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Effectiveness of energy renovations: a reassessment based on actual consumption savings

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Abstract
Energy renovations offer unique opportunities to increase the energy efficiency of the built environment and for the existing housing stock, they are the most important solution. Usually, the energy savings are based on modelling calculations. However, recent research has shown that the predicted energy consumption differs largely from the actual consumption. In this paper, the effectiveness of energy measures is re-assessed based on actual consumption data. We utilize a monitoring system, which contains information about the energy performance of around 60 % of the Dutch non-profit housing sector (circa 1.2 million dwellings). We connect the data from this monitoring system to the actual energy consumption data from Statistics Netherlands on a dwelling level. Using longitudinal analysis methods, from 2010 to 2014, we are able to identify the energy efficiency improvements of the stock and determine the effectiveness of different measures in terms of actual energy savings. The results reveal the actual energy savings of different efficiency measures and highlight the significance of the actual energy consumption when a renovation is planned or realized.

Introduction
The existing housing sector plays an important role towards achieving the energy efficiency targets worldwide and in the European Union (EU) (European Commission 2016; SER, 2013; Ürge-Vorsatz et al., 2007). The energy performance of buildings is so poor that the sector is among the most significant CO_2 emission sources in Europe (BPIE, 2011). Existing buildings account for approximately 40 % of the energy consumption in the European Union (EU), and are responsible for 36 % of the CO_2 emissions (European Commission, 2008 and 2014). A large percentage of this energy consumption is assigned to the residential sector. On average households consume 24.8 % of the total energy consumption in the EU (Eurostat, 2016).

Energy renovations in existing dwellings offer unique opportunities for reducing the energy consumption and greenhouse gas emissions. Energy renovation is instrumental for reaching the EU and national 2020 goals (Saheb et al., 2015). It has implications for growth and jobs, energy and climate, as well as cohesion policies. Renovating existing buildings is a 'win-win' option for the EU economy (Saheb et al., 2015). Although there have been various energy renovation actions of dwellings in Europe and the Netherlands, the assessment and monitoring of the savings achieved is not adequate. Monitoring the energy improvements of the existing housing stock and can provide valuable information, concerning the energy savings that can be achieved both in terms of actual and predicted energy consumption. The patterns of the predicted energy reduction in most cases differ from the actual energy consumption (Filippidou et al., 2016; Balaras et al., 2016; Majcen et al., 2013, Tigchelaar et al., 2011). Predicted or modelled energy consumption can differ from the actual consumption by as much as 50 % less or 30 % more in dwellings (Majcen et al., 2016). Previous research (Balaras et al., 2016; Majcen et al., 2013; Sunikka-Blank & Galvin 2012) has highlighted the performance gap - the difference between predicted and actual energy consumption, in different building stocks. The focus on actual consumption is increasing and studies on the gap between the predicted and actual energy consumption of buildings start to appear in Europe.

This paper examines the impact of thermal renovation measures on both the predicted and actual energy consumption of the renovated non-profit stock in the Netherlands. The actual savings reveal the true effect of renovations on the reduction of energy consumption. The actual energy savings also highlight the impact of the number and combinations of measures on the dwellings' performance. First, we analyse the energy saving measures (ESMs) realized and then their impact on the actual and predicted energy consumption. In the following background section 2 we discuss energy renovation concepts and definitions. Section 3 focuses on the data and research methods used. In section 4 we present the results of the analysis and in section 5 we draw conclusions based on the outcomes of the research.

Energy renovations and savings

Throughout Europe, national approaches to building stock monitoring have evolved separately. Information about the progress of energy performance improvements is not only needed to track the progress of policy implementation (Boermans et. al., 2015) but better information and data are necessary to help develop roadmaps in order to achieve more energy efficient buildings (BPIE, 2011).

The 2012 Energy Efficiency Directive (EED) and the 2010 Energy Performance of Buildings Directive (EPBD) are the EU's main legislation for the reduction of the energy consumption in buildings. In article 4 of the EED, Member States are required to establish long-term strategies for mobilising energy renovations in their building stocks (BPIE, 2014). A recent evaluation of the EED (BPIE, 2014) found that energy renovation plans or guidelines are still lacking in identifying the most effective measures for each climate, country (according to its national energy regulations), type of dwelling, size, age, operation, and maintenance, dwelling envelope, and many more. On top of this, there was no clear definition of the term energy renovation at a European level, thus making the implementation of ESMs more difficult.

New buildings and major renovations in the Netherlands are required to meet specific standards e.g. R_c values of floors, facades, roofs and U values of windows, as of January 2015 (van Eck, 2015). In addition, the term major renovation is used for dwellings where more than 25 % of their envelope area is renovated (van Eck, 2015), which is in accordance to the 2010 recast of the EPBD (European Parliament and the Council, 2010). Only minimum insulation standards are applied for minor renovations or isolated ESMs, without an energy performance calculation being necessary (van Eck, 2015).

Research on the energy renovations of dwellings usually focuses on selected cases (exemplary buildings) or case studies (Khoury et al., 2016; Mastrucci et al., 2014). Up to now, and due to the difficulty of acquiring actual energy consumption data on big datasets much of the research performed focused on the predicted energy savings of renovated building stocks (Ballarini et al., 2014; Mata et al., 2013). In practice the situation is similar with most professionals using the predicted energy savings as a reference for future renovations. However, based on outcomes of both the research on the performance gap and on the energy renovations the impact of these renovations on the actual energy consumption is expected to be significantly different. Previously published research conducted on the social housing stock of the Netherlands on isolated energy renovation measures by Majcen et al., 2016 found several discrepancies between the predicted and actual energy savings, of single efficiency measures, ranging from 0.58 (ratio of actual/predicted savings) to 2.5. Filippidou et al., (2016) describe the annual frequencies of 7 renovation measures in the Netherlands. Using an energy performance monitor they analyse the energy efficiency measures realized in the non-profit housing sector and the impact on the energy performance of the dwellings. There are several definitions of which measures constitute an energy renovation and the different levels of one. The term 'renovation' is used to cover modernization, retrofit, restoration, rehabilitation, and renovation actions that go beyond mere maintenance of the building stock (Meijer et al., 2009). According to the European Commission, there are three types of energy renovations: the implementation of single measures (including the low-hanging fruit), the combination of single measures (which can be termed "standard renovation") and the deep or major energy renovation – referring to renovations that capture the full economic energy efficiency potential of improvements (European Commission, 2014). Still, the definitions of a standard or deep renovation are vague. In this paper, we will examine renovated dwellings based on single energy saving measures (ESMs) and combinations of ESMs, which can either be standard or deep renovations.

Data and methods

This study includes an inventory of ESMs of the non-profit rented stock in Netherlands from 2010 to 2014. Moreover, we examined the effectiveness of these measures based on actual and predicted energy savings as annual values between 2010 and 2014. In the Netherlands, 85 % of households are heated with natural gas (ECN, 2014). Thus, for the purposes of this study we focus on the gas consumption data. We used two different datasets to achieve the identification of the measures and examine their effectiveness. In both datasets, an encrypted identifier variable for each dwelling is used, comprising of the address, postcode and housing number.

DATA

First, we used the SHAERE database ("Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing" – in English: Social Rented Sector Audit and Evaluation of Energy Saving Results). SHAERE is the official tool for monitoring the progress in the field of energy saving measures for the non-profit housing sector. SHAERE is the first monitoring database of the energy efficiency evolution of the building stock in the Netherlands with microdata information, on a dwelling level. It includes information on the dwellings' geometry, envelope, installations characteristics and the predicted heating energy consumption based on ISSO publication 82.3 (ISSO, 2009). In more detail, the data include the U values (thermal transmittance, W/m^2K) and R_c values (thermal resistance, m^2K/W) of the envelope elements, the type of installation for heating,

Table 1. Number of dwellings reported in SHAERE per year.

Year of reporting	Amount of individual dwellings reported	Percentage of the total stock
2010	1,132,946	47.2 %
2011	1,186,067	49.4 %
2012	1,438,700	59.9 %
2013	1,448,266	60.3 %
2014	1,729,966	73.7 %
2015	1,275,390	53.3 %

domestic hot water (DHW) and ventilation and the predicted energy consumption. The data are categorized as variables per dwelling. It is a collective database in which the majority of the housing associations participate (Filippidou et al., 2015). This monitor became operational in 2010. Housing associations report their stock at the beginning of each calendar year accounting for the previous year (e.g., in January 2014 reporting for 2013) (Aedes, 2016). They report the energy status of their whole dwelling stock using two specific software (Aedes, 2016 and Tigchelaar, 2014), whose basis is the Dutch energy labelling methodology (ISSO, 2009). The database includes data from 2010, 2011, 2012, 2013, 2014 and 2015, on the performance of the stock in the form of energy certificates. Table 1 presents the number of dwellings reported in SHAERE every year.

Second, we matched the data from SHAERE database, on microdata level, to the actual energy consumption data, which is collected by Statistics Netherlands from energy companies. The companies report the billing data, which are calculated on the basis of the dwellings' meter readings annually. In order to compare the data of the predicted heating gas consumption and the actual gas consumption from the Statistics Netherlands a climatic standardization was applied. The Statistics Netherlands data corresponded to the years of 2009, 2010, 2011, 2012, 2013 and 2014.

The analysis is based on longitudinal data using the identifier variable to follow the energy saving measures of the dwellings. In order to identify the ESMs we follow and examine seven ESM variables. These include: heating system (type and efficiency), domestic hot water system (type and efficiency), ventilation system (type), floor insulation (R_c value), roof insulation (R_c value), façade insulation (R_c value), and type of glass (U value).

METHODS

Selection of the data sample

The initial dataset from SHAERE comprised 2,189,591 dwellings containing records from 2010 to 2015. Data filtering was required from the beginning of the data analysis and especially when we coupled the SHAERE dataset to the actual energy consumption dataset of the Statistics Netherlands. The maximum amount of records per dwelling can be six (2010–2015). 1,794,415 dwellings, 82 % of the initial records, were coupled on an address basis with the actual energy consumption data from the Statistics Netherlands. After the double cases control, 1,752,427 unique dwellings formed the sample.

In continuity, we performed different controls for dwellings' missing data on gas, electricity and district heating consumption. 45,625 (2.6 %) cases were excluded. Also, the cases with district heating had to be eliminated due to lack of individual metering – 92,545 (5.3 %) cases were removed. The number of cases forming the sample at this point was 1,706,775.

Furthermore, we removed the dwellings that had unrealistic values of gas consumption (<15 m^3 and >6000 m^3). We also eliminated dwellings with default set values in all variables and with unrealistic useful living area (when <15 m^2 or >800 m^2) – 1,602,391 cases remained. The boundaries are based on the distribution of the gas consumption and living area variables – we exclude outliers and illogical values. We, then, selected the dwellings with records both in 2010 and 2014. Dwellings that were renovated in 2014 or 2015 had to be excluded, as the actual gas consumption data are available until 2014. The final sample comprised 650,460 dwellings.

Renovated dwellings

The goal of this paper is to examine the impact of thermal renovation measures on both the predicted and actual energy consumption of the renovated non-profit stock in the Netherlands. Throughout the paper we focus on the renovated stock. For this reason, we applied the following method in order to select the renovated stock though the ESM variables.

The insulation variables are based on the thermal resistance (R_c value), the glazing on the thermal transmittance (U value), and are numerical variables. However, in order to identify the improvements of the ESMs, the categorization of the insulation and glazing variables was necessary. The values and boundaries used to distinguish between the levels of insulation derive from the Dutch ISSO publication 82.3 and presented in Table 2 and Table 3 (ISSO, 2009). By creating the categorical variables we were able to identify any improvements of the envelope insulation, in this case ESMs, through the yearly reports. The installation variables (heating system, DHW and ventilation) are already categorical. These seven categorical variables form the group of thermo-physical ESMs examined in this paper.

We, then, create seven variables indicating the improvement of one of the seven ESM variables. These change variables show the improvement or not of each ESM variable (dichotomous variables). We go on creating a single "number of ESM" variable to indicate the number of measures applied in each dwelling. The minimum value of this variable is 0, suggesting that the dwelling belongs to the non-renovated stock, and the maximum is 7, suggesting that a complete renovation was realized.

Table 2. Insulation categories for floor, roof and façade based on the ISSO 82.3 (2009).

Characterization	R_c value floor W/(m²K)	R_c value roof W/(m²K)	R_c value façade W/(m²K)
No-insulation	$R_c \leq 0.32$	$R_c \leq 0.39$	$R_c \leq 1.36$
Insulation	$0.32<R_c \leq 0.65$	$0.39<R_c \leq 0.72$	$1.36<R_c \leq 2.86$
Good insulation	$0.65<R_c \leq 2$	$0.72<R_c \leq 0.89$	$2.86<R_c \leq 3.86$
Very good insulation	$2<R_c \leq 3.5$	$0.89<R_c \leq 4$	$3.86<R_c \leq 5.36$
Extra insulation	$R_c >3.5$	$R_c >4$	$R_c >5.36$

Table 3. Window categories based on the ISSO 82.3 (2009).

Characterization	U value window W/m²/K
Single glass	U≥4.20
Double glass	2.85≤U<4.20
HR+ glass	1.95≤U<2.85
HR++ glass	1.75≤U<1.95
Triple insulation glass	U<1.75

Actual and predicted energy savings

Consequently, we focus on the dwellings that had at least one ESM realized – i.e. the renovated stock. The coupling of the SHAERE data with the Statistics Netherlands microdata allows us to access the actual gas consumption before and after the ESMs are applied. To calculate the energy savings, we subtracted the gas consumption in 2014 from the one in 2010. This deduction forms the two main variables of this analysis per dwelling – the actual gas savings, where we subtract the actual gas consumption, and the predicted gas savings, where we subtract the modelled gas consumption, as explained by Equations 1 and 2. In order to compare the actual and predicted savings we applied climate correction factors to the gas consumption. The energy label calculation reported in SHAERE, assumes 2620-heating degree days (ISSO, 2009), therefore we applied correction factors to the actual gas consumptions supplied by the Statistics Netherlands.

The actual and predicted energy savings are calculated as follows:

$$Savings_{actual} = Q_{actual,before} - Q_{actual,after} \quad [\text{kWh/m}^2\text{/year}] \quad (1)$$

$$Savings_{predicted} = Q_{predicted,before} - Q_{predicted,after} \quad [\text{kWh/m}^2\text{/year}] \quad (2)$$

where:

$Q_{actual,before}$ Space heating demand before renovation, Statistics Netherlands

$Q_{actual,after}$ Space heating demand after renovation, Statistics Netherlands

$Q_{predicted,before}$ Space heating demand before renovation, calculated according to ISSO 82.3 (ISSO, 2009)

$Q_{predicted,after}$ Space heating demand after renovation, calculated according to ISSO 82.3 (ISSO, 2009)

This study examines the different single ESMs and combinations of ESMs realized in the renovated stock. In the following, Results and Discussion, section we present the outcomes from the twofold analysis performed. In the first part we present the amount of ESMs realized per dwelling and the actual and predicted energy savings achieved based on the number of ESMs. Relatedly, we introduce the type of single and combination ESMs realized in the renovated stock and the actual and predicted savings categorized by the ESMs applied. The single ESMs are based on the change variables, described above in the Renovated Dwellings sub-section, for the dwellings that only had one ESM realized. But for the dwellings that more than one ESM was realized, we created new variables to identify the combinations of ESMs.

In the second part, in order to explain the gap between the actual and the predicted energy savings, we perform a linear multivariate regression analysis to the renovated stock of the dwellings. Through the regression analysis we aim to understand the effect of the different single ESMs and how the improvement of the ESMs can be used as predictors and explain the actual and the predicted savings. We used seven independent variables: the seven change dichotomous variables (improvement or not of the heating system, domestic hot water system, ventilation, floor insulation, roof insulation, façade insulation, and type of glass). We performed the multivariate analysis for the whole renovated stock both on the actual and the predicted energy savings (as dependent variables). In the following section the results of the twofold analysis are presented.

Results and discussion

This section, first, discusses the amount of measures applied per dwelling and the effect of it on the actual and predicted energy savings. We then go on introducing the effect of different, single ESMs on the yearly energy savings between 2010 and 2014 for the dwellings that had only one ESM realized. Furthermore, the effect of various combinations of ESMs on the energy savings is analysed for the dwellings that more than one ESMs were realized. In the final part of the section we present the outcomes of the linear multivariate regression.

The mean gas consumption savings in this paper are expressed in kWh/m² and as a result are not floor area weighted (for example a dwelling of 500 m² weighs the same as a 40 m² apartment). In this way, the scale effect is neutralized. We used the Statistics Netherlands dataset to determine the gas consumption pre- and post-renovation. We used the 2009 or 2010 gas data for the pre-renovation values and the 2014 data for the post-renovation consumption values. Groups of dwellings with less than 10 cases could not be exported from the Statistics Netherlands environment for privacy issues and would not be statistically significant. They are, therefore, excluded from the analysis.

The maximum amount of ESMs is 7. Table 4 depicts the amount of dwellings and the number of measures applied per dwelling. According to SHAERE, when we examine the percentage of dwellings with at least one measure (266,391 dwellings), the division between 1 and 2 measures is flat. As the amount of measures increases, the amount of dwellings decreases and only 0.1% of the dwellings had seven measures performed. In 59 % of dwellings no action was taken and these 384,069 dwellings form the non-renovated stock of 2010–2014 (in light grey font in Table 4). 24.4 % of the dwellings had a combination of measures performed, meaning at least two or more ESMs. In the continuity of this paper we focus only on the renovated stock and the ESMs that were applied.

Figure 1 presents the mean actual and predicted gas savings categorized per number of ESMs and the ratio between mean actual savings and mean predicted savings. If the ratio is equal to 1 there is no gap between actual and predicted savings. A ratio below 1 reveals an over-prediction of the actual savings and above 1 an under-prediction. In the cases where one ESM was performed there is almost no gap between actual and predicted gas consumption (ratio=0.93). However, when 2 or more ESMs have been realized the models we use over-predict the savings by a factor of 0.66 (actual/predicted ratio) in the case of 2 ESMs to a factor of 0.38 in the case of 7 ESMs. It seems that as the number of measures increases, the gap between actual and predicted savings is also increasing. This phenomenon can be explained partly by the fact that housing associations rely on specific "traditional" measures in the form of business as usual (e.g. upgrading to a better efficiency boiler) that yield actual savings. Moreover, an investment practice is highlighted where the dwellings being renovated are the ones that are in need of such complete renovations. Existing literature, supports the fact that the least efficient dwellings do not consume as much as we predict they would (Majcen et al., 2013) and that is also supported by Figure 1 where the predicted savings of the dwellings with 5, 6 and 7 ESMs are much over-predicted. Nevertheless, the number of measures alone cannot answer the questions set in this study. For this reason, we continue the analysis presenting the type of ESMs (both single ESMs and combinations) applied and the impact on the mean actual and predicted gas savings.

108,131 dwellings (16.6 % of the sample) had 1 ESM realized between 2010 and 2014. Table 5 depicts the frequency and ratios of mean actual to predicted gas savings of the ESMs. Replacing the heating and DHW systems and glazing are the most popular single ESMs. Figure 2 depicts the effect of these single measures on the actual and predicted savings.

Table 4. Number of ESMs realized during 2010–2014.

Number of ESMs	Frequency (number of dwellings)	Percentage
0	384,069	59.0
1	108,131	16.6
2	100,211	15.4
3	35,506	5.5
4	14,052	2.2
5	5,871	0.9
6	1,967	0.3
7	653	0.1
Total	650,460	100.0

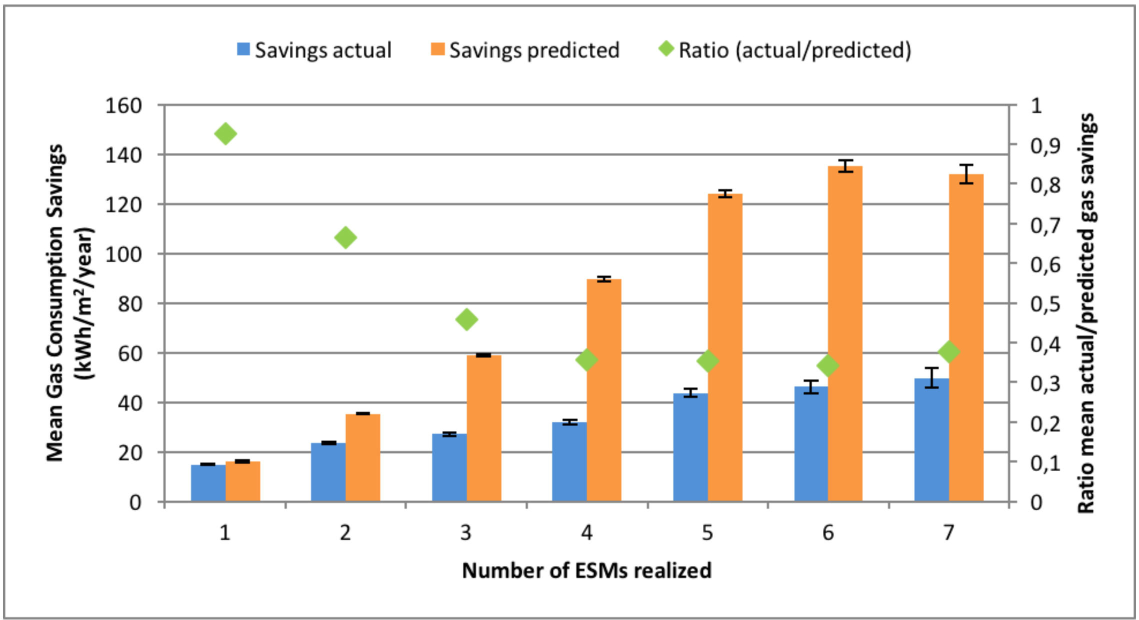

Figure 1. Mean actual and predicted gas consumption savings based on the number of ESMs realized.

Table 5. Inventory of ESMs.

ESMs	Frequency	Ratio mean actual/predicted savings
ESM heating system	18,036	1.33
ESM DHW system	8,878	0.49
ESM heating and DHW systems	63,675	0.77
ESM ventilation system	24,934	4.87
ESM glazing	16,521	0.90
ESM roof insulation	10,392	0.46
ESM façade insulation	16,182	0.55
ESM floor insulation	14,414	1.04

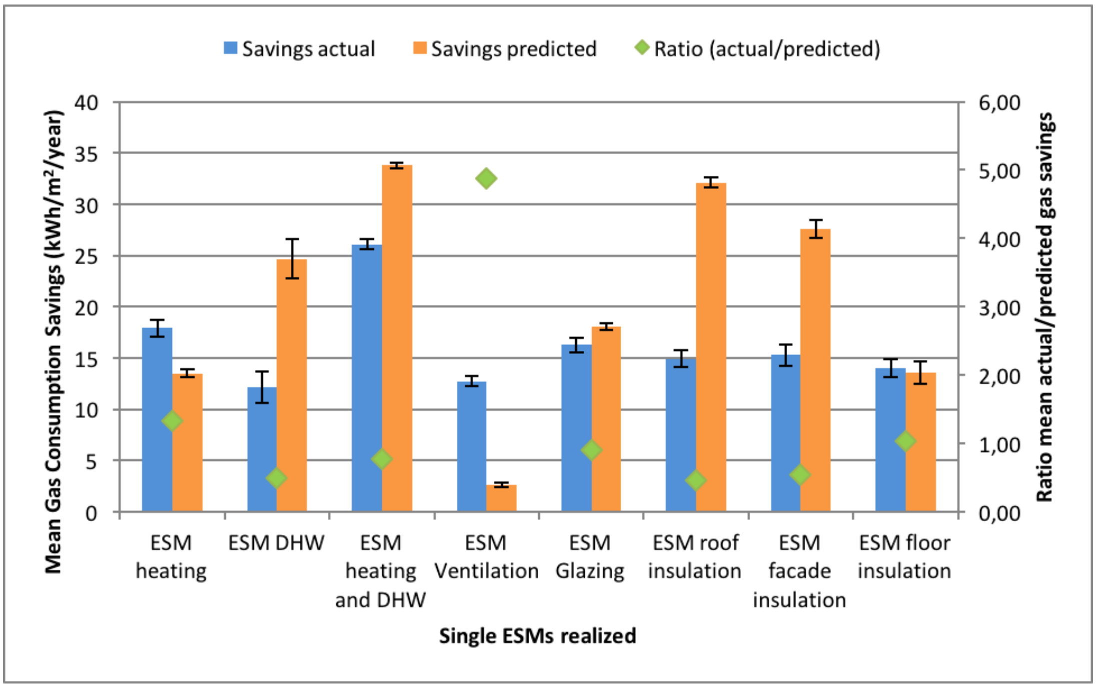

Figure 2. Mean actual and predicted gas consumption savings for dwellings with single ESMs.

Figure 2 presents the mean actual and predicted savings categorized per type of ESM applied. The mean actual gas savings derive from the Statistics Netherlands data and the predicted from SHAERE. The dwellings depicted in Figure 2 are the ones where only one of these ESMs have been performed with the exception of the ESM heating and domestic hot water (DHW) systems because in the Netherlands in 80–90 % of the cases the systems are combined. As a result, we also regard the combined change of the heating system and the DHW system as one ESM. This way we present the effect of each individual ESM on the actual and predicted savings. In most cases, the predicted savings are higher than what is actually achieved by a factor of 0.46 to 0.90 (actual/predicted ratio). However, in the case of the heating system change and the ventilation the actual savings achieved are higher than the predicted. In the case of ventilation the actual savings are 4.87 (actual/predicted ratio) higher than the predicted ones, which is larger than any other ratio. However, the same air flow rates are assumed by the calculation method for both mechanical and natural ventilation systems. The ESM where the mean actual and predicted savings are almost the same is the floor insulation with a ratio of 1.04. Figure 2 shows that predicted savings are closer to the actual ones for the heating (space heating and DHW) systems and glazing than for the envelope insulation ESMs. This phenomenon can be attributed to the fact that most of the old stock's envelope insulation values (façade, roof, floor) are 'simply' based on the regulations in the building year (Rasooli et al., 2016).

While 16.6 % of the dwellings had only one ESM applied, 24.4 % of the dwellings had a combination of ESMs performed, meaning at least two or more ESMs. We examined a total of 22 different combinations of measures. Table 6 presents the combinations of ESMs studied along with the number of dwellings were each combination has been applied and the ratio of actual to predicted savings.

These combinations of ESMs were based of the frequency of the individual ESMs, the combinations where a standard renovation is depicted (see 5 to 14) and the ones representing deep or more advanced renovations (see 15 to 22). In all cases of the 22 combinations examined the mean predicted savings are much higher than the mean actual savings achieved.

The combinations of measures in Figure 3 are depicted in ascending order of the mean actual gas savings. This way we want to highlight both the gap between mean actual/predicted savings and the difference in actual savings between the combinations of

Table 6. Index of combination of ESMs.

Index of combinations of ESMs	Combinations of ESMs	Frequency	Ratio mean actual/ predicted savings
1	Primary and secondary heating system	1,584	0.21
2	Heating system and domestic hot water system	63,675	0.77
3	Heating system and ventilation	9,256	0.72
4	Heating system and glazing	6,379	0.58
5	Heating system and roof insulation	2,993	0.35
6	Heating system and façade insulation	5,373	0.48
7	Heating system and floor insulation	7,208	0.55
8	Heating system, glazing and roof insulation	944	0.41
9	Heating system, glazing and façade insulation	2,223	0.38
10	Heating system, glazing and floor insulation	1,407	0.51
11	Heating system, ventilation and glazing	1,835	0.53
12	Heating system, ventilation and roof insulation	577	0.30
13	Heating system, ventilation and façade insulation	2,090	0.41
14	Heating system, ventilation and floor insulation	2,554	0.45
15	Heating system, glazing, ventilation and roof insulation	490	0.29
16	Heating system, glazing, ventilation and façade insulation	770	0.32
17	Heating system, glazing, ventilation and floor insulation	910	0.31
18	Heating system, glazing, ventilation, roof and façade insulation	417	0.32
19	Heating system, glazing, ventilation, roof and floor insulation	472	0.32
20	Heating system, glazing, ventilation, roof, floor and façade insulation	71	0.45
21	Heating system, domestic hot water system, ventilation, glazing, roof, floor, and façade insulation	642	0.38
22	Glazing, roof, floor and façade insulation	2,898	0.40

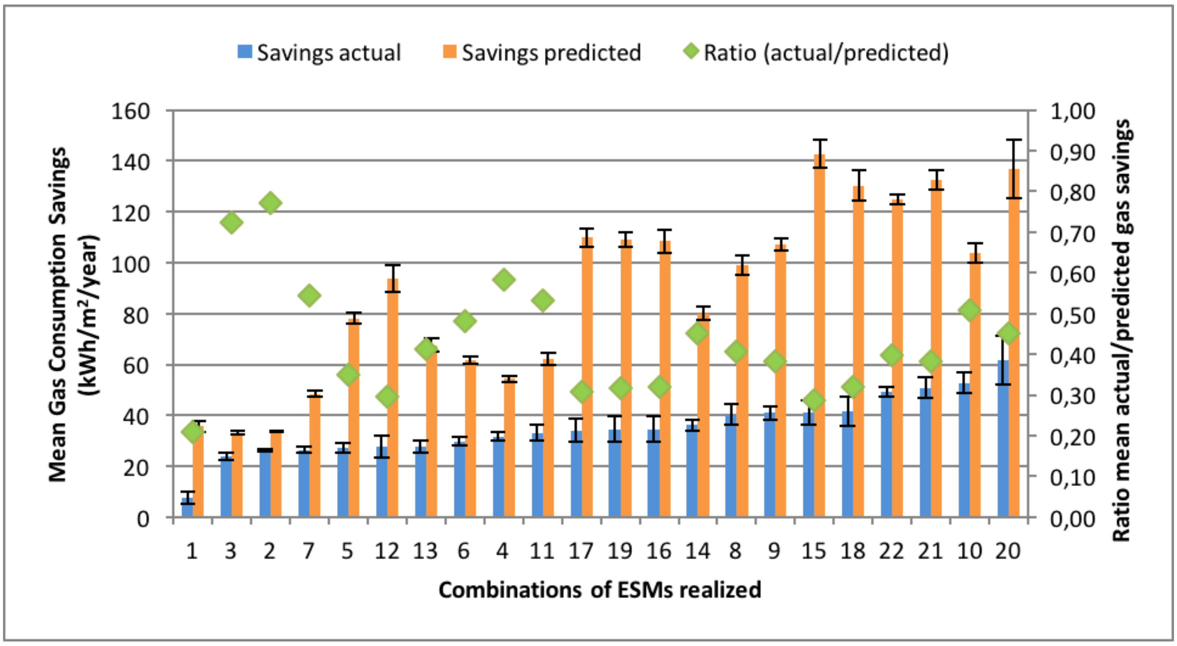

Figure 3. Actual and predicted gas consumption savings for dwellings with combinations of ESMs realized.

ESMs. The smallest over-prediction of the energy savings can be found in the combinations 2 and 3, in comparison to the rest of the combinations. It is our understanding that in the modelled results, in this case the predicted savings, a much more positive picture of the insulation of the dwellings, the energy installation and the occupant behavior is assumed than what is actually happening. In reality, the synergy of two or more ESMs can prove to achieve less or more actual savings and the gap between the two can be smaller. These results highlight the issue of the gap between actual and predicted energy consumption in terms of savings after renovation measures have been realized. When only the primary heating system is involved, the predicted savings are much closer to the actual (see Figure 2). Table 6 also depicts the reality of simple combinations of ESMs being realized much more frequently than standard or deeper combinations of ESMs. The results indicate that depending on the mix of ESMs the ratios are fluctuating as well. The biggest differences occur when 5 or more ESMs are presented (see 16 to 22 in Figure 3). This may be due to assumed occupant behavior (including indoor temperature and hours of heating system operation) or wrong predictions of the state of the dwelling before an ESM takes place (Balaras et al., 2016; Majcen et al., 2016; Galvin 2014).

To examine, in more detail, the effect of the different ESMs on the actual and the predicted savings we also performed two multivariate linear regressions. Table 7 presents the results of the regressions. The dependent variable for the first regression is the actual savings and for the second regression the predicted savings. The purpose of this regression is not to best understand the factors explaining the savings and the difference between actual and predicted but rather to understand the different weights the ESMs have on them.

The R^2 of both actual and predicted savings is disappointing. In both regressions the predictors do not explain sufficiently the savings. That is understandable as we only include the improvement or not (dummies) of the ESMs. In that respect, we focus on the Beta coefficients of the predictor variables as we want to examine the effect of different ESMs on the gas consumption savings as a renovation process. Our goal is not to create a model that will explain in the best way the actual and the predicted savings achieved.

All independent variables are significant for both regression analyses ($p<0.001$). The independent variables best explaining the actual savings are the improvement of the ESM heating and ESM glazing. We observe the Beta coefficients of these ESMs to be the highest with a positive relationship to the actual savings (Table 7 – Actual Savings). In reality, this means that the change of the heating system and the glazing are affecting the actual savings more positively than other ESMs. The effect is 10.584 kWh/m² savings for the heating system and 7.262 kWh/m² for glazing when looking at the B coefficients. The envelope insulation and ventilation ESMs are not affecting the actual savings as much as heating and glazing, based on the Beta coefficients. We could say that a dwelling where heating system and glazing ESMs are applied, is expected to achieve higher actual savings.

On the other hand, the independent variables best explaining the predicted savings are ESM roof insulation, ESM façade insulation and ESM DHW. The Beta coefficients of these ESMs were higher compared to the rest (Table 7 – Predicted Savings). These independent variables do not coincide with the ones explaining the actual savings. This fact highlights the differences between the actual and the predicted gas consumption savings. Table 7 depicts how much can just the applied ESMs explain the savings and to what degree each ESM explains better the savings or has a larger effect compared to other ESMs.

Conclusions

The goal of this paper was to examine the impact of thermophysical renovation measures on both the predicted and actual energy consumption of the renovated non-profit stock in the

Table 7. Multivariate linear regression analyses on the actual and predicted savings [kWh/m²/year].

	Actual Savings (R^2= 1.6 %)				Predicted Savings (R^2= 27.5 %)			
	B	Std. Error	Beta	Sig.	B	Std. Error	Beta	Sig.
(Constant)	8.987	0.241		*	-5.947	0.187		*
ESM Heating system vs. Not changed	10.584	0.313	0.089	*	10.007	0.243	0.093	*
ESM DHW vs. Not changed	5.247	0.305	0.044	*	31.461	0.237	0.290	*
ESM Ventilation vs. Not changed	1.910	0.269	0.014	*	9.233	0.208	0.075	*
ESM Glazing vs. Not changed	7.262	0.287	0.050	*	24.708	0.223	0.188	*
ESM Roof vs. Not changed	7.979	0.331	0.048	*	5.678	0.256	0.302	*
ESM Façade vs. Not changed	5.319	0.293	0.036	*	31.709	0.227	0.238	*
ESM Floor vs. Not changed	5.014	0.303	0.033	*	16.248	0.235	0.117	*

**=<0.001*

Netherlands. We focused on the actual savings as they can reveal the true effect of renovations on the reduction of energy consumption. The actual energy savings also highlighted the impact of the number and combinations of measures on the dwellings' performance. First we analysed the ESMs realized and then their impact on the actual and predicted energy consumption savings.

One of the main outcomes of this work is the fact that in the majority of renovated dwellings either 1 or 2 ESMs have been realized (78.2 % of the renovated stock). This fact highlights the lack of deep renovations in the non-profit stock in the Netherlands. When 2 or more ESMs have been realized the modelled savings are over-predicted by a factor of 0.66 (actual/predicted ratio) in the case of 2 ESMs to a factor of 0.38 in the case of 7 ESMs. As the number of measures increases the gap between actual and predicted savings is also increasing.

When we examined the single ESMs, we concluded that the heating systems (space heating and DHW) and glazing are predicted better than the ventilation and insulation values. Furthermore, ESMs of the combined heating system and DHW and the glazing yield the highest actual gas savings. The ESM of ventilation was the most under-predicted. The reason for that is probably the assumed air flow rates of the model. In the combinations of ESMs the results reveal that in most dwellings standard renovations have been performed (2 ESMs usually) rather than deep renovations. The gap between actual and predicted savings is larger when more ESMs are applied. Several reasons can be attributed to this effect. Predominantly, the assumed occupant behavior (including indoor temperature and hours of heating system operation) by the models used to predict the savings is a common factor causing the gap. However, falsely input envelope insulation variables, often based on the consumption year, is another issue raised by the results of this study.

The results of the regression analyses only revealed that the improvements ESMs alone do not explain the actual or predicted savings – the R^2 in both regressions was very low. However, our goal was not to create a model that would explain in the best form the actual and the predicted savings achieved. The change of the heating system and the glazing are affecting the actual savings more positively than other ESMs, based on the Beta coefficients. On the other hand, the ESM roof insulation, ESM façade insulation and ESM DHW affect the predicted savings more than the rest of the ESMs. We have to keep in mind that these regression analyses were performed to better understand the effect of ESMs on the savings and not to provide explanations about the gap between actual and predicted savings. It is in the plans for future studies to include the state that a dwelling reaches after renovation and the interactions between the ESMs in the regressions to better understand the effect of combinations of ESMs and the different types of renovations (in terms of ambition) on the actual and predicted savings.

In conclusion, this paper showed the significance of the actual energy savings on understanding the impact of the number and combinations of measures applied to dwellings. The reality is far different from what is modelled at the time. This can be a demoralizing factor when housing associations take decisions to renovate or not parts of their stock. The predicted savings cannot be considered accurate with the current calculation models when compared to the actual savings. The main question to be answered by future research is how can we determine the effectiveness of ESMs and packages of ESMs if no actual energy savings are provided. Large statistical studies maybe the answer to providing more realistic energy saving values.

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