Energy Policy 61 (2013) 460–471

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

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

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HIGHLIGHTS

- Floor area, ownership, salary and value predict the change in actual gas use well.
- Mentioned variables are insignificant or have small impact on theoretical use.
- Energy consumption of less energy efficient systems is overestimated.
- Accurate model assumptions and inspections would reduce the discrepancies.
- Big discrepancies stem from misassumption of temperature, heated floor area, *U* values.

ARTICLE INFO

Article history:
Received 14 February 2013
Accepted 6 June 2013
Available online 8 July 2013

Keywords:
Energy label
Theoretical gas consumption
Actual gas consumption

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., 2013). 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.

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.

The motivation for the present study was a previous paper by Majcen et al. (2013), 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 (Fig. 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

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http://dx.doi.org/10.1016/j.enpol.2013.06.018

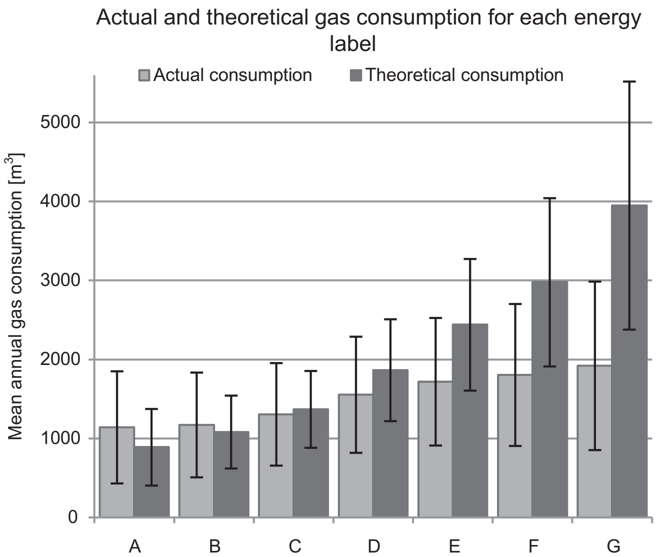

Fig. 1. Gas consumption in dwellings across label categories with ±1 std. deviation (Majcen et al., 2013).

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., 2013), which is the final aim of such an energy label.

1.1. Actual vs. theoretical heating energy consumption

Results similar to those shown in Fig. 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 et al. (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. (2013) 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. (2013) 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 Fig. 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 (Fig. 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. (2013) 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 Ó Gallachóir (2011). Majcen et al. (2013), 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 2 provides a brief overview of the Energy Labelling Framework in the Netherlands. Section 3 presents the sample data, the research methods and the regression analysis. The results and methods of the sensitivity analysis are given in Section 4. Finally, a discussion follows in Section 5 and our conclusions are presented in Section 6.

2. The method used to calculate the energy label and the data used

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