) has set the guidelines for dwelling performance certification, called energy label already in 2002. Label certificates in The Netherlands were issued in 2007 to encourage the transformation of the dwelling stock towards a lower energy consumption. The certificate provides each labelled dwelling with a theoretical energy consumption for heating, which is in most cases not a good estimation of the dwellings consumption in practice. As a consequence, using this consumption for payback time calculation, policy targets and similar leads to wrong conclusions. In this paper, we analyse the consumptions of dwellings from two datasets in order to find out which factors are responsible for the variation in actual and theoretical heating energy consumption. The analysis shows that whereas dwelling characteristics alone explain 64.3 % variation in theoretical gas consumption, all available variables (including dwelling and household characteristics, occupant behaviour and comfort) can only explain 23.8 % of variation, out of which more than half is accounted for by occupant characteristics.

Introduction
The Dutch energy label assesses dwellings energy performance based on a steady state energy model of a dwelling (detailed methodology in Majcen, 2013b), resulting in an energy label which ranges from A (good performance) to G (poor performing dwelling). Dwellings are required to acquire a label at the moment of sale or rent, although non-compliance is currently not sanctioned in most member states. Still, the number of performance certificates in The Netherlands has reached 2.5 million by April 2014 (Compendium voor de Leefomgeving website, 2014), slightly over a third of the dwelling stock. The label strives to promote improvements of energy performance among the existing dwellings. The targets for dwelling stocks energy savings in the Netherlands is 90 PJ by 2020 (Koepelconvenant energiebesparing gebouwde omgeving, 2012), using 617 PJ as baseline for year 2008. This target covers residential and non-residential dwellings as well as existing and new construction. The target is based on actual consumption data, which is important, since, numerous research in the recent past highlighted the fact that the actual energy use in individual dwellings deviates from the predicted consumption, which compromises the effectiveness of the implemented policy measures (Majcen et al., 2013a). There is a general consensus among academics that in poor performing dwellings the heating energy use is overestimated (Sharpe and Shearer, 2013; Majcen et al., 2013a) and in well-performing dwellings the trend is opposite (Laurent et al., 2013). The phenomenon is shown on the example of Netherlands in Figure 1.

THEORETICAL VS. ACTUAL GAS AND PRIMARY ENERGY USE
The discrepancy between theoretical and actual heating consumption observed in Figure 1 has already been studied extensively all over Europe (Laurent et al., 2013) as well as in the Netherlands (Guerra Santin and Itard 2012, Majcen et al. 2013a, Majcen et al., 2013b, Tigchelaar et al., 2011). However, the label certificate in the Netherlands does not specify the energy use for heating, but rather natural gas (in m^3), electricity (in kWh),

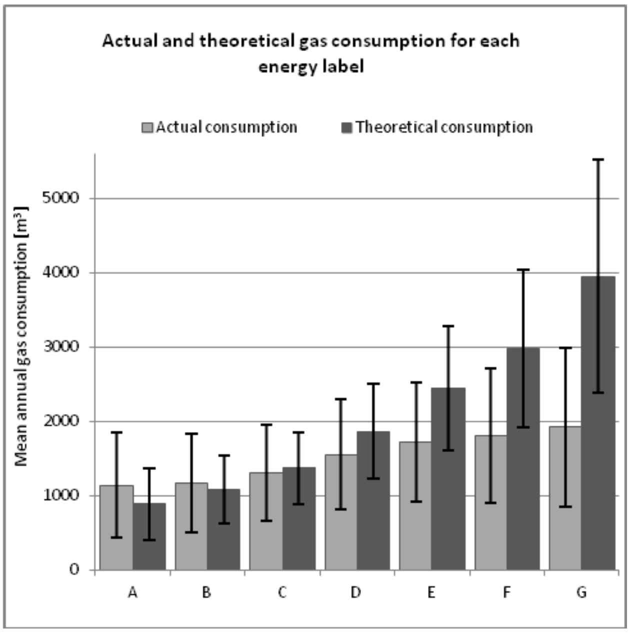

Figure 1. Gas consumption in dwellings across label categories with ±1 st. deviation (Majcen et al., 2013a). From class G to A, theoretical gas consumption decreases by a factor 4.5 while actual consumption only by ca. 1.5. Note that the two bars differ from each other in each category, this difference is in this paper referred to as the DBTA (difference between theoretical and actual gas use).

and total primary energy (in MJ). Gas use in the Netherlands corresponds almost entirely to heating (space and water). It is important to note that dwellings with a more efficient label do have a significantly lower actual gas consumption.

In theory, the differences between theoretical and actual gas consumption are thought to arise from a multitude of factors. Theoretical gas consumption is based on normalized conditions such as indoor temperature of 18 degrees and 2620 degree days, heating the whole floor area, a standardised number of occupants (number of occupants is a function of the floor area), ventilation rate assumed on the basis of the characteristics of the construction elements (for example length of window frames) etc. (Majcen, 2013b). However, the way that occupants use the building in reality differs from these assumptions. According to several authors (Gill et al., 2010, Guerra Santin, 2010, Haas et al., 1998), occupant behaviour and lifestyle is thought to be a key factor in the discrepancy between theoretical and actual heating energy use and is correlated to energy performance itself. It seems that in poor performing dwellings the occupants are encouraged to conserve by the intrinsic poor performance of the dwelling itself (for example – never heat unoccupied bedrooms), while the situation in well-performing dwellings is opposite since a small increase in overall indoor temperature causes only a small change in the total energy bill. Sometimes even the installation itself encourages people to heat all the apartment (for example low temperature floor heating). Since the theoretic calculation normalises many parameters that inherently differ in dwellings' with different performance, a mismatch appears. This phenomenon has already been described in Majcen et al. (2013a) and Majcen et al. (2013b).

State of the art

Many studies address the correlations between actual energy use and potential influencing factors. A good overview of these studies can be found in a paper by Wei et al. (2010). Among those, one can find dwelling related factors such as type of the dwelling or its age, but also a multitude of occupant and behaviour related factors. In this paper, we distinguish four groups of parameters: dwelling, household, occupant behavioural characteristics and comfort. The effect of dwelling characteristics alone has already been widely tackled through better engineering models, and therefore this study focuses on effect of behavioural factors (which sometimes also interacts with dwelling characteristics).

Regarding the dwelling characteristics, Linden et al. (2006) found that occupants in detached houses adopt a lower set point temperature than those in apartments. Hunt and Gidman (1982), Guerra Santin et al. (2009) and French et al. (2007) all found a negative correlation between age and set point temperature. Furthermore, dwellings with a programmable thermostat seem to be heated more than those without (de Groot et al., 2008) and Santin et al. (2010). Also the relation between aspects of building quality and indoor temperature has been previously quantified in the papers from Haas et al. (2010) as well as Shipworth et al. (2009) and Raynaud (2014), who all found that more insulated dwellings have a higher indoor temperature.

Furthermore, studies also explore a multitude of household related characteristics that could influence actual energy use, such as number of occupants, which tend to be correlated with a higher energy consumption (Sardianou, 2008 and Oreszczyn et al., 2006). Apart from the direct influence of the household feature on heating practices, it might also be that dwellings in different performance classes host certain characteristic households (for example, lower income occupants in dwellings with a poorer performance), which would in turn also cause a difference in energy use. Past studies have also shown that older occupants prefer a higher indoor temperature and that people with lower income tend to have a lower indoor temperature (Guerra Santin, 2010).

Even though difficult to describe statistically, occupant behaviour seems to be the one of the reasons for actual energy use not coinciding with theoretical. Under the term behaviour we understand factors such as, presence at home, setpoint temperature, ventilation practices, number of showers number of heated bedrooms, heating of halls and etc. Gill et al. (2010) have shown that a composite variable describing efficient vs. inefficient behaviour would account for more than half (51 %) of the variation in heating energy use. Occupant behaviour is also strongly dependent on the characteristics of the dwelling and at the same time clearly has a significant impact on dwellings actual performance. Behavioural practices are also expected to cross correlate with a multitude of characteristics of the occupant (their age, income, type of employment etc.).

Last but not least, dwelling energy performance also relates to occupants' perceived comfort – the general notion is the better the performance, the more comfortable the occupants (Hong et al., 2009). Therefore, one can expect that more people will feel cold in dwellings with a lower performing labels. However, as formulated by Mishra et al. (2013), conditioned spaces (these are generally well performing) have narrower comfort zones compared to free running buildings (generally poorer performing), which could suggest an opposite trend with occupants actually being more comfortable in low performing dwellings, where they can manipulate the indoor climate better.

Anyhow, existing performance certificates are designed to be used solely to compare dwellings performance with other labelled dwellings and therefore policy makers, investors, researchers, homeowners and other parties for whom pay-back time of a measure is relevant should understand that for any kind of future projections a more realistic consumption has to be considered instead. Since acquiring actual energy data is costly, difficult (privacy laws) and sometimes even impossible (in case we want to renovate an existing building and accurately predict the savings), one should be able to model the consumption better. With dynamic modelling of individual dwellings and the occupants one can estimate the consumption much more accurately. However, this is complex, expensive and does not work on a dwelling stock level. This paper tries to understand what influences actual energy consumption and to what extent, so that in the future, more accurate projections can be made. To find this out, we use label certificate data coupled with actual energy data.

Goal and scope

This paper aims to compare how different dwelling, household, behavioural and comfort characteristics affect the actual and the theoretical heating energy use.

Based on previously conducted studies, we expected to discover certain patterns between the four parameter groups observed in this study and in Figure 2 we summarize our hypothesis. In the first part of this paper we looked for correlations between several parameters (belonging to one of the four groups) and theoretical and actual gas consumption. The thickness of arrows in Figure 2 demonstrates the hypothesised effect size. Our hypothesis is that occupant behaviour and characteristics have a relatively large effect on the actual heating energy (natural gas) consumption, but no effect on theoretical gas consumption, since the theoretical calculation assumes standardised behaviour. However, it might be that the occupant behaviour differs between the label categories and that's why a correlation (not causality) could be detected also with theoretical gas use. It could be that differently performing dwellings correlate with certain behaviours, such as higher setpoint temperature in well performing dwellings and lower temperature in poor dwellings.

Behaviour in this paper signifies occupants' lifestyle practices and their habits, while household characteristics relates to their demographic properties (age, household type etc.). Besides the occupant, we also examined the effect of dwelling characteristics. Here one expects to find the opposite – they should correlate very strongly with the theoretical gas consumption, but the correlation with actual consumption will probably be much weaker. The fourth parameter besides occupant behaviour, household and dwelling characteristics is perceived comfort. In Figure 2 it is depicted as an extension of gas consumption boxes, since our hypothesis was that this is in fact another output of the studied system. We believe comfort to be yet another performance indicator just like energy use. One can expect differently performing dwellings to have a different % of people dissatisfied with the temperature, humidity or air velocity conditions in the house. Comfort is likely to have a stronger correlation with theoretical gas use, since we hypothesise that different performing dwellings might not be equally comfortable. A smaller correlation might be found with actual gas use due to an indirect correlation with theoretical gas use.

Methodology

DATA

The paper is based on a dataset gathered for a study commissioned by the Rekenkamer Amsterdam, the audit office of Amsterdam municipality with the objective of evaluating the subsidies given to social housing corporations by the municipality in previous years. Since it was not possible to get reliable longitudinal data on the dwellings that were actually renovated, the study was based on analysing the energy consumption of dwellings for different label categories

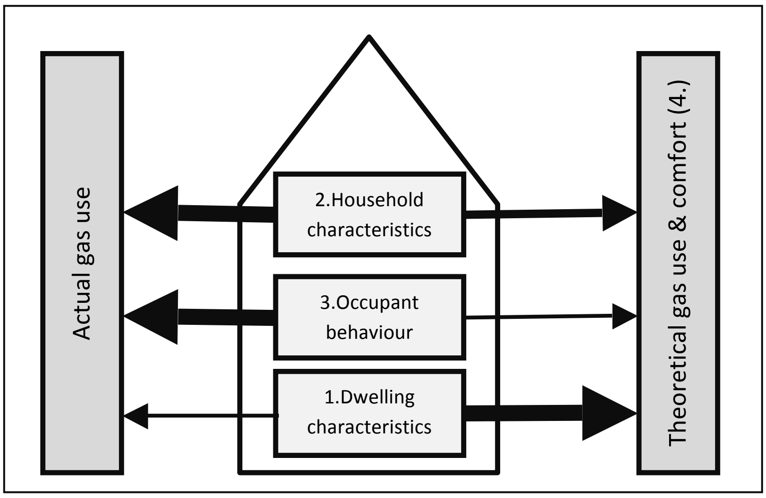

Figure 2. Effects of different parameter groups on actual and theoretical gas consumption.

and comparing them among each other (Majcen and Itard 2014). This paper is based on the same dataset. However, to strengthen the findings of this study, cross checks were made using WOON 2012 dataset. Both Rekenkamer and WOON data are presented below.

Rekenkamer dataset

The original dataset initially contained 245,841 label certificates issued for the Amsterdam area since 2007. After removing district heating, removing non-independent residential units and dwellings with floor area above 1,000 m^2, a sample of about 1,000 dwellings out of the remaining dataset (140,480) was surveyed. Moreover, dwellings that have not been changed in the last three years were selected, in order to make sure that the energy consumption corresponds to the recorded state of the dwelling and the occupants. By law, a meter reading has to performed in a household every three years. Most households do in fact report their meter readings every year, since otherwise they will pay an estimated fee for their annual energy use, but a fraction (estimated to up to 20 %) does not report it. Therefore, by setting a bandwidth of three years we assure more certainty regarding actual consumption data. Then, the survey results were coupled with the actual energy use and the final sample turned out to contain 460 households.

The survey was short (12 min time to fill out online version) but was designed in a way to capture information as condensed as possible. It included 42 questions about dwelling properties that are not present in the label certificate (number of rooms, type of occupancy, thermostat type, water saving shower head etc.), household properties (number, age of occupants, ability to pay energy bill), behaviour of occupants (presence at home, heating and ventilation practices, showering, energy efficient behaviours etc.) and comfort (feeling too warm or cold, too much draught).

WOON dataset

The Dutch Ministry of the Interior and Kingdom Relations carries out a study of energy performance of the Dutch dwelling stock (Woon Energy) every 5 to 6 years as a part of a larger survey of Dutch dwellings (Woon – Woon Onderzoek Nederland, which stands for Housing survey Netherlands). For the validation and comparison of the results obtained in the Rekenkamer survey, the Woon survey from 2012 was used, which was done on a sample of 4,800 representative Dutch dwellings. A general report using this data is publicly available (Tigchelaar and Leidelmeijer, 2013), however, the survey was much richer than described in the mentioned report and is of excellent quality to validate and provide depth to the Rekenkamer data.

Actual energy data standardization

Both Rekenkamer and WOON datasets were merged with standardised actual energy consumption data from the CBS. To enable a comparison between the Statistics Netherlands data and theoretical gas consumption data, a standardisation had to be applied. The Statistics Netherlands data was for the entire calendar year of 2012, which had 2,878.8 degree days. The energy label calculation, on the other hand, assumes 2,620 degree days (for method description see Majcen, 2013), therefore a correction factor of 2,878.8/2,620 had to be applied to the actual gas consumptions supplied by the CBS.

EXPLORATORY ANALYSIS

It is important how the new datasets relate to previously conducted research in The Netherlands. The theoretical and actual energy consumptions according to the two datasets mentioned above are therefore plotted in Figure 3 together with the results of a previous study by Majcen et al. (2013a), denoted as '2010 Label study' (results of the same dataset uncorrected for floor area were shown above in Figure 1). This study analysed consumption of all Dutch label certificates issued in the year 2010 together with actual consumption for the year 2009, containing about 200,000 records. The confidence interval is the smallest in 2010 label study, since it contained the most records. It is also notable that this dataset shows the highest actual energy consumption in poor performing label categories. In newer datasets WOON (energy data from 2010) and Rekenkamer (energy data from 2012) the sample sizes were much smaller (4,800 and 460 respectively). Interestingly, these two datasets do not demonstrate any significant differences in any of the label categories, actual as well as theoretical. It is notable that the actual energy consumption of these samples is lower despite the fact that equal degree day standardization was applied in all three datasets. If we compare the consumption by year, the actual gas consumption seems to be lower in more recent years. This could be due to the fact that degree days method does not account efficiently for annual variations or it might be that to some extent a reduction in actual gas consumption can be attributed to a decreased household size or a decreased consumption of gas for cooking, which is also a recent trend in The Netherlands. To find out what exactly causes these differences, another study should be done.

Despite the differences in actual gas consumption among the samples, theoretical consumption is much more comparable within each label category. Moreover, the phenomenon of over and underpredicted actual gas use remains the same in all three datasets, which makes the two selected samples appropriate for analysis.

STATISTICAL ANALYSIS

The characteristics investigated in this paper are summarized in Table 1. After examining the correlations between all available variables belonging to either of the 4 mentioned parameter groups, the descriptive results were revised. All variables that were significantly correlated to either actual or theoretical gas consumption were included in the linear regression analysis. Before a regression analysis multicollinearity was checked using a correlation matrix and no problematic (above 0.4) cross correlations were detected.

Spearmans rho (rank correlation) was used for establishing correlations between continuous variables. Spearmans correlations revealed a lot of significant correlations between continuous variables and gas consumptions with more detectable correlations coming from the WOON dataset. This was to be expected due to the larger sample size. However, the fact that most correlations found in the Rekenkamer data were present also in WOON data adds strength to our analysis. Since the two datasets made use of two different surveys, not all variables were the same and the results were no always comparable. However, from the ones that we could compare, it is notable that floor area and number of occupants had no significant correlation with actual gas use in the WOON dataset. Moreover,

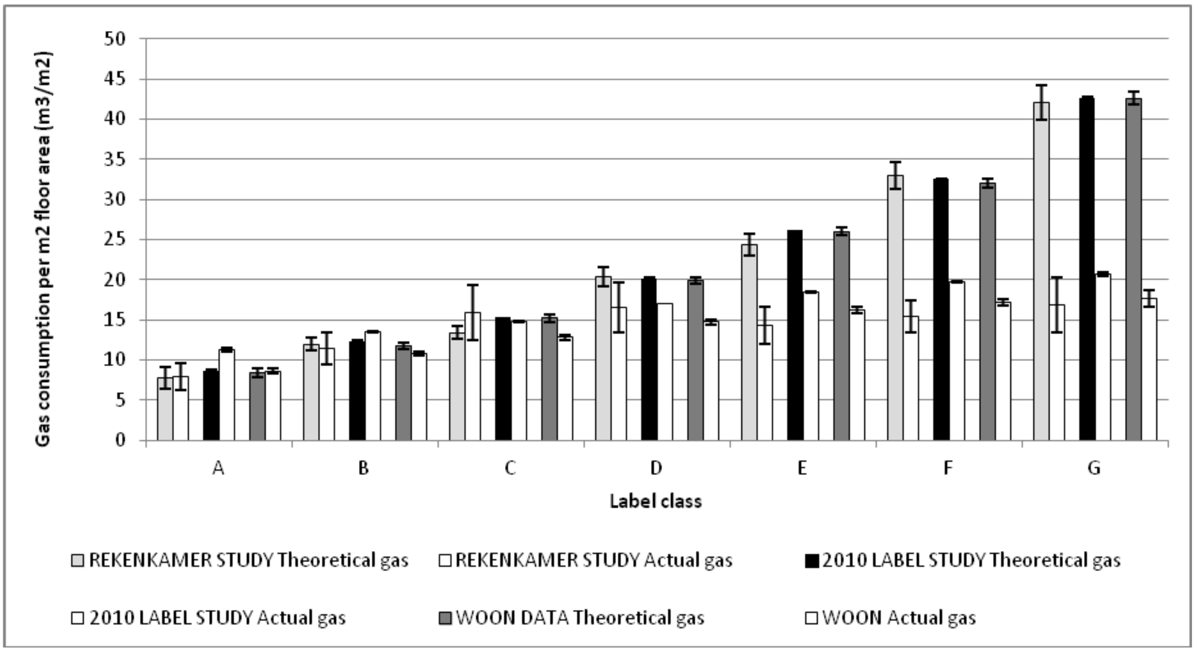

Figure 3. Average actual and theoretical gas consumption per m² dwelling including the 95 % confidence interval.

Table 1. Parameters investigated in the paper divided into four groups (*cat. means a variable was categorical and cont. that it was continuous) and their significance in the Rekenkamer dataset when correlating with actual/theoretical gas use per m² (marked with [1]/[2]).

Dwelling characteristics	Label class (cat.), dwelling type (cat.), heating type (cat.), ventilation type (cat.), electrical boiler presence (cat.)[1], heating of the hall yes/no (cat.)[12], programmable thermostat presence (cat.)[1], floor area (cont.)[2], number of rooms (cont.)[12], age of the building (cont.)
Household characteristics	Ownership type (cat.)[1], Household composition (cat.)[2], education (cat.)[2], ability to pay the energy bills (cat.)[2], age of respondent (cont.)[1], spendable income (cont.)[1], number of occupants (cont.)[2]
Occupant behaviour	Perception dwellings/ households energy performance (cat.), awareness of the label certificate (cat.)[12], ventilation practices – living room/ kitchen/ bathroom/ bedrooms (cat.)[12], ventilation habits weekends (cat.)[1], perceived household energy behaviour (cat.)[2], presence of water saving shower head (cat.)[1], not setting thermostat too high (cat.), not ventilating while heating (cat.)[2], no energy saving measures taken (cat.), number of weekdays of presence – morning(cont.)[12], number of weekdays of presence – midday(cont.)[2], number of weekdays of presence – evening(cont.)[12], number of weekdays of presence – night(cont.)[12] , average temperature during the day – day(cont.)[2], average temperature during the evening(cont.)[2], average temperature during the night(cont.)[2], average temperature when nobody at home(cont.) , showers per week (cont.)
Perceived Comfort	Perception of heat/cold(cat.)1, Perception of dry/humid(cat.)[12] and perception of draft (cat.)[1], Unpleasant long waiting for hot water (cat.)[12]

[1] Insignificant correlation/Chi-square/Mann-Whitney U with actual gas consumption per m².

[2] Insignificant correlation/Chi-square/Mann-Whitney U with theoretical gas consumption per m².

age of respondent had a significant correlation with theoretical gas consumption in the Rekenkamer data but not in the WOON dataset, however in the linear regression model, age was no longer a significant predictor. Another variable that surprised us was the ventilation practice in the weekend (vs. during the week). Theoretically we do not see why this variable would have an effect on theoretical gas consumption, but since it demonstrated significant correlation we also included it in the regression analysis later on.

For categorical and binary variables, we observed whether or not the categories differ from each other significantly regarding the distribution of energy consumption. Kruskal Wallis's non parametric test for independent measures was used for variables with more than 2 categories and Mann Whitney's U statistic was calculated for binary variables. Variables are divided into 4 groups, according to the groups of parameters as described in Figure 2 and Table 1. Except for the results in Table 1, we decided not to show descriptive results in this paper due to constraints regarding length. We rather focus on the regression analysis, for which we used only variables that were significant in previously done correlation testing.

Linear regression analysis was conducted using manual backward-elimination of insignificant variables because of the many categorical predictors, which are considered separately using the automated SPSS method. We manually removed the variables (or combination of dummies that together form a variable) with the highest p-value (and not statistically significant) step by step until only statistically significant variables remain. Dummy coding was used in order to enable inclusion of categorical variables.

Linear regression results

Regression analysis of the Rekenkamer dataset showed that with the variables used (see Table 1 for all variables included, and Table 3 and Table 4 for final model of significant variables) one can explain 23.8 % of the variance in the actual energy use and 65.1 % in theoretical. Regressions were also performed per group of characteristics, to see how much variance in total gets explained by a single group.

For actual consumption, each additional 10 year to building age results in 0,39±0,1 m^3/m^2 more gas consumption. Note that this is only true in the exact combination of predictors used in the regression analysis. Conversely, 10 m^3 less floor area causes a decrease in consumption for about 1,18±0,2 m^3/m^2. Both these variables were also significant predictors for theoretical gas use, building age about twice as strong and floor area about a third half less.

Presence and indoor temperature are two variables that have effect on actual consumption. For each additional day of midday presence, actual gas use is 0.631 m^3/m^2 higher, whereas night-time presence has the opposite effect of lowering gas use by 0.995 m^3/m^2. Each additional night time temperature also increases the gas use for 0.123 m^3/m^2 and midday temperature for 0.242 m^3/m^2.

Dwelling type is a variable significant only when regressing theoretical gas consumption. Flats with staircase entrance, semidetached houses and row houses seem to consume more theoretical gas use than gallery flats.

When it comes to heating type, types have a significantly lower theoretical gas consumption than gas stove. An even better predictive power is however encountered looking at theoretical gas consumption. All installation systems relate to a lower theoretical gas use than gas stove. Installation system has no detectable effect on actual gas consumption.

Regarding household composition, it can be noted that all household types with an elderly occupant have a higher gas consumption. Furthermore, people who find it really easy to pay the energy bill seem to consume less gas in reality than the people who find it 'only' easy. The occupants with only averagely efficient behaviour and the ones that set thermostat too high turned out to consume more gas.

Table 2. Adjusted R^2 values and the model error of regression analyses of the Rekenkamer dataset.

R^2 values [model error]	Dwelling characteristics	Household characteristics	Occupant behaviour	Comfort	Total
Actual gas use per m^2	8.6 [7.96]	3.1 [8.19]	10.7 [7.55]	0	23.8 [6.89]
Th. Gas use per m^2	64.3 [7.37]	4.3 [11.76]	7.5 [11.52]	0	65.1 [7.31]

Table 3. Regression analysis of actual gas consumption per m^2 floor area (in case of categorical variables, the reference category is referred to as 'vs. …').

	adj. R^2=23.8 %; model error=6.89	B	Std. Error	Beta	Sig.
	(Constant)	8.901	3.108		.004
Dwelling characteristics	Age of the building	.039	.010	.181	.000
	Floor area	-.118	.021	-.302	.000
	Age of the respondent	.084	.029	.166	.004
	Number of occupants	1.195	.467	.142	.011
Household characteristics	Missing vs. very easy to pay energy bill	3.502	4.072	.039	,390
	Rel. easy vs. very easy to pay energy bill	-2.136	.830	-.135	.010
	A bit hard vs. very easy to pay energy bill	.002	1.100	.000	.999
	Very difficult vs. very easy to pay energy bill	1.054	1.957	.026	.590
Occupant behaviour	Number of weekdays of presence – midday	.631	.207	.168	.002
	Number of weekdays of presence – night	-.995	.360	-.134	.006
	Average temperature during the day	.242	.104	.110	.021
	Average temperature at night	.123	.051	.116	.015
	Missing vs. energy efficient behaviour	7.545	4.946	.068	.128
	Average vs. energy efficient behaviour	2.125	.751	.133	.005
	Inefficient vs. efficient behaviour	3.715	1.874	.090	.048

Table 4. Regression analysis of theoretical gas consumption per m² floor area.

	adj. R^2=65.1 %; model error=7.31	B	Std. Error	Beta	Sig.
	(Constant)	30.656	2.752		.000
Dwelling characteristics	Age of the building	.097	.012	.287	.000
	Floor area	-.079	.019	-.134	.000
	Maisonette vs. gallery house	3.314	2.434	.044	.174
	Portiek appartment vs. gallery house	2.650	1.082	.098	.015
	Row house vs. gallery house	3.621	1.666	.074	.030
	Semidetached vs. gallery house	18.661	2.851	.204	.000
	Missing data vs. gallery house	2.125	7.372	.008	.773
	Heating with η<83 % boiler vs. gas stove	-4.427	2.225	-.066	.047
	Heating with η>90 % boiler vs. gas stove	-11.717	2.773	-.136	.000
	Heating with η>96 % boiler vs. gas stove	-14.530	1.321	-.546	.000
	Heating with η>83 % vs. gas stove	-6.478	1.624	-.162	.000
	Heating other vs. gas stove	-16.705	5.359	-.092	.002
	Shower boiler vs. combined gas boiler (no hot water reserve)	5.814	1.737	.099	.001
	Kitchen boiler vs. combined gas boiler (no hot water reserve)	5.039	1.437	.126	.001
	El.boiler vs. combined gas boiler (no hot water reserve)	1.328	2.691	.015	.622
	Other vs. combined gas boiler (no hot water reserve)	-1.710	3.186	-.016	.592
Occupant b.	Ventilating in the week missing data vs. weekends more ventilation*	6.285	2.123	.090	.003
	Ventilating in the week equal vs. weekends more ventilation	1.336	.878	.050	.129
	Ventilating in the week less vs. weekends more ventilation	3.709	1.732	.068	.033
Comfort	Perception of draft yes/no (binary)	-1.910	.847	-.065	.025

** As advocated by Cohen and Cohen (1975) we kept missing values in a separate dummy variable in order to retain as many records as possible.*

Our hypothesis was that dwelling related parameters would correlate more with the theoretical gas use than with actual and as shown in Table 2, this was a correct hypothesis. Regarding the floor area, in both cases, a larger floor area means a lower gas consumption per m² (Table 3 and Table 4). However, though, the effect is bigger in the regression of actual gas consumption than in theoretical, meaning that the consumption of gas per m² dwelling is even smaller in reality than expected theoretically.

Age of the building complies with the hypothesis and has a smaller impact on actual than on theoretical gas use, just like dwelling type and installation system (both have no effect on actual gas consumption). This makes sense, since age is known to relate well to dwellings performance. However, actual heating consumption depends also on other factors.

Furthermore, our hypothesis was also correct in predicting a higher correlation of household and behavioural variables with actual gas use, which was detected in household composition ability to pay energy bills, presence at home, setpoint temperature and efficiency of behaviour (how energy efficient do occupants think their behaviour is). Presence and indoor temperature are two very important parameters in determining actual gas use of a dwelling. Midday presence correlates to an increased actual gas use, however, the more presence at night, the lower the actual gas use. It seems that people who are not often sleeping elsewhere tend to have a lower gas use. Conversely, the ones that often sleep elsewhere (they should in fact be heating their house less) have a higher actual gas consumption. There could however, be an indirect relationship between people in better performing dwellings and the weekends spent away (wealthier people, more work related travel etc.).

Dwelling and installation type were not relevant predictors of actual gas consumption, however, as hypothesised in the beginning, both were more strongly correlated with theoretical gas use. Semidetached houses have a larger outside wall area, which could contribute to why they relate so well to theoretical gas use. Moreover, they have a larger floor area out of which some bedrooms are often not heated – this occurs less in gallery apartments. In the future, a regression model could be made using the variables utilized in this study and theoretical gas consumption as predictors for actual gas consumption as dependent variable. Based on the resulting B coefficients, correction factors could be applied to parameters which would turn out as significant (such as installation type, dwelling type etc.), in order to obtain theoretical gas consumption that fits the actual consumption better. A follow up study will be carried out to explore this option.

The fact that elderly correlate with higher gas consumption signify that they probably have higher comfort standards. The lower gas use of people who find it really easy to pay the bill might mean that they live in better performing houses. Moreover, people's efficiency behaviour, which includes the way they manipulate the thermostat is responsible for an analogous change in gas use. However, the causality and interactions between the variables is very complex, and the results have to be interpreted with care, an example of this is the rather mysterious effect of the variable describing weekend ventilation practices (in relation to ventilating practice during the week). However, as the most significant predictor is the category with missing data, this variable is probably not demonstrating any real effects.

Remarkably, low performing dwellings do tend to have a higher share of occupants who have detected draft, which also partly proves the hypothesis about comfort mentioned in the beginning.

Discussion

The two important factors are the errors in the certificates and uncertainties in actual consumption data quality. Regarding the first, it seems that many times the inspection is not carried out as accurately as it should be and the certificate doesn't correspond to the real state of the dwelling. A 2011 study has proved a rate of inaccuracy of the label certificate of 16.7 % and in 2013 the inaccuracy was 21.2 % (the percentage corresponds to the number of certificates where label class was wrong), although the research in 2013 only looked at non-residential building (VROM Inspectie, 2011 and Inspectie Leefomgeving en Transport, 2013). However, there was a trend of the improvement in preceding years, so the certificate accuracy in the sample used should be sufficient. Nevertheless, one should note that certificates of poor performing dwellings carry a greater risk of uncertainty since determining their construction features is a more tedious and error prone process due to a lack of documentation and many of the characteristics are assumed on the basis of the construction year of the dwelling. On the other hand, newer dwellings are usually much easier to inspect as all the construction properties are well known.

The second important factor that is to some extend beyond the scope of this paper is the quality of energy data. The data originates from Statistics Netherlands, a governmental organisation that collects this data from energy companies. The companies report the billing data, which is calculated on the basis of meter readings. In some cases the occupants do not report the meter reading and in such instances, the consumption is based on the average consumption of dwellings in the region managed by one network management company, corrected for climatic variations (Informatiecode Elektriciteit en Gas, 2014). Experience from the European project BEEM UP that made use of data provided by an energy company, showed that in the years 2010–2014 the data was estimated in 20 to 50 % of the cases annually for both gas and electricity. The mentioned code, however, obligates the network managing company to collect the meter readings by themselves at least once in 36 months which ensures at least some basic actualisation of the data.

In the paper we found dwelling and household characteristics to be relatively easy to record via a survey if compared to the other two parameter groups. The two slightly more complex parameters among household characteristics were household composition and education. A really clever survey design is needed here to really capture groups that demonstrate differences when it comes to gas use. Since so far, few guidelines based on scientific findings are available, our survey questions might have been too granulated (for example, it doesn't seem to matter whether there are 3 children and 2 adults and 3 children and 3 adults). This was even more of a problem in variables such as presence at home, where it seemed as if presence in the morning and midday were the only ones significant. It might be better to have a good composite variable for presence, like was done in the Rekenkamer, 2014. Besides clever design of survey questions, results of regression analysis might also depend on sample selection. Our studies sample was not selected randomly which has some disadvantages (less chance of a good representatively) and some advantages (enough data points to show correlations also in extreme consumptions).

It remains unclear how well the degree day method really corrects for the heating intensity, and in this paper we showed some uncertainties regarding actual use of different samples in The Netherlands. In the regression analysis for this paper we only included the variables that had an effect on theoretical or actual gas use when analysed independently, since these are the variables that could exhibit the most relevant effects on the dependent variables. In theory the variables we omitted (Table 1) could exhibit secondary effect after the influence of the main predictors is accounted for in the regression analysis. It would, however, be useful to either confirm or refute the existence of such secondary effects in a further study by analysing the regression results using various automatic regression methods – stepwise, forward and backward. By examining results we would then find out whether the variables which we excluded in this study exhibit real effects and in which combinations of predictors they become significant.

Conclusion and future work

This study proves the previously discovered discrepancies between theoretical and actual gas use across different performance classes by showing examples from 2 different data sources for The Netherlands. It seems that normalised building use irrespective of building typology and installation characteristic does not yields accurate predictions about heating energy use. To avoid confusion among users of dwellings' performance certificates, this has to be improved. The paper shows that by using actual heating energy data, it is very well possible to find out which factors influence it more in detail (Table 5).

The analysis showed once again, that using detailed survey data, it is still very hard to explain variance in the actual heating energy. However, the variation in the theoretical gas use is easier to explain using variables which are usually more easily available, such as dwelling characteristics.

In further analysis we will conduct a regression analysis of the difference between theoretical and actual gas consumption. It can be that a variable has effect to actual gas consumption, but it is compensated for also in theoretical gas consumption and consequently there is no effect on DBTA (difference between theoretical and actual gas use). For example, dwelling type might have a significant impact on actual gas consumption

Table 5. Summary of regression results per parameter group for all independent variables.

	Actual gas use	Theoretical gas use
Dwelling char.	Building age, floor area	Building age, floor area, dwelling type, inst. type
Household char.	Elderly, ability to pay the bill	/
Occupant char.	Midday presence, night temp., presence, eff. of behaviour, thermostat setting	Ventilation practices
Comfort	/	Draft perception

but that can be true also for correlation with theoretical gas consumption and consequently there is no effect of dwelling type on DBTA. If the effect is not taken into account as strongly in theoretical as in actual gas consumption we can expect there will still be an effect of that variable on DBTA.

Moreover, in the future it would be interesting to use actual gas use as a dependent variable and theoretical gas use with other available parameters as predictors. That way one could find out how the existing calculation has to be modified in order to get closer to actual gas use, and how much of the variance can be explained with this method. It could be limited to modifying dwelling and/or household characteristics only, since in that way the performance certificates remain comparable or we could obtain an even more accurate prediction by expanding the prediction to occupant behaviour and comfort perceptions well.

Another thing to investigate is the fact that differently performing dwellings are influenced by predictors differently has to be considered in future studies as well. In this paper, the analysis was done for total sample, but different predictors might be relevant in differently performing dwellings. Ideally, regression analyses should be performed per label category in the future, however a large enough sample is required for that. We could expect for example, that the efficiency of installation systems might play a big role in the low performing dwellings, but no role in well performing dwellings (since they all have very good installation systems). A more detailed follow up study will explore these relations.

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