7 Conclusions

§ 7.1 Introduction

The main element of the roadmap to a low carbon economy, drafted by the European Commission, is that by 2050, the EU (European Union) should cut greenhouse gas emissions to 80% below 1990 levels (European Commission 2011). This general target is further broken down into more specific goals for the power generation & distribution sector, the transport sector, agriculture sector and the buildings sector. The potential to reduce emissions from houses and office buildings can almost reach an emission free sector – by around 90% in 2050 (European Commission 2011).The same goal is followed in the Netherlands, as a member state of the EU. Additionally the Netherlands is following the 2030 goal of reducing the greenhouse gas emission by at least 40%, increase the share of renewable energy to at least 27% and reduce the total energy use (as an EU average) with at least 27% - compared to 1990 levels (European Commission 2014; Government of the Netherlands 2018). Further, a shorter term goal is set for the non-profit housing sector to reach an average energy label B in 2021 and a longer term goal of CO_2 neutrality in the non-profit housing sector by 2050 (Aedes 2017).

This research sought to provide insight into the progress of the energy performance towards emission neutrality, in the existing housing stock, through the application of energy renovations. The specific sub-goals of this thesis were to determine the energy renovation rate of the stock and the impact of the applied renovations on both the predicted and actual heating energy consumption. The difference of predicted and actual energy savings was analysed through longitudinal statistical modelling in renovated and non-renovated dwellings. In essence, we examined the effect that the improvement of thermo-physical characteristics of dwellings has on efforts to make the existing housing stock almost emission-neutral by 2050, as advocated by the European Commission (European Commission 2011).

Monitoring is essential to understand and further examine the energy performance of housing stocks. Descriptive and longitudinal statistical analyses have been carried out to determine the energy efficiency state, the energy renovation rate of the non-profit housing stock of the Netherlands along with the ESMs that took place the since 2010 and their impact on the dwellings' heating energy consumption.

Two sources of data were used: the SHAERE database and the actual heating energy consumption data from Statistics Netherlands. SHAERE is a monitoring database of the energy performance of the non-profit housing stock in the Netherlands. This monitor became operational in 2010 and contains information about the energy performance of the Dutch non-profit housing sector (circa 1.2 million dwellings). Housing associations report their stock to Aedes (the umbrella organization of housing associations) at the beginning of each calendar year accounting for the previous year (e.g., in January 2014 reporting for 2013). They report the energy status of their whole dwelling stock, every year, using the Vabi Assets software, whose basis is the Dutch energy labelling methodology (ISSO, 2009). The data comprise of thermo-physical characteristics (thermal transmittance [U-value] and thermal resistance [R_c-value] values of the envelope elements, the typology of dwellings, the year of construction, etc.), heating and ventilation installations, theoretical energy consumption, CO_2 emissions, the average EI (Energy Index) and more. The variables are categorized per dwelling (microdata). A considerable part of the non-profit housing stock is included in SHAERE – the response rate is more than 50% of the population, each year. The actual energy consumption data from Statistics Netherlands are collected, annually, from energy companies since 2009 (Majcen 2016). The companies report the billing data, which are calculated on the basis of the dwellings' meter readings annually. The datasets include values of gas and electricity use. The existence of district heating is also included without, however, values of heat used, due to the lack of individual meters. The data are collected on a dwelling level based on the address, which is encrypted.

The first part of this thesis (Chapter 2), used SHAERE database to examine the current energy efficiency state of the non-profit housing sector. Descriptive statistics where used to show the distribution of the thermo-physical characteristics of the stock, heating and ventilation installations and theoretical and actual heating energy consumption. This first part established the background knowledge needed to further analyse the energy renovation rate of the non-profit housing.

Further, the objective, presented in Chapter 3, was to determine the energy renovation rate in the Dutch non-profit housing sector over the years 2010 - 2014. We presented an analysis of the trends of the energy improvement rate through these years, for both the whole period and also the annual values. The data used derived from SHAERE, the official tool for monitoring progress in the field of energy saving measures for the non-profit housing sector in the Netherlands. The study consisted of longitudinal data analysis using variables from the monitoring system – namely the EI and the energy labels.

After establishing the energy renovation rate of the stock, we identified the energy improvements implemented in the non-profit housing sector in the Netherlands and assess their impact on the energy performance of the dwellings. We used longitudinal data and analysed the improvements of the stock for a three years' period, namely from ultimo 2010 to ultimo 2013, based on seven different dwelling characteristics and systems. We were able to track accurately the energy improvements applied in the non-profit housing and analyse their impact on the EI for this period. The main outcome of Chapter 4 is that there are many improvements applied, but that they are too small to attain the ambitious national goal of an average EI of 1.25 in 2020.

Monitoring the energy improvements of the existing housing stock can provide valuable information, concerning the energy savings that can be achieved both in terms of actual and predicted energy consumption. The predicted energy reduction in most cases differs from the actual energy consumption (Balaras et al. 2016; Filippidou et al. 2016b; Majcen et al. 2013; Tigchelaar et al. 2011). In Chapter 5 we examined the impact of thermal renovation measures on both the predicted and actual heating energy consumption of the renovated non-profit stock in the Netherlands. The actual savings revealed the real effect of renovations on the reduction of heating energy consumption and highlight the impact of (combinations of) measures on the dwellings' performance.

Having gained valuable information and experience when tracking the energy performance changes of the stock, in Chapter 6 we dealt with the estimation and prediction of future renovation rates. The accurate prediction of renovation rates can expedite the process towards emission-neutrality of the stock and assist in the design and implementation of energy efficiency policies. Using dynamic building stock modelling and statistical analyses of empirical data (SHAERE database) we predicted the energy renovation rates of the non-profit housing stock until 2050.

The following sections present the conclusions and recommendations drawn from this research. Section 7.2 replies to the research questions set in the Introduction Chapter 1 of this thesis. Section 7.3 sums up the conclusions of this research. Section 7.4 brings attention to issues of data quality and monitoring as lessons learned during the realization of the research study. Sections 7.5 and 7.6 present recommendations for further research and final remarks.

§ 7.2 Effect of energy renovations towards an emission-neutral building stock

Q.1 How efficient is the Dutch non-profit housing stock in terms of energy performance?

This first research question aimed at setting the current energy performance state of the Dutch non-profit housing stock. We approached the matter of energy efficiency of the stock, in 2015, through descriptive statistics of key variables form SHAERE database. We have concluded that the stock is not efficient in terms of energy performance. Based on the EI, the "assigned" energy label would be D for the non-profit housing in 2015. The envelope insulation levels are not adequate – especially when considering the façade insulation values. In addition, the energy installation of the dwellings can be characterized rather "traditional" with high efficiency gas boilers dominating the stock. Last, the mean predicted gas consumption is 178.95 kWh/m^2 whereas the mean actual gas consumption is 119.30 kWh/m^2 – lower than the Dutch average of 151.80 kWh/m^2. Figure 7.1 shows the distribution of the energy labels of the non-profit housing sector from 2010 to 2014.

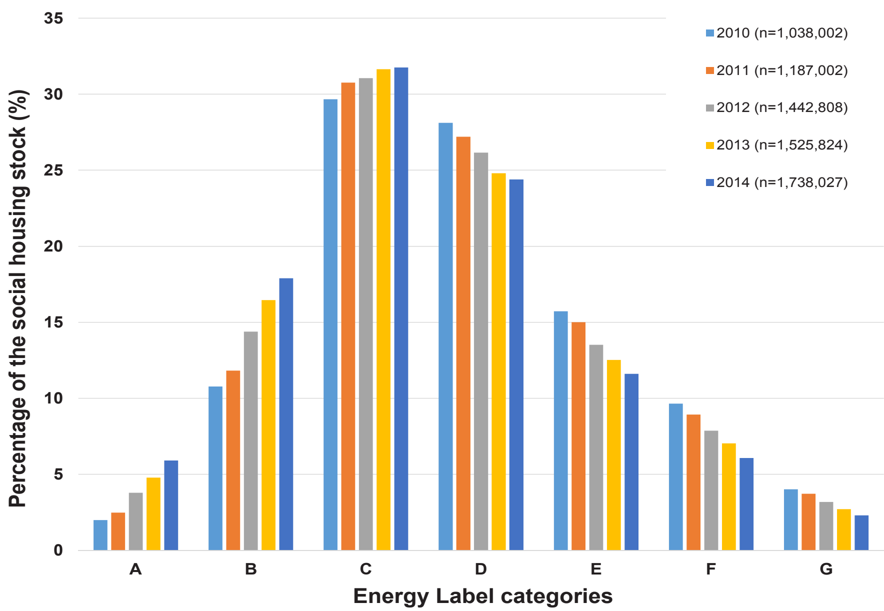

FIGURE 7.1 Distribution of the energy labels of the non-profit rented housing sector in SHAERE database

A What are the insulation levels of the envelope?

The average R_c-value of the roof was 1.50, classified as very well insulated, whereas the R_c-value of floors was 0.94, classified as well insulated. The average R_c-value of walls was 1.38 which classifies as poorly insulated. The average U-value of windows was 2.88 – classified as double glazing.

TABLE 7.1 Descriptive statistics for Rc-values of roof, floor, facades and U-value of windows

		R_c-VALUE ROOF m^2K/W	R_c-VALUE FLOOR m^2K/W	R_c-VALUE FAÇADE m^2K/W	U-VALUE WIN-DOW W/m^2K
N	Valid	869254	867131	1358544	1358464
	Missing	504841	506964	15551	15631
Mean		1.49	0.94	1.37	2.88
Median		1.30	0.41	1.30	2.90
Std. Deviation		1.04	1.02	0.91	0.79

B Which are the most frequent installations – space heating, domestic hot water and ventilation?

The distribution of the heating system is shown in Table 7.2. The majority of non-profit dwellings operate on a condensing gas boiler with $\eta \geq 0.95$. The situation is similar for the domestic hot water installations. The majority of the non-profit housing dwellings have a condensing combi-boiler with $0.90 \leq \eta \leq 0.95$ installed (see Table 7.3). The rest of the distribution is similar to the space heating installation. Table 7.4 shows the distribution of the ventilation systems in the non-profit housing sector based on data reported in SHAERE. Mechanical exhaust systems (54%) and natural ventilation (41%) are the most widely used systems. Only 4% of dwellings have balanced – mechanical supply and exhaust – system installed with the possibility of heat recovery.

TABLE 7.2 Distribution of heating system – frequencies and percentages from SHAERE 2015

TYPE OF HEATING SYSTEM	FREQUENCY	PERCENTAGE (%)
Condensing boiler (η≥0.95)	930127	74%
Improved non-condensing boiler (η= 0.80-0.90)	178557	14%
Condensing boiler (η=0.90-0.925)	42026	3%
Gas/oil stove	40548	3%
"Conventional" boiler (η<0.80)	29973	2%
Condensing boiler (η=0.925-0.95)	19595	2%
Heat pump	16722	1%
µCHP	2751	0%
Electric stove	484	0%
Total	1260783	100%

TABLE 7.3 Distribution of DHW system – frequencies and percentages from SHAERE 2015

TYPE OF DHW SYSTEM	FREQUENCY	PERCENTAGE
Condensing combi-boiler (η=0.90-0.95)	859253	66%
Improved non-condensing boiler (η=0.80-0.90)	172310	13%
Tankless gas water heater	100625	8%
District heating	76228	6%
Electric boiler (<20L)	74557	6%
Conventional" boiler" (η<0.80)	2979	0%
Heat pump	6402	0%
Gas boiler	697	0%
µCHP	4	0%
Total	1293055	100%

TABLE 7.4 Distribution of ventilation system – frequencies and percentages from SHAERE 2015

TYPE OF VENTILATION SYSTEM	FREQUENCY	PERCENTAGE
Mechanical exhaust	739199	54%
Natural	557910	41%
Mechanical supply and exhaust. (balanced) central	57859	4%
Mechanical supply and exhaust. (balanced)	2193	0%
Total	1357161	100%

c What is the modelled and actual final heating energy consumption?

Table 7.5 presents the results of the comparison between predicted ,from the energy labelling method, gas consumption as reported in SHAERE and the actual gas consumption of dwellings as reported in Statistics Netherlands. The mean values difference is 60 kWh/m²/year. The mean gas consumption for the Dutch households, as reported by Statistics Netherlands in 2015, is 151.80 kWh/m² (Statistics Netherlands 2017).

TABLE 7.5 Comparison of predicted and actual gas consumption in the non-profit housing sector

	PREDICTED GAS CONSUMPTION (N = 1151720)	ACTUAL GAS CONSUMPTION (N=1097812)
Mean value	178,95 (kWh/m²/year)	119,30 (kWh/m²/year)

This first research question of the thesis aimed at setting the current energy performance state of the Dutch non-profit housing stock. A complete and detailed assessment of the current efficiency state of the non-profit housing stock in the Netherlands is necessary in order to examine the energy renovation rates and energy saving measures realised.

Q.2 What is the energy renovation rate of the housing stock?

The renovation rates for the non-profit housing stock of the Netherlands were presented, based on the changes in the energy performance of about 800,000 dwellings for the period of 2010 to 2014. The necessary data were drawn from the SHAERE monitoring system containing information about the energy performance of approximately 60% of all dwellings in the sector. The method used follows the changes of the dwellings' thermo-physical properties and reported energy performance.

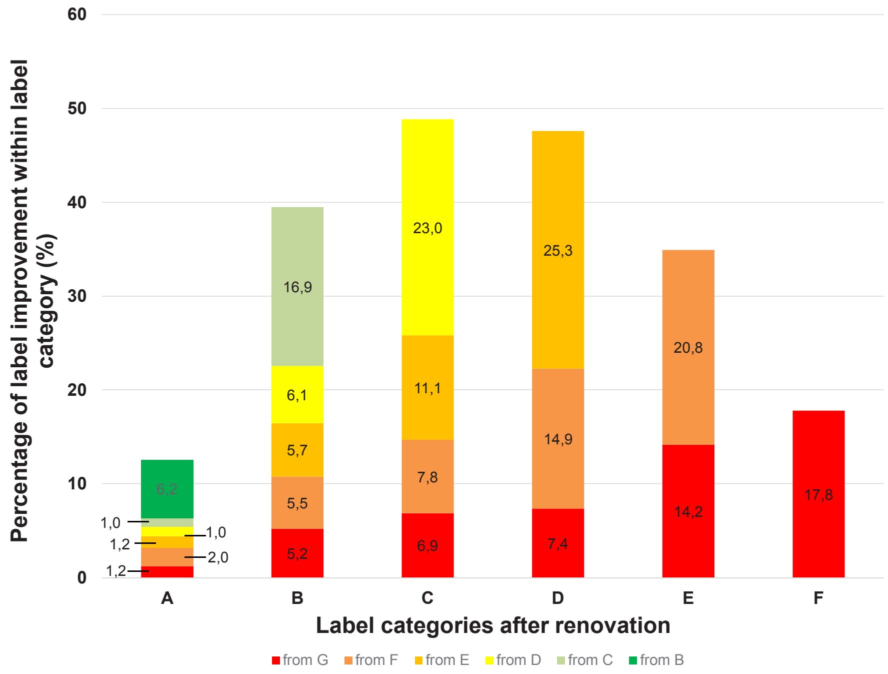

FIGURE 7.2 Improvement of labels of the non-profit rented housing sector from 2010 to 2014

The results have shown that although a number of energy improvements have been realized, they only resulted in small changes of the energy efficiency of the dwellings. In 2014, 5.5% of the dwellings improved by at least one label category, whereas 94.5% of the dwelling reports did not change a label category. The 'one label step improvement' rates range from 3.8% (2014) to 8.2% (2012). The 'two label step improvement' rates are significantly lower ranging from 1.02% (2014) to 1.83% (2012). The deep energy renovation rates (interpreted here as 'at least 3 label steps improvement') are considerably low ranging from 0.6% (2011) to 0.9% (2012) being the highest rate.

Even though 28.0% of the dwellings have improved (towards a 'higher' energy label category) in the 2010-2014 period, only 3.5% had a major renovation (at least three label steps). This percentage depicts the major energy improvement pace of the non-profit housing sector in the Netherlands for a period of four years.

A Are the energy efficiency targets of the non-profit housing stock reachable?

In the Netherlands, the majority of policy measures aimed to reduce the energy consumption by increasing the energy performance of buildings through the improvement of the energy labels. The short term goal of the non-profit housing sector is set to reach an energy label B by the end of 2020. Whereas, the long term goal coincides with the EU goal for an emission neutral housing stock by 2050. Thus far, the results show that although many energy improvements have been realized, they result in small changes in the energy efficiency of the dwellings. Deep energy renovation rates are very low. If this pace continues, progress will be too slow to reach national and international policy targets. In the non-profit housing sector, if the goal of an average label B is to be reached by 2020, the energy efficiency measures should be decided as packages of measures, rather than single measures because deeper renovations are needed. The pace in the period under investigation is too low to fulfil the ambitious goals of the national Covenant agreed in 2012 or reach the EU goals for energy efficiency. If the linear extrapolation of the EI, as shown in Figure 7.3, is followed, then the EI in 2020 will be 1.41. Several stakeholders argue that the renovation pace will increase, as there are several policies in effect. However, the results point out that there is a very limited movement towards the A (A+, A++ included) labels, which may indicate that the decrease of the EI will slow down, simply because most of the low hanging fruit (e.g., easy to implement single energy improvement measures such as double glazing windows) has already been picked.

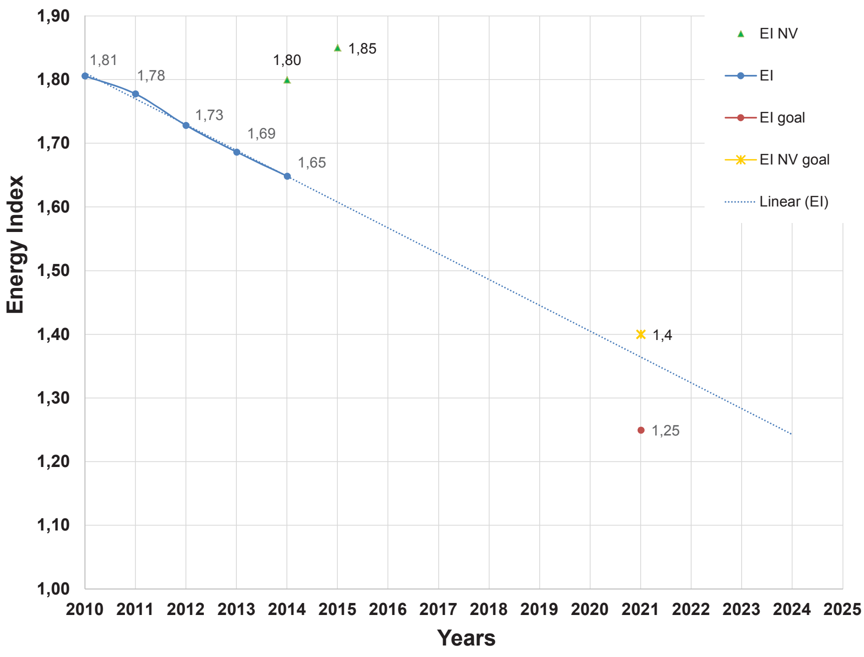

FIGURE 7.3 The Energy Index (EI) development of the non-profit rented housing sector in SHAERE database

B What are the lessons learned from the policies applied in the sector and their implementation progress?

When energy improvements are difficult to implement in non-profit housing, then the implementation will be even more difficult for the privately owned or rented dwellings. The structure of ownership and the buildings are more dispersed and fragmented than in the non-profit housing sector. As a result, in order to motivate private owners to renovate the residential stock, more concerted policies and market uptake plans are required from the central authorities, though strict and tailored implementation from the national governments will also play a major role.

Based on the results, we do not expect future improvements when it comes to the energy renovation pace if the same policies are followed. At the same time, there is also a change in the policies regarding the energy labelling of dwellings and the calculation of the EI in the Netherlands. A change in the methodology of the calculation of the EI is in force since June 2015. From now on, the re-calculation of the matching EI-Energy label is important. Another change in the energy label certificates was already implemented at the start of 2015. A new, easy to acquire and cheaper energy label is in force, based on a different calculation method without an inspection taking place. These changes are affecting the realization of several co-existing policies, and will also have implications with the implementation of energy improvement measures in the existing housing stock, especially in the non-profit housing sector, where specific targets regarding the EI have been agreed.

Q.3 What are the energy efficiency measures realised the last years?

In the previous section, we presented the renovation rates for the non-profit housing stock. However, a better understanding of the type and effect of the energy renovations is needed to draw conclusions about future policies and regulations. In order to reply to Q.3, we examined the energy efficiency measures currently applied in the sector and their effects on energy performance. We established a method based on statistical modelling and data analysis of thermo-physical properties regarding the energy efficiency, general characteristics and energy performance of 757,614 households. As a result, we provided insight into the energy efficiency measures applied to the existing residential stock.

A Are the envelope elements and installations being renovated at the same frequency?

The results show a mixed picture. On the one hand, they show that the housing associations have taken many measures to improve the energy performance of their stock. This seems to be a result of the intensified discussions in the sector about energy saving and climate protection. On the other hand, the progress in the energy performance of the housing stock is rather modest. We identified a tendency for conventional rather than innovative maintenance measures in most of the seven thermo-physical characteristics examined: a typical example is the improvement of a boiler of η=0.80 to a condensing combi-boiler of η=0.90-0.95 instead of a heat pump or a µCHP solution. Further, where energy improvements do take place, usually only one or two measures are carried out per dwelling. Most of the changes regard the heating and domestic hot water (DHW) systems, as well as the glazing. But, the rest of the building envelope elements are not improved at the same frequency.

B Are energy renovations being realized as single measures or combinations?
Housing providers generally do not seem to execute major renovations, but much smaller investments. Most of the changes concern the heating, DHW systems, and the glazing. The rest of the building envelope elements are not improved at the same frequency. The data show that the goals for this sector will be hard to achieve if the same strategy for renovation is followed, taking into account the percentages of change. The energy renovations, based on the easiest to achieve measures, do not yield the results that are expected towards the 1.25 average EI. One could also argue that the goals set for the non-profit housing sector are too ambitious and despite the efforts for energy renovations the goals remain too difficult to attain.

So far, we have shown that the impact on the energy performance based on the theoretical energy performance is as expected: the impact increases with the number of measures. However, we must be cautious when discussing the energy performance of dwellings. As previous research has shown (Guerra-Santin et al. 2012; Majcen et al. 2013; Balaras et al. 2016) it is crucial to consider the difference between the modelled energy performance of dwellings and the impact on the actual energy consumption. Further research is necessary to examine the impact of the energy efficiency measures implemented in the sector on the actual energy consumption of the dwellings.

Q.4 What is the impact of the energy renovations on the actual gas consumption savings?

Replying to Q.4, we examined the effectiveness of energy renovations re-assessing them based on actual consumption data. We connect the data from SHAERE to the actual heating energy consumption data from Statistics Netherlands on a dwelling level. Using longitudinal analysis methods, from 2010 to 2014, we were able to identify the energy efficiency improvements of the stock and to determine the effectiveness of different measures in terms of actual energy savings. The results revealed the actual energy savings of different efficiency measures, highlighting the significance of the actual energy consumption when a renovation is planned or realized.

A What is the difference between predicted and actual heating energy consumption savings of the renovated dwellings?

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 52% – compared to the actual savings – in the case of 2 ESMs, and by 163% in the case of 7 ESMs. As the number of measures increases the gap between actual and predicted savings is also increasing. Moreover, we examined the non-renovated stock for the period 2010-2014. We found out that without any energy renovation taking place, a reduction of 11 kWh/m^2/year occurred. Several reasons can explain this reduction, such as changes in the method of calculations by the energy companies reporting to Statistics Netherlands, possible effects from occupant behaviour change or mistakes in reporting in the SHAERE database that need further investigation.

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. As mentioned above, 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 behaviour (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. These falsely input variables can cause both under- and over-prediction of the actual energy savings. Further research on known cases where this has occurred would provide a more accurate insight into the degree that the phenomenon is responsible for the gap between actual and predicted energy savings.

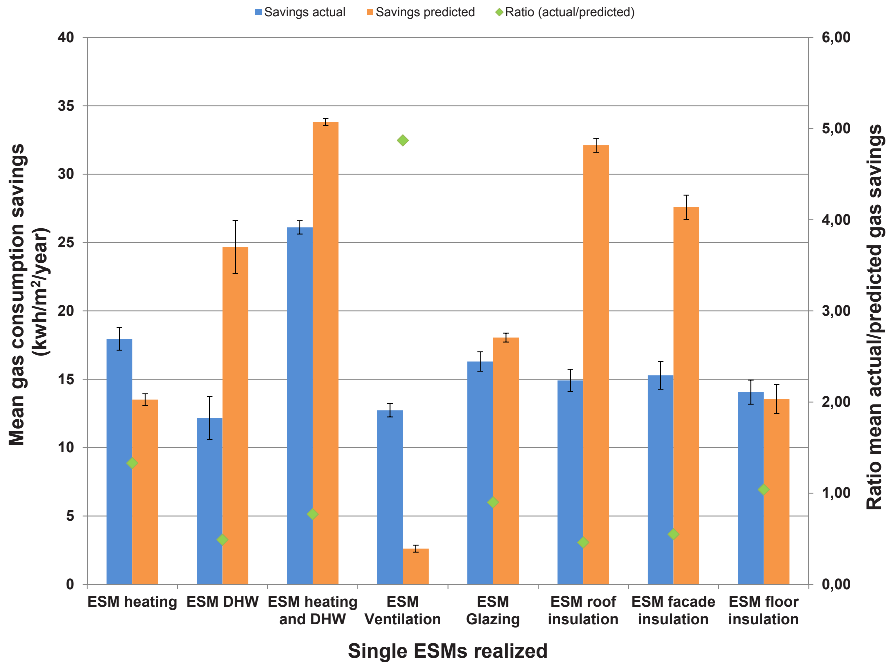

FIGURE 7.4 Mean actual and predicted gas consumption savings for dwellings with single ESMs

Figure 7.4 depicts 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 7.4 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).

B Which are the most frequent combinations of energy efficiency measures?

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 7.6 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.

TABLE 7.6 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	1584	0.21
2	Heating system and domestic hot water system	63675	0.77
3	Heating system and ventilation	9256	0.72
4	Heating system and glazing	6379	0.58
5	Heating system and roof insulation	2993	0.35
6	Heating system and façade insulation	5373	0.48
7	Heating system and floor insulation	7208	0.55
8	Heating system, glazing and roof insulation	944	0.41
9	Heating system, glazing and façade insulation	2223	0.38
10	Heating system, glazing and floor insulation	1407	0.51
11	Heating system, ventilation and glazing	1835	0.53
12	Heating system, ventilation and roof insulation	577	0.30
13	Heating system, ventilation and façade insulation	2090	0.41
14	Heating system, ventilation and floor insulation	2554	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	2898	0.40

c What is the effect of the different energy saving measures on the predicted and the actual savings?

To examine, in more detail, the effect of the different ESMs on the actual and the predicted savings we performed two multivariate linear regressions on the renovated stock (266,391 dwellings). Table 5.4 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 results of the regression analyses 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. Our goal was to determine the effect of the different energy saving measures on the predicted and the actual savings. The change of the heating system and the glazing are affecting the actual savings more positively than other ESMs. 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 and interpret the effect of combinations of ESMs and the different types of renovations (in terms of ambition) on the actual and predicted savings.

Q.5 Can energy renovation rates be accurately predicted?

Questions 1 to 4 established the background for the energy efficiency state, energy renovations, and the renovations' impact on the predicted and actual heating energy consumption of the housing stock. But can we predict the renovation rates towards an 2050 anticipated emission neutral housing stock?

The forecasting and prediction of renovation rates is not only important to better understand the process and levels of energy renovations achieved. It can serve as a powerful tool to improve the design and implementation or policies and regulations on an EU and national level. Usually, legislators and policy makers rely on goals and "needed renovation rates" to create roadmaps and policies. These are not reliable and are far away from what is actually happening in the building stocks worldwide. This chapter aimed at introducing different methods of analysis and calculation of renovation rates for the non-profit housing stock of the Netherlands.

A What methods can be used to accurately predict energy renovation rates?

Approaches to monitor the building stock have evolved separately across countries in Europe. Information about the progress of energy performance renovations is necessary to track the progress of policy implementation and its effectiveness. To this day, each country is gathering and analysing data for the development of their building stocks individually and in a different manner. Some collect data through the Energy Performance Certificates (EPCs) databases and others perform housing surveys in representative samples. In some cases, information gained through the investments on energy renovations are used to calculate the progress. To address the shortcomings and challenges of building stock monitoring, there is a need for a new method for the estimation of renovation rates that can be used for consistent and scalable analyses of building stocks.

We combined two different methods to simulate and assess the energy renovation rate of the Dutch non-profit housing stock. First we applied the dynamic dwelling stock model which has been developed and validated in NTNU (Norwegian University of Science and Technology), Norway. The input parameters are based on statistical information for the development of the non-profit housing stock. Second, we used yearly records gathered centrally and stored in SHAERE, the time series database by housing associations through the energy labelling of their stocks. Ultimately, we compared the renovation rates resulting from the dynamic modelling and the analysis of empirical energy epidemiology data. As a result, we were able to suggest renovation rates for various types of renovation measures, which should be applied in studies of future development of energy demand in the dwelling stock.

The methods followed in this paper represent two different approaches to building monitoring regarding energy renovation rates and ESMs. Despite the fact that in the dynamic modelling method the renovation is a probability function and in the statistical method the renovation is an ESM or a group of ESMs calculated from a time series dataset, we match the definitions by assigning specific single ESMs or combinations of ESMs to renovation cycles (years).

B How do predicted energy renovation rates compare to empirically calculated rates?

According to the simulated results, using the dynamic building stock model developed by Sartori et al., 2016, the renovation rates are quite stable for all cycles. The 40 year renovation cycle rate, that is commonly assumed to represent major or deep renovations, is stable at 1% and is expected to increase to 1.2% from 2020 and remain as such until 2050. The empirical results show rates at around 1% for the recent years as well. These results are nowhere close to the expected 2-3% referred to in legislations (Artola et al. 2016).

These contrasting methods, both in terms of time and approach of the renovation process, provide unique results and observations. The long term prediction, that is possible using a dynamic stock model like this one, provides information on a global scale and can be used on a policy level to improve the manner in which actions are applied for the energy upgrade of the building stocks. On the other hand, empirical results, like the ones derived from SHAERE, provide short-term information on specific ESM replacement rates that are valuable for subsidy schemes and other forms of energy improvement enforcement by national and local governmental bodies. We have shown that a combination of methods like the ones used in this paper, are necessary for better use and application of policies. Epidemiological data can help determine short term and long term goals and details about the renovation processes. Concurrently, dynamic building stock modelling can be used to predict renovation rates using the aforementioned epidemiological data and assist in the planning of policies.

§ 7.3 Overall conclusion

Throughout Europe, national approaches to building stock monitoring have evolved separately. Nevertheless, monitoring the building stocks energy performance is gaining attention. Information about the progress of energy performance improvements is not only needed to track the progress of policy implementation but better information and data are necessary to help develop roadmaps in order to achieve more energy efficient buildings. The main research question of this thesis was:

What is the energy efficiency progress of the non-profit housing stock, through energy renovations, and what is their impact on the actual heating energy consumption?

The main conclusion of the thesis is that the energy efficiency progress of the non-profit housing stock, in the Netherlands, through the application of energy renovations is too slow. We conclude that attaining the short term goals of achieving an average energy label B in the non-profit housing stock is not probable by 2021. The renovation rates of single measures are much higher than the “major energy renovation” rates, in the non-profit housing stock on the Netherlands. These results suggest a lack of pro-activity by the housing associations and not-carefully planned actions to renovate deeply their housing stocks but rather work on a maintenance basis. However, we also emphasize that collective agreements, like the Covenant of the non-profit housing sector, can have a positive impact on the uptake of energy renovations in the existing housing stocks. The percentage of dwellings with an energy label in the non-profit housing sector is larger than the one of the national housing sector, which serves as an indication of how collective agreements can enforce policy. SHAERE itself is also an example of what national agreements can entail.

Regarding the energy performance progress, we highlighted the importance of data monitoring and prediction of future renovation rates – by comparing long and short term prediction methods. We conclude that the rate of major renovations, is stable at

1.0% and is expected to increase to 1.2% from 2020 and remain as such until 2050. The empirical, from SHAERE, results show rates at around 1% for the recent years as well. We highlight, based on current knowledge and the modelling of historical data, that major renovation rates are not expected to increase if the current renovation activity remains as is.

The impact of energy renovations can be measured by either the effect on the performance or the savings achieved. We shed light on the difference between predicted and actual energy savings occurring after renovations. Modelled savings are over-predicted by 52% – compared to the actual savings – in the case of 2 ESMs, and by 163% in the case of 7 ESMs. As the number of measures increases the gap between actual and predicted savings is also increasing. 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.

In conclusion, the gathering and analysing of building epidemiological data can ensure the tracking of renovations, energy savings and the degree of implementation of current policies. The situation is, of course, not ideal as the monitoring can be further improved and the coupling with actual energy consumption can become standard practice. Moreover, the design of policies that can be implemented to promote energy renovations, the improvement of the quality of housing stocks as well as the indoor air quality is of outmost importance for most of the EU countries and worldwide.

§ 7.4 Data quality in the built environment

When it comes to research for energy renovations in the built environment, dynamic databases using time series data prove to be extremely useful. Longitudinal data are very important to follow the actual energy performance of housing stocks. Datasets and monitoring systems with detailed information, like SHAERE or EPC (Energy Performance Certificate) databases, are necessary to evaluate policies, predict future renovation rates and conclude on best practices for different housing stocks. One of the strengths of SHAERE is the very large amount of data (more than 50% response rate in all years studied) and its representativeness. The large dataset is important since the study aimed at calculating the energy improvement pace of the sector. In this sense, the monitoring system can set an example for the rest of the housing sectors. SHAERE has proven to be a rich database on the energy performance of the non-profit sector. However, issues of data quality have been identified and require further analysis.

This research was based on the dwellings' physical properties and the reported energy consumption, in order to examine the improvements and pace of energy renovations using SHAERE. Concerning the quality of data used and the impact on the results of this study, two points should be mentioned. First, we cannot be completely confident about the quality of the inspections taking place in the sector. As a result, concerns have been raised about accuracy of the input data in SHAERE. Although there has not yet been a study regarding the quality of SHAERE, a series of studies carried out by the Inspection Service of Ministry of Housing, for the official energy labels database of the Netherlands, report that in several samples studied from 2009 to 2011deviations from the reported to the actual energy label are decreasing (VROM-Inspectie 2009; VROM-Inspectie 2010; VROM-Inspectie 2011). Hence, there seems to be a trend of improvement. However, further research is required to determine the amount of wrongly reported values of dwellings. We recommend that input methods be tested and validated in future monitoring systems.

In SHAERE, for the period of 2010 - 2014, about 2.4% of the dwellings analysed presented a decrease of their energy performance. This percentage, when examined for the calculations performed for each year, was found to decrease from 1.9% in 2011 to 0.7% in 2014, as more dwellings were reported. The decreasing of the energy performance reported can be attributed to two main reasons. Firstly, it could be an administrative correction during the process of data input. And secondly, it could be caused by wrong inspection procedures. In both cases, it is very difficult to determine the reason. The monitor could be further improved if it contained data on a possible renovation: is the dwelling renovated and, if so, in which year. Until the 1990s, renovations in the non-profit housing sector were subsidised by the national government. Because of this, and because this type of interventions is relevant for today's asset management, there is good chance that housing associations still have this data available (Stein et al., 2016). This way, the major issue regarding falsely input variables, and specifically more so U-values of envelope elements, could be improved. A pilot study would have to be carried out to check this and its applicability.

The actual heating energy consumption data, acquired from Statistics Netherlands, are collected by energy companies since 2009. Yet, the submission of meter readings by the companies is obligatory every 3 years in the Netherlands. As a result, estimated 10-20% of dwellings instead of a meter reading would be filled in with the average energy consumption of a similar building (Majcen 2016). While this fact can impede with our analyses, we did not analyse individual dwellings but worked with groups of dwellings. We are confident that our results are accurate. Moreover, we worked with data before and after renovation measures were realized and tried to select the most past energy consumption data and the most recent, which often was 3 or 4 years apart.

Last, in all calculations, regarding actual energy savings and consumption, a degree day correction was applied. This correction was set to the number of degree days used in the national calculation method (SHAERE data) to be able to compare the predicted and actual values. The number of degree days used in the method are set based on the assumption that when the indoor temperature is 18°C then heating is needed. Still, this method may introduce small discrepancies since the heating practice does not only depend on the air temperature outside but also on the chosen heating season for each dwelling.

§ 7.5 Recommendations

This research concluded that based on the renovation rates achieved since 2010 attaining the European and national goals is not probable. Moreover, we found out that the rate of major or deep renovations, is stable at 1.0% and is expected to increase to 1.2% from 2020 and remain as such until 2050. This thesis, also, 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. As the number of measures increases the gap between actual and predicted savings is also increasing. There are several recommendations that can derive from these results. Below, we start with recommendations for policy makers and legislators. Then, we also propose several actions for practical implementation and further research on the subject of energy renovations.

§ 7.5.1 Recommendations for policy

In terms of policies applied on the energy efficiency of the built environment, based on this work, three main recommendations can be formulated.

Development of energy renovation rates prediction

One of the first outcomes of this work was the energy renovation rates realized in the non-profit housing stock since the creation of SHAERE. The value of these results lies with their possible use. In Chapter 6, we used dynamic building stock modelling to predict future renovation rates. We concluded that deep energy renovation rates will be 1.2% after 2020. So far, policy makers and legislators depend on rates that are calculated based on the needed outcomes to ensure the achievement of goals set. This fact can be counterproductive because the needed energy renovation rates do not reflect what is actually the rate at which ESMs are realized. Especially when renovation rates are hardly calculated on the basis of national building stocks. We recommend, through the monitoring and gathering of energy performance data of building stocks, the accurate prediction of renovation rates to be used in policy making. This way home owners and housing associations can understand the urgency of energy renovations needed. In addition, if the renovation rates can be accurately predicted then the needed rates can also be translated into numbers of homes and levels of energy renovations.

Use of monitoring databases

As said before in this chapter, the gathering and analysing of epidemiological data can ensure the tracking of renovations, energy savings and the degree of implementation of current policies. SHAERE was used for all of the above. This was a challenging task, but in the last decade more countries started developing some kind of monitoring database Brøgger & Wittchen 2017; Hamilton et al. 2017; Dascalaki et al. 2016; Droutsa et al. 2016; Corrado & Balarini 2016; Serghides at al. 2016; Stein et al. 2016).. These have to be updated and used accordingly in order to provide any information needed to ensure the decarbonisation of the built environment. Working with SHAERE, we have learned that data quality is a difficult issue to tackle. Moreover, data mining, cleaning and organising is a challenging process. Despite these issues, the creation of databases like SHAERE prove to be extremely helpful in the monitoring process of energy efficiency of building stocks. Furthermore, collective agreements, like the Covenant of the non-profit housing sector which resulted in the creation of SHAERE, can have a great impact on the uptake of energy renovations in the existing housing stocks. The percentage of dwellings renovated in the non-profit housing sector is larger than the one of the total sector, which serves as an indication of how collective agreements can be implemented.

Use of actual energy savings

One of the results highlighted in this research is the difference between predicted and actual energy savings. In the process of completing this research we worked closely with Aedes, the umbrella organization of housing association in the Netherlands. In our latest collaboration for the annual sustainability benchmark that they produce for their members the average heating energy consumption of the sector was added. This is an example where actual energy consumption data can be used to better inform stakeholders. We recommend, based on the outcomes of this work, actual energy savings to be taken into account when designing or implementing policy measures. The difference of predicted versus actual energy savings is too great to ignore and can lead to false decisions or selection of ESMs that could be less effective than other. In addition, actual energy consumption data are easy to couple with monitoring databases.

§ 7.5.2 Recommendations for practice

A main outcome from Chapters 3 to 5 was that energy renovations implemented in the non-profit housing sectors are based on a "maintenance" level rather than based on energy renovation agendas and plans. We recommend that stakeholders from practice use the research results and develop energy renovation plans for the future. This way more ambitious and major renovations can be achieved. Moreover, the most efficient ESMs can be planned for specific types of dwellings and buildings. Monitoring can prove useful not only for the whole sector but also for the housing associations as entities.

The effectiveness of ESMs is largely depicted on the actual energy savings. We recommend that housing association use actual energy consumption results to plan future energy renovations. As a result, instead of conventional solutions, based on maintenance plans, combinations of energy measures resulting in an overall improvement of the energy performance of dwellings could be achieved. The non-profit sector has a large potential for improvement. The support from governmental bodies through subsidies and other economic incentives is also important amidst the economic crisis of the housing sector. Based on the work performed during this research (see Appendix C), in cases were municipal support was offered it resulted in the application of more concrete energy renovation plans by the housing associations (Filippidou et al. 2016a).

§ 7.5.3 Recommendations for future research

Based on the outcomes of this research we propose three main lines of future research. First, the continuation of statistical studies of energy renovation is needed to understand barriers, practises and effectiveness of renovation measures based on different criteria (e.g. different occupants, building types and more). Second, the determination of falsely input characteristics through new methods instead of guessing based on building year is essential to reduce the difference of predicted to actual energy savings. Third, the determination of the driving forces steering the decision-making process regarding the application of specific energy efficiency measures is valuable information that can help improve our understanding of renovation rates and ESMs applied.

Predictions of the energy savings that can be achieved from the renovation of the stock should be based on the actual and not the theoretical consumption of energy. That way, more information about which combinations of renovation measures are more efficient for different typologies of buildings can also be used. Future research has to take into account the relationship between measures, packages of measures, major renovations on the one hand and the different characteristics of sub-stocks on the other.

The current longitudinal study on the energy improvements and the impact on the energy performance of the dwellings showed the progress of the non-profit housing sector. Large statistical studies and building epidemiological data maybe the answer to providing more realistic energy saving values. However, we also need to use cross-sectional data to analyse the impact of energy efficiency measures on the actual energy consumption. Using cross-sectional data and focusing on cases studies, we can assess more in depth the energy renovation practises. A combination of longitudinal and cross-sectional data analyses is the necessary approach on the matter of energy efficiency in the building sector. Both the quantitative and qualitative characteristics of the energy renovations are crucial to achieve the energy consumption savings. For example, what is the impact of the occupant on the realized energy savings? Moreover, the connection of this results to policies applied or that will be in force in the future is of great importance.

Apart from the statistical studies needed to better comprehend renovation practises, future research should focus on the precise determination of buildings' thermo-physical characteristics. We expect that if these values (R_c and U-values of envelope elements, efficiency of energy installations – heating systems and domestic hot water systems – actual heated floor area and actual air flow rates) are correctly input in the monitoring systems the prediction of energy savings due to renovations can improve dramatically. Research performed on the determination of wall's U-values has already showed that new and innovative methods can accurately predict the thermal resistance of envelope elements (Rasooli et al. 2016).

The classification system of the envelope insulation values used in our methods (Chapters 2,4 and 5) is based on the ISSO 82.3 publication − describing the methodology to evaluate the energy performance of Dutch dwellings. The classes are based on construction year periods and insulation thickness. This method may not be the optimal for the characterization of the insulation levels. However, it was chosen to correspond to the building practise, building regulations and their evolution in the Netherlands. Different methods, using either the nominal values of the variables or a more detailed classification (more classes) should be studied in further research projects. This would enable the comparison of results and their validation.

Following the assessment on the efficacy of the ESMs applied and due to the fact that housing associations act collectively, their motivation on choosing some ESMs over other is important to research. For this reason, a qualitative analysis on the driving forces of the housing associations could be performed. Examining smaller scale renovation activities will enable, the monitoring of the practice of energy renovations in order to go back and compare the results of this method to the results of the efficacy of the measures from monitoring databases like SHAERE. Through this analysis the decision making process of the housing associations performing an energy renovation plan can be assessed.

§ 7.6 Final remarks

The goal of this thesis was to determine and predict the energy renovation rate of the stock, and to study the impact of the applied renovations on both the predicted and actual heating energy consumption. In essence, we examined the effect energy renovations of dwellings have on efforts to make the existing housing stock almost emission-neutral by 2050. We focused on the actual savings as they can reveal the true effect of renovations on the reduction of energy consumption. The difference of predicted and actual energy savings was analysed through longitudinal statistical modelling in renovated and non-renovated dwellings. The actual energy savings highlighted the impact of the number and combinations of measures on the dwellings' performance.

In conclusion, through this research we bring attention to the gathering and analysing of building energy epidemiological data. These can ensure the tracking of renovations, energy savings and the degree of implementation of current policies. The situation is, of course, not ideal as the monitoring can be further improved and the coupling with actual energy consumption can become standard practice. This research emphasizes the importance of monitoring the progress of energy renovations of buildings stocks and their actual effect on energy savings. Different methods can be used to track and predict energy renovation rates and the development of the energy performance of building stocks. The choice depends on the question or situation at hand – this can be global, national, municipal or a case study. Nevertheless, the renovation activity is expected to be greater than the construction and demolition activity in the future and as such we need to bring awareness to the actual impact and effectiveness of energy renovations.

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