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Actual heating energy savings in thermally renovated Dutch dwellings

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HIGHLIGHTS

- Performance gap is lower in more efficient buildings.
- Replacements of gas boilers – the most energy reduction among renovation measures.
- Replacing the ventilation system yields a much larger reduction than expected.
- How well are the standard values of the calculation methods defined?
- Provide large public building performance databases including actual use data.

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ABSTRACT

The register of the Dutch social housing stock was analysed, containing 300.000 dwellings, renovated between 2010 and 2013. The main objective was twofold: to evaluate the performance gap in these dwellings before and after the renovation and to establish what renovation measures achieve the highest reduction of consumption, particularly in practice (actual savings). The results showed large performance gaps in dwellings with low R and high U values, local heating systems, changes from a non-condensing into a condensing boiler and upgrades to a natural ventilation system. Regarding the actual effectiveness of renovation measures, replacement of old gas boilers with more efficient ones yields the highest energy reduction, followed by deep improvements of windows. Installing mechanical ventilation yields a small reduction compared to other measures, but still much larger than theoretically expected. The paper shows once more that the calculation method currently in use cannot be considered accurate if compared to actual consumption. The study demonstrated that unrealistic theoretical efficiencies of heating systems and insulation values are causing a part of the performance gap. Nowadays, large datasets of buildings thermal performance and actual consumption offer an opportunity to improve these misconceptions.

1. Introduction

1.1. Background

Energy Performance of Buildings Directive is, since its first adoption in 2002, the main policy driver in reducing energy consumption in buildings in Europe. By proposing several actions such as a national performance calculation methodology (Article 3), performance certification of new and existing buildings (Article 11 and 12), cost optimality calculation (Article 5), the directive strives to raise awareness and increase investments leading to an accelerated transformation of the dwelling stock. To ensure that the directive is paving the way towards achievement of the set goals, monitoring of the dwelling stock efficiency is paramount on the national and European level to prove whether or not the improvements in efficiency are driving towards the desired targets and to reflect on the adopted policies and apply amendments where necessary. For this study, we used a non-public register called SHAERE, which includes the annual performance of almost all dwellings of social housing associations between 2010 and 2013. In The Netherlands the social housing stock represents about a third of the total dwelling stock and is supposed to set nationwide example for lowering the stock's energy consumption. Each year, the associations record the state of most of their dwellings, including their energy performance. Previously published research

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conducted on the mentioned data analysed the renovation pace between the years 2010 and 2013 (Filippidou et al., 2015, 2016). This paper builds upon these findings by observing theoretical and actual heating energy consumption before and after thermal renovation, which allows to compare the performance gap (difference between theoretical and actual gas consumption) before and after renovation, providing a much needed validation of the current label calculation method. Moreover, the theoretical reductions in dwellings where specific measures have been taken are compared with the actual metered reductions. This helps to pinpoint the most effective renovation measure in terms of achieved savings. The outcomes obtained by using different analysis methods are compared, making the analysis robust and offering an insight into the accuracy of the methods.

Several definitions are used throughout the paper. Dwelling properties include 5 dwelling characteristics: type of space heating installation, hot tap water system, ventilation system, window thermal quality and the quality of insulation of roof, floor and wall. The later three are aggregated into one variable referred to as the insulation of the envelope. A renovation measure is defined as a change in at least one of these 5 parameters from one category into another (the continuous properties for insulation and window quality have been categorised). A pre-label is a complete thermal recording of the dwelling, including all dwellings energy labels, theoretical heating demand and dwelling properties, but not necessarily registered as an official label certificate. Label registration is the act of submitting the pre-label data to the competent authority, thereby obtaining an official label certificate. Energy index is calculated according to the national standards on the basis of total primary energy demand, summing up the energy required for heating, hot water, pumps/ventilators and lighting, and subtracting any energy gains from PV cells and/or cogeneration and finally correcting this sum for the floor and envelope area. The performance gap is the difference between theoretical and actual gas consumption of a dwelling or group of dwellings.

1.2. State of the art

Filippidou et al. (2015, 2016) describes the annual frequencies of 7 renovation measures in The Netherlands. According to the author, 16.8% of the dwellings have improved their label class between years 2010 and 2013. Another study analyses the Dutch dwelling stock and the measures taken based on a survey of about 4000 representative dwellings (Tigchelaar and Leidelmeijer, 2013). The results show that the energy index of dwellings has improved from 2.09 to 1.89 (label E to label D) in the years 2006–2012, which is comparable to the pace of improvement as described by Filippidou et al. (2016), where the index dropped from 1.81 in 2010 to 1.69 in 2013. The sample analysed in the study by Tigchelaar and Leidelmeijer was relatively large, representative, and not limited to social housing associations but used cross sectional and not longitudinal data. The third study is a national monitoring carried out in The Netherlands (Hezemans et al., 2012) on the basis of a survey – managers of housing corporations were asked to report on to the changes in the stock retroactively. An assumption was made that implementing two saving measures (insulation of an envelope part or a replacement of heat installation) coincides with 20% reduction in energy use. In the mentioned years together it was established that about 950,000 dwellings were made 20–30% more energy efficient. This monitoring was indirect (the assumption that two measures correspond to 20% energy reduction is a very rough one), used survey instead of measured data and analysed relatively small samples which affects representativeness. However, it was the best available at that time and the assumption about two measures coinciding with a 20% reduction has been made due to serious gaps in existing knowledge about actual energy saving of renovation measures.

These three studies delivered information about the thermal measures taken in the housing stock but not on their effectiveness to achieve energy savings. Studying the actual energy savings of thermal renovation measures enables a precise evaluation of renovation strategies and policy effectiveness. Previous research showed that in The Netherlands, well performing dwellings consume more than expected and that poor dwellings consume up to half less than expected (Majcen et al., 2013a, 2013b) causing the actual energy savings to be smaller in reality than expected. One of the causes of this performance gap is the fact that theoretical calculations rely on the same normalised conditions (for example average indoor temperature) regardless of the dwelling quality, even though in practice it turns out that the indoor environment differs greatly in poor performing dwellings from the one in efficient dwellings. The gap seems to be difficult to explain statistically, mostly due to the complex nature of the variation in actual gas consumption. However, differences in average indoor temperature and in the quality of estimation of insulation and ventilation flow rates in dwellings of different quality and socio-economic factors were shown to be important factors in explaining this gap (Majcen et al., 2015). Menkveld studies the relation between the energy saving measure taken and the actual energy reduction using the national energy label database, which is dominated by social housing associations (about 70% of social housing and 30% of private dwellings, Majcen et al., 2013a). However, this study observes cross sectional dwelling data (only one record in time available for each dwelling), comparable also with previous analysis done by Majcen et al. (2013a, 2013b), Tigchelaar and Leidelmeijer (2013).

Up until recently, international research papers which evaluated operational energy consumption based their analysis on purely on theoretical heating energy (Adalberth, 1997; Winther and Hestnes, 1999; Dodoo et al., 2010; Thormark, 2002). As shown, theoretical consumption can diverge from the actual consumption by as much as 50% less or 30% more. In more recent years, the focus on actual consumption is increasing and studies of the performance gap are starting to appear all over Europe. They indicate results, similar to the Dutch ones – an overprediction of inefficient (Tigchelaar et al., 2011; Cayre et al., 2011; Hens et al., 2010) and underprediction (Haas and Biermayr, 2000; Branco et al., 2004; Marchio and Rabl, 1991) of efficient dwellings. The phenomenon of underestimated theoretical consumption is also referred to as 'rebound effect' (Berkhout et al., 2000). This means that an efficient technology (such as thermally renovated dwellings) cut energy bills but thereby encourage increased consumption. Next to the rebound effect, the term 'pre-bound effect' can also be found in the literature, describing the overprediction of consumption in old, inefficient dwellings (Sunikka-Blank and Galvin, 2012). A comprehensive overview of the literature can be found in Majcen et al. (2013a). International studies of adverse effects of the gap are presented in Majcen et al. (2013b), and a review of the international paper that examine the causes of the gap was done by Majcen et al. (2015).

Despite the multitude of monitoring studies and studies on the performance gap, there seems to be a lack of studies analysing the efficiency of renovation measures at the stock level. However, the gap in the literature is understandable since no large scale data about the dwelling stock's energy performance and actual energy use was available previously. Despite this, an objective and representative evaluation of the undertaken saving measures is paramount in order to evaluate and improve the effect of current retrofit policies. The objective of this paper is therefore to fill this data gap by studying actual consumption of dwellings on a large scale.