CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 1

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Actual energy savings by upgrading boilers and windows: the results of a large scale study in the Netherlands

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Abstract

The assessment in the whole building stock of actual energy savings resulting from thermal renovation of dwellings was up to now limited by the high costs of such a monitoring operation. The emergence of large databases at national level, however, makes this assessment possible, producing very valuable results for policy makers and the building sector. This paper presents the results of a large scale study in the Netherlands, where a national energy label database containing yearly updated data about 2 million social rented dwellings, was coupled at address level to the actual energy database from Statistics Netherlands. The dwellings in which only the boilers or only the windows were upgraded between 2011 and 2013 were selected and their heating energy consumption before and after renovation were compared. In more than 30.000 dwellings the heating system, and only the heating system, was upgraded. In almost 16.000 dwellings old glazing –and only the glazing- was replaced by a more efficient one. The energy savings in these dwellings were analyzed and compare to the expected savings before renovation, showing in general much lower savings than expected. The research also shows that the energy consumption relating to efficient heating systems and high efficiency glazing is well predicted, while this prediction is very poor in houses with low efficiency heating system or single glass. In these cases the actual energy use is much lower than predicted. This is a main reason for not achieving predicted energy savings after a thermal renovation.

Keywords - component; Thermal renovation; Buildings; Building stock; Actual energy savings; Predicted energy savings; Performance gap; boilers; windows; glazing; Assessment of energy consumption

1. Introduction

The assessment at building stock level of actual energy savings resulting from thermal renovation of dwellings was up to now limited by the high costs of such a monitoring operation. That is why only assessments at project level are found in (scientific) literature. The emergence of large databases at national level, however, makes the assessment at the level of the whole building stock possible, producing very valuable results for policy makers and the building sector. Several papers (e.g. [1], [2], [3]) used such databases to study the actual energy efficiency of the Dutch building stock by using statistical methods. In these papers correlations between actual energy use and energy label, type of heating and insulation levels were demonstrated. Some correlations were very weak or couldn’t be found though. The results also demonstrated that there is a large gap between the heating energy usage predicted by the Dutch energy labelling model [4] in different categories of energy labels, heating systems and insulation levels and the actual energy consumption in these categories. In general a poorly efficient house or system leads to a large overstimation of its energy consumption, meaning that it actually uses much less energy than predicted. The reverse is seen – to a lesser extent – in energy efficient houses or systems. This clearly indicated the possibility that energy saving targets of building renovations, generally based on calculations using the energy labelling method would not be achieved. However, these results were based on observations on different categories of houses in the whole building stock and not on observing the results of renovations themselves. It could not be excluded that the results of renovation could be different. The present paper adresses therefore very specifically the analysis of the energy consumption of a large sample of renovated dwellings, before and after renovation.

For this large scale study in the Netherlands, the energy label database SHAERE, property of the association of Dutch social housing associations (Aedes), containing yearly updated data about 2 million dwellings, was coupled at address level to the actual energy database from Statistics Netherlands. Social housing in the Netherlands is a very large sector, not restrained to very low incomes, and entails 33% of all Dutch dwellings. About 80% of these social rented dwellings is included in SHARE. In this database, actual gas and electricity use of each Dutch dwelling is registered yearly. It has been possible to select out of these databases the dwellings that had undergone a thermal renovation between 2011 and 2013 and to compare their heating energy consumption before and after renovation. The size of the database made it possible to isolate dwellings in which only one renovation measure was taken, giving the possibility to describe statistically the effect of taking such a renovation measure and to assess its average efficiency. In this paper we adress specifically the upgrade of boilers and glazing, as these were shown in [5] to be the most common thermal renovation measures in the Netherlands.

2. Methodology

The SHAERE register is a raw, full export of the entire energy performance certificate calculation of social rented houses, according to the Dutch standard [4], containing dwellings for each year from 2010 on. The data in SHAERE does not consist of registered label certificates, but of so-called pre-labels. A pre-label is a label certificate of a dwelling that may have not been registered at the authorities yet but has nevertheless been recorded internally by a housing association. According to Aedes, the Dutch association of housing associations, who owns SHAERE, pre-labels are updated whenever a renovation measure takes place and are considered accurate because housing associations report to use these pre-labels as an asset management tool [6]. Aedes provided the data from 243 Dutch housing associations (in 2011 there were a total 289 associations in The Netherlands) in years 2010, 2011, 2012 and 2013, meaning that renovations during this period can be traced. For this paper we selected the dwellings that were renovated and used the data pre-and post-renovation (also called longitudinal data).

It is important to note, that social housing represents 33% of the Dutch dwelling stock and even though some properties differ with the private sector [1], such a larger sample does offer a great deal of representativeness.

The database included dwellings geometry, envelope and installation system characteristics for space heating and hot tap water, as well as the theoretical heating energy consumption calculated according to the Dutch ISSO standard [4]. After deleting double cases, cases with multiple records during one year (it is then impossible to know which one is the most recent) and cases with an unrealistically small or large floor area (<15 m^2 and >500 m^2), the dataset was reduced from the initial 5,205,979 cases to 4,606,749 cases over four years.

Most Dutch dwellings are heated by gas, and in the SHAERE sample almost 90% of the dwelling records (over all four year together) had a gas-powered hot tap water system and 93% had a gas-powered heating system. District heating systems and collective systems had to be removed due to the inaccurate actual consumption data for such installations. Electrical heating systems, mostly heat pumps, have been omitted to keep the scope limited and results more accurate (electricity consumption is not easily comparable to gas consumption and a large part if it is determined by appliances and lighting which further complicate the analysis). Further deletion of non-independent dwellings (student rooms, rooms in elderly homes etc.) resulted in a dataset of 3,728,143 pre-labels. As the actual energy consumption data from Statistics Netherlands was not yet available for the year 2014, we narrowed the sample further to the period of 2010 – 2012, resulting in 2,726,600 pre-label reports. For the measures that were taken in 2013 we would namely not be able to find corresponding actual gas consumption.

The actual gas use data provided by the Statistics Netherland is collected from the energy companies, which base it on the annual meter readings done by the occupants. The actual gas consumptions corresponded to the climatic year regarding the degree days, therefore corrections were applied to compare these consumption values with the theoretical ones.

The abovementioned SHAERE sample of 2,726,600 reported pre-labels corresponds to 1,234,724 individual dwellings. In this dataset, every dwelling contained one or several pre-labels. Dwellings with at least two pre-labels were selected, in total they amount to 909,369 dwellings. Due to missing actual gas consumption data and the fact that the categories containing less than 30 dwellings were deleted because they lead to high 95% confidence intervals and low statistical significance, the sample was reduced to 644.586 dwellings. For dwellings with more than two pre-labels, the first and the last one were selected. Since dwelling observations were annual, last actual gas consumption before the first pre-label report year was used as baseline and the first available consumption data after the last pre-label report year. For example, for dwellings having the first pre-label report in 2010, gas data from 2009 was used and for dwellings having their last pre-label report in 2012, gas data for 2013 was used. Another condition was that both actual and theoretical consumptions have to be valid before and after the renovation (between 15 and 6000 m^3).

In addition all dwellings having more than one property changed were eliminated, meaning that dwellings in our sample have one and only one property changed, either the type of gas boiler or the average window U-value. Additionally, impossible combinations of hot tap water and space heating systems were eliminated (see section 3). Table 1 shows the amount of dwellings in our sample for these two categories.

Table 1: sizes of analyzed subsamples

	Space heating and hot tap water boiler	U value windows
Total final sample size (number of dwellings)	30,749	15,744

The heat transfer coefficient (U-value) is registered per house for each window of the house. To simplify the analysis we computed the average U-value of the windows in each dwelling using the formula below based on basic thermodynamic principles.

$$U_{average} = \left(\frac{U_1 \cdot A_1 + U_2 \cdot A_2 + (\dots) + U_n \cdot A_n}{A_1 + A_2 + (\dots) + A_n}\right) \qquad (1)$$

To simplify the detection of changes in window quality in between years, this U-value was discretised into a finite number of categories to get roughly the same number of dwellings in each category. The categories are described in Table 2.

Table 2: Categories of windows U-values used

Average U-value windows [W/Km^2]	>4	3.7-4.0	3.1-3.7	2.93-3.1	2.9-2.93	2.6-2.93	1.8-2.6	<1.8
Categorized U- value	U8	U7	U6	U5	U4	U3	U2	U1

The heating installation systems were all gas powered. The least efficient system (η=65%, according to [4]) is a local gas heater (referred in the paper as LG), where local means that the heater – a gas stove - is situated in one or two places in the apartment, most commonly the living room, and sometime the master bedroom. The rest of the bedrooms are in this case not heated. Old gas boilers[1], with air intake from inside the house have an efficiency between 65% and 83%, referred in our paper as η<83%. More modern, but still non –condensing boilers[2], have, according to [4], an efficiency between 83% and 90% and are referred as η>83%. There are several high efficiency condensing boilers with efficiencies of 90[3], 94[4] and 96%[5], referred to as η<90%, η<94% and η<96%. The heaters for hot tap water are similar, in most cases the heater for space and water is combined, and in cases where it is not combined, the households use an on-demand tankless gas boiler for water heating (referred later in the paper as 'On-d'). The methodology [4] predicts several water efficiencies of water heaters: conventional (referred as 'CC') (η<83%); improved ('CI') (83%<η<90%); high efficiency condensing boiler ('CH') (η>90%).

3. Upgrade of boiler for space heating and hot tap water system

This section shows the actual and theoretical energy savings of dwellings which had an improvement in only their space heating and hot tap water installation. The two systems are viewed together despite the fact that in the SHAERE database, these were two separate variables. However, during the preliminary analyses many illogical combinations of space heating and hot tap water were observed, such as a combined high efficiency hot tap water boiler together with local gas heater. Such an installation is impossible in practice, since 'combined' boiler means that it is used also for heating. Because of this hot tap water and heating were analysed together, only looking at the dwellings with a logical combination of the two systems. Furthermore, for better readability we only show the results for dwellings which had an improvement in both, heating and hot tap water systems and not just in one. This way the amount of results is manageable and the most interesting combinations are studied.

In this sample of 30,749 cases, heating and hot tap water installation was changed according to the information in SHAERE database. Figure 1 summarized the results. The above part of figure 1 shows both the actual and theoretical gas savings, while the part below also shows the absolute values of the gas consumptions before and after renovation. The number of cases in each category change are given above. In-between both graphics the change in category is given. The first line is for the change in hot tap water system and the second line for the change in space heating system, see end of section 2 for the meaning of the abbreviations. The 95% confidence intervals (black lines) is the range of values for which it is sure with 95% that it contains the average values of the total population. The higher the amount of cases, the smaller the confidence interval and therefore the more representative the data. Differences

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[1] CR ketel in Dutch
[2] VR ketel in Dutch
[3] HR100-ketel in Dutch
[4] HR104-ketel in Dutch
[5] HR107-ketel in Dutch

between categories can be assumed significant (meaning that these difference would be found as well in a larger sample or in the total population) only if their confidence intervals do not overlap. For the categories with few cases (n<127) the results are in general non- conclusive, meaning that the averages are true in the studied sample but cannot be generalized to larger samples.

First observation is that most systems were changed from CI/η>83 to CH/η<96, meaning that in 23,902 houses (77,7%) an improved efficiency non condensing boiler for hot tap water and space heating was upgraded by the (generally combined) high efficiency condensing boiler with the highest efficiency. This upgrade did not led to the expected energy savings. The actual savings are 28% lower than the expected ones.

Second observation is that in all categories the performance gap is high: much less savings are achieved than predicted, except in the category On-d/η<83 to CI/η>83. In this category the tankless water boiler and the old non condensing space heating boiler were changed by a (generally combined) improved efficiency non condensing boiler for hot tap water and space heating. The category On-d/η>90 to CH/η<96 shows also identical results, but, because of the large 95% confidence interval, the results are not very conclusive. In all other categories (with n>127), the actual savings are 33 to 1.4 time smaller than expected. On average on all cases, the actual gas savings are 172 m3/year, while the expected savings were 270 m3/year, meaning that on average only 62% of the expected savings are achieved.

The analyses of lower part of the graphics gives more information about the causes of this poor prediction. A large performance gap before the renovation does not lead to a large performance gap after the renovation. Visually, there does not seem to be a correlation between the size of the performance gap before and after the renovation. It does seem that dwellings are better predicted after renovation than before, meaning that theoretically better performing installations are better predicted. From both part of the figure, some interesting findings can be highlighted:

- The predictions for local gas heater (LG) are very poor as are the predictions of gas savings when upgrading these heaters. This phenomenon was already observed in [1] and is thought to arise from the definition of the normalized heating area in the calculation method [4]. When a local gas heater is installed, the heated surface area is much smaller than indicated in [4]
- Improvements within the category of non-condensing boilers (η<83 and η>83) are reasonably well predicted and seem to generally lead to more savings than expected.
- Only one category with improvements within the categories of condensing boilers (η< 90/η< 96) was found, and although the results are not completely conclusive (large 95% confidence interval), these improvements seem to lead to more savings than expected.

- The prediction of improvements from non-condensing boilers to condensing boilers seem to generally lead to much less gas savings than expected.

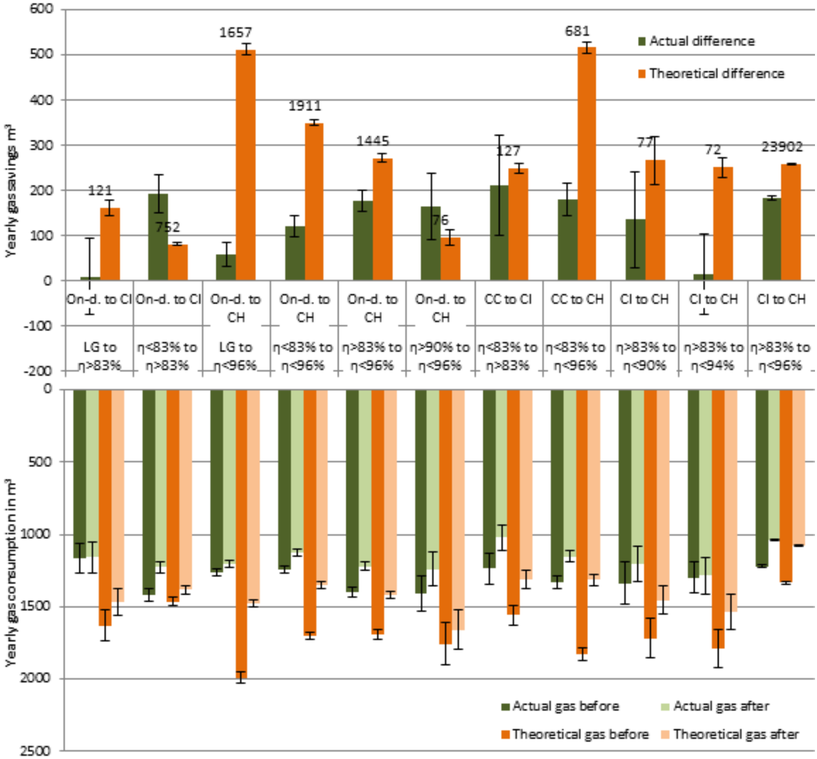

Figure 1: Actual and theoretical gas savings (above) and consumption before and after renovation (below) in dwellings with upgraded hot tap water and heating installation system. Black line: 95% confidence interval.

4. Upgrade of window quality

This section shows the actual and theoretical gas savings of dwellings which had an improvement in their window quality exclusively.

Figure 2 reveals that dwellings that had a drastic change in window quality (U8-U2,U7-U1) tend to have an actual gas reduction lower than the theoretical. Some more moderate changes have an actual reduction closer or exceeding the predicted one (U6 to U3, U5 to U2), which is also the case for some small improvements (U2 to U1 or U8 to U7). It is questionable whether such small improvements are real changes or administrative corrections, since one would imagine that in most cases when windows are replaced, the improvement is bigger. However, it could also be that only one or a few windows were replaced. On average over all cases, improving the window quality led to 96 m^{3}gas actually saved per dwelling yearly, while the prediction was 134 m^3, meaning that 72% of the predicted savings were achieved.

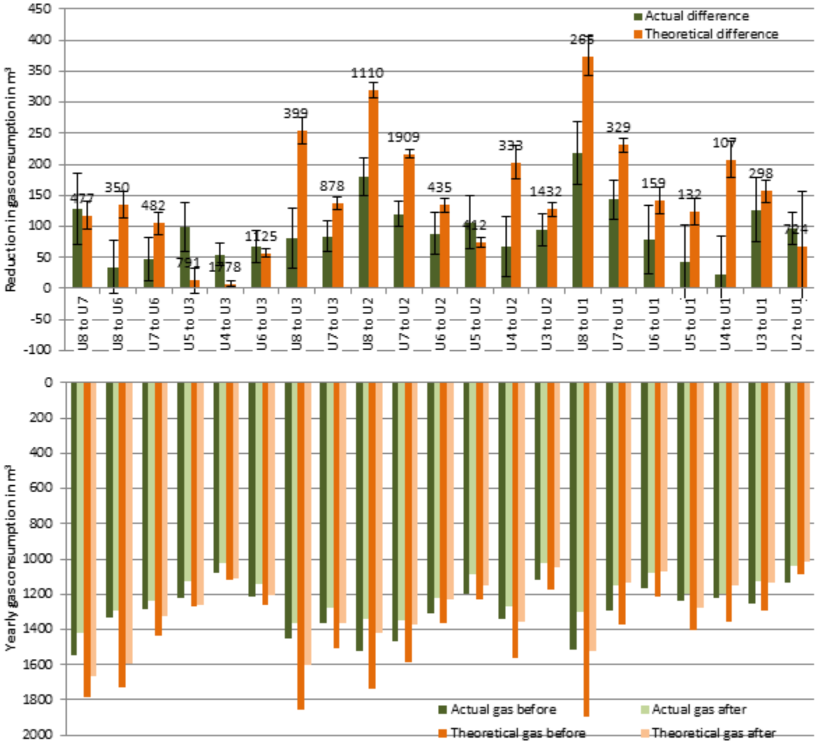

Figure 2: Actual and theoretical gas savings (above) and consumption before and after renovation (below) in dwellings with upgraded windows (U-value). Confidence intervals are omitted in the bottom graphic for better readability.

Looking at the absolute gas consumption before and after renovation one can see (bottom graph in figure 2) some overpredictions. In general large overpredictions occur with windows of low thermal quality (i.e. U8, U7) and better insulated windows are better predicted. However, large differences between the prediction quality can be observed in a same glazing category, which poses the question how accurate were the inspections that led to the predicted values.

5. Conclusions and recommendations

It seems that better performing systems in general exhibit a smaller performance gap, such as boilers with a higher efficiency and better window insulation.

In terms of the performance gap between actual and theoretical consumption, low U-values of insulation are well predicted, as well as efficient heating systems. On the other hand high U values, local heating systems and changes from a non-condensing into a condensing boiler are not well predicted. One can now see that not only is the indoor temperature not well predicted [2] but also the efficiencies of systems and U-values. Although not reported in this paper, similar results are obtained when observing the thermal quality of the envelope (heat resistance of walls). Of course it may also be that other parameters, like a tendency of people to use higher temperature set points when they get a more efficient system may play a role. It may also be that older systems are better maintained than usually assumed.

The results, however, pose a question of how well the standard values are really defined in the calculation method. It could be that excessively low efficiencies have been attributed to inefficient systems simply because of misconception and lack of knowledge. Our results tend to show that the standard values should be revised. Generally more attention is put to the definitions of correct standard efficiencies of new systems, as this is in the advantage of the market. It may be that for older systems, that are only marginally produced, but are still massively present in buildings, less attention has been paid to the correct determination of their efficiency. This is however of outmost importance to determine correctly energy savings potentials.

Large datasets such as the SHAERE database investigated in this paper are now arising across Europe and few experience is available about how to handle them. The results of large samples are statistically robust and representative, and selecting subsamples from the data offers insight into specific combinations of measures and allows identification of best practices. Energy performance registers should be made publicly available, possibly already coupled with actual consumption data.

It is of utmost importance to ensure building performance databases of sufficient quality and trustworthy input data. Ensuring such level of quality is not simple. This paper has highlighted the importance of analysing dwelling stock registers for both the validation and evaluation of energy label calculation.

Overall, this paper has shown once more that the calculation method currently in use cannot be considered accurate if compared to actual consumptions. The question that remains is how to, under these circumstances, determine the effectiveness of a specific renovation measure, which is of importance on dwelling level and even more so on the level of the whole stock. If theoretical methodology is to be used as baseline without the use of actual consumption at some point in the process as calibration, realistic standard values have to be prescribed.

References

[1] Majcen, D., Itard, L., Visscher, H., 2013a. Actual and theoretical gas consumption in Dutch dwellings: What causes the differences? Energy Policy 61, 460–471.

[2] Majcen, D., Itard, L., Visscher, H., 2013b. Theoretical vs. actual energy consumption of labelled dwellings in the Netherlands: Discrepancies and policy implications, Energy Policy 54, 125–136.

[3] Majcen, D., Itard, L., Visscher, H., 2015. Statistical model of the heating prediction gap in Dutch dwellings: Relative importance of building, household and behavioural characteristics, submitted to Energy and Buildings in June 2015

[4] ISSO 82.3 Publication Energy Performance Certificate—Formula Structure (Publicatie 82.3 Handleiding EPA-W (Formulestructuur’), Senternovem, October 2009
[5] Filippidou, F., Nieboer, N., Visscher, H., 2015. Energy efficiency measures implemented in Dutch non-profit housing sector, ECEEE 2015 Summer Study proceedings, Hyeres, France.
[6] Visscher, H., Majcen, D., Itard, L. 2013. Gebruik van de SHAERE-database voor het monitoren van het Convenant Energiebesparing Huursector, Technische Universiteit Delft, Faculteit Bouwkunde, OTB - Onderzoek voor de Gebouwde Omgeving