Energy and Buildings 105 (2015) 43–59

Contents lists available at ScienceDirect

Energy and Buildings

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

Statistical model of the heating prediction gap in Dutch dwellings: Relative importance of building, household and behavioural characteristics

Daša Majcen*, Laure Itard, Henk Visscher

OTB—Research for the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology, Julianalaan 134, 2628BL Delft, The Netherlands

ARTICLE INFO

Article history:
Received 16 March 2015
Received in revised form 24 June 2015
Accepted 4 July 2015
Available online 20 July 2015

Keywords:
Theoretical heating energy consumption
Actual heating energy consumption
Performance gap
Regression analysis

ABSTRACT

The European Performance of Buildings Directive (EPBD) set the regulatory framework for a cost-effective improvement of the existing dwellings in 2002. The transformation of the stock towards higher efficiency is expected to be stimulated by labelling of the dwellings. The certificate itself is required to contain a list of potential cost-effective measures for the dwellings' thermal retrofit. However, the theoretical heating consumption provided in the certificate is not a good baseline for the calculation of cost effectiveness, as it is based on normalised dwelling conditions. Normalised conditions include a constant occupancy, constant indoor temperature and normalisations of other parameters, which in reality differ in different types of dwellings. The discrepancies between the normalised theoretical and actual heating consumption are also referred to as the performance gap. In this paper, we examined these discrepancies using the example of The Netherlands. Using descriptive statistics and multiple regression, we investigated several parameters thought to have a different effect on actual and theoretical heating energy use – dwelling, household, occupant behaviour, as well as comfort – in order to propose improvements to the current theoretical consumption calculation. Aside from analysing the total sample, the data is regarded separately for overpredicted and underpredicted consumption records.

1. Introduction

Dwellings represent a great potential for future energy savings. Several policy measures have been undertaken in the EU and nationally to encourage the transformation of the dwelling stock towards lower energy consumption. The European Performance of Buildings Directive (EPBD) has set the guidelines for dwelling performance certification, called the energy label, since 2002 and label certificates in The Netherlands have been issued since 2007. The Dutch energy label assesses dwellings' energy performance based on a steady-state energy model (detailed methodology is described in [30]), resulting in an energy label that ranges from A (good thermal performance) to G (poor thermal performance). Dwelling owners are required to possess a label at the moment of sale or rent, although non-compliance is currently still not sanctioned. Still, the number of performance certificates in The Netherlands reached 2.5 million by April 2014 [2], slightly over a third of the dwelling stock.

The target for dwelling stocks energy savings in The Netherlands is 110PJ by 2020 [24], using 617PJ as a baseline for the year 2008. This target covers residential and non-residential dwellings as well as existing and new construction. However, preceding this target, The Dutch federation of housing associations (Aedes) committed itself in the 'Covenant Energy Savings Housing Associations Sector' [3] to achieve a 24 PJ reduction of the consumption of natural gas in the existing social housing stock (represented by roughly a third of the country's stock) between 2008 and 2018. Under the 'More with Less' (Meer met Minder [4]) programme, the Dutch government and external stakeholders (corporations, real estate companies, and other stakeholders) have committed themselves to achieving a reduction of 30% of the energy consumption (100 PJ) of buildings by 2020. Comparing these two targets with the 90PJ target from 2012, which contains the residential as well as the non-residential sector, reveals that the ambitions have dropped significantly in the past. The new target is finally based on actual consumption data, which is important, since numerous research projects in the recent past highlighted the fact that the actual energy use in individual dwellings deviates from the predicted consumption. In poor performing dwellings, the heating energy use is overestimated [29,44] and in well-performing dwellings, the

* Corresponding author. Tel.: +0031 6 1985 4496.
E-mail address: d.majcen@tudelft.nl (D. Majcen).

http://dx.doi.org/10.1016/j.enbuild.2015.07.009
0378-7788/

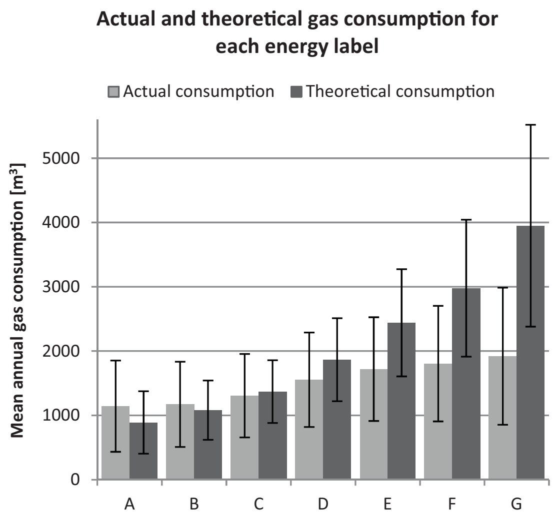

Fig. 1. Gas consumption in dwellings across label categories with ±1 st. deviation [29]. Note that the two bars differ from each other in each category, this difference is in this paper referred to as the DBTA (difference between theoretical and actual gas use).

trend is the opposite [26,29], therefore using theoretical data as baseline which compromises the effectiveness of policy measures [29].

The phenomenon of discrepancies also called the performance gap [43], is shown on the example of The Netherlands in Fig. 1. This discrepancy is of crucial importance for the success of EPBD in the long run, since the directive states (Article 1 of EPBD) that it promotes the improvement of the energy performance of buildings within the Union, taking into account cost-effectiveness and to successfully estimate the cost effectiveness one needs to be certain of the baseline consumption. This study as well as in Fig. 1 analyses the heating component of the total primary energy consumption, which is the basis for the label certificate. The average total primary energy consumed in each label category, is available in [29]).

1.1. Theoretical vs. actual gas and primary energy use

The discrepancy between theoretical and actual heating consumption observed in Fig. 1 has already been studied extensively all over Europe [26] as well as in The Netherlands [15,29,30,39]. However, the label certificate in The Netherlands does not specify heating energy use, but rather gas (in m^3), electricity (in kW h), and total primary energy (in MJ). Gas use in The Netherlands corresponds almost entirely to heating (space and water) and is also the scope of this paper. In The Netherlands, dwellings are predominantly heated with gas and heating is necessary for roughly 200 days in the year, and since there is rarely any cooling demand (nor are the majority of dwellings equipped with air conditioning), heating represents the majority of the dwellings' energy use. A small fraction of dwellings is heated by electricity, but in our sample they were excluded. From the data used, one could not distinguish gas for cooking from gas for heating; therefore it was included in the analysis. However, cooking represents a small fraction, less than 5% on household level, and is constant regardless of dwellings performance. Therefore it does not skew the analysis.

It is important to note that If we correlate theoretical gas consumption with actual, we do get a significant result (albeit correlation is weaker in reality that one might expect). In other words, dwellings with a more efficient label do have significantly lower actual gas consumption (Fig. 3). In that sense, the label correctly predicts dwellings' thermal performance. To illustrate, [13] found the Pearson's correlation between actual end theoretical energy use for space heating within a sample of 185 dwellings to be 0.391 and the correlation in the two samples studied in this paper was 0.532 (N = 4106) and 0.320 (N = 468), respectively. However, at the same time, neither the 185-dwelling sample of [13] nor a larger sample from the same study of 563 dwellings demonstrated a correlation between the theoretical and actual total primary energy consumption, meaning that better performing dwellings do not necessarily have lower total primary energy consumption. This is logical because the actual total primary energy use includes the total electricity use of the dwellings (including all household appliances) while the theoretical primary energy use includes only the electricity use relating to the building (lighting, pumps, & ventilators but no household appliances). It was also shown that electricity use remains rather constant regardless of the label class (Fig. 12 in [29]), which decreases the correlation strength. To prevent that, the present paper focuses on gas consumption only.

1.2. What causes the discrepancies?

The differences between theoretical and actual gas consumption (DBTA) 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 of the entire floor area, a standardised number of occupants (which is a function of the floor area), infiltration rate assumed on the basis of the characteristics of the construction elements (for example length of window frames), etc. (Tables 7 and 4 in [30]). The way that occupants use the building in reality probably differs from these assumptions. According to several authors [10,13,17], 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. To elaborate, it is believed 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 the physical properties of the dwelling cause a certain type of behaviour; for example, occupants in dwellings with floor heating often do not have a choice but to condition the entire floor area, a practice opposite to the one in many poor performing dwellings with a sole heating element in the living room. Since the theoretic calculation normalises many parameters that inherently differ in dwellings' with different performance, a mismatch appears. The fact that behaviour and dwellings are so intertwined makes the causality analysis of the difference between theoretical and actual gas consumption (DBTA) very challenging.

Looking at different performance classes, the DBTA seems to be positive in poor performing dwellings (later on referred to as overpredition), meaning that theoretical gas use is higher than actual. In the most extreme cases the theoretical gas use can be as high as double of the actual consumption. This phenomenon seems to arise from the fact that poor performing dwellings are in fact under heated. On the other hand, underpredictions are characterised by an actual consumption higher than the theoretical, which occurs in well performing dwellings. In literature the expression 'rebound effect' is also used [38], meaning that the consumption of energy increases when applying a saving measure. In the same paper, the overprediction of theoretical heating energy consumption is referred to as the pre-bound effect.