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Parameters that influence the probability on lower-than-expected energy savings - *a pre- and post renovation energy consumption analysis of 90,000 renovated houses in the Netherlands*

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Abstract. Thermal renovations are considered to be an effective measure to reduce residential energy consumption. However, they often result in lower-than-expected energy savings. In this paper, we investigate some parameters that influence the probability on lower-than-expected energy savings. We do this by comparing actual pre- and post-renovation energy consumption of 90,000 houses in the Netherlands. The results of this study confirm that the effect of the parameters differ per renovation measure. For every renovation measure, the energy performance gap post renovation plays a significant role. This implies that the use of actual energy consumption data to determine the potential energy savings could therefore help to reduce the number of renovations resulting in lower-than-expected energy savings. Also, the energy efficiency state of the building pre-renovation plays an important role. One should take into account that renovations of energy inefficient buildings more frequently result in lower-than-expected energy savings than renovations of relatively energy efficient buildings. For the type of house we found that multifamily houses more often result in lower than expected savings when building installations are improved, while single-family houses renovations more frequently result in lower energy savings than expected when the building envelope insulation is improved. These insights can contribute to the decision making process whether or not to take a certain renovation measures, they can also help to manage expectations on housing stock level and individual building level.

1 Introduction

A significant amount of the total energy in the world is used for buildings. The residential sector is one of the main consumers. The Dutch residential sector is responsible for 25.7% of the final energy consumption in the Netherlands (eurostat). Within the Dutch residential sector energy is primarily used for space heating. Therefore, policymakers see a large energy saving potential in this sector.

Thermal renovations are considered to be an effective measure to reduce residential energy consumption. Therefore, many policymakers set renovation targets to reduce residential energy consumption. For example, the energy agreement in the Netherlands (Energie akkoord) states that the energy label of at least 50,000 dwellings per year should improve by renovations from the year 2021. It is expected that those renovations will reduce residential energy consumption by 32.4%. This amount of potentially saved energy is based on the theoretical average energy consumption of a house per energy label.

However, previous studies have shown large discrepancies between the average actual and theoretical energy consumption per energy label [1-3]. The studies show that buildings with a "high" energy label (A-C) use on average more energy than calculated and buildings with a "low" energy label (E-G) use less energy than expected [1]. Consequence of this finding is that thermal renovations often result in lower-than-expected energy savings [4]. This is also confirmed in several studies [1, 10-14] With the direct consequence that energy saving targets from policy makers are often not met.

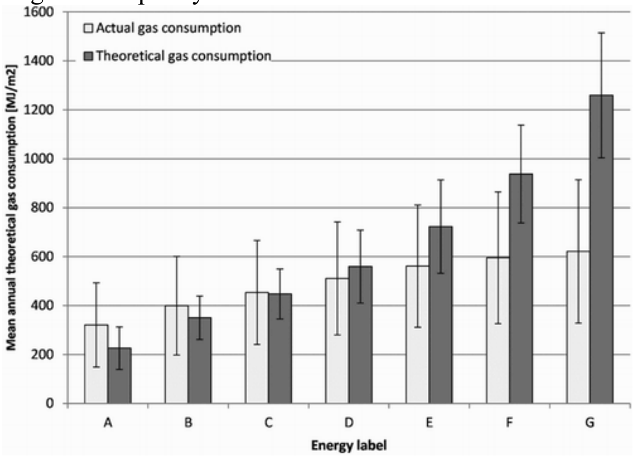

Figure 1 difference between actual and theoretical energy consumption (Van den Brom, P. et al (2018))

Policymakers are not the only ones that rely on the results energy consumption calculations. Theoretical

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energy consumption data are for example used to determine payback times of renovation measures and they also often form the basis for energy performance contracts. Therefore, it is important to gain better insight when thermal renovation result in lower-than-expected energy savings. In this paper we investigate this by determining the influence of energy efficiency state before the renovation, type of house, income, occupancy, and the energy performance gap before renovation on the probability that energy renovations result in lower-than-expected energy savings. To determine this both actual and expected energy consumption data of pre- and post-thermal renovations are required. This kind of data is rare, especially for actual energy consumption. Therefore, most studies on this topic use case studies. However, in this study, we had the possibility to use a large dataset containing almost 90,000 renovated houses. This made it possible for us to investigate on a larger scale which parameters increase or decrease the probability on lower-than-expected savings.

Because several studies showed that the both occupants and building characteristics influence residential energy consumption [5-8], and therefore potentially also the probability on lower-than-expected energy savings, we take both into account in the analyses. A previous study shows that there is an interaction between the type of renovation measure and the parameters that influence the probability on lower-than-expected energy savings after a thermal renovation [9], meaning that some parameters influence the probability on lower-than-expected savings more for one type of renovation measure than for another type of measure. It was, however, not shown how they differ per renovation measure. Hence, this study investigates the influence of the previously mentioned parameters per renovation measure, and compare their impact on the probability on lower-than-expected energy savings.

The structure of this paper is as follows: Because this research is a continuation of a previous study in the next section we will give a short summary of the findings of that study. This is followed up by a description of the definition of thermal renovations in this paper. In the fourth section of this paper the method and data used for this study are explained. The fifth section presents and discusses the research results. Finally, we draw conclusions and provide recommendations for further research.

2 Background

In a previous research, about the actual saving effects of thermal renovations, significant differences between actual and estimated energy savings after a thermal renovation are indicated [9]. Also other studies detected this phenomenon [1, 10-14]. The results of the previously mentioned research [9] also indicate that the gap between expected and calculated energy saving is different per renovation measure. Additionally, it shows that the probability on lower-than-expected energy savings after a thermal renovation is influenced by the following parameters: energy efficiency state of the building before thermal renovation, type of house (single/multi family house), income of the occupant, occupancy (at home/not at home during the day), and the magnitude of the energy performance gap before a thermal renovation. The influence of those parameters differs per renovation measure. However, the previous research did not investigate how much their influence differs per renovation measure. A better insight in the differences of impact of those parameters on the energy savings after a thermal renovation will help to determine the most effective renovation measure per dwelling and also to manage energy saving expectations after a thermal renovation.

3 Definition thermal renovations in this paper

Because this paper is a continuation of a previous study [9] we use the same method to define thermal renovations. Four different types of renovation are distinguished: single renovation measures, improvement of all building installations, improvement of insulation of the entire building envelope and deep renovations.

Since there are several types of single renovation measures that can be applied we divide this group in "sub groups": improvement of roof insulation, improvement of floor insulation, improvement of façade insulation, improvement of windows, improvement of heating system, improvement of domestic hot water (dhw) system, and the improvement of combination dhw& heating system. The last "single renovation measure": improvement of combination dhw & heating system might seem a bit strange in this category, but most buildings in the Netherlands use a combined heating and dhw system we decided to consider the improvement of heating and dhw system as a single renovation measure.

The second thermal renovation that we define in this paper is a significant improvement in the insulation level of the entire building envelope. Because some of the houses in the database are apartments which are not directly located below a roof or ground floor we define this renovation measure if at least two components are significantly improved in terms of insulation. The third type of thermal renovation that we define are significant improvements of all building installations (heating, dhw and ventilation). The final type of thermal renovation is when at least three building components are significantly improved, we will refer to this as deep renovations.

In this study something is considered a renovation if its properties significantly improve. This means, for example, for windows that the U value of the window has to improve significantly and for heating systems that the efficiency has to increase significantly. To decide if the improvement is significant we used the categorisation of ISSO 82 (Table 1).

This research does not distinguish between the different levels of renovation e.g. we don't take into account if a roof is renovated category 1 to 2 or from 1 to 5. Although this could also be an interesting topic for research in this study we assume that the renovation and the level of renovation is a choice that is taken carefully considering available budget on the moment of renovation, available techniques and practical aspects. The research of Majcen et al. [15] provides more insights on this topic.

Table 1 energy renovations (source: Van den Brom, P. et al (2019))

Table 1
Categories of building characteristics based on ISSO 82.1 2011.

Catg.	Window (frame + glazing)[W/m2K]*	Floor insulation[Km²/W]	Façade insulation[Km²/W]	Roof insulation[Km²/W]	Heating system	dhw	Ventilation
1	Single glass(U ≥ 4.2)	No-insulation(Rc ≤ 0.32)	No-insulation(Rc ≤ 0.36)	No-insulation(Rc ≤ 0.39)	Local gas heater	Tankless gas water heater	Natural ventilation
2	Double glass(2.85 ≤ U < 4.2)	Insulated cavity 32 < Rc ≤ 0.82	Insulated cavity 0.36 < Rc ≤ 0.86	Insulated cavity 0.39 < Rc ≤ 0.89	Conventional boiler (η < 0.80)	Electric boiler	Mechanical exhaust ventilation
3	HR + glass(1.95 ≤ U < 2.85)	Up to 40 mm insulation 0.82 ≤ 1.15	Up to 40 mm insulation 0.86 ≤ 1.36	Up to 40 mm insulation 0.89 ≤ 1.22	Improved non-condensing boiler (η = 0.8–0.90)	Conventional combi boiler (η = 0.80)	Demand based mechanical exhaust ventilation**
4	HR + + glass(1.75 ≤ U < 1.95)	40–80 mm insulation 1.15 < Rc ≤ 2.15	40–80 mm insulation 1.36 < Rc ≤ 2.36	40–80 mm insulation 1.22 < Rc ≤ 2.22	Condensing boiler(η = 0.925–0.95)	Improved non-condensing combi boiler(η = 0.80–0.9)	Balanced ventilation with heat recovery***
5	Triple insulation glass (U < 1.75)	80–120 mm insulation 2.15 < Rc ≤ 3.15	80–120 mm insulation 2.36 < Rc ≤ 3.36	80–120 mm insulation 2.22 < Rc ≤ 3.22	Condensing boiler(η = 0.90–0.925)	Condensing combi boiler(η = 0.90–0.95)	
6		120–160 mm insulation 3.15 < Rc ≤ 4.15	120–160 mm insulation 3.36 < Rc ≤ 4.36	120–160 mm insulation 3.22 < Rc ≤ 4.22	Condensing boiler(η > 0.95)		
7		160–200 mm insulation 4.15 < Rc ≤ 5.15	160–200 mm insulation 4.36 < Rc ≤ 5.36	160–200 mm insulation 4.22 < Rc ≤ 5.22			
8		More than 200 mm insulatin Rc > 5.15	More than 200 mm insulatin Rc > 5.36	More than 200 mm insulatin Rc > 5.22			

* Wooden/plastic window frames are assumed
** Mechanical exhaust ventilation, rate is determined by CO_2 level in the house
*** Mechanical ventilation system (inlet and exhaust) that uses a heat recovery system to minimize heat loss due to ventilation

4 Data

Two different datasets are used in this paper. The first one is the SHAERE database, which origins from the umbrella organisation of the Dutch social housing companies in the Netherlands (AEDES). This database is initially invented to monitor the energy efficiency rate of the Dutch social housing stock. Because 30% of the total housing stock in the Netherlands is social housing and the SHAERE database contains information of 60% of all social houses in the Netherlands, this database contains a significant amount of the total housing stock in the Netherlands. However, one should keep in mind that the database is a bit biased because only social houses are included which are not completely representative for the entire Dutch housing stock.

In general, the social housing stock has more multifamily houses compared to the total housing stock the houses are on average also a bit smaller. Also they the types of occupants in the social housing sector differ from the national average. For example, there are relatively more people unemployed and more people with a low income. However, because the social housing stock in the Netherlands covers such a big amount of the total housing stock there are also people with a high or average income that live in houses of the Dutch social housing sector.

Because the SHAERE database is used as a monitoring system of the energy efficiency state of the social housing stock it contains almost all input variables that are required to calculate the energy label of dwellings (e.g. insulation level of façade, floor and roof, window type, type of heating system, type of dhw system and calculated residential energy consumption). These data are present for five years (2010-2014).

To get more information about the occupants and the actual residential energy consumption we used a second database that origins from Statistics Netherlands (2010-2014). To make the actual energy consumption comparable with the theoretical energy consumption in the SHAERE database the energy consumption data was corrected for degree days.

To make the data useful for our analysis we filtered the data. First of all because approximately 90% of the Dutch households use gas as a heating source for their homes and because the majority of the energy consumption in a house is used for heating, we studied only dwellings that use gas as a heating source (127,183 cases). We didn't take residential energy consumption into account in this research. Also dwellings with collective heating systems were deleted from the database because there were some doubts about the reliability of the data. Furthermore, cases with a floor space of over 1000m2 and dwellings with gas consumptions higher than 500,000 MJ were discarded from the analysis (150 cases and 10 cases). Because energy companies in the Netherlands are only required to provide energy consumption data every three years all cases with exactly the same energy consumption data from one year to another are deleted from the database (307,975 cases).

Because many people expect that the change of occupant has a large influence on the gap between measured and expected energy savings we only included houses with the same occupant pre- and post-renovation in the analysis. Finally, as we explained in the previous section, we consider in the analysis 4 different renovation groups, if the renovation doesn't belong in one of those groups it is not taken into account in the analysis. This implies directly that this study does not aim to give an overview on the amount of renovations that are applied, it only aims to give a better insight in when we can expect lower-than-expected energy savings. Leaving out all the above mentioned cases we analysed 87,513 houses that are renovated between 2010 and 2014.

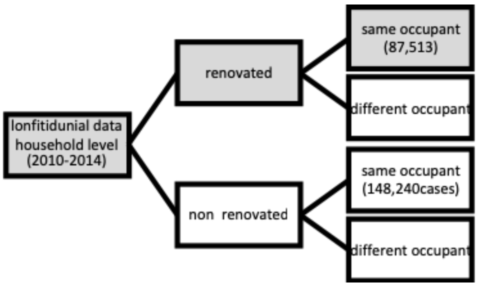

Figure 2 Analysed data (adapted from Van den Brom, P. et al (2019))

5 Method

To determine which parameters influence the probability on lower-than-expected energy savings we conduct the following analysis: First we select based on the results of a previous study the variables that might have an effect on the probability of lower-than-expected energy savings (energy efficiency state of the building before thermal renovation, type of house (single/multi family house), income of the occupant, occupancy (at home/not at home during the day), and the magnitude of the energy performance gap before a thermal renovation.). After this we split the file based on different renovation measures (table 1). With the split file we conduct a binary logistic analysis for every renovation measure separately. We do this by using the backward logistic regression method. The results of the regression will show to which extend the different parameter influence the probability on lower-than-expected energy savings. After this the results are interpreted and discussed. We start by analysing the effect size of the binary logistic regression per renovation measure. After this we analyse the odds ratios of the logistic models per renovation measure. The odds ratio is the ratio of the probability of success and the probability of failure.

Only the renovation measures with significant effect sizes are analysed. Based on this we can conclude which parameters have the highest contribution to the probability on lower-than-expected energy savings after a thermal renovation. We also compare the results per renovation measure.

6 Results & Discussion

In this section, we present and explain the results of the logistic regression analysis per renovation measure. The dependent variable is the variable that indicates if a thermal renovation resulted in lower-than-expected energy savings (1) or not (0). The independent variables in the regression are: the energy efficiency state of the building before the thermal renovating, type of house, income, occupancy and the energy performance gap before renovation. The logistic regression is conducted for each renovation measure separately. The aim of the logistic regression model is to determine to which extend the parameters influence the probability on lower-than-expected energy savings and to determine the differences per renovation measure and to determine if and how much this differs per renovation measure. In the first part of this results section we show the effect size of the models. After this we present and compare the odds ratio values to explain which parameters influence the probability on lower-than-expected energy savings per renovation measure.

6.1 effect size

Table 2 shows the effect size per renovation measure. The larger the Cox & Snell R^2 and Nagelkerke R^2 the larger the explanatory power of the model. The largest effect size is for deep renovations, followed by insulation of the entire building envelope, improvement of combination heating and DHW system. This indicates that at least some of the used predictor variables have a significant effect on the probability that thermal renovations result in lower energy savings as predicted. Floor insulation, improvements of the ventilation system and window improvements have such a small effect size that we can conclude that the predictor variables have no effect on the probability of lower-than-expected energy savings.

Table 2 effect size per renovation measure

	Cox & Snell R^2	Nagelkerke R^2
roof insulation	0.032	0.048
floor insulation	0.001	0.001
façade insulation	0.095	0.138
window improvement	0.017	0.023
improvement of heating system	0.051	0.068
improvement of DHW system	0.030	0.058
improvement of combination DHW & heating system	0.126	0.174
improvement of ventilation system	0.010	0.013
insulation of entire building envelope	0.150	0.227
improvement of installations	0.101	0.142
deep renovation	0.230	0.379

6.2 effect of predictor variables

In the previous paragraph we concluded that the parameters do not contribute to a better prediction of the probability on lower-than-expected energy savings for floor insulation, improvement of ventilation system, and improved window. Therefore, these renovation measures are not discussed in this section.

This section compares the odds ratio of the different parameters per renovation measure. The odds ratio is an indicator of the change in odds resulting from a unit change in the predictor. For this analysis it means that if we want to predict the probability on lower-than-expected energy savings after a thermal renovation the probability increases if the odds ratio has a value higher than one and decreases if the odds ratio has a value lower than one.

The odds ratios of the logistic models per renovation measure are shown in table 2. If you look at the table you will notice that for the all renovation measures the odds ratios are different per type of renovation measure. The table also shows that the energy efficiency state of the building before a thermal renovation has a relatively high influence on the probability of lower-than-expected energy savings.

For almost all renovation measures the odds ratio increases when the energy performance gap before renovation becomes bigger. The improvement of the hot water system is the only exception. For this renovation measure the opposite is true.

If the energy efficiency state of the house decreases the probability on lower-than-expected energy savings becomes lower. (this might seem contra intuitive but the energy efficiency state is reflected in the Energy Index which has a higher value if the building is less energy efficient).

For the type of dwelling the results show that the probability of lower than expected savings after renovation is smaller if roof insulation, change of heating system, change of dhw system or building installations are applied. An increased probability on lower-than-expected energy savings is expected if the building is reinsulated, deep renovations are executed, or an improved combination dhw & heating system are installed.

Income seems to only influence the probability of lower-than-expected savings after a renovation if the combination DHW & heating system is improved. Oocupancy decreases the probability if building facades are reinsulated, the heating system is improved, the combination dhw & heating system is improved and if all building installations are improved.

Nevertheless, we can conclude that if there is a big gap between actual and theoretical energy consumption before the renovation the probability on lower-than-expected savings is almost always increasing. This result should be an extra incentive for careful investigation of the energy efficiency state of the building before renovation measures are applied. Also, the use of actual energy consumption data pre-renovation could contribute limit the probability on lower-than-expected energy savings. The second most important measure is the energy efficiency state of the building. The results show that for almost every case the probability on lower energy savings than expected increases when the energy efficiency of the building becomes worse. Also, the type of house (single or multifamily) influences the probability on lower energy savings than expected. In general, we can say that a single family house increases the probability that insulation measures result in lower-than-expected savings, while for renovations that include improvement of installations the probabilities increases for multifamily houses.

Table 2 results logistic regression odds ratio

	roof insulation	façade insulation	improvement of heating system	improvement of DHW system
energy efficiency of the building before renovation	1.325	1.454	1.661	3.967
single family house versus multy family house	0.739		0.572	0.457
income above modal versus income below modal				
occupancy		0.794	0.769	
energy performance gap before renovation	1.036	1.115	1.054	0.949

	improvement of combination DHW & heating system	insulation of the entire building envelope	improvement of installations	deep renovation
energy efficiency of the building before renovation	0.763	1.636		
single family house versus multy family house	1.104	1.717	0.638	2.001
income above modal versus income below modal	1.082			
occupancy	0.761		0.599	
energy performance gap before renovation	1.13	1.149	1.113	1.227

7 Conclusion

Based on the findings of this research we, can confirm that the influence of the energy efficiency state before the renovation, type of house, income, occupancy, and the energy performance gap before renovation influence the probability on lower-than-expected savings. Their influence is indeed different per renovation measure. The results indicate that using actual energy consumption of the building before renovation to predict energy savings after a thermal renovation could reduce the probability of lower-than-expected energy savings. If energy inefficient buildings are renovation one should take into account that the probability on lower-than-expected energy savings is higher than when energy efficient buildings are renovated. Also, the type of house has an influence on the probability of lower-than-expected energy savings after a thermal renovation. Renovations aiming to increase the insulation rate of (part of) the building envelope result for single family houses more often in lower-than-expected energy savings compared to multi-family houses. For improvements in building installations systems the opposite is true. For the cases that occupancy was significant higher occupancy rates decrease the probability on lower-than-expected energy savings.

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