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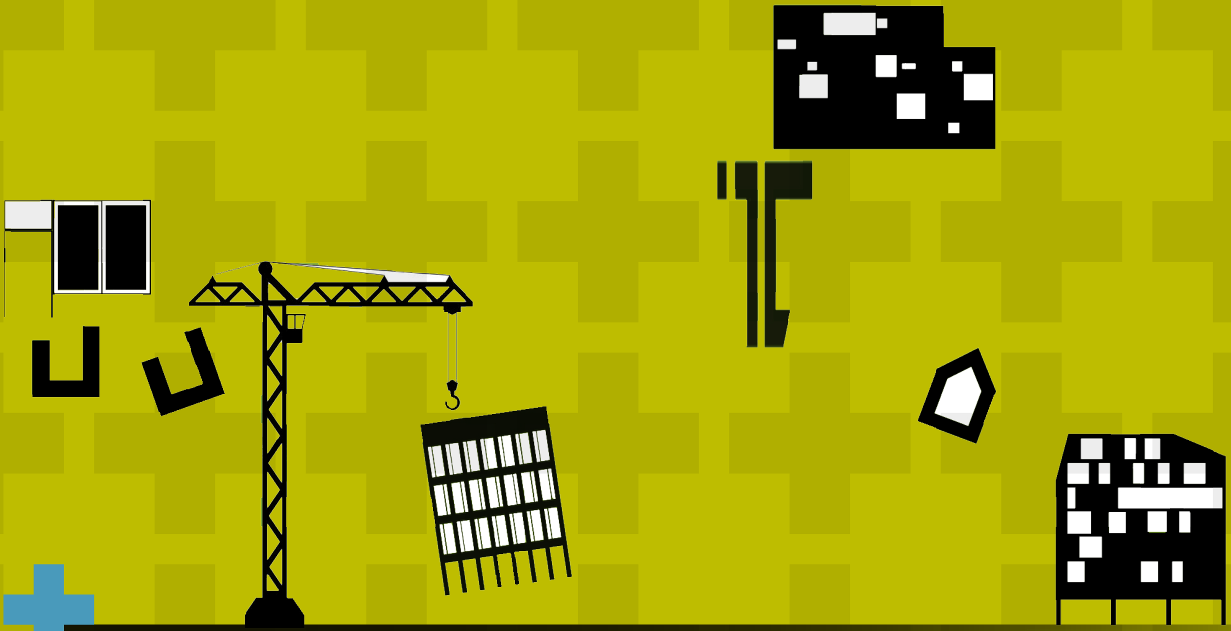
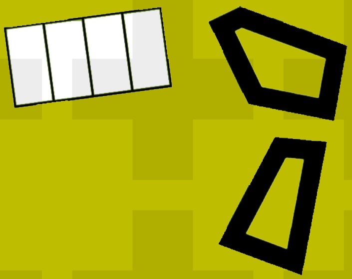


Energy performance progress of the Dutch non-profit housing stock: a longitudinal assessment

Faidra Filippidou



Energy performance progress of the Dutch non-profit housing stock: a longitudinal assessment

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Στα ταξίδια που μας περιμένουν

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Summary

Worldwide, buildings consume a large part of the total energy delivered. In the context of all the end-use sectors, buildings represent the largest sector with 39% of the total final energy consumption, followed by transport in the EU (European Union)[1]. A considerable percentage of this energy consumption is attributed to the residential sector. The building sector plays a major role in order to meet the energy saving targets set in the EU and in the Netherlands. This is particularly true for existing buildings, because they will constitute the major part of the housing stock over several decades. The renovation activity is expected to be greater than the construction and demolition activity in the future.

Policy targets and regulations are in force at the EU level to ensure the energy efficiency improvement of the building stock. The Energy Performance of Buildings Directive ([EPBD] 2002, recast 2010) is the main legislative and policy tool in EU and focuses on both new and existing buildings. At the same time, the building sector plays a prominent role in the Energy Efficiency Directive ([EED] 2012). Relatedly, in the Netherlands, the foundation of energy efficiency policy has been a number of national cross-cutting measures and EU derived policies that play a large role; like the strengthening of standards for new buildings or dwellings and energy labels for existing ones.

The focus of this research is the existing dwelling stock and its energy performance progress. 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 also better information and data are necessary to help the development of roadmaps towards a more energy efficient building stock.

This research seeks to provide insight into the energy performance progress, of the existing non-profit housing stock in the Netherlands, through the application of energy renovations. The non-profit housing stock comprises 30% of the housing market in the Netherlands and a large part of the policies towards a more efficient housing stock rely on the non-profit housing sector. To that end, we determine the energy renovation rate of the stock and the impact of the applied renovations on both the predicted and actual energy

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[1] European Commission (2017). Statistical pocketbook 2017. Retrieved from https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2017_en [accessed 21.5.2018].

consumption. The difference of predicted and actual energy savings is analysed through longitudinal statistical modelling in renovated and non-renovated dwellings. Based on the knowledge gained on the renovation rates of the non-profit housing stock we compare and evaluate future renovation rates through dynamic building stock modelling and empirical data validation. In essence, we examine 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 since 2011.

Research methods and data

The main research question of the research is what is the energy efficiency progress of the non-profit housing stock, through energy renovations, and what is their impact on the actual energy consumption. Data availability played a pivotal role to the completion of this research. We were able to use building energy epidemiology methods due to the amount of longitudinal data and their level of detail.

Two sources of data are used: the SHAERE (“Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing” – in English: Social Rental Sector Audit and Evaluation of Energy Saving Results) database and the actual 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, which includes the vast majority of the rental dwellings in the Netherlands. 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). The data comprise of physical characteristics (thermal transmittance [U-value] and resistance [Rc-value] values of the envelope elements, the typology of dwellings, the year of construction, etc.), heating and ventilation installations, predicted energy consumption, CO_2 emissions, the average energy performance coefficient (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. The companies report the billing data, which are calculated on the basis of the dwellings’ meter readings annually. The datasets include values from 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.

Based on the research questions and data available, the energy efficiency state of the Dutch non-profit housing stock is analysed, initially, through descriptive statistics of the dwellings' thermo-physical characteristics. Then, the rate of energy renovations is determined using longitudinal data and analysis methods based on the energy performance of dwellings before and after energy saving measures are realised.

In continuity, specific energy saving measures are examined to gain insight of the practices in the non-profit housing sector. Furthermore, we study the impact of these energy renovations on both the theoretical (model predicted) and actual energy consumption of the stock. Subsequently, based on the knowledge gained on the renovation rates of the non-profit housing stock, we examine future renovation rates through dynamic building stock modelling and empirical data validation.

Effect of energy renovations towards an emission-neutral building stock

The energy efficiency state of the Dutch non-profit housing stock

The first part of this research uses data from SHAERE to examine the current energy efficiency state of the non-profit housing sector at the end of 2015. Descriptive statistics are applied to examine the distribution of the physical characteristics of the stock, heating and ventilation installations and theoretical and actual energy consumption of 1,374,095 dwellings. We conclude that, on average, the stock is not efficient in terms of energy performance. Based on the Energy Index, the average "assigned" energy label would be D in 2015 (in a scale from A to G). The envelope insulation levels are not adequate – especially when considering the façade insulation values. In addition, the space heating installations of the dwellings can be characterized rather "traditional" with high efficiency gas boilers dominating the stock. The situation is similar when we examine the domestic hot water (DHW) installations as it is very common to use combi-boilers, in the Netherlands. Moreover, 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. In terms of actual gas consumption the non-profit housing stock is more efficient than the national Dutch housing stock. This first part laid the essential knowledge of the energy efficiency state of the stock to further analyse the energy renovation rates and practices of the non-profit housing sector.

Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing stock

Further, the objective is to determine the energy renovation rate in the Dutch non-profit housing sector over the years 2010 - 2014. We present an analysis of the trends of the energy improvement rate through these years, for both the whole period and also the annual values, as shown in Figure Sum 1. We have identified that based on the renovation rates achieved since 2010 attaining the short term goals of achieving an average energy label B in the non-profit housing stock by the end of 2020 is not probable.

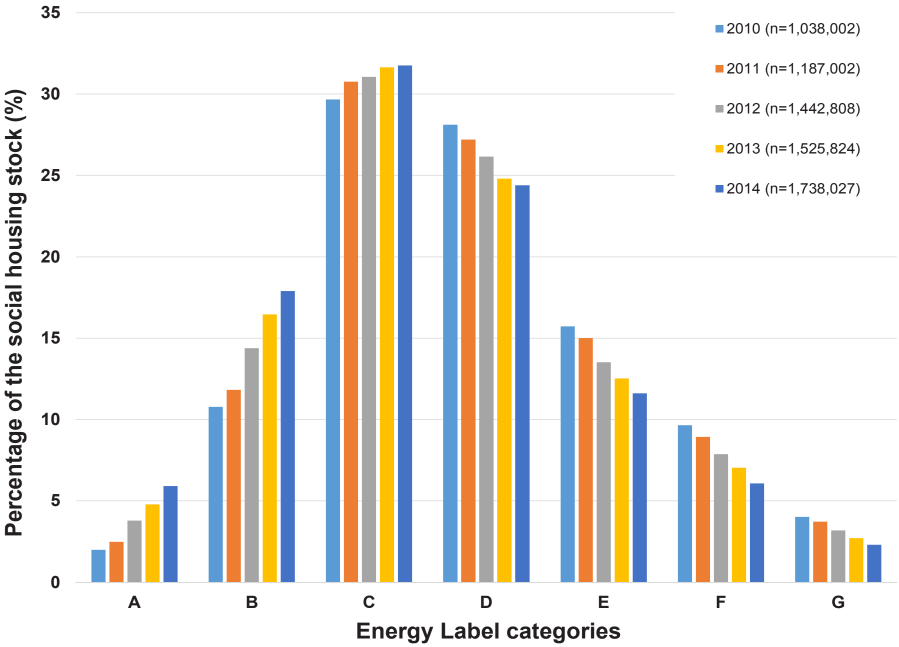

FIGURE SUM.1 Energy label distribution in the non-profit housing stock 2010-2014

The results show that although a number of energy improvements have been realized, they only resulted in small changes of the energy efficiency of the dwellings. Even though 28.0% of the dwellings have improved (towards a 'higher' energy label category), only 3.5% had a major renovation. This percentage depicts the major energy improvement pace of the non-profit housing sector in the Netherlands for a period of four years. In the 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.

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. In addition, in the owner occupied sector the expected intrinsic motivation is difficult to decode. 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.

Energy efficiency measures implemented in the Dutch non-profit housing sector

After establishing the energy renovation rate of the stock, we have 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 use longitudinal data and analysed the improvements of the stock for a three years' period, namely from ultimo 2010 to ultimo 2013, based on different dwelling characteristics and systems. We are able to track accurately the energy improvements applied in the non-profit housing and analyse their impact on the Energy Index for this period.

The progress in the energy performance of the housing stock is rather modest. We identify a tendency for conventional rather than innovative maintenance measures in most of the physical characteristics examined. Further, where energy improvements do take place, usually only one or two measures are carried out per dwelling. 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 average energy label B by 2020 goal. 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.

Based on our outcomes, the non-profit housing sector should focus more on the energy efficiency of its dwellings through the implementation of carefully planned energy agendas. This way, instead of conventional solutions, based on maintenance plans,

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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.

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

Monitoring the energy improvements of the existing housing stock can provide valuable information. There is a need to reassess the energy savings 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. We examine 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 real effect of renovations on the reduction of energy consumption and highlight the impact of (combinations of) energy saving measures (ESMs) on the dwellings' performance.

One of the main outcomes of this work is 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 examine 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 possible changes in the method of calculations by the energy companies reporting to Statistics Netherlands (such as a difference of the LHV [Lower Heating Value] of the gas used), 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 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. These falsely input variables can cause both under- and over-prediction of the actual energy savings.

The results indicate that the energy savings effect of some ESMs are easier to predict with more accuracy than others. This research 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.

Energy renovation rates in the Netherlands: comparing long and short term prediction methods

We apply the dynamic building stock model on the non-profit housing sector for the long term prediction of renovation rates and then compared the results of the empirical SHAERE data. The methods followed in this research 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). 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 based on the dynamic modelling results. The empirical results show major renovation 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 low renovation rates show that an increasing speed of energy renovation is not expected if the investment policies of housing providers keep following the central variables in the model (population, persons per dwelling). This phenomenon suggests that a change in investment policies is needed.

These contrasting methods, both in terms of time and approach of the renovation process, provide unique results and observations. The long term prediction, which is possible using a dynamic stock model like the one we used here, provides information on a global scale and can be used on a policy level to improve the way actions are applied for the energy upgrade of the building stocks. On the other hand, empirical results, like the ones deriving from SHAERE, provide short-term information on specific

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ESM replacement rates that are valuable for subsidy schemes and other forms of energy improvement enforcement by national and local governmental bodies. We show that a combination of methods like the ones used in this paper, are necessary for better use and application of policies.

Conclusion

The objective was to determine and predict the energy renovation rate of the stock and the impact of the applied renovations on both the theoretical (model predicted) and actual energy consumption. We have identified that based on the renovation rates achieved since 2010 attaining the short term goals of achieving an average energy label B is not probable. The improvement of the energy performance takes pace through relatively small interventions rather than deep renovations. However, the impact that collective agreements and relatively short-term goals, like the 2020 goal of the non-profit housing sector, can have on the uptake of energy renovations in the existing housing stocks is highlighted in this thesis. The percentage of dwellings with an energy label 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 enforce a policy. SHAERE itself is also an example of what national agreements can entail.

Regarding the energy savings achieved after an energy renovation, the results indicate that the effect of some ESMs are easier to predict with more accuracy than others. Still, we found that renovations are realized as single or two ESMs in the non-profit housing sector and not frequently enough as combinations of measures. We, also, shed light on the difference between predicted and actual energy savings occurring after renovations. This research 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.

In this research, we highlighted the importance of data monitoring and prediction of future renovation rates. We applied the dynamic building stock model on the non-profit housing sector and then compared the results of the empirical SHAERE data. 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. The empirical results show rates at around 1% for the recent years as well. We emphasize, 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.

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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Samenvatting

In gebouwen wordt een groot deel van de totale geleverde energie geconsumeerd: in de Europese Unie (EU) vertegenwoordigen gebouwen de grootste sector met 39%[2] van het totale eindverbruik van energie, gevolgd door vervoer . Een aanzienlijk percentage van dit energieverbruik wordt toegeschreven aan de residentiële sector. De bouwsector speelt een belangrijke rol om te voldoen aan de energiebesparingsdoelen die zijn vastgesteld in de EU en in Nederland. Dit geldt met name voor bestaande woningen, omdat deze in de komende tientallen jaren het grootste deel van de woningvoorraad zullen uitmaken. De renovatieactiviteit zal naar verwachting in de toekomst groter zijn dan de bouw- en sloopactiviteit.

Beleidsdoelstellingen en -regelgeving zijn op EU-niveau van kracht om de energie-efficiëntie van de gebouwen te verhogen. De richtlijn energieprestaties van gebouwen ([EPBD] (oorspronkelijk uit 2002, herzien in 2010) is het belangrijkste wetgevings- en beleidsinstrument in de EU en richt zich zowel op nieuwe als bestaande gebouwen. Tegelijkertijd speelt de bouwsector een prominente rol in de energie-efficiëntierichtlijn ([EED] 2012). In Nederland geldt een aantal van de EU afgeleide beleidsmaatregelen die een grote rol spelen, zoals verscherping van de energie-eisen aan nieuwe gebouwen en energielabels voor bestaande gebouwen.

De focus van dit onderzoek ligt op de bestaande woningvoorraad en de voortgang van zijn energieprestaties. In heel Europa zijn de nationale benaderingen voor het volgen van de voorraad afzonderlijk geëvolueerd, maar gemeenschappelijk is dat het monitoren van de energieprestaties van de gebouwenvoorraad meer aandacht heeft gekregen. Dergelijke informatie is niet alleen nodig om de voortgang van de implementatie van het beleid te volgen, maar ook om de ontwikkeling van routekaarten voor een meer energie-efficiënt gebouwenbestand te bevorderen.

Dit onderzoek beoogt inzicht te verschaffen in de voortgang van de energieprestatie van de bestaande sociale-huurwoningvoorraad in Nederland. De sociale-huursector beslaat 30% van de woningmarkt in Nederland, waarmee een groot deel van het beleid voor een efficiëntere woningvoorraad van deze sector afhankelijk is. Daartoe, bepalen we de energie-renovatiesnelheid van de voorraad en de impact van de toegepaste renovaties op zowel het voorspelde als het daadwerkelijke energieverbruik. Het verschil tussen

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[2] European Commission (2017). Statistical pocketbook 2017. Retrieved from https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2017_en [accessed 21.5.2018].

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voorspelde en feitelijke energiebesparingen wordt geanalyseerd via longitudinale statistische modellering in gerenoveerde en niet-gerenoveerde woningen. Op basis van de kennis die is opgedaan over de renovatie maatregelen in de sociale-huursector, vergelijken en evalueren we toekomstige renovatiewaarden door dynamische modellering van gebouwvoorraden en empirische gegevensvalidatie. In essentie onderzoeken we het effect dat de verbetering van thermofysieke eigenschappen van woningen heeft op de inspanningen om de bestaande woningvoorraad bijna emissieneutraal te maken tegen 2050, zoals de Europese Commissie sinds 2011 bepleit.

Onderzoeksmethoden en gegevens

Voor het onderzoek zijn in hoofdzaak twee gegevensbronnen gebruikt: de SHAERE-database ("Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing"), en de feitelijke energieverbruiksgegevens van het CBS (Centraal Bureau voor de Statistiek).

SHAERE is een monitoringdatabase van de energieprestaties van de voorraad sociale-huurwoningen in Nederland. Deze monitor is in 2010 operationeel geworden en bevat informatie over de energieprestaties van de Nederlandse sociale-huursector, die het overgrote deel van de huurwoningen in Nederland omvat. Woningcorporaties rapporteren hun woninggegevens aan Aedes (de nationale koepelorganisatie) aan het begin van elk kalenderjaar. Daarin wordt de stand van zaken op 31 december van het voorgaande jaar gegeven. De gegevens omvatten per woning onder andere de warmteweerstanden van elk van de bouwelementen, het woningtype, het bouwjaar, de aanwezige verwarmings- en ventilatie-installaties, het modelmatig voorspelde energieverbruik (inclusief gerelateerde CO_2-emissies) en de Energie-Index. Een aanzienlijk deel van de sociale-huurwoningvoorraad is opgenomen in SHAERE - het responspercentage varieert per jaar, maar is tot nog toe altijd meer meer dan 50% van alle woningen in de sector geweest.

De feitelijke energieverbruiksgegevens van het CBS worden sinds 2009 jaarlijks verzameld bij energiebedrijven. De bedrijven rapporteren de factuurgegevens, die jaarlijks worden berekend op basis van de meterstanden van de woningen. De datasets bevatten waarden van het gebruik van gas en elektriciteit. Het bestaan van stadsverwarming is ook inbegrepen, echter zonder gebruik van waarden van warmte, vanwege het ontbreken van individuele meters. De gegevens worden per woning verzameld op basis van het adres.

Op basis van de onderzoeksvragen en de beschikbare gegevens is de energie-efficiëntie van de Nederlandse sociale-huurwoningvoorraad geanalyseerd, aanvankelijk door middel van beschrijvende statistieken van de thermofysieke kenmerken van de woningen. Vervolgens is het tempo van energierenovaties bepaald. Daarna zijn specifieke energiebesparende maatregelen onderzocht om inzicht te krijgen in de praktijken in de sociale-huurwoningsector. Verder is het effect van deze energierenovaties bestudeerd op zowel het theoretische (voorspelde model) als het daadwerkelijke energieverbruik van de voorraad. Daarnaast zijn op basis van de kennis die is opgedaan over de renovatiepercentages van de sociale-huurwoningvoorraad, de toekomstige renovatiewaarden onderzocht door dynamische modellering van gebouwvoorraden en empirische gegevensvalidatie.

Effect van energierenovaties naar emissieneutrale gebouwen

De energie-efficiëntiestaat van de Nederlandse sociale woningvoorraad

In het eerste deel van dit onderzoek zijn gegevens van SHAERE gebruikt om de energieprestatie van de woningen in de sociale-huursector aan het einde van 2015 te onderzoeken. We concluderen dat de voorraad gemiddeld niet efficiënt is in termen van energieprestaties. Op basis van de energie-index zou het gemiddelde "toegewezen" energielabel D zijn (op een schaal van A tot G). De isolatieniveaus van de enveloppen zijn niet toereikend, vooral wanneer de waarden van de gevelisolatie in beschouwing worden genomen. Bovendien kunnen de ruimteverwarmingsinstallaties van de woningen eerder als "traditioneel" worden gekenmerkt; hoogrendementsketels blijken in de voorraad dominant. De situatie is vergelijkbaar wanneer we de installaties voor huishoudelijk warm water (DHW) onderzoeken, aangezien het in Nederland heel gebruikelijk is om combi-boilers te gebruiken. Bovendien is het gemiddelde voorspelde gasverbruik 178.95 kWh/m², terwijl het gemiddelde werkelijke gasverbruik 119.30 kWh/m² is - lager dan het Nederlandse gemiddelde van 151.80 kWh/m2. In termen van daadwerkelijk gasverbruik is de sociale-huurwoningvoorraad efficiënter dan de nationale Nederlandse woningvoorraad.

Gaan we snel genoeg? Het verbetertempo in de Nederlandse sociale-huursector

In het tweede deel van het onderzoek is ingegaan op het tempo waarin de sociale-huurwoningvoorraad is verbeterd. Dit is gedaan voor de periode 2010 - 2014, Figure Sam 1. We hebben vastgesteld dat bij handhaving van het tempo in die periode het bereiken van een gemiddeld energielabel B in de gehele sociale-huursector tegen het einde van 2020 niet waarschijnlijk is.

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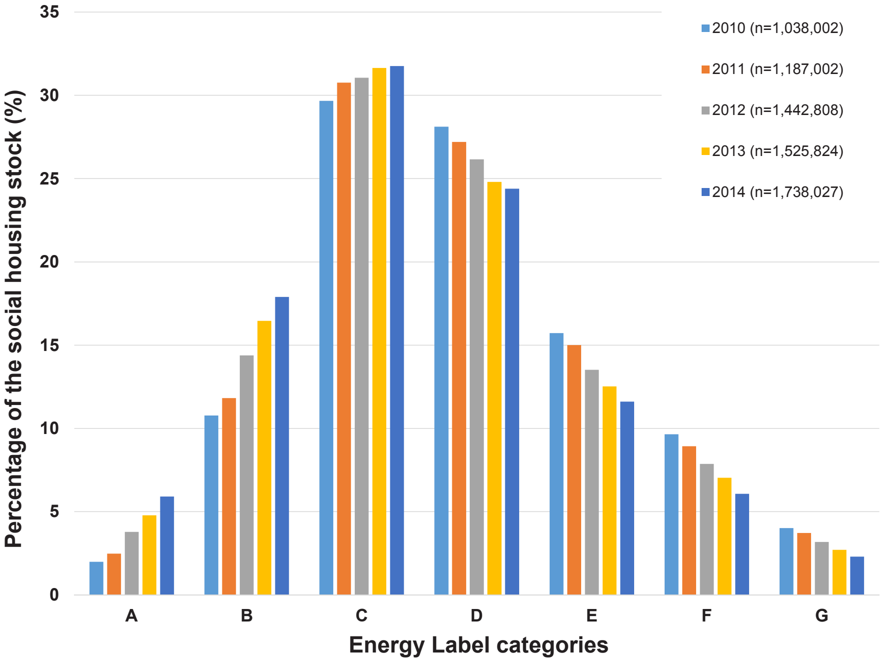

FIGURE SAM.1 Aantal woningen in de sociale-huurwoningvoorraad naar energielabel, 2010-2014

De resultaten tonen aan dat, hoewel veel energieverbeteringen zijn gerealiseerd, deze slechts hebben geleid tot kleine veranderingen in de energie-efficiëntie van de woningen. Hoewel 28.0% van de woningen is verbeterd naar een 'hogere' energielabelcategorie, heeft slechts 3.5% een ingreep met minstens vier energiemaatregelen ondergaan; in veruit de meeste verbeterde woningen zijn ‘slechts’ één of twee maatregelen genomen. Als in de sector het doel van een gemiddeld label B in het jaar 2020 moet worden bereikt, moeten meer integrale pakketten maatregelen worden toegepast, in plaats van afzonderlijke maatregelen, omdat diepere renovaties nodig zijn.

Wanneer energieverbeteringen moeilijk te implementeren zijn in de sociale-huursector, dan zal de implementatie naar verwachting nog moeilijker zijn in de particuliere-huursector en in de koopsector,. de eigendomsstructuur meer verspreid en gefragmenteerd is dan in de sociale-huursector. Bovendien is in de particuliere sector de intrinsieke motivatie naar verwachting lager dan in de sociale sector.

Energie-efficiëntiemaatregelen in de Nederlandse sociale-huurwoningsector

Na vaststelling van het verbeteringstempo van de energieprestatie in de woningvoorraad hebben we de genomen energiemaatregelen onderzocht en hebben we hun impact op de energieprestaties van de woningen beoordeeld. De vooruitgang in de energieprestaties van de woningvoorraad is eerder bescheiden. We identificeren een neiging tot conventionele in plaats van innovatieve onderhoudsmaatregelen in de meeste van de onderzochte fysische eigenschappen. Verder, waar energieverbeteringen plaatsvinden, worden gewoonlijk slechts één of twee maatregelen per woning uitgevoerd. Zoals we hierboven al hebben aangegeven, lijken corporaties over het algemeen geen grote renovaties uit te voeren, maar vooral veel kleinere investeringen. De meeste veranderingen betreffen de verwarming, warmwatersystemen en de beglazing. De andere onderdelen van de buitenschil worden minder vaak verbeterd. Uit de gegevens blijkt dat de doelen voor deze sector moeilijk te bereiken zijn als dezelfde strategie voor renovatie wordt gevolgd, rekening houdend met de percentages van verandering. De energierenovaties, op basis van de eenvoudigst te bereiken maatregelen, leveren niet de resultaten op die naar verwachting zullen worden verwacht voor het gemiddelde energielabel B tegen 2020. Men zou ook kunnen beweren dat de doelstellingen voor de sociale-huursector te ambitieus zijn en ondanks de inspanningen voor energierenovatie blijven de doelen te moeilijk om te bereiken.

Op basis van onze uitkomsten, zou de sociale-huursector zich meer moeten richten op de energie-efficiëntie van zijn woningen door de implementatie van zorgvuldig geplande energieagenda's. Op deze manier kunnencombinaties van energiemaatregelen worden toegepast die resulteren in een algemene verbetering van de energieprestatie van woningen. De non-profitsector heeft een groot potentieel voor verbetering.

Effectiviteit van energiemaatregelen: een herbeoordeling op basis van werkelijke besparingen op het verbruik

Eerder onderzoek heeft uitgewezen dat er een groot verschil kan zijn tussen het modelmatig voorspelde energieverbruik in een woning en het werkelijke energieverbruik. Onderzocht is de impact van energiemaatregelen (ESM) op zowel het voorspelde als het daadwerkelijke energieverbruik in de sociale-huursector in Nederland.

Een van de belangrijkste resultaten van dit werk is dat in de meeste gerenoveerde woningen 1 of 2 ESMs zijn gerealiseerd (78% van de verbeterde voorraad). Dit feit benadrukt het gebrek aan diepgaande renovaties in de sociale-huurvoorraad in Nederland. Wanneer twee of meer ESMs zijn gerealiseerd, worden de gemodelleerde besparingen te hoog voorspeld met 52% - in vergelijking met de werkelijke besparingen - in het geval van 2 ESMs en met 163% in het geval van 7 ESMs. Naarmate het aantal maatregelen hoger is, is ook de kloof tussen werkelijke en voorspelde besparingen groter. Bovendien onderzoeken we de niet-gerenoveerde voorraad voor de periode 2010-2014. We ontdekten dat er zonder enige energie-renovatie plaatsvond, een reductie van 11 kWh/m²/jaar plaatsvond. Verschillende redenen kunnen deze reductie verklaren, zoals mogelijke wijzigingen in de berekeningsmethode door de energiebedrijven die rapporteren aan het CBS (zoals een verschil in de LHV [lagere verwarmingswaarde] van het gebruikte gas), mogelijke effecten van gedragsverandering door gebruikers of fouten in de rapportage in de SHAERE-database die verder onderzoek vereisen.

Wat de afzonderlijke typen energiemaatregelen betreft blijkt dat de energiebesparing bij vervanging van verwarmingssystemen (ruimteverwarming en warm water) en beglazing beter wordt voorspeld dan de besparing bij verandering van het ventilatiesysteem of de isolatie van de bouwdelen. Verder leveren ESMs van het gecombineerde verwarmingssysteem en het DHW en de beglazing de hoogste werkelijke gas besparing op. Het ESM voor ventilatie was het meest onder-voorspeld. De reden hiervoor is waarschijnlijk de veronderstelde luchtstroomsnelheid van het model. In de combinaties van ESMs laten de resultaten zien dat in de meeste woningen standaard renovaties zijn uitgevoerd (meestal 2 ESMs) in plaats van ingrijpende renovaties. Zoals hierboven vermeld, is de kloof tussen werkelijke en voorspelde besparingen groter wanneer meer ESMs worden toegepast. Aan dit effect kunnen verschillende redenen worden toegeschreven. Overwegend, het veronderstelde gebruikersgedrag (inclusief binnentemperatuur en aantal uren werking van het verwarmingssysteem) door de gebruikten modellen voor het voorspellen van de besparingen, is een veel voorkomende factor die de kloof veroorzaakt. De variabelen voor vals ingevoerde isolatiemateriaal, vaak gebaseerd op het verbruiksjaar, is echter een ander probleem dat naar voren komt uit de resultaten van dit onderzoek. Deze foutieve invoervariabelen kunnen zowel een onder- als een over voorspelling van de werkelijke energiebesparingen veroorzaken.

De resultaten geven aan dat het energiebesparende effect van sommige ESMs met meer nauwkeurigheid gemakkelijker te voorspellen is dan andere. Dit onderzoek toonde het belang van de daadwerkelijke energiebesparing voor het begrijpen van de impact van het aantal en de combinaties van maatregelen toegepast op woningen. De realiteit is heel anders dan wat er toen werd gemodelleerd. Dit kan een demoraliserende factor zijn wanneer woningcorporaties beslissingen nemen om te renoveren of niet delen van hun voorraad. De voorspelde besparingen kunnen met de huidige berekeningsmodellen niet als nauwkeurig worden beschouwd.

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Energierenovatie percentages in Nederland: vergelijking van voorspellingsmethoden voor de lange en de korte termijn

We passen het dynamische model van gebouwenscenario toe op de sociale-huurwoningsector voor de lange termijn voorspelling van renovatiewaarden, en vergeleken vervolgens de resultaten met de empirische SHAERE-gegevens. De methoden die in dit onderzoek worden gevolgd, vertegenwoordigen twee verschillende benaderingen voor het bouwen van monitoring met betrekking tot energie renovatie tempo en ESMs. Ondanks het feit dat in de dynamische modelleringsmethode de renovatie een waarschijnlijkheidsfunctie is en dat bij de statistische methode de renovatie een ESM of een groep ESMs is, berekend op basis van een tijdreeksgegevensreeks, we matchen de definities door specifieke afzonderlijke ESMs of combinaties van ESMs toe te wijzen tot renovatiecycli (jaren). Uit het model is gebleken dat de snelheid van grote of diepe renovaties stabiel is op 1.0% per jaar en naar verwachting zal stijgen tot 1.2% vanaf 2020 en zo blijven tot 2050. De empirische resultaten laten ook de laatste jaren grote renovaties zien van ongeveer 1%. We benadrukken, op basis van de huidige kennis en de modellering van historische gegevens, dat grote renovatie-snelheden naar verwachting niet zullen toenemen als de huidige renovatieactiviteit blijft zoals ze is. De lage renovatietempo laat zien dat een toenemende snelheid van energierenovatie niet is te verwachten als het investeringsbeleid van woningaanbieders de centrale variabelen in het model blijft volgen (bevolking en personen per woning). Deze contrasterende methoden, zowel in termen van tijd als benadering van het renovatieproces, leveren unieke resultaten en observaties op. De voorspelling op lange termijn, die mogelijk is met behulp van een dynamisch voorraadmodel zoals we hier gebruikten, biedt informatie op een wereldwijde schaal en kan op beleidsniveau worden gebruikt om de manier waarop acties worden toegepast voor de energie-upgrade van de gebouwen te verbeteren. Aan de andere kant verschaffen empirische resultaten, zoals die voortvloeien uit SHAERE, korte termijn informatie over specifieke ESM-vervangingsratio's die waardevol zijn voor subsidieregelingen en andere vormen van handhaving van energie-verbetering door nationale en lokale overheidsinstanties. We laten zien dat een combinatie van methoden zoals die in dit document worden gebruikt, noodzakelijk is voor een beter gebruik en toepassing van beleid.

Conclusie

Dit onderzoek heeft zich gericht op het tempo van verbetering van de energieprestatie in de woningvoorraad en het effect van de genomen maatregelen op zowel het modelmatig voorspeldeals het werkelijke energieverbruik. We hebben vastgesteld dat op basis van de voortgang in de periode 2010-2014 het bereiken van de van een gemiddeld energielabel B niet waarschijnlijk is. De verbetering van de energieprestaties verloopt met relatief kleine ingrepen in plaats van ingrijpende renovaties. De impact die collectieve overeenkomsten en relatief korte-termijndoelen, zoals de 2020-doelstelling van de sociale-huursector, kunnen hebben op de acceptatie van energierenovaties in de bestaande woningvoorraden, wordt echter benadrukt in dit proefschrift. In de sociale-huursector is het percentage woningen met een door deskundigen vastgesteld energielabel aanmerkelijk groter dan in andere woningsectoren, wat een indicatie is van hoe collectieve afspraken een beleid kunnen afdwingen. SHAERE zelf is ook een voorbeeld van wat uit nationale overeenkomsten kan voortkomen.

Met betrekking tot de energiebesparingen die zijn bereikt na een energie-renovatie, geven de resultaten aan dat het effect van sommige maatregelen met meer nauwkeurigheid te voorspellen is dan dat van andere maatregelen. Het blijkt dat de werkelijke besparing sterk kan afwijken van wat er wordt gemodelleerd. Dit kan een demoraliserende factor zijn wanneer woningcorporaties beslissingen nemen om te renoveren of niet delen van hun voorraad.

In dit onderzoek hebben we het belang van gegevensbewaking en voorspelling van toekomstige renovatiepercentages benadrukt. We pasten een dynamisch model met betrekking tot de ontwikkeling het aantal woningen naar ouderdom toe op de sociale-huursector en vergeleken vervolgens de resultaten met de empirische SHAERE-gegevens. De resultaten geven aan dat de snelheid van grote of diepe renovaties in de afgelopen jaren stabiel is geweest op een niveau van 1.0%, naar verwachting zal stijgen tot 1.2% vanaf 2020 en zo zal blijven tot 2050. Hieruit is af te leiden dat grote renovatie-snelheden niet zijn te verwachten, tenzij het gangbare investeringsbeleid wezenlijk wijzigtis.

Door dit onderzoek vestigen we de aandacht op het verzamelen en analyseren van epidemiologische gegevens over gebouwenergie. Deze kunnen zorgen voor het volgen van renovaties, energiebesparingen en de mate van implementatie van het huidige beleid. De situatie is natuurlijk niet ideaal, omdat de motitoring verder kan worden verbeterd en de koppeling met het werkelijke energieverbruik standaard kan worden. Dit onderzoek benadrukt het belang van het monitoren van de voortgang van energierenovaties van gebouwenvoorraden en hun daadwerkelijke effect op energiebesparingen. Verschillende methoden kunnen worden gebruikt om de renovatiesnelheden van energie te volgen en te voorspellen en de ontwikkeling van de energieprestaties van gebouwvoorraden. De keuze hangt af van de vraag of situatie in kwestie - dit kan een wereldwijde, nationale, gemeentelijke of casestudy zijn. Niettemin wordt verwacht dat de renovatieactiviteit groter zal zijn dan de nieuwbouw- en sloopactiviteit. Daarom is inzicht in de daadwerkelijke impact en effectiviteit van energierenovaties van groot belang.

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1 Introduction

§ 1.1 Energy consumption in the built environment

The rapid growth of urban areas has led to the unsustainable use of resources (Langeweg et al. 2000; Bhatta 2010; UN 2014). The impacts of urban areas are evident in regions which supply cities with food, water, energy and absorb pollution and waste (UN 2014). At the same time, the current world population, of 7.6 billion, is predicted to reach 8.6 billion in 2030 and 9.8 billion in 2050 (UN 2017). Moreover, the urban population, in 2014, accounted for 54% of the total global population. This signifies a 20% increase since 1960. In 2014, the majority of people - 54% - were living in urban areas and this percentage is estimated to rise in the future (WHO 2017). In Europe, 72.5 % of European Union (EU)-28 countries inhabitants lived in cities, towns and suburbs in 2014 (Eurostat 2016b). Nevertheless, differences between countries exist. Figure 1.1 shows the urban population growth of the Netherlands in comparison to the EU, Germany, Spain, France, Slovenia and Sweden. The Netherlands is characterised by a high level of population density and a high share of urban land use, whereas in most of the Scandinavian countries and Spain much lower levels of urban land use are present (Eurostat 2016b).

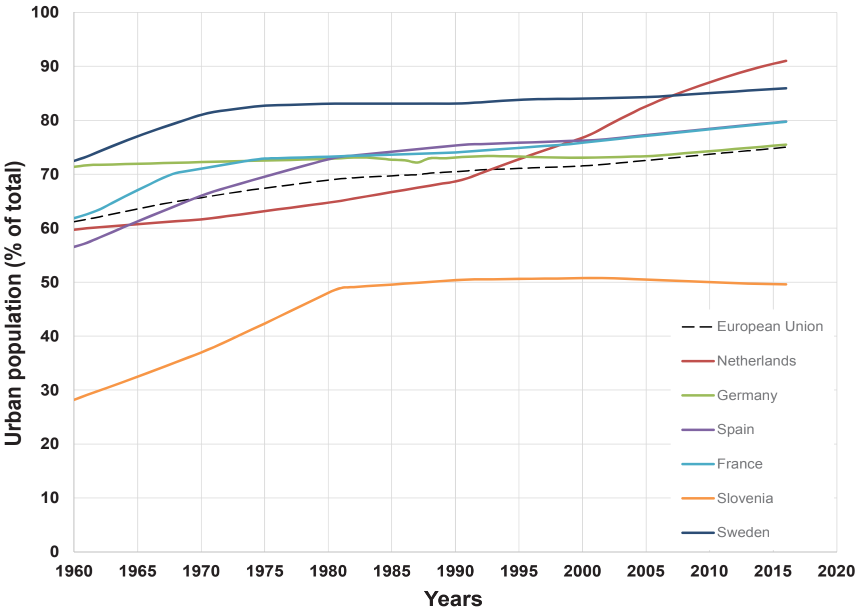

FIGURE 1.1 Examples of urban population as a percentage of the total population, in Europe, based on World Bank statistics 1960 – 2016 (source: The World Bank 2017)

In this context, the main challenge is to accommodate a greater number of people while reducing the impacts on the environment, which are the main cause for climate change (IPCC 2014). Relatedly, the improvement of the quality of life of city residents is a priority (EEA 2015). Households have a large impact on energy intensity and final energy consumption, as Figure 1.2 shows. The energy intensity[3] of households, depicted on the left hand side of Figure 1.2, is increasing and at the same time 25.4% of the final energy consumption in the EU 28 was attributed to the sector in 2015 (24.8% in 2016), shown on the right hand side of Figure 1.2 (EEA 2013; Eurostat 2016a). The potential for energy consumption reduction of households is large and is set as a key priority in the policy goals and directives by the European Commission (Paulou et al. 2014; Saheb et al. 2015). One of the most prominent ways to reduce the energy consumption of residential dwellings is through energy renovations.

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[3] Energy intensity is is expressed as the ratio between gross inland energy consumption and GDP, in a calendar year. To make comparisons across countries possible, the indicator is presented as an index, compared to 1990. (EEA 2013)

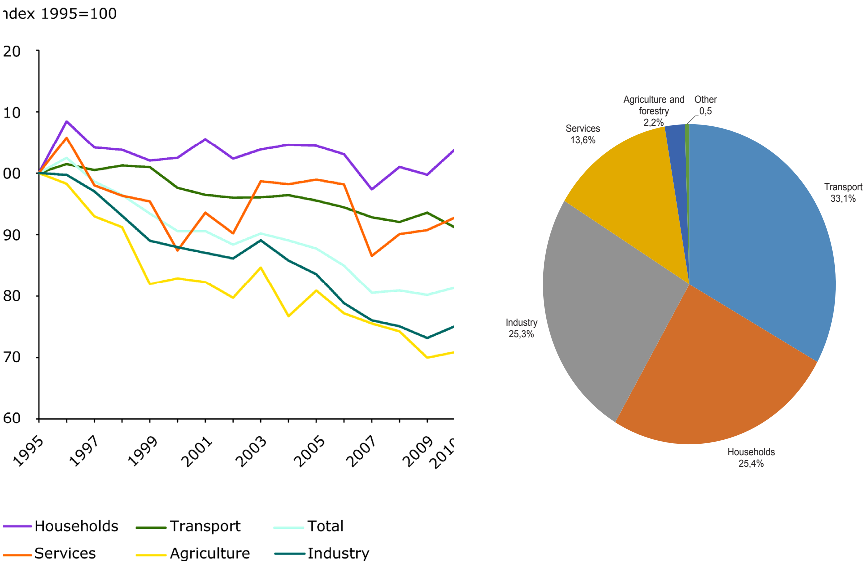

FIGURE 1.2 Energy consumption intensity and final energy consumption per sector in the EU 28 (sources: EEA 2013 and Eurostat 2016a)

§ 1.2 Energy efficiency and renovations

Energy efficiency, of buildings, is a topic where several definitions can apply. It is often misunderstood as energy conservation. *Energy efficiency* of a dwelling or building refers to its energy performance through its physical properties, energy installations, appliances and occupant behaviour (EIA 2016). The energy efficiency of a dwelling is the combination of the thermodynamic approach[4] of thermal efficiency and energy consumption intensity (Tanaka 2008). Whereas, *energy conservation* refers to less heating or less use of electronic devices, leading to a reduced energy consumption in total – it relates mostly to occupant behaviour (EIA 2016).

The energy performance of buildings is generally insufficient and the levels of energy consumed in them place the sector among the most significant CO_2 emission sources

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[4] Thermal efficiency is the term used in thermodynamics that measures the ratio of heat and/or work to the energy input. The maximum efficiency is 1 (100%) as defined by the second law of thermodynamics.

in Europe – 33% of the total final energy is consumed in buildings (BPIE 2011). A considerable percentage of this energy consumption is attributed to the residential sector, as on average dwellings are responsible for 24.8% of the total energy consumption in the EU (Eurostat 2016a). The energy savings potential of existing dwellings is expected to be large.

To cope with the issues at hand, the EU has set policy targets and regulations to ensure the energy efficiency improvement of the building stock. Apart from the general roadmap to emission neutrality of the building stock by 2050, the Energy Performance of Buildings Directive ([EPBD] 2002, recast 2010, European Commission 2016) is the main legislative and policy tool in EU and focuses on both new and existing buildings. At the same time, the building sector plays a prominent role in the Energy Efficiency Directive ([EED] European Parliament 2012). In 2008, the EPBD was applied, setting the goals for the built environment higher. Under this directive, all Member States must establish and apply minimum energy performance requirements for new buildings, for major renovation of buildings and for replacement or retrofit of building elements (heating and cooling systems, roofs, walls, etc.). The revised EPBD requires Member States to also guarantee that by the end of 2020, all new buildings are ‘nearly zero-energy buildings’ (Beuken 2012; van Eck 2015).

In the Netherlands several policy measures have been in place since the last quarter of the 20th century, mainly through building decrees. The energy consumption of buildings has been regulated since 1975 consisting of limits on transmission losses based on insulation values (Boot. 2009). In 1995 these limits were expanded to include the national “EPC” (Energy Performance Coefficient) which is a non-dimensional figure that expresses the energy performance of a building depending on the energy consumed for space heating, hot water, lighting, ventilation, humidification and cooling. In addition, in 2008, the EPBD is applied, setting the sets of goals for the built environment high. 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). The majority of policy measures focus on the energy efficiency of buildings and the energy neutrality of new buildings. However, the realization of energy efficient measures or energy renovations of the dwellings could go even further and achieve the ambitious goals set on a national and European level.

Energy neutrality of the building stock is hard to achieve relying only on newly built dwellings. Existing buildings will dominate the housing stock for the next 50 years based on their life cycle; in the Netherlands, the annual rate of newly built buildings is 0.6% of the existing residential building stock in 2014 (Statistics Netherlands 2015). Therefore, renovation activity is expected to be greater than construction and demolition activity in the future. Renovations offer unique opportunities for reducing energy consumption and greenhouse gas emissions, and are instrumental for reaching the EU 2020/2030/2050 goals (Saheb et al. 2015). This has implications for growth and jobs, energy and climate, and cohesion policies (Paulou et al. 2014 and Saheb et al. 2015). Renovating existing buildings is seen as a 'win-win' option for the EU economy (Saheb et al. 2015). While there have been various energy renovations of dwellings in Europe, the assessment and monitoring of these renovations is limited (Hamilton et al. 2017; Dascalaki et al. 2016; Droutsa et al. 2016; Corrado & Balarini 2016).

Though there is a great deal of research on the energy efficiency and energy consumption of the housing stock, little has been published on the rate of improvement and the impact of energy renovations on actual energy consumption. And even though the energy efficiency policies and initiatives implemented in the Netherlands make it an ambitious goal-setter in the EU residential sector, there is no evidence of a steady reduction of gas and electricity consumption compared to the 1990 levels (Majcen et al. 2013). On the contrary, the total energy (gas and electricity) consumed by households increased by 11% from 1990 to 2008 (Majcen et al. 2013). Furthermore, the rate of renovations and the amount of energy savings achieved are essential to reach the ambitious goals set on a national and European level. It is critical to attain insight into whether these goals can be achieved. There are contradicting studies: some argue that the goals are reachable, and others mention that any progress is based on estimated values of energy consumption so the realization could be much more difficult (Balaras et al. 2016; Majcen et al. 2013; Sunikka-Blank & Galvin 2012).

§ 1.3 Non-profit housing

The tenure mix of dwellings bears a significant relevance to the ability to renovate. The total amount of dwellings in the Netherlands is 7.5 million (BZK 2016b). The owner occupied sector comprises 55.8% of the total, whereas the rental sector amounts to 43.5% (BZK 2016b). The ownership type is unknown for the remaining 0.7% (BZK 2016b). The vast majority of the rental sector belongs to housing associations forming the non-profit housing sector. In this dissertation, we focus on the Dutch non-profit housing because the sector comprises approximately 2.3 million homes, which adds up to 30% of the total housing market (BZK 2016a). This is a unique situation, as the Netherlands have the highest percentage of non-profit housing in the EU (Braga & Palvarini 2013). The non-profit housing sector can be expected to be a leading example when it comes to energy efficiency goals due to its intrinsic social values and different

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organization and behaviour from the private sector. It is considered as a service of general economic interest by the EU due to the fact that it can ensure the right to housing and be a key player in achieving the Europe 2020/2030/2050 targets (Braga & Palvarini 2013).

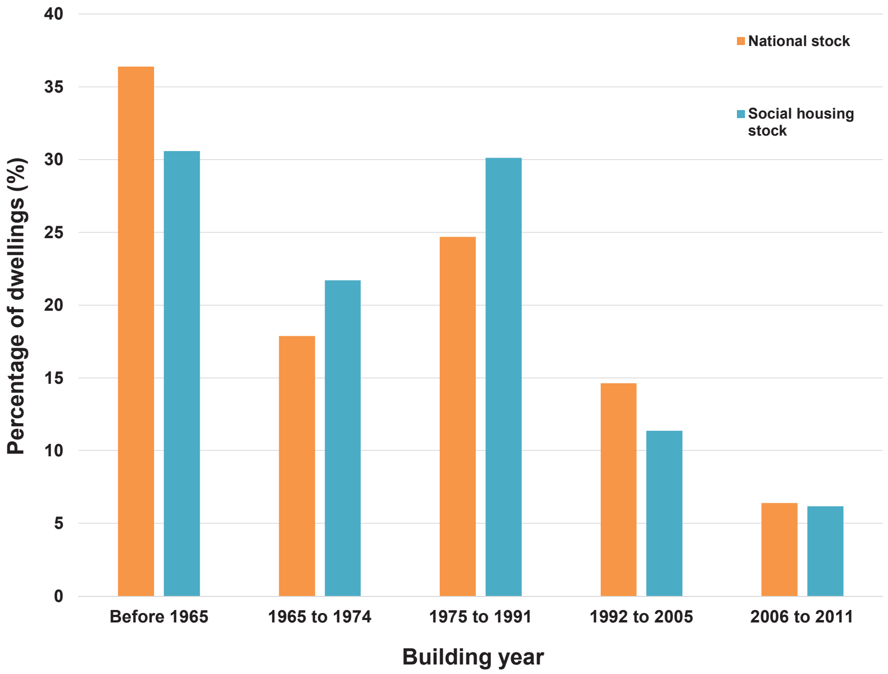

FIGURE 1.3 Comparison of building year cohorts distribution between the national and social housing stock. (source: Agentschap NL 2011 and SHAERE database)

Non-profit housing is typically owned by the public sector; however, there is an increasing trend towards non-public involvement or the privatization of the non-profit housing sector in Europe (Braga & Palavarini 2013). Since the beginning of the 1990s the Dutch non-profit housing sector deviated from government control and public financing and became a financially independent sector. In the Netherlands, non-profit housing is almost entirely in the hands of private organisations (Elsinga & Wassenberg 2014; Priemus 2013; BPIE 2011; Kemeny 2002). These organizations can be better described as "hybrid" – they act between government, market and community (Nieboer & Gruis 2016). They have to manage the different and frequently competing interests from each of these three entities (Nieboer & Gruis 2016). The housing organizations have to fulfil several mandatory goals regarding the provision and allocation of homes.

For this thesis, we consider the non-profit rented housing stock of the Netherlands, also referred to as social housing, where a significant amount of data are available, for two main reasons. First, the non-profit housing sector in the Netherlands is the largest in Europe, having a share of 31% of the total stock. We use a newly formed source of data that includes 60% of the dwellings in the sector. This fact advances the research, providing the opportunity to work on a representative sample of the national housing stock, in terms of construction but necessarily typology (see Figures 1.3 & 1.4). Having such an extensive and representative sample of dwellings is a stepping stone for the provision of statistically significant results. Second, the non-profit housing sector is making decisions about energy efficiency and sustainable solutions collectively and is being subsidised by the state for goals promoting the energy neutrality of the country.

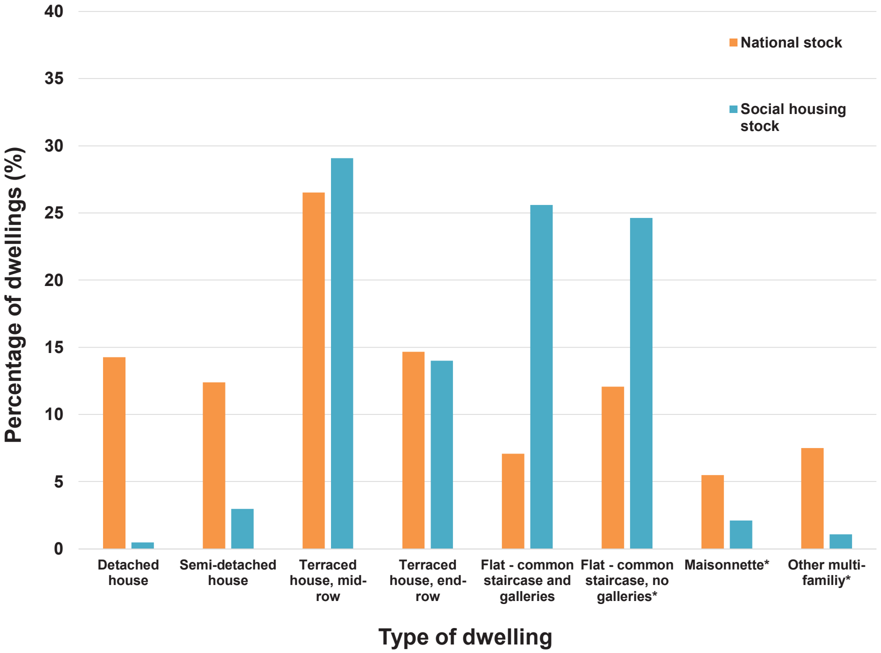

FIGURE 1.4 Comparison of type of dwelling cohorts' distribution between the national and social housing stock. (source: Agentschap NL 2011 and SHAERE database)

Energy savings and sustainability are high on the housing associations' agenda, especially since 2008, when the EPBD started being implemented (Aedes 2018). According to the Energy Saving Covenant for the Rental Sector ("Convenant Energiebesparing Huursector"), the current aim of the non-profit housing sector is to achieve an average EI (Energy Index - Dutch energy performance coefficient for existing dwellings) of 1.25 by the end of 2020 (BZK 2014), which is within the bands of an energy label B. The Covenant was signed by, among other stakeholders, Aedes (the umbrella organisation of housing associations), the national tenants' union and the national government. The goal of the agreement means an energy saving of 33% on the theoretical/predicted energy consumption in the period of 2008 to 2021 (CECODHAS Housing Europe 2012).

§ 1.4 Problem definition and aim of thesis

There is a present need to research the energy renovation practice and progress of energy performance in the existing housing stock. Monitoring is essential and can provide valuable information concerning the energy savings that can be achieved, in terms of both actual and predicted energy consumption. The predicted energy reduction, in most cases, differs from the actual energy consumption (Filippidou et al. 2016; Balaras et al. 2016; Majcen et al. 2013, Tigchelaar et al. 2011). The mean predicted or modelled energy consumption in dwellings can be as much as 50% less or 30% more than the actual consumption (Majcen et al. 2016). Moreover, 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. Therefore, the focus on actual consumption is increasing, and studies of the gap between the predicted and actual energy consumption of buildings have started to appear in Europe.

The aim of the current research is to examine the progress of the energy performance towards emission neutrality, in the existing housing stock, through the application of energy renovations. To do so, we analyse, first, the energy efficiency state of the stock. Furthermore, we assess the type of energy renovations, their pace and their impact on the energy performance and the actual energy savings. In other words, we provide insight into the effect that the thermo-physical characteristics of dwellings have on efforts to make the existing housing stock emission-neutral.

§ 1.5 Research questions

In this section we introduce the main research question and the four subsequent questions defined for this research study:

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

The sub-questions are formed as follows:

1 How efficient is the Dutch housing stock in terms of energy performance?
The first research question aims to ascertain the current energy performance state of the Dutch non-profit housing stock. We approach the efficiency of the stock in 2015, in terms of descriptive statistics of the main elements of thermo-physical, dwelling characteristics, installations, modelled and actual energy consumption. It is important to understand the efficiency state of the stock in order to further examine the process of energy renovations and their effect on the buildings' performance and final energy consumption. The research question can be broken down into the following sub-questions:

   a What are the insulation levels of the envelope? (Chapter 2)
   b Which are the most frequent installations – space heating, domestic hot water and ventilation? (Chapter 2)
   c What is the modelled and actual final energy consumption? (Chapter 2)

2 What is the energy renovation rate of the housing stock?
Understanding the pace at which energy renovations are realised is of great importance to the implementation of energy efficiency policies in the built environment. Question 2 follows up on the energy efficiency state established in Chapter 2. We aim to determine the actual renovation rate of the non-profit housing stock in order to conclude if the targets set are reachable and if not, what are the policy instruments needed to increase this rate. Four sub-questions derive from research question 2:

   a Are the energy efficiency targets of the non-profit housing stock reachable? (Chapter 3)
   b What are the lessons learned from the policies applied in the sector and their implementation progress? (Chapter 3)

3 What are the energy efficiency measures realised the last years?
Energy renovations in existing dwellings offer unique opportunities for reducing the energy consumption and greenhouse gas emissions on a national scale in the

Netherlands but also on a European and global level. Although there have been initiatives for energy renovations of dwellings in the Netherlands, the assessment and monitoring of these renovations has been lacking. Monitoring the energy improvements of the existing housing stock is necessary and can provide valuable information concerning the technical characteristics and the future potential of the measures applied. We reply to this question by investigating what the energy improvement measures in the Dutch non-profit housing sector are over the last years and how they impact the energy performance of the dwellings. The sub-questions are:

a Are the envelope elements and installations being renovated at the same frequency? (Chapter 4)
b Are energy renovations being realized as single measures or combinations? (Chapter 4)

4 What is the impact of the energy renovations on the actual gas consumption savings? 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 (Balaras et al. 2016; Majcen et al. 2013; Sunikka-Blank & Galvin 2012). In order to set realistic goals for energy efficiency and policies that deliver the results needed it is significant to understand the actual savings that are achieved by renovating the existing housing stock. Answering the above mentioned research question, we re-assess the effectiveness of energy efficiency measures based on actual consumption data through time series statistical modelling. The last sub-questions are:

a What is the difference between predicted and actual energy consumption savings of the renovated dwellings? (Chapter 5)
b Which are the most frequent combinations of energy efficiency measures? (Chapter 5)
c What is the effect of the different energy savings measures on the predicted and actual the savings? (Chapter 5)

5 What is the predicted energy renovation rate of the stock up to 2050?
The rate at which energy renovations are realized and the energy performance level achieved after the renovations are crucial factors for an energy-efficient built environment, as stated in Chapter 3. Energy renovation rates assumed by EU officials and policy makers usually range from 2.5-3% (BPIE 2011; Sandberg et al. 2016;). However, at current rates it is claimed that more than 100 years will be needed to renovate the EU building stock (European Commission 2016). The main question addressed in Chapter 6 is what the estimated renovation rates for the Dutch non-profit housing stock are for different types of renovations, depending on the level of

renovation and energy saving measures applied. Answering this question can help evaluate current and previous policies but also shape future ones.

- a What methods can be used to accurately predict energy renovation rates? (Chapter 6)
- b How do predicted energy renovation rates compare to empirically calculated rates? (Chapter 6)

§ 1.6 Data and methods

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. Moreover, advanced quality information and data are needed to help develop roadmaps and future policies resulting in energy efficient buildings. 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 (Filippidou et al. 2017). In some cases, information gained through the investments on energy renovations are used to calculate the progress.

As mentioned beforehand, for this thesis, we consider the non-profit rented housing stock of the Netherlands, also referred to as social housing, where a significant amount of data are available. Through empirical data and a synthesis of methods, we are able to provide new results regarding the progress of energy renovations in the existing housing stock. In 2008, after the formulation of the Covenant on energy saving targets, Aedes started a monitoring system of the dwellings called Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing (Social Rented Sector Audit and Evaluation of Energy Saving Results) abbreviated SHAERE. This monitor became operational in 2010 and contains information about the energy performance of around 60% of the Dutch non-profit housing sector (circa 1.2 million dwellings). Housing associations report their stock to Aedes at the beginning of each calendar year accounting for the previous year (e.g., in January 2014 reporting for 2013) (Aedes 2018). 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). As a result, SHAERE consists of the actual characteristics of all dwellings of the participating housing associations at the end of each calendar year. SHAERE is the first monitoring database of the energy efficiency evolution of the building stock in the Netherlands

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with microdata information, on a dwelling level. We connect each record to the specific dwelling, it refers to, based on an encrypted identifier variable (dwelling ID) that consists of the dwelling's post code, address, number and possible number addition. It is a time series database including a maximum of five records per dwelling – 2010, 2011, 2012, 2013 and 2014. Table 1.1 shows an example of the structure of the database connecting the dwelling ID with the Rc for roof variable. In the same manner all available variables are connected to each dwelling based on the ID.

TABLE 1.1 Example of the structure of SHAERE (variables dwelling ID and Rc-value roof)

DWELLING ID	R_c-ROOF.2010 [m^2K/W]	R_c-ROOF.2011 [m^2K/W]	R_c-ROOF.2012 [m^2K/W]	R_c-ROOF.2013 [m^2K/W]	R_c-ROOF.2014 [m^2K/W]
#1	0.6	1.1	1.1	1.1	1.1
#2	0.9	2.3	-	2.3	2.3
#3	-	-	3.1	-	3.1
...	...	...	...	...	...

The database includes data from 2010, 2011, 2012, 2013 and 2014, on the performance of the stock in the form of energy certificates. The data comprise of physical characteristics (thermal transmittance [U-value] and resistance [Rc-value] values of the envelope elements, the typology of dwellings, the year of construction, etc.), heating and ventilation installations, theoretical energy consumption[5], CO_2 emissions, the average EI and more (Filippidou et al., 2016). The variables are categorized per dwelling. A considerable part of the non-profit housing stock is included in SHAERE. However, the number of homes differs per year, as not all dwellings are reported every year (e.g. one can have 2 records whereas another one can have all five). Table 1.2 presents the exact numbers.

TABLE 1.2 Number of dwellings reported in SHAERE per year

YEAR OF REPORTING	AMOUNT OF INDIVIDUAL DWELLINGS REPORTED	PERCENTAGE OF THE TOTAL NON-PROFIT 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%

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[5] The theoretical energy consumption is calculated according to the ISSO 82.3 norm (ISSO 2009)

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In this thesis, the Dutch EI will be examined through consecutive years in order to calculate the energy renovation rate based on the energy performance of the dwellings (Chapter 3). The EI is the official coefficient for measuring the energy efficiency of an existing dwelling, and is often categorised into an energy label, ranging from A to G (see Table 1.3).

The EI is related to the total theoretical energy consumption of a building or a dwelling: Q_{total}. According to the norm of the calculation of the EI, as shown in Equation 1.1, it is corrected taking into account the floor area of the dwelling and the corresponding heat transmission areas.

The EI is calculated as follows:

$$EI = \frac{Q_{total}}{(155 * A_{floor} + 106 * A_{loss} + 9560)}$$

Equation 1.1

Q_{total} refers to the modelled characteristic yearly primary energy use of a dwelling, and includes energy for space heating, domestic hot water, additional energy (auxiliary electric energy needed to operate the heating system, i.e., pumps and funs), lighting of communal areas, energy generation by photovoltaic systems, and energy generation by combined heat and power systems under the assumption of a standard use (Filippidou et al. 2016; Visscher et al. 2012; ISSO 2009). A_{floor} refers to the total heated floor area of the dwelling, whereas A_{loss} refers to the transmission heat loss are in the dwelling, such as a cellar (Filippidou et al. 2016; Visscher et al. 2012; ISSO 2009). The numerical values in the denominator are: 155 is the factor for the reference energy consumption per m^2 correction, regarding the useful living area (MJ/m^2); 106 is the correction factor compensating for the transmission losses (MJ/m^2); and 9560 is a standard amount of energy used for existing dwellings (MJ) (NEN 2012).

TABLE 1.3 Connection of Energy Index with the Energy Label in the Dutch context and the primary heating energy consumption (ISSO, 2009)

ENERGY LABEL	ENERGY INDEX	MEAN THEORETICAL PRIMARY HEATING ENERGY CONSUMPTION (kWh/M²/YEAR) (MAJCEN ET AL., 2013)
A (A+, A++)	<1.05	96.8
B	1.06 – 1.3	132.5
C	1.31 - 1.6	161.6
D	1.61 - 2.0	207.8
E	2.01 - 2.4	265.0
F	2.41 - 2.9	328.0
G	> 2.9	426.9

The main focus of the thesis is on the dwellings that have been reported more than once (i.e. where data have been inputted by the housing associations in repeated years) in order to pinpoint and research the energy improvements performed each year. We use longitudinal data to observe the changes of the energy performance of the same dwellings. We observe whether or not the inputted data have changed from 2010 to 2014. We start with the changes in the EI and we move on to thermo-physical variables.

We develop an inventory of ESMs (Energy Saving Measures) of the non-profit rented stock in Netherlands from 2010 to 2014.We examined the effectiveness of these measures based on actual and predicted energy savings as annual values between 2010 and 2014. We connect the data from the SHAERE monitoring system to the actual heating energy consumption data from Statistics Netherlands on a dwelling level. Using longitudinal analysis methods we are able to identify the energy efficiency improvements of the stock and to determine the effectiveness of different measures in terms of actual energy savings.

However, the estimation of future renovation rates is of great importance and can assist in future energy efficiency policies. To that end, we applied the dynamic dwelling stock model for the non-profit housing stock and then compared the projected renovation rates with the results of the statistical analysis using SHAERE database. As a result, we predict the energy renovation rates in the Netherlands using dynamic building stock modelling and statistical regression analysis. The dynamic dwelling stock model aims at describing the long-term development over time of the size and age composition of the dwelling stock in a country or region, in this case the social housing stock of the Netherlands (Sandberg et al. 2016 & Sartori et al. 2016). The statistical data analysis approach is using SHAERE database and the energy renovation rates of several parameters. Figure 1.5 summarizes, the relationship of methods, data and their presentation through the chapters of the thesis.

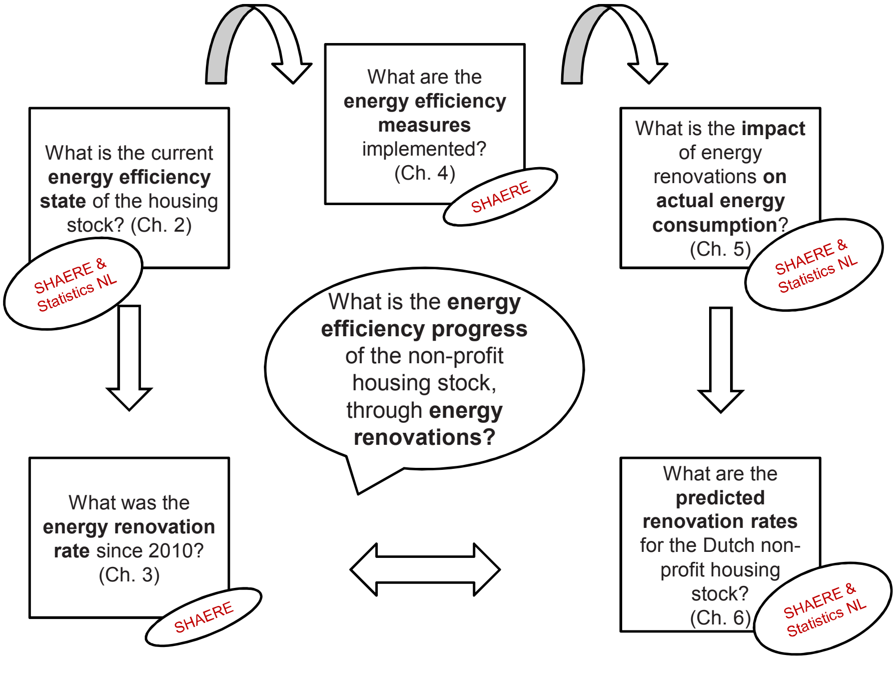

FIGURE 1.5 Thesis connection of research questions and data used

§ 1.7 Limitations

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, prove to be extremely useful to evaluate policies, project future renovation rates and conclude on best practices for different housing stocks (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). One of the strengths of SHAERE is the very large amount of data (more than 50% response rate each year), which is more than half of the dwellings of the non-profit housing sector in the Netherlands. 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.

This research was based on the dwellings' physical properties and the reported heating energy consumption, in order to examine the improvements and pace of energy renovations. Concerning the quality of the 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, reported that in a sample of 120 labels issued in 2009, 60.8% of the inspected labelled dwellings had an EI that deviated more than 8% (Majcen et al. 2013a; VROM-Inspectie 2009). In 2010, only 26.7% had a different EI (VROM-Inspectie 2010) and in 2011, 16.7% of labels deviated more than 8% in their EI (VROM-Inspectie 2011). In 2013, the inspection was carried out only for office buildings. Hence, there seems to be a trend of improvement, although the studied samples are small (Majcen et al., 2013a). 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, data with regard to a new reference date are 'simply' added as new records to the existing dataset, meaning that the database must first be restructured to connect the information about a dwelling with regard to several reference dates (Stein et al. 2016; Filippidou & Nieboer 2014). This is a time-consuming procedure which had to be repeated every year. The situation is exacerbated by the fact that individual dwellings do not have an own ID, where data regarding different reference dates could be coupled (Stein et al. 2016; Filippidou & Nieboer 2014). So far, and for this thesis, this was done by creating an encrypted ID variable based on address information (postal codes, street numbers and possible extensions), but although the Dutch postal codes are very refined (on sub-street level), this method is still less reliable than an individual ID. As a result, in future monitoring systems we recommend the use of a unique ID for dwellings from the beginning of the system.

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). A pilot would have to be carried out to check this and its applicability.

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§ 1.8 Added value of the research

§ 1.8.1 Scientific contribution

Many studies focus on the impact of the built environment, and more specifically the residential sector, on the total heating energy consumption and how it can be improved. Previous research has focused on the impact of building components, occupants and different socio-economic factors, including the implementation of policies, on the energy performance of buildings or residential dwellings (van den Brom et al. 2018; Rasooli et al. 2016; Majcen et al. 2016; Majcen et al. 2013; Santin et al. 2009) . The availability of large datasets, during the last decade, has laid the groundwork for empirical evidence on the development of the energy efficiency of building stocks. Despite this, the limited availability of detailed empirical data on the energy demand of dwellings complicates our understanding of the impact of technologies used (e.g. energy installations) and policies applied (Hamilton et al. 2017).

The objectives of this work, are focused on crucial elements of the energy renovation and efficiency processes to fill in the gap in literature of what is the impact of state-of-the-art measures of dwellings in the non-profit housing stock. 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) except for a few dealing with epidemiological methods (Hamilton et al. 2017). Up to now, and due to the difficulty of acquiring actual heating 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). The ability to track renovations of a dwelling stock heavily relies on data availability. For this research, we were able to work with SHAERE and Statistics Netherlands longitudinal data. We start by introducing the energy efficiency state of the non-profit housing stock in the Netherlands and we then move in to examine how fast is this stock being renovated the last years. We then analyse which were the energy saving measures implemented and what is the most efficient way to determine which sets of measures would be more beneficial based on predicted and actual heating energy consumption.

At the same time, international comparisons on the energy refurbishment processes and efficiency measures of the housings stocks between countries and different refurbishments processes are important to understand the methods and approaches used in research. The comparisons were implemented through the IEE (Intelligent Energy Europe) of the EU programme EPISCOPE. Energy monitoring and future energy renovation scenario indicators were developed. This resulted in the special issue journal publication "Towards an energy efficient European housing stock: Monitoring, mapping and modelling retrofitting processes"(Visscher et al. 2016) and a comparison of the energy renovation rates of 11 EU countries publication that can be found in Appendix B(Sandberg et al. 2016). The non-profit housing stock of the Netherlands and the results on the energy renovation pace and the energy efficiency state were examined according to the dwellings typology (age, type, characteristics), as part of the EPISCOPE project and through the collaboration with NTNU (Norwegian University of Science and Technology) for the prediction of renovation rates (Chapter 6).

§ 1.8.2 Societal contribution

The application and societal impact of every research is the core driving force for its completion. The way the research outcomes are applied in the real world is of great importance. In addition to the quantitative research of the renovation pace and process of the housing stock, the results of this research provide an insight as to which types of energy renovations create the strongest impact regarding energy efficiency. They provide a link to the qualitative data that are assessed relating to the explanation of the renovation pace process and the energy saving measures.

As stated in the start of this sub-section one of the goals of every research performed is to be of use to several sectors and stakeholders involved. Apart from the goal to add something to the combined effort of the Netherlands and the EU for the targets set in improving the energy efficiency of the residential sector, there is a need to provide information and work with the non-profit rented housing organizations. Answers to questions like which are the most efficient energy renovation solutions for the Dutch non-profit housing benefit the housing organizations and as a result the tenants of the dwellings as well.

The outcomes of this work can be critical and useful to the entity of the stakeholders involved in the housing sector and especially the social housing. From the organizations managing the stock, to the occupants living in the houses, the neighbourhoods and how they deal with the energy efficiency aspect of their homes to governmental authorities that will create policies and measures towards this path, we tried to provide clear and useful results that can be of use to the majority of the aforementioned stakeholders.

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§ 1.9 Structure of thesis

This study contains five components that support its main goal to discover how achievable energy neutrality is in the built environment. In order to answer the main question, first we need to understand the current energy efficiency state of the non-profit housing stock, as presented in **Chapter 2**. We examine the efficiency of the stock in 2015 in terms of descriptive statistics of the main elements of the thermo-physical and dwelling characteristics. These include the age, type, useful floor area, thermal resistance (R_c-value) of the envelope (roof, facades and floor), thermal transmittance (U-value) of the windows, heating and domestic hot water (DHW) systems, ventilation system and energy production systems, if present.

In **Chapter 3**, the energy renovation pace for the non-profit housing stock of the Netherlands is introduced, based on the changes in the energy performance of about 800.000 dwellings for the period of 2010 to 2014. We identify the number of dwellings in the non-profit housing sector that showed an improved energy performance during the period of 2010-2014, and then compare it to the non-renovated sample of dwellings. Moreover, we also analyse the energy improvements of the stock per year to get a more detailed view and assess the trend of the energy renovation pace.

However, to get a better picture of the energy renovations applied in the sector, a thorough examination of the renovation measures is necessary. In **Chapter 4**, we identify the specific energy efficiency measures that have been realised between 2010 and 2013. In order to assess the effect of the measures on energy performance, an analysis of the changes in the energy systems and envelope elements of the dwellings is presented.

Usually, the energy savings are based on modelling calculations. However, in **Chapter 5,** we re-assess the effectiveness of energy measures based on actual consumption data. We examine the impact of thermal renovation measures on both the predicted and the actual heating energy consumption of the renovated non-profit stock in the Netherlands. Actual savings not only reveal the true effect of renovations on the reduction of heating energy consumption but they also highlight the impact of the number and combinations of measures on the dwellings' performance. Consequently, we address the gap between predicted and actual energy savings and its impact on regulations and policies concerning the energy efficiency of the built environment.

So far, we have analysed the energy efficiency state of the non-profit housing stock and the energy renovations that have taken place since 2010. Having a clear picture of the present and past is essential for the prediction of future renovations and the evolution of the housing stock. Despite common efforts, throughout Europe, national approaches to monitor the building stock have evolved separately. Information about the progress of the energy renovations is required to track the progress of policy implementation. To address the shortcomings and challenges identified, there is a need for a new methodology that can be used for consistent and scalable analysis of building stock across multiple countries. For this reason, in **Chapter 6,** we provide insight into the future renovation rates of the Dutch non-profit housing stock, using two different methods. First, based on the empirical data of SHAERE, we use regression forecasting to show at which rate renovations must happen to reach energy neutrality. Then, we apply the dynamic dwelling stock model developed in NTNU ("Norges Teknisk-Naturvitenskapelige Universitet" – in English: Norwegian University of Science and Technology) to compare the renovation rates and reach conclusions regarding the ways in which energy neutrality in the building stock can be achieved. The application of the dynamic model is the result of a fruitful collaboration with the Industrial Ecology group in NTNU and a month-long visit in Trondheim, Norway.

Chapter 7 completes this study. The findings of this thesis are brought together to draw general conclusions. Moreover, the limitations of the study, the contributions to both policy and practice, and recommendations for future research are discussed.

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2 Energy efficiency state of non-profit housing stock in the Netherlands

Note:
In this chapter, the energy efficiency state of the non-profit housing stock of the Netherlands is presented. The necessary data are drawn from the monitoring system SHAERE, that contains information about the energy performance of approximately 60% of all dwellings in the sector. The method used is based on descriptive statistics of the dwellings' physical properties and reported energy performance. The chapter sets the background needed to answer the main research question of the thesis – what is the energy efficiency progress of the non-profit housing stock through energy renovations and their impact on actual heating energy consumption.

This chapter material was used for the Aedes benchmark for the energy performance of the non-profit housing stock in 2016.

§ 2.1 Introduction

Improving energy efficiency of buildings is widely considered as the one of the most promising, fast and cost-effective ways to mitigate climate change and achieve the 2020 and 2050 goals set for the built environment (European Commission 2011; Aedes 2017). Energy efficiency of the building stock is hard to achieve if we only focus on the design of new dwellings. In this chapter, we will analyse the energy efficiency state of the existing Dutch non-profit housing stock using data from 2015.

We examine the energy efficiency state of the stock using data from the SHAERE monitoring system. The data from SHAERE include the age, type, useful floor area, thermal resistance (R_c-value) of the envelope (roof, facades and floor), thermal transmittance (U-value) of the windows, heating and domestic hot water (DHW) systems, ventilation system, the predicted heating energy consumption and energy production systems, if present. We also use actual heating energy consumption data from Statistics Netherlands to calculate the mean actual energy consumption of the stock.

The chapter aims 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 pace and energy saving measures realised. The following sections present the results and conclusions drawn from this chapter. Section 2.2 presents the development of energy efficiency policies in the built environment. The SHAERE monitoring system is presented in 2.3. Section 2.4 sums up the methods used. Section 2.5 brings attention to the results of the research study. Section 2.6 presents the conclusions of this chapter.

§ 2.2 Energy efficiency policies

In the Netherlands, the energy efficiency of buildings has been regulated since 1975 consisting of limits on transmission losses based on insulation values (Boot 2009). In 1995 these limits were expanded to include the national “EPC” (Energy Performance Coefficient), a non-dimensional figure expressing the energy performance of a building, which depends on the energy demand for space heating, hot water, lighting, ventilation, humidification and cooling. The Dutch EPC is calculated by dividing the calculated energy demand of a building by a standard energy performance. The standardized energy performance is based on the heat transfer surface and the total heated area of the dwelling (NEN 2012). At the beginning (1996) the EPC value was set to 1.4, a number easily reached by the construction techniques of the time. Later on EPC values were tightened to 1.2 in 1998, 1.0 in 2000, 0.8 in 2006, 0.6 in 2011 with a reduction at 0.4 in 2015 in order to achieve nearly zero energy buildings (nZEB) by 2020 as shown in Figure 2.1(Beuken 2012).

From 2008 onwards the energy label is a compulsory measure to be undertaken with the transfer of dwellings, as a result of the EPBD (Energy performance Buildings Directive) (European Commission 2010). The energy label was originally meant for dwellings older than 10 years (Koppert 2012). The idea is that the energy performance of dwellings built over the last 10 years is sufficient and insulation measures are not cost-effective for newly built dwellings. The enforcement of the energy label is put to practice in 2013, where owners are obliged to deliver an energy label at the notary when transferring a dwelling in the Netherlands (Koppert 2012). The second purpose of issuing the energy labels is the insight in the energy performance and the possibilities to improve it, based on the energy performance advice (EPA) which in turn can lead to actual energy efficiency measures. The energy label is based on an energy performance calculation or EPA provided by certified bodies according to the BRL9500-01/ 9501 building standard in the Netherlands (Koppert 2012). Advisors are authorised to deliver an energy label and give ‘tailor made energy performance advice’, EPA. As a result of the EPA, the EI (Energy Index) was created that is a performance coefficient for the existing building stock denoting the energy efficiency of a building.

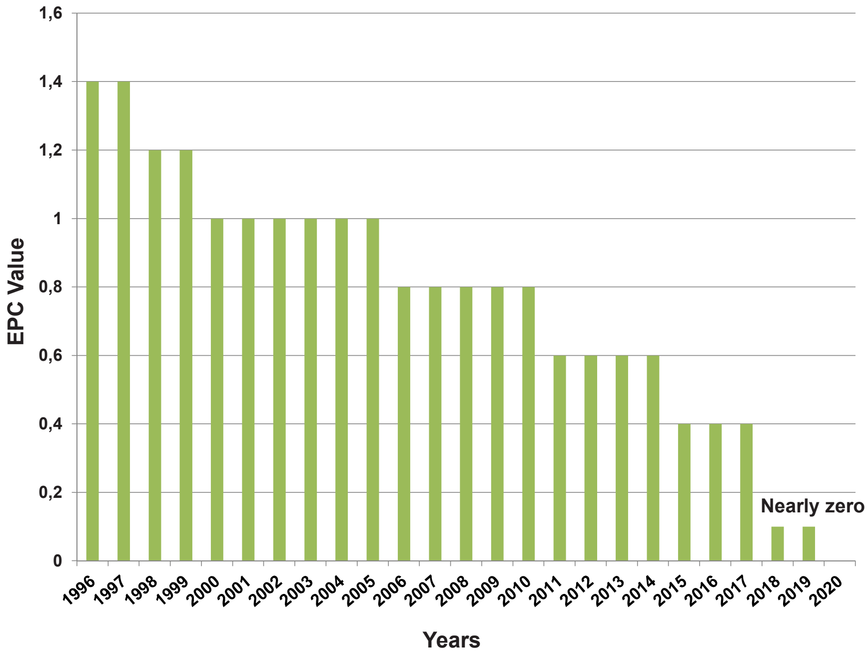

FIGURE 2.1 Evolution of the regulatory Energy Performance Coefficient (EPC) for new and extensively renovated buildings in the Netherlands

The EI is directly connected to the total predicted energy consumption. According to the calculation it is corrected for the floor area of the dwelling and the corresponding heat transmission areas, as shown in Equation 2.1, in order to not impede larger dwellings and dwellings with greater envelope proportions adjoining the unheated spaces at constant insulation properties and efficiencies of the heating/ventilation/lighting system (Visscher et al. 2012). A shape correction is applied as well taking into account the infiltration losses within space heating demand, while the air permeability coefficient depends on the buildings' shape factor. Such corrections for compactness are common also in other European countries, though it has been argued that not correcting would better promote energy efficient architectural designs (Visscher et al. 2012).

The EI is calculated as follows:

$$EI = \frac{Q_{total}}{(155*A_{floor}+106*A_{loss}+9560)} \qquad \text{Equation 2.1}$$

Q_{total} refers to the modelled characteristic yearly primary energy use of a dwelling, and includes energy for space heating, domestic hot water, additional energy (auxiliary electric energy needed to operate the heating system, i.e. pumps and funs), lighting of communal areas, energy generation by photovoltaic systems, and energy generation by combined heat and power systems under the assumption of a standard use (Filippidou et al. 2016; Visscher et al. 2012; ISSO 2009). A_{floor} refers to the total heated floor area of the dwelling, whereas A_{loss} refers to the transmission heat loss area in the dwelling, such as a cellar (Filippidou et al. 2016; Visscher et al. 2012; ISSO 2009). The numerical values in the denominator are: 155 is the factor for the reference energy consumption per m^2 correction, regarding the useful living area (MJ/m^2); 106 is the correction factor compensating for the transmission losses (MJ/m^2); and 9560 is a standard amount of energy used for existing dwellings (MJ) (NEN 2012).

Energy savings and sustainability are set as a priority in the non-profit housing sector, especially since 2008, with the implementation of the EPBD (Aedes 2017). The main energy efficiency policy for the sector is described in the Energy Saving Covenant for the Rental Sector (Convenant Energiebesparing Huursector 2012). The short term goal of the non-profit housing sector is to achieve an energy label B, corresponding to an average EI of 1.25, by the end of 2021 (BZK 2014; Aedes 2017). The Covenant is a voluntary agreement between Aedes – the umbrella organisation of housing associations – the national tenants union, and the national government. The goal of the agreement means a reduction by 33% of energy consumption compared to the 2008 levels (BZK 2014).

In 2015, the method for the EI-Energy label (ISSO 2009) calculation was changed and a point system was introduced. In Table 2.1, we compare the two systems. The new method is the "Nader Voorschrift" (English: Further prescription) and it is linked to the WWS [Woningwaarderingsstelsel (English: Housing evaluation system)] system. This new method is thought to be more detailed and updated than the EI-Energy label method (Vabi 2016; RVO 2018). We refer to this change of method because it can have an impact on the realization of goals and the decision making in terms of energy renovations from housing associations. For a full calculation of the EI NV (Energy Index Nader Voorschrift) see NEN 7120 documentations (NEN 2017). According to the new method and the first results, depicted in Figure 2.2, there is a deviation between the mean EI and the mean EI NV in 2014 in the non-profit housing stock – the only year that both were present in SHAERE. Based on the first evaluation, commissioned by the Netherlands Enterprise Agency, there is a clear link between the two mean values (EI and EI NV) but also an obvious spread of values making the deviation that we see in Figure 2.2 expected (Berben & Kuijpers 2014). Nevertheless, the short term goal of the non-profit housing stock for an average energy label B by the end of 2020 remains, just the EI value for the goal has changed from 1.25 to 1.40 (Aedes 2017).

TABLE 2.1 Comparison of the EI values to the newly introduced EI NV, since 2015 (Berben & Kuijpers 2014)

ENERGY LABEL	ENERGY INDEX (EI)	EI NV – AFTER 2015
A++	EI ≤ 0,5	EI ≤ 0,6
A+	0,5 < EI ≤ 0,7	0,6 < EI ≤ 0,8
A	0,7 < EI ≤ 1,05	0,8 < EI ≤ 1,2
B	1,05 < EI ≤ 1,3	1,2 < EI ≤ 1,4
C	1,3 < EI ≤ 1,6	1,4 < EI ≤ 1,8
D	1,6 < EI ≤ 2,0	1,8 < EI ≤ 2,1
E	2,0 < EI ≤ 2,4	2,1 < EI ≤ 2,4
F	2,4 < EI ≤ 2.9	2,4 < EI ≤ 2.7
G	EI > 2.9	EI > 2.7

There are several studies supporting the fact that the regulations on energy consumption and the application of the national EPC have driven households to lower their consumption in the country (Guerra-Santin & Itard 2012; Beerepoot & Beerepoot 2007). On the other hand, several other recent studies argue that the estimated energy consumption is different than the actual consumption and so the impact of the EPC on the energy consumption of the dwellings can be lower than reported (Majcen et al. 2013, Balaras et al. 2016). Monitoring is essential to examine the energy performance of housing stocks. Descriptive statistics were used in this chapter to determine the energy efficiency state of the non-profit housing stock of the Netherlands and the estimated and actual mean heating energy consumption.

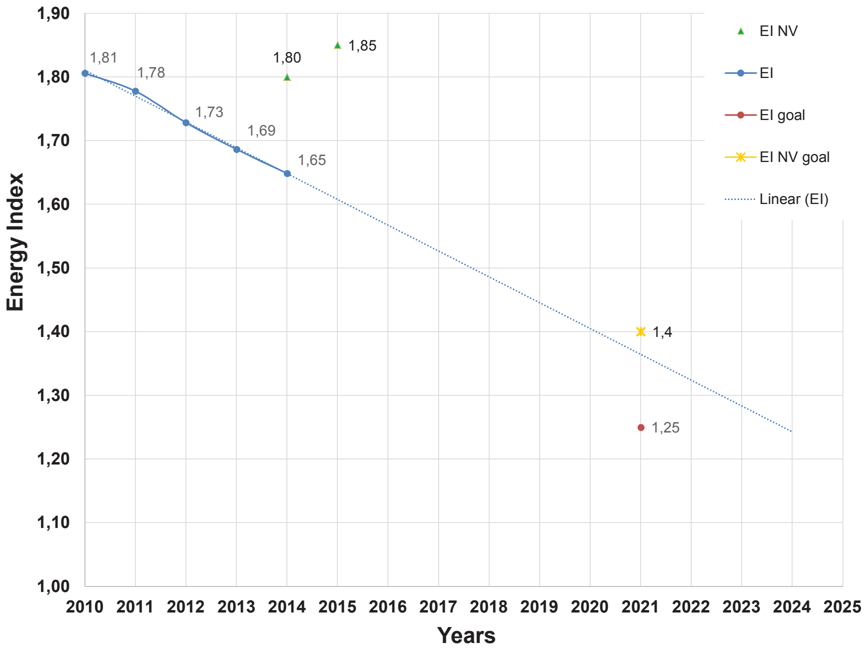

FIGURE 2.2 EI development 2010-2015 following the difference in the methods (data from SHAERE)

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. 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 heating energy consumption data from Statistics Netherlands are collected, annually, from energy companies since 2009 (Majcen 2016). The datasets include values from 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 is collected on a dwelling level based on the address, which is encrypted.

§ 2.3 SHAERE monitoring system

In 2008, after the formulation of the Covenant on energy saving targets, Aedes started the monitoring system of dwellings called SHAERE. The monitor became operational in 2010. Housing associations report their stock to Aedes 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 participation of housing associations is voluntary, resulting in the variation of the amount of dwellings included in the database each year. On average, more than 50% of the population of non-profit dwellings is reported each year. As a result, SHAERE consists of the actual characteristics of all dwellings of the participating housing associations at the end of each calendar year. 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.

The data included in SHAERE differ from the official energy labelling data (Energy Performance Certificates) registered at the Ministry of the Interior and Kingdom Relations of the Netherlands. The monitor includes all detailed information required for an energy label calculation. However, it does not include the official registered energy labels, only, but “pre-labels” (Majcen 2016). A pre-label is an unofficial label certificate of a dwelling that may have not been registered to the Dutch state but is recorded and updated internally, by the housing association according to Aedes, whenever a renovation measure is realised. The recording of the energy renovation measures and the consequent update of the pre-label is performed due to the fact that the housing associations perform these updates as a form of asset management of their stocks (Visscher et al. 2013).

SHAERE is the official tool for monitoring the progress in the field of energy saving measures for the non-profit housing sector. 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, domestic hot water (DHW) and ventilation and the predicted heating 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). More information about the variables can be found in Appendix A where a list of variables included in SHAERE is recorded.

§ 2.4 Methods

We approach the efficiency of the stock, in 2015, in terms of descriptive statistics of the main elements of dwelling characteristics, thermo-physical characteristics, installations, modelled and actual heating energy consumption. It is important to investigate the efficiency state of the stock in order to further examine the process of energy renovations and their effect on the buildings' performance and final energy consumption.

Using SHAERE, three main groups of variables are examined in this chapter. These are the dwelling characteristics (area, construction year etc.), the envelope insulation values (roof insulation, façade insulation etc.) and the installation variables (space heating system, DHW etc.). In the first group, we use descriptive statistics of the net floor area, the construction year and type of dwelling of the 1,374,095 dwellings reported in 2015.

The second group of variables, from SHAERE, consists of the envelope insulation values. Four variables are used – the R_c-values (thermal resistance, m^2K/W) of roof, floor and façades and the U-value (thermal transmittance, W/m^2K) of windows. These R_c- and U-values are nominal variables. We use descriptive statistics of the aforementioned nominal to present the energy efficiency state of the non-profit housing stock and we also categorize the variables to provide an understanding and "translation" of the values, based on the ISSO publication 82.3 (ISSO 2009). Table 2.2 and Table 2.3 depict the classification of R_c- and U-values based on the Dutch standardization institute.

ISSO publication 82.3 lays out the methodology to calculate and characterise the energy performance of Dutch dwellings. It connects the building regulations, applied through several building decrees in the country, to the practical characterization of insulation values, among other topics. The basis of the classification system used in this chapter and the thesis, is the abovementioned method. The classification systems founds on the construction periods, used in the Netherlands, insulation thickness used in each construction period and the distribution of the R_c-values. We choose to treat the envelope elements separately in order to correspond to the application of energy saving measures, as performed in practice.

TABLE 2.2 Insulation categories created for floor, roof and façade based on the ISSO 82.3 Publication (ISSO 2009)

CHARACTERIZATION	R_c-VALUE ROOF [m^2K/W]	R_c-VALUE FLOOR [m^2K/W]	R_c-VALUE FAÇADE [m^2K/W]
No-insulation	$R_c \leq 0.39$	$R_c \leq 0.32$	$R_c \leq 1.36$
Basic insulation	$0.39 < R_c \leq 0.72$	$0.32 < R_c \leq 0.65$	$1.36 < R_c \leq 2.86$
Good insulation	$0.72 < R_c \leq 0.89$	$0.65 < R_c \leq 2$	$2.86 < R_c \leq 3.86$
Very good insulation	$0.89 < R_c \leq 4$	$2 < R_c \leq 3.5$	$3.86 < R_c \leq 5.36$
Extra insulation	$R_c > 4$	$R_c > 3.5$	$R_c > 5.36$

TABLE 2.3 Window categories created and based on the ISSO 82.3 Publication (ISSO 2009)

CHARACTERIZATION	U-VALUE WINDOW [W/m^2K]
Single glass	$U \geq 4.20$
Double glass	$2.85 \leq U < 4.20$
HR+ glass	$1.95 \leq U < 2.85$
HR++ glass	$1.75 \leq U < 1.95$
Triple insulation glass	$U < 1.75$

The third group of variables refers to the energy installations in dwellings. These include the type of space heating system, the DHW system, the ventilation system and the solar energy system (solar boilers or photovoltaic systems). The energy installation systems are categorical variables.

Next, we matched the data from SHAERE, on microdata level, to the actual heating 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 correspond to the years of 2009, 2010, 2011, 2012, 2013 and 2014. For this research, we worked with the latest available dataset, which was the 2014 one.

§ 2.5 Results

Based on the 2015 data from SHAERE, the mean net floor area of the non-profit housing stock dwellings was 80.44 m^2. The mean building year is 1972 and the median 1974. Figure 2.3 shows the distribution of the variable construction year of the non-profit housing stock. We can observe that in certain periods more dwellings were built than in other – especially after the end of the second world war.

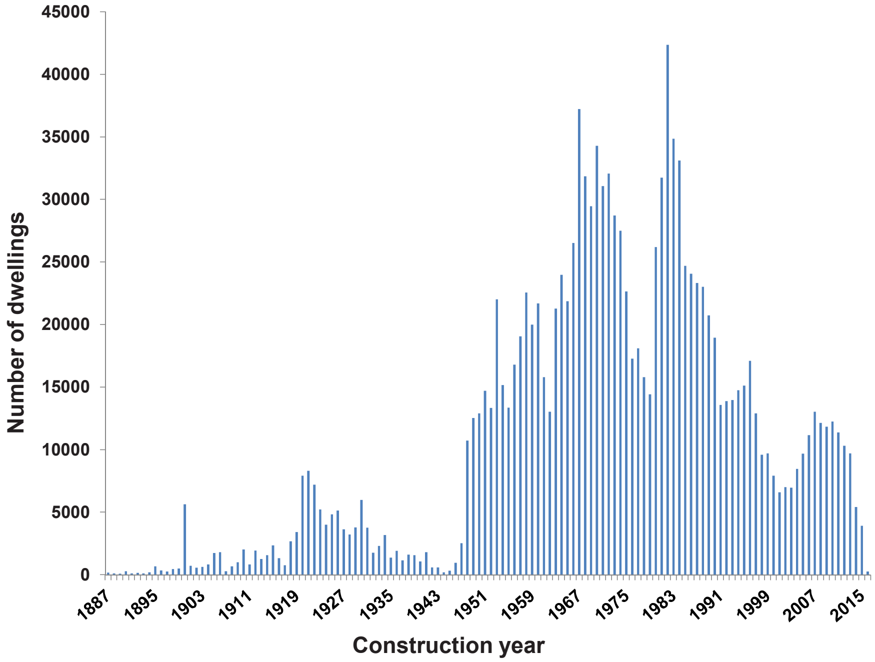

FIGURE 2.3 Construction year distribution based on SHAERE 2015

The total amount of dwellings in the Netherlands is 7.5 million. The owner occupied sector amounts to 55.8% of the total, whereas the rental sector comprises 43.5% of the total (BZK 2016). The ownership type is unknown for the remaining 0.7% (BZK 2016). The majority of the non-profit housing stock, 53.3%, are multifamily dwellings. The rest 46.7% single family dwellings are in their vast majority terraced houses. Figure 2.4 depicts the distribution of the construction period and type of dwelling for the non-profit housing.

FIGURE 2.4 Age and type of dwelling distribution based on SHAERE 2015

§ 2.5.1 What are the insulation levels of the envelope?

The level of insulation of the envelope has a big impact on the energy performance of the dwellings. In Table 2.4 we present the mean, median and standard deviation values of the thermal resistance values of the roof, floor and façade and the thermal transmittance value of the windows. The average R_c-value of the roof was 1.49, classified as very well insulated, whereas the Rc of floors was 0.94, classified using the specific classification system as well insulated. The average R_c-value of walls was 1.37 which classifies as poorly insulated, based on the classification system whose foundation is the ISSO 82.3. The average U-value of windows was 2.88 – which classifies as double glazing.

TABLE 2.4 Descriptive statistics for Rc-values of roof, floor, facades and U-value of windows 2015

		R_c-VALUE ROOF [m^2K/W]	R_c-VALUE FLOOR [m^2K/W]	R_c-VALUE FAÇADE [m^2K/W]	U-VALUE WINDOW [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

Table 2.5 to Table 2.7 show the distribution of the envelope insulation values in categories, based in the ISSO 82.3 publication. The majority of dwellings are equipped with very well insulated roofs (41.4%) whereas the second largest group of dwellings is not insulated (13.2%). The majority of dwelling floors, on the other hand, is not insulated (27.9%) and the largest group of dwellings after that is well insulated (14.6%). The situation is different for the façades. The largest share of dwellings (52.7%) are not insulated and following, 40.9% of the dwellings are poorly insulated. Here, for clarification purposes we need to state that the nominal values presented in Table 2.4 are showing a more detailed view of the levels of envelope insulation.

TABLE 2.5 Rc-value roof categorized, based on the ISSO 82.3 Publication (ISSO 2009), from SHAERE 2015

		FREQUENCY	PERCENT (%)
Valid	No-insulation (R_c ≤0.39)	180875	13,2
	Basic insulation (0.39<R_c ≤0.72)	28056	2,0
	Good insulation (0.72<R_c ≤0.89)	69787	5,1
	Very good insulation (0.89<R_c ≤4)	568236	41,4
	Extra insulation (R_c >4)	22300	1,6
	Total	869254	63,3
Missing	System	504841	36,7
Total		1374095	100,0

TABLE 2.6 Rc-value floor categorized, based on the ISSO 82.3 Publication (ISSO 2009), from SHAERE 2015

		FREQUENCY	PERCENT (%)
Valid	No-insulation ($R_c \leq 0.32$)	382709	27,9
	Basic insulation ($0.32 < R_c \leq 0.65$)	132065	9,6
	Good insulation ($0.65 < R_c \leq 2$)	199989	14,6
	Very good insulation ($2 < R_c \leq 3.5$)	134241	9,8
	Extra insulation ($R_c > 3.5$)	18127	1,3
	Total	867131	63,1
Missing	System	506964	36,9
Total		1374095	100,0

TABLE 2.7 Rc-value façade categorized, based on the ISSO 82.3 Publication (ISSO 2009), from SHAERE 2015

		FREQUENCY	PERCENT (%)
Valid	No-insulation ($R_c \leq 1.36$)	724362	52,7
	Basic insulation ($1.36 < R_c \leq 2.86$)	561927	40,9
	Good insulation ($2.86 < R_c \leq 3.86$)	52785	3,8
	Very good insulation ($3.86 < R_c \leq 5.36$)	17361	1,3
	Extra insulation ($R_c > 5.36$)	2109	0,2
	Total	1358544	98,9
Missing	System	15551	1,1
Total		1374095	100,0

Table 2.8 presents the distribution of glazing categories. The vast majority of dwellings (60.0%) are equipped with double glazing, 14.2% have HR+ glass and 18.2% have HR++ glass. Only 0.4% of dwellings are equipped with triple insulated glass and 6.1% have single glazing. The following sub-section will shed light in the distribution of the energy installation of dwellings in order to get a better idea of the energy performance of the non-profit housing sector.

TABLE 2.8 U-value window categorized, based on the ISSO 82.3 Publication (ISSO 2009), from SHAERE 2015

		FREQUENCY	PERCENT (%)
Valid	Single glass (U≥4.20)	84396	6,1
	Double glass (2.85≤U<4.20)	824428	60,0
	HR+ glass (1.95≤U<2.85)	194810	14,2
	HR++ glass (1.75≤U<1.95)	249577	18,2
	Triple insulation glass (U<1.75)	5253	0,4
	Total	1358464	98,9
Missing	System	15631	1,1
Total		1374095	100,0

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

The energy installations of dwellings are an important factor determining their energy performance and ultimately the final heating energy consumption. In this sub-section we are presenting the distribution of the space heating system, DHW system and ventilation system. Moreover, we are introducing the amount and square meters of solar boiler and photovoltaic systems installed in the non-profit housing stock in 2015.

The distribution of the heating system is shown in Table 2.9. The table presents a detailed image of the space heating installations. It includes the numbers of dwellings and percentages that are equipped with each of systems. The vast majority of non-profit dwellings (74%) operate a condensing gas boiler with $\eta \geq 0.95$. Other space heating solutions in the sector include improved non-condensing boilers with $0.80 \leq \eta \leq 0.90$ and condensing boilers with efficiencies of 0.90-0.95. In the Netherlands, 85% of households are heated with natural gas (ECN 2015). Solutions like heat pumps or µCHPs [6] are still rare with only 1% of dwellings having installed one.

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[6] µCHP is a micro-Combined Heat and Power energy system producing heat and electricity

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TABLE 2.9 Distribution of heating system – frequencies and percentages from SHAERE 2015

TYPE OF HEATING SYSTEM	FREQUENCY	PERCENT (%)
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%

The picture is similar for the domestic hot water installations. Usually, the condensing gas boilers are combined systems and include the DHW installation a well. The majority of the non-profit housing dwellings have a condensing combi-boiler with 0.90≤ η≤0.95 installed. The rest of the distribution is similar to the space heating installation. However, 6% of dwellings are connected to a district heating system for the provision of DHW. Table 2.10 shows the number of dwellings distributed to each DHW system.

TABLE 2.10 Distribution of DHW system – frequencies and percentages from SHAERE 2015

TYPE OF DHW SYSTEM	FREQUENCY	PERCENT [%]
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 2.11 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 2.11 Distribution of ventilation system – frequencies and percentages from SHAERE 2015

TYPE OF VENTILATION SYSTEM	FREQUENCY	PERCENT [%]
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%

Two solar energy systems are reported, if installed, in SHAERE. These are solar boilers, either for DHW, space heating or both, and photovoltaic systems – amorphous, multicrystalline and monocrystalline. Unfortunately, the amount of dwellings with either system is quite low in the non-profit housing sector. The application of solar systems for the production of thermal energy or electricity is not popular. Only 189,335 m^2 of solar boilers are installed in the non-profit housing sector.

TABLE 2.12 Distribution of solar boiler systems – frequencies and percentages from SHAERE 2015

TYPE OF SOLAR BOILER	FREQUENCY	PERCENT [%]
No solar boiler	1344709	98%
Solar boiler for DHW	28467	2%
Combi solar boiler (DHW and space heating)	710	0,1%
Solar boiler for space heating	90	0,0%
Total	1373976	100%

The distribution of photovoltaic systems is not very different from the solar boilers. Less than 2% of dwellings have a photovoltaic system installed. This amounts to 186,574 m^2 of installed photovoltaic systems.

TABLE 2.13 Distribution of photovoltaic systems – frequencies and percentages from SHAERE 2015

TYPE OF PHOTOVOLTAIC SYSTEM	FREQUENCY	PERCENT [%]
No system	1343251	98%
Multicrystalline	16824	1%
Monocrystalline	6561	0,5%
Amorphous	903	0,1%
Total	1374095	100%

§ 2.5.3 What is the modelled and actual final heating energy consumption?

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 (Majcen 2016). As a result, estimated 10-20% of dwellings instead of a meter reading are filled in with the average energy consumption of a similar building (Majcen 2016). While this fact can be problematic for our analysis, we did not evaluate individual dwellings but worked with mean values. Subsequently, we are confident that our results are accurate. For this research we are working with gas consumption data. As mentioned before, the majority of Dutch dwellings are heated with gas and in the non-profit housing sector this percentage is more than 95%.

In all calculations, regarding actual gas 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 below 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.

TABLE 2.14 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/m^2/year)	119,30 (kWh/m^2/year)

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Table 2.14 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 between predicted and actual gas consumption is 60 kWh/m^2/year. The mean gas actual gas consumption for the Dutch households, as reported by Statistics Netherlands in 2015, is 151.80 kWh/m^2 (using 80m^2 mean net floor area) (Statistics Netherlands 2017). It appears that the non-profit housing stock is consuming less gas than the total housing stock in the Netherlands.

§ 2.6 Uncertainties and limitations

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.

The actual energy consumption data, acquired from Statistics Netherlands, are collected by energy companies since 2009. Yet, the delivery 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.

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The classification system used in our methods 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. Based on the construction period tables and the insulation thickness the specific boundaries were chosen. We follow the construction periods which correspond also to the energy renovation targets that once should follow and comply with. 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) could be studied in further research projects.

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.

§ 2.7 Conclusions

Research for energy performance in the built environment can provide information to aid the achievement of goals set and is a cornerstone for the design of effective policies. Dynamic databases using longitudinal data prove to be extremely useful. Longitudinal data are very important to follow the energy performance progress 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.

This chapter aimed at determining the energy efficiency state of the non-profit housing sector, analysing the latest available data. The main research question of the chapter was how efficient is the Dutch non-profit housing stock in terms of energy performance. 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.

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 of the non-profit housing sector. The large dataset is important since in this chapter we aimed at describing the energy performance of the non-profit housing sector. As such, 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.

In conclusion, we determined the energy efficient state of the non-profit housing stock. This chapter brings together the background knowledge needed in order to track the energy renovations, calculate the energy savings and evaluate the degree of implementation of current policies.

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3 Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing using the national energy labelling database

Note:
In the previous chapter, the energy efficiency state of the stock was presented. Existing dwellings will dominate the housing stock for at least the next 50 years, based on their life cycle. Moreover, energy renovations in dwellings offer unique opportunities to reduce both energy consumption and greenhouse gas emissions. In this chapter, the renovation rates for the non-profit housing stock of the Netherlands are presented, based on the changes in the energy performance of about 800,000 dwellings for the period of 2010 to 2014. The necessary data are drawn from a monitoring system (SHAERE: "Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing" – in English: Social Rental Sector Audit and Evaluation of Energy Saving Results) that contains information about the energy performance of approximately 60% of all dwellings in the sector. The method used follows the changes of the dwellings' physical properties and reported energy performance. 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.

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Abstract

The existing housing stock plays a major role in meeting the energy saving targets set in the Netherlands as well as in the EU. Existing buildings account for 38% of the final energy consumption in the European Union (EU), and they are responsible for 36% of the CO_2 emissions. Energy renovations in dwellings offer unique opportunities to reduce both energy consumption and greenhouse gas emissions. In this article, the renovation rates for the non-profit housing stock of the Netherlands are presented, based on the changes in the energy performance of 856,252 dwellings for the period of 2010 to 2014. The data necessary are drawn from a monitoring system that contains information about the energy performance of approximately 60% of all dwellings in the sector. The method used follows the changes of the dwellings' physical properties and reported energy performance. The results show that although many energy improvements have been realized, they result in small changes of the energy efficiency of the dwellings. Deep energy renovation rates are very low. If this pace continues, the progress is too little to reach national and international policy targets. The renovation rates are not high enough and the trends seem difficult to reach.

§ 3.1 Introduction

The energy performance of buildings is generally so inadequate that the levels of energy consumed in them place the sector among the most significant CO2 emission sources in Europe (BPIE 2011). Existing buildings are responsible for 36% of the CO2 emissions in the European Union (EU) (European Commission 2008 and 2014). In the context of all the end-use sectors, buildings represent the largest sector with 38% of the total final energy consumption, followed by transport (European Commission 2016a). A considerable percentage of this energy consumption is attributed to the residential sector, as on average dwellings consume 24.8% of the total energy consumption in the EU (Eurostat 2016). The building sector plays a major role in order to meet the energy saving targets set in the Netherlands and in the EU (SER 2013; Ürge-Vorsatz et al. 2007). This is particularly true for existing buildings, because they will constitute the major part of the housing stock over several decades. The renovation activity will be greater than the construction and demolition activity in the future.

Policy targets and regulations are in force, at an EU level, to ensure the energy efficiency improvement of the building stock. The Energy Performance of Buildings Directive ([EPBD] 2002, recast 2010) is the main legislative and policy tool in EU and focuses on both new and existing buildings. At the same time, the building sector plays a prominent role in the Energy Efficiency Directive ([EED] 2012). Relatedly, in the Netherlands, the foundation of energy efficiency policy has been a number of national cross-cutting measures and EU derived policies that play a large role; like the strengthening of standards for new buildings or dwellings and energy labels for existing ones (EPBD) (ECN 2015). Additional measures target split incentives. In 2013, a revolving fund for savings in buildings was created – 150 million euros from the government and 450 million from market parties (ECN 2015).

The energy savings potential of the existing dwellings is large. In the Netherlands, policy measures have been employed since the last quarter of the 20th century, mainly through building decrees. The energy consumption of new buildings has been regulated since 1975 consisting of limits on transmission losses based on insulation values (Boot, 2009). In 1995 these limits were expanded to include the national "EPC" (Energy Performance Coefficient) which is a figure expressing the energy performance of a building depending on the energy consumed for space heating, hot water, lighting, ventilation, humidification and cooling. The energy performance of the existing housing stock is being regulated through energy labels (A to G – most efficient to least efficient), since 2008, when the EPBD was implemented in the Netherlands. The average energy label in 2015 was C (RVO 2015). As the years pass, more dwellings adopt an energy label and thus far 2.9 million have one. The majority of these dwellings belong to the rental sector.

Despite the regulations and directives, there is a greater focus on newly built dwellings, achieving nearly zero energy standards, than on energy renovations of the building stocks. Nonetheless, energy renovations of dwellings are considered to be more sustainable and cost-effective than demolition and rebuilding (Itard & Klunder 2007), and should be given priority and incentives, especially taking into account the low and declining construction rates in the EU (Pombo et al. 2016; Thomsen & Van der Flier 2002). Energy renovations offer unique opportunities for reducing the energy consumption and greenhouse gas emissions. Energy renovation is instrumental for reaching the EU 2020 goals (Saheb et al. 2015). Moreover, renovations of the existing building stock have implications for growth and jobs, energy and climate, and cohesion policies (European Commission 2014; Saheb et al. 2015). Renovating existing buildings is seen as a 'win-win' option for the EU economy (Saheb et al. 2015). However, there are challenges mainly relating to the financing, market uptake and occupant awareness of energy renovations. Further, although there have been various energy renovation actions of dwellings in Europe (see Section 2), the assessment and monitoring of the pace of these renovations is lacking.

The tenure mix of dwellings bears a significant relevance to the ability to renovate regarding both the energy performance and the impact on the pace of energy renovations. The total amount of dwellings in the Netherlands is 7.5 million. The owner occupied sector comprises 55.8% of the total, whereas the rental sector amounts to 43.5% (BZK 2016b). The ownership type is unknown for the remaining 0.7% (BZK 2016b). The vast majority of the rental sector belongs to housing associations forming the non-profit housing sector. In this paper, we focus on the Dutch non-profit housing because the sector comprises approximately 2.3 million homes, which adds up to 30% of the total housing market (BZK 2016a). This is a unique situation as the Netherlands have the highest percentage of non-profit housing in the EU. The non-profit housing sector can be expected to be a leading example when it comes to energy efficiency goals due to its intrinsic social values.

Although no common definition for the non-profit housing sector is used, three elements are shared across the European non-profit social housing sectors: a mission of general interest, affordable housing for the low-income population and realization of specific targets, defined in terms of socio-economic status or the presence of vulnerabilities (Braga & Palvarini 2013). Non-profit housing is typically owned by the public sector; however, there is an increasing trend towards non-public involvement or the privatization of the non-profit housing sector in Europe, as is the case in Ireland, UK, Austria, France, and Denmark. Since the beginning of the 1990s the Dutch non-profit housing sector deviated from government control and public financing and became an independent sector. In the Netherlands, non-profit housing is almost entirely in the hands of private organisations (Elsinga & Wassenberg 2014; Priemus

2013; BPIE 2011; Kemeny 2002). These organizations can be better described as "hybrid" – they act between government, market and community (Nieboer & Gruis 2016). They have to manage the different and frequently competing interests from each of these three entities (Nieboer & Gruis 2016). The housing organizations have to fulfil several mandatory goals regarding the provision and allocation of homes.

Energy savings and sustainability are high on the agenda of the non-profit housing sector, especially since 2008 (Aedes 2013). The main energy efficiency policy for the sector is described in the Energy Saving Covenant for the Rental Sector ("Convenant Energiebesparing Huursector", 2012). The current aim of the non-profit housing sector is to achieve an average energy performance indicator, called Energy Index (EI), of 1.25, corresponding to an energy label B, by the end of 2020 (BZK 2014). The Covenant is a voluntary agreement between Aedes – the umbrella organisation of housing associations – the national tenants union, and the national government. The goal of the agreement means a reduction by 33% in energy consumption compared to the 2008 levels (BZK 2014; CECODHAS Housing Europe 2012). This voluntary agreement is a prominent example of policy implementation in organized housing. Agreements like this one could be enforced in communities and other public or private bodies to ensure energy efficiency of housing stocks. However, the application of such agreements is difficult in the owner-occupied housing sector where the owner bears the energy efficiency investment weight alone and is difficult to motivate.

The main aim of the article is to determine the actual renovation rate of the non-profit housing stock in order to conclude if the targets set are reachable and if not, what are the policy instruments needed to increase this rate. The energy renovation rate for the non-profit housing stock of the Netherlands is presented based on the changes in the energy performance of about 856,252 dwellings for the period of end 2010 to the end of 2014. We aim to identify the amount of dwellings in the non-profit housing sector of the Netherlands that showed an improved energy performance during this period. Moreover, we also analyse the energy improvements of the stock per year to get a more detailed view of the trend of the energy renovation rate. Through this study we highlight the importance of monitoring the energy renovations in the housing stock.

A common definition of an energy renovation is lacking. In 2014, the European Commission published the guidelines to finance the energy renovation of buildings. According to these guidelines, 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). We define the energy improvement rate as the amount of dwellings that were improved by at least one label step in a specific amount of time (e.g., one year). In addition we also refer to the dwellings that improved towards the highest energy performance (labels A or B). We define the deep renovation pace as the amount of dwellings that improved by at least 3 label categories. We have chosen this minimum of three ‘steps’, because this improvement in energy efficiency involves the application of a serious package of measures and is in line with several subsidy schemes.

This paper is structured as follows. The second section presents an overview of energy efficiency goals and improvements in several European countries. The third section describes the data and methods of our research. The fourth section presents the results. The fifth section deals with our experiences concerning the database and the longitudinal data analysis. Finally, the sixth section elaborates on policy implications and draws conclusions.

§ 3.2 Energy efficiency regulations, goals and insights in progress

The European Environmental Agency (EEA) reports that the EU is going to achieve its 20-20-20 climate, renewable energy and energy efficiency targets (EEA 2015). The climate targets refer to the Greenhouse Gas (GHG) emissions projected to be 27% lower in 2030 compared to the 1990 levels (based on 2014 data); moreover, the goal for a 20% reduction in 2020 will be met (EEA 2015). The renewable energy targets refer to 20% share of Renewable Energy Sources (RES) in energy consumption. The energy efficiency targets refer to the level of primary and final energy consumption. The energy efficiency target for 2020 is defined as an absolute target. It is set 20% below the level in primary energy consumption of 2005 (EEA, 2015). Apart from the prevailing “20-20-20” goals, when it comes to reducing the primary energy consumption at the EU level, the Energy Efficiency Directive 2012/27/EU (EED) is in place. All Member States have their own national plans to achieve the targets as required by the EED. Since 2005, the levels of energy consumption have been decreasing (EEA 2015); however, the complete implementation and enforcement of the national energy efficiency policies is required to achieve the goals of 2020. The Netherlands, along with seven other Member States (Belgium, Estonia, France, Germany, Malta, Poland and Sweden), have not achieved the required savings (BPIE 2014; EEA 2015). This means that they are only on track towards either the primary or the final energy consumption targets, and not both – despite the fact that the Netherlands reduced both primary and final energy consumption in 2012, as compared to 2005. The 2.0% reduction in primary energy (on average 0.3% per year) is not sufficient to be considered on the right track towards meeting its 2020 target (i.e., an 11.3% reduction in primary energy consumption between 2005 and 2012, or 0.8% per year)[7]. However, the Netherlands made better progress in 2013 in comparison to 2012 reducing the primary energy consumption and the gap towards the projected targets. Some of the reasons that targets are still not reached for the Netherlands, are the very low shares of RES in total (electricity, heating and cooling, transport) and in particular for the heating and cooling sectors relating to buildings. On the other hand, twenty Member States are considered to be on track towards their 2020 energy efficiency targets (EEA 2015). Still, the national targets set by the Member States are not always sufficient compared to the set EU targets (EEA 2015). Thus, all Member States need to enhance the reduction or limitation of their energy consumption by better implementing and further developing their energy efficiency policies.

The 2012 EED and the 2010 EPBD- are the EU's main legislation for the reduction of the energy consumption in buildings. Observing recent trends and policies in Europe, the EED focuses on energy savings in buildings, transport, products, and processes (European Parliament, Council of the European Union 2012). Among other obligations, 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 energy efficiency measures more difficult.

In 2008, the EPBD of the EU was implemented in the Netherlands. Under this directive, all Member States must establish and apply minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls, etc.). They must, also, ensure the certification of the energy performance of existing buildings when they are sold or re-rented. Furthermore, the regular inspection of boilers and air-conditioning systems in buildings is also required. The revised EPBD of 2010 requires Member States to also guarantee that by the end of 2020, all new buildings are 'nearly zero-energy buildings' (Beuken 2012; van Eck 2015). New buildings and major renovations in the Netherlands are required to meet specific standards e.g. thermal resistance (R_c-value) of floors, facades, roofs and thermal

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[7] Source: Eurostat 2014, reported targets under Article 3 of the EED (Eurostat, 2014)

transmittance (U-value) 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 energy efficiency measures, without an energy performance calculation being necessary (van Eck 2015).

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). At the time, each country is gathering and analysing data for the development of their building stocks differently. Some collect data through the Energy Performance Certificates (EPCs) databases and others perform housing surveys in representative samples. Another way is to collect information through the investments on energy renovations and calculate the progress. In this paper, we use yearly records gathered centrally and stored in a dynamic database by housing associations through the energy labelling of their stocks. Similarly, every country regards energy renovations in a different way when it comes to the level of performance achieved after one. Concerted guidelines for data collection, energy renovation definitions and implementation of policies are much needed on an EU level.

However, there is a limited amount of data available regarding the pace of the energy renovation of the building stocks in Europe. Detailed knowledge of the renovation rates, achieved in the housing stocks, is of great importance as they help monitor the progress of energy renovation and their impact on the energy performance of the housing stocks. Renovation rates can help predict future energy consumption values of the housing stocks and the overall reduction of energy consumption on a global scale. Apart from helping realize the challenging goals set for the built environment, renovation rates are also important to understand how quickly and what energy performance level can be achieved. They also relate to other issues in the built environment, such as fuel poverty. Ultimately, renovation rates are an indication of the progress of the buildings stocks and a tool for achieving future goals and policies.

Due to the fact that each country has implemented different national plans for the efficiency of the housing stock, the assessment methods and the reported progress are also different. The availability of data is limited to the goals that countries set, the investments that took place for the renovation of the stock or in terms of energy consumption reduction. In Denmark, the final heating energy consumption of residential dwellings in 2014 was 45% lower per square meter in comparison to 1975 data but there is no actual energy renovation rate reported (Danish Government

2014; Wittchen & Kragh 2014). In the UK, the country's 26 million dwellings were responsible for 27% of all UK CO_2 in 2008 (Dowson et al. 2012; Utley & Shorrock 2008). According to the yearly housing survey, in the UK, in 2013-2014 the English housing continued to improve but there is no reported renovation rate (English Government 2014). In Germany, the annual renovation rates reported are based on the m^2 of improved elements of the envelopes of the existing stock. Nearly 1% p.a. of residential buildings built up to 1978 added exterior wall insulation (IWU 2010), and the thermal insulation of top floor ceilings is between 1% and 2% p.a. (IWU 2010). Based on a study by the Institut Wohnen und Umwelt (IWU), with data retrieved form a large survey on thermally renovated dwellings, for the period of 2000-2009 the annual renovation rate was 1% (IWU 2010).

Sandberg et al. (2016) use historical statistical data and a dynamic model to compare the renovation rates of dwellings between countries. They estimate the renovation activity resulting from the natural ageing process of the dwelling stock in each country involved. This definition relates to deep energy renovation happening every 40 or 50 years. The basis of the model is a populations' need to reside. The input parameters are the drivers in the system, the historical population development and the development of the number of persons per dwelling (Sandberg et al. 2016). The model includes, in the form of probability functions, the historic demolition and construction rates of each stock and the share of dwellings that are never demolished (e.g. monuments). The main outputs are the construction, demolition and renovation rates. Most scenario analyses and roadmap reports on energy renovations and savings usually calculate high energy renovation rates, for the near future, of 2.5-3%, in order to achieve the goals (BPIE 2011; European Parliament, Council of the European Union 2012; Sandberg et al. 2016). The results of Sandberg et al. indicate renovation rates between 0.6% (for Serbia) to 1.6% (for Great Britain) over 2015. The rates projected for 2030 and 2050 remain quite stable with no sudden positive developments. For the Netherlands the renovation rate is 1.3% over 2015 and 1.4% over 2030 and 2050.

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 (BZK 2014). The energy performance of an existing building is expressed by the EI, which is the figure relating the modelled annual primary energy consumption, the total heated floor area, the heating losses. The EI typically takes values between 0 (extremely good performance) to 4 (extremely bad performance), and is categorised in energy labels (see Section 3.3).

Although there has been a great deal of research on the energy efficiency and consumption of the housing stock, little has been published on the improvement pace. In a previous publication by the authors the pace of several energy improvement measures is reported – with the majority of dwellings having improved the heating system and the glazing (Filippidou et al. 2016). Even though the energy efficiency policies and initiatives implemented in the Netherlands place it at one of the leading positions of the EU residential sector, there is no evidence of a steady reduction of the gas and electricity consumption compared to the 1990 levels (Majcen et al. 2013a). On the contrary, the total energy consumed (gas and electricity) by households increased by 11% from 1990 to 2008 (Majcen et al. 2013a). According to the energy module of the Dutch National Housing Survey ("Woononderzoek Nederland" – WoON), Laurent et al. (2013) stated that the energy performance has increased since 2006. However, it was also found that the energy performance of the non-profit sector was low in comparison to the rest of the residential stock (Tigchelaar & Leidelmeijer 2013). The non-profit sector has a large potential for improvement.

§ 3.3 Data and methods

This study focuses on the non-profit sector, which forms 30% of the Dutch housing stock and is representative in terms of building typology (Stein et al. 2016; Filippidou & Nieboer 2014). Moreover, the non-profit housing sector is more active than the owner-occupied when it comes to energy renovations. A detailed analysis of the energy renovation rates in the non-profit housing will lead to more extensive knowledge on what type of energy renovations are undertaken. Furthermore, we identify the energy efficiency achieved after the energy renovations and we discuss what can be expected in terms of renovation rates in the future.

In this paper, the Dutch EI will be examined through consecutive years in order to calculate the energy renovation pace based on the energy performance of the dwellings. The EI is the official coefficient for measuring the energy efficiency of an existing dwelling, and is often categorised into an energy label, ranging from A to G (see Table 3.1).

The EI is related to the total theoretical energy consumption of a building or a dwelling: Q_{total}. According to the norm of the calculation of the EI, as shown in Equation 3.1, it is corrected taking into account the floor area of the dwelling and the corresponding heat transmission areas.

The EI is calculated as follows:

$$EI = \frac{Q_{total}}{(155*A_{floor}+106*A_{loss}+9560)}$$

Equation 3.1

Q_{total} refers to the modelled characteristic yearly primary energy use of a dwelling, and includes energy for space heating, domestic hot water, additional energy (auxiliary electric energy needed to operate the heating system, i.e., pumps and funs), lighting of communal areas, energy generation by photovoltaic systems, and energy generation by combined heat and power systems under the assumption of a standard use (Filippidou et al. 2016; Visscher et al. 2012; ISSO 2009). A_{floor} refers to the total heated floor area of the dwelling, whereas A_{loss} refers to the transmission heat loss areas in the dwelling, such as a cellar (Filippidou et al. 2016; Visscher et al., 2012; ISSO, 2009). The numerical values in the denominator are: 155 is the factor for the reference energy consumption per m^2 correction, regarding the useful living area (MJ/m^2); 106 is the correction factor compensating for the transmission losses (MJ/m^2); and 9560 is a standard amount of energy used for existing dwellings (MJ) (NEN, 2012).

TABLE 3.1 Connection of Energy Index with the Energy Label in the Dutch context and the primary energy consumption (ISSO, 2009)

ENERGY LABEL	ENERGY INDEX	MEAN THEORETICAL PRIMARY ENERGY CONSUMPTION (KWH/M2/YEAR) (MAJCEN ET AL., 2013)
A (A+, A++)	<1.05	96.8
B	1.06 – 1.3	132.5
C	1.31 - 1.6	161.6
D	1.61 - 2.0	207.8
E	2.01 - 2.4	265.0
F	2.41 - 2.9	328.0
G	> 2.9	426.9

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 pace. In 2008, after the formulation of the Covenant on energy saving targets, Aedes started a monitoring system of the dwellings called Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing (Social Rented Sector Audit and Evaluation of Energy Saving Results) abbreviated SHAERE.

This monitor became operational in 2010. Housing associations report their stock to Aedes at the beginning of each calendar year accounting for the previous year (e.g., in January 2014 reporting for 2013) (Aedes 2015). They report the energy status of their whole dwelling stock, every year, using the Vabi Assets software (Tigchelaar 2014), whose basis is the Dutch energy labelling methodology (ISSO 2009). As a result, SHAERE consists of the actual characteristics of all dwellings of the participating housing associations at the end of each calendar year. 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. We connect each record to the specific dwelling, it refers to, based on an encrypted identifier variable (dwelling ID) that consists of the dwelling's post code, address, number and possible number addition. It is a time series database including a maximum of five records per dwelling – 2010, 2011, 2012, 2013 and 2014. Table 3.2 shows an example of the structure of the database connecting the dwelling ID with the EI variable. In the same manner all available variables are connected to each dwelling based on the ID.

TABLE 3.2 Example of the structure of SHAERE (variables dwelling ID and EI)

DWELLING ID	EI.2010	EI.2011	EI.2012	EI.2013	EI.2014
#1	1.1	1.1	1.1	1.1	0.9
#2	2.7	2.3	-	2.3	2.3
#3	-	-	3.1	-	3.1
…	…	…	…	…	…

The database includes data from 2010, 2011, 2012, 2013 and 2014, on the performance of the stock in the form of energy certificates. The data comprise of physical characteristics (thermal transmittance [U-value] and 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 and more (Filippidou et al. 2016). The variables are categorized per dwelling. A considerable part of the non-profit housing stock is included in SHAERE. However, the number of homes differs per year, as not all dwellings are reported every year (e.g. one can have 2 records whereas another one can have all five). Table 3.3 presents the exact numbers.

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TABLE 3.3 Number of dwellings reported in SHAERE per year

YEAR OF REPORTING	AMOUNT OF INDIVIDUAL DWELLINGS REPORTED	PERCENTAGE OF THE TOTAL NON-PROFIT 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%

This study focuses on the dwellings that have been reported more than once (i.e. where data have been inputted by the housing associations in repeated years) in order to pinpoint and to study the EI each year. We use longitudinal data to observe the changes of the EI of the same dwellings. We observe whether or not the inputted data have changed from 2010 to 2014 and, in section 4.3, we also analyse the data per year 2010 - 2011, 2011 - 2012, 2012 - 2013 and 2013 - 2014.

At the beginning of every data analysis, extensive data filtering is required. The initial amount of dwellings was 2,151,620. The first step was to exclude the dwellings that were present in the database but bore no information. The second step was to remove potential double cases from the data. When reports with exactly the same address, the same energy index (EI) and reporting year were found, one of the duplicate records was removed. Cases with exactly the same address, the same reporting year, but different EI were also removed, as it is not possible to know which EI was the most recent or correct one. Thus, an amount of 0.25% of the initial records in the database were excluded, this way, from the analysis. Having finished this part of the data filtering, 2,146,014 dwellings with records formed the complete database.

In order to identify and study the energy improvements, we focus on the dwellings that have been reported more than once – meaning that dwellings reported only once had to be removed as their progress cannot be tracked. There were 435,571 unique dwellings with only one report between 2010 and 2014 (20.2% of all records). The amount of 1,716,049 dwellings was analysed.

Essentially, due to the longitudinal nature of the data we have one dataset. In this one, a maximum of 1,716,049 dwellings are present. These dwellings can have two or more reports with a maximum of five (2010, 2011, 2012, 2013 and 2014). In section 4.1, all dwelling records in the period 2010 - 2014 are included because we present the progress of the EI distribution each year. And we assume that, despite not all dwellings being updated each year, the number of dwellings reported each year is high enough to be representative for the non-profit sector. In section 4.2, we only take into account the dwellings that had a record in both 2010 and 2014 to observe the progress in this period (856,252). And in section 4.3, we examine the progress per year – records in both 2010 - 2011 (911,598 dwellings), 2011 - 2012 (868,990 dwellings), 2012 - 2013 (1,132,727 dwellings) and 2013 - 2014 (1,384,831 dwellings).

We determine and examine the energy improvement pace of the social housing stock, observing the whole reported stock for four consecutive years and tracking down the differences in the EI. Due to the fact that the records of existent but also new, to the system, dwellings are added to the database each year, some discrepancies are present. Apart from the double records and missing data that we mentioned above, dwellings with an increasing EI can appear – meaning that the energy performance of a dwelling can deteriorate. In these cases the data are "illogical" since a deterioration is impossible to occur in just one year. Thus, if an increase of the EI was observed over the years, we assume this to be an administrative correction. In these cases, the EI was corrected to the level of the EI before the deterioration occurred, and perceived as no improvement or decrease of the energy performance. As a result, these dwellings are perceived as non-renovated. For 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 shown to be decreasing from 1.9% over 2011 to 0.7% over 2014, as more dwellings were reported. The increase of the EI 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. However, the percentage of dwellings with an increasing EI is very low.

§ 3.4 Results and discussion

This section first presents the energy efficiency status of the non-profit housing sector in the Netherlands, and then goes into the energy renovation pace results between the end of 2010 and the end of 2014.

§ 3.4.1 Energy efficiency state 2010-2014

Figure 3.1 presents the distribution of the energy labels of the non-profit housing stock for four different years (2010 - 2014). In the first column of the graph (A label), the A+ and A++ labels are also include

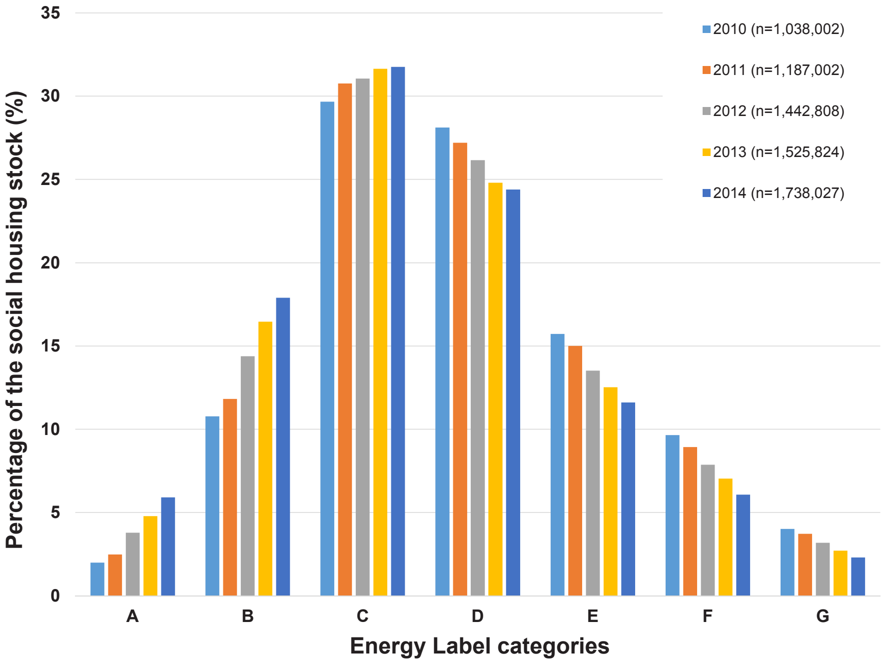

FIGURE 3.1 FDistribution of the energy labels of the non-profit rented housing sector in SHAERE database

It is clear that there is a tendency towards an increasing performance through the years. The labels denoting a relatively inefficient home (D, E, F, and G) show a decline through the years, whereas the 'higher' efficiency labels (A, B, C) show an increase. The same trend in progress is reported, by the Netherlands Enterprise Agency, for the officially registered energy labelled dwellings on a national scale (owner occupied, private rented and non-profit housing) (RVO 2015). The distribution of the labels in SHAERE corresponds to an average EI of 1.71 or an average label D.

In 2010, the average EI was 1.81, in 2011 it was 1.73, in 2012 it was 1.72, in 2013 it was 1.69 and in 2014 it was 1.65 (see Figure 3.2). These averages refer to the non-profit housing stock each year taking into account new construction and demolished dwellings[8]. A linear projection of this decrease reveals that one of the central goals of the national Dutch covenant, namely an average EI of 1.25 in 2020, is not reachable if the improvement rate remains the same. The EI would then be 0.16 too high

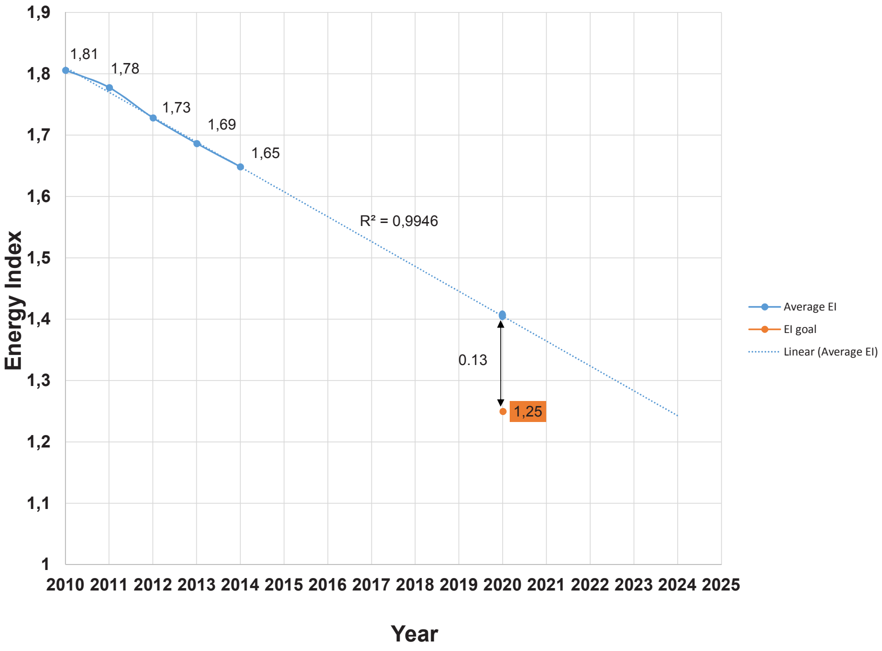

FIGURE 3.2 The Energy Index (EI) development of the non-profit rented housing sector in SHAERE database

§ 3.4.2 Energy improvements 2010 - 2014

This sub-section focuses on the dwellings that were reported both in 2010 and 2014 and highlights the renovated stock. Table 3.4 presents the changes in the energy performance rating between the end of 2010 and the end of 2014. The table is best

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[8] However, the dwellings reported in the following sub-sections (4.2 and 4.3) are the ones that were reported multiple times – new construction and demolition are not included.

read starting by each column, representing the labels in 2010 and the total amount of dwellings in each label category. For example, the amount of dwellings with an energy label B is 87,682. Below the total number of dwellings, we present the distribution of the energy labels in 2010 (in %). The diagonal line of the table represents the non-renovated dwellings (in italic font). Continuing, reading each row, we show the improvement of dwellings in label steps in the period of 2010 to 2014. For example, starting from the first row, the number of A labelled dwellings is unchanged as they cannot move to a "higher" label category. But from the labelled B dwellings (in 2010), 5,453 had their label improved to A in the period until 2014. In the same manner, 2,541 dwellings had their label upgraded from C, in 2010, to A in the period until 2014. The percentage of improvement, at the bottom of Table 3.4, emphasizes the amount of improved dwellings from a specific label category to another. This percentage is relatively high for the most inefficient dwellings, whereas for label category A, the percentage is 0.

TABLE 3.4 Number of dwellings according to energy label in 2010 and 2014 (n=856,252)

		2010							
		A	B	C	D	E	F	G	Labels in 2014
2014	A	*16977*	5453	2541	2426	1584	1538	384	3.6 %
	B		*82229*	44973	15119	7340	4323	1647	18.2 %
	C			*218506*	54042	14293	6090	2171	34.8 %
	D				*173059*	32504	11638	2326	25.6 %
	E					*72670*	16194	4473	10.9 %
	F						*38186*	5621	5.1 %
	G							*14945*	1.7 %
	Total	16977	87682	266020	247646	128391	77969	31657	856252
	Labels in 2010	2.0 %	10.2 %	31.1 %	28.9 %	15.0 %	9.1 %	3.7 %	100 %
	Improvement	0.0 %	0.6 %	5.5 %	8.7 %	6.5 %	4.6 %	1.9 %	28.0 %

Dwellings with an improved label were 28.0% (239,680 of 856,252) in total, while 72.0% (616,572 of 856,252) of the dwelling reports did not change label category (in italic font in Table 3.4).

Figure 3.3 highlights the results of the improved dwellings presented in Table 3.4. The colours in this figure refer to the state at the end of 2010, whereas each of the bars refers to the label at the end of 2014. For example the bar labelled B in 2014 (after renovation), includes 5.2% of G labelled dwellings in 2010 that were updated to label

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B until 2014, 5.5% of F labelled, 5.7% of E labelled, 6.1 of D labelled and 16.9% of C labelled dwellings in 2010 that were updated to B until 2014.

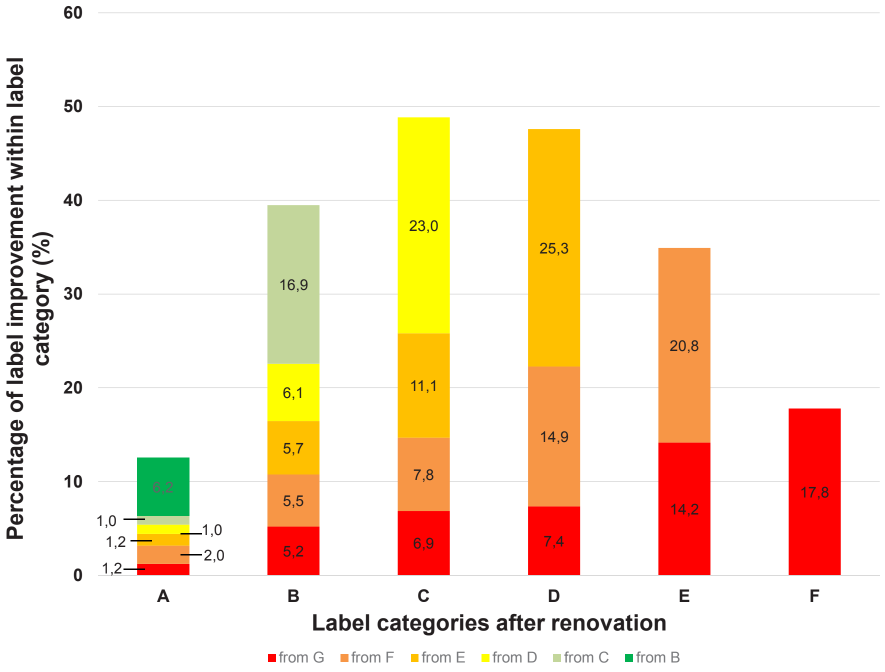

FIGURE 3.3 Improvement of labels of the non-profit rented housing sector from 2010 to 2014

The main message of Figure 3.3 is that most changes are, what we refer to as, 'small label steps'. The majority of dwellings improved by one 'label step' in the period 2010 - 2014. The majority of the dwellings that moved to label A, after renovation, came from a B, C or D label, but not from E, F and G. Similarly, the majority of the E, F and G labels moved to D and E labels. The number of dwellings that improved three or more label categories (e.g., from G to C, F to B, D to A) correspond to, only, 1.4% of the 856,252 dwellings, and form 12.4% of the ones that had their label improved by at least one step (29,829 of the 239,680).

The amount of renovated dwellings – on a national scale – projected to be needed by the Dutch Environmental Assessment Agency in order to reach the EU and national goals of energy efficiency is 170,000 (van den Wijngaart et al. 2014). If we were to allocate 30% – the percentage of non-profit housing of the complete housing stock – of these 170,000 to the non-profit housing stock, the amount of dwellings needed

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would be 51,000. The 29,829 non-profit renovated dwellings, based on our results, are 58.5% of what would be needed from the non-profit housing sector if the simple 30% analogy was applied. However, non-profit dwellings are expected to be renovated at higher rates due to the social values and the concerted actions of the housing associations. Owner-occupied dwellings (55.8% of the housing stock) are estimated to have lower renovation rates and renovated number of dwellings. The deep energy renovations in the non-profit sector are not enough to support and fulfil the goals set by the government.

§ 3.4.2.1 Energy improvements per year

The same analysis was performed on the available data for a year-by-year overview. Table 3.5 reports the changes in 2011 (in comparison to 2010), while Table 3.6, Table 3.7 and Table 3.8 report the changes in 2012, in 2013 and in 2014 respectively. The numbers in italic denote the dwellings of which the label category did not change in the specific period. The tables should be read in the same manner as Table 3.4.

TABLE 3.5 Number of dwellings according to energy label in 2010 and 2011 (n=911,598)

		2010							
		A	B	C	D	E	F	G	Labels in 2011
2011	A	*17890*	1499	119	211	136	136	43	2.2 %
	B		*95343*	11096	2057	1318	746	255	12.2 %
	C			*258190*	20595	3676	1343	461	31.2 %
	D				*230383*	14112	3518	611	27.3 %
	E					*125627*	8796	1672	14.9 %
	F						*75784*	3411	8.7 %
	G							*32570*	3.6 %
	Total	17890	96842	269405	253246	144869	90323	39023	911598
	Labels in 2010	2.0 %	10.6 %	29.6 %	27.8 %	15.9 %	9.9 %	4.3 %	100 %
	Improvement	0.0 %	0.2 %	1.2 %	2.5 %	2.1 %	1.6 %	0.7 %	8.3 %

In 2011, 8.3% of the dwellings (75,811 of 911,598) had improved their energy performance with one or more label categories (the sum of all dwellings above the diagonal in Table 3.5), whereas 91.7% of the reported dwellings did not change label category (835,787 dwellings, the sum of the diagonal cells in Table 3.5).

TABLE 3.6 Number of dwellings according to energy label in 2011 and 2012 (n=868,990)

		2011							
		A	B	C	D	E	F	G	Labels in 2012
2012	A	*20654*	3247	871	590	340	580	204	3.0 %
	B		*99140*	18563	4056	2076	1210	343	14.4 %
	C			*252528*	24885	4795	1400	517	32.7 %
	D				*206733*	15228	4560	664	26.1 %
	E					*104750*	7270	1628	13.1 %
	F						*62750*	2413	7.5 %
	G							*26995*	3.1 %
	Total	20654	102387	271962	236264	127189	77770	32764	868990
	Labels in 2011	2.4 %	11.8 %	31.3 %	27.2 %	14.6 %	8.9 %	3.8 %	100 %
	Improvement	0.0 %	0.4 %	2.2 %	3.4 %	2.6 %	1.7 %	0.7 %	11.0 %

In 2012, we compared the report for a certain dwelling in 2012 with the one in 2011. 95,440 dwellings out of the 868,990, for the 2011 - 2012 (Table 3.6) analysis, which corresponds to 11.0% of the sample, had an improved energy efficiency state. 89.0% (773,550) of the dwellings did not change label category.

TABLE 3.7 Number of dwellings according to energy label in 2012 and 2013 (n=1,132,727)

		2012							
		A	B	C	D	E	F	G	Labels in 2013
2013	A	*41238*	2383	915	908	331	160	59	4.1 %
	B		*162606*	13666	4268	1844	1324	339	16.2 %
	C			*346107*	17511	4294	1392	341	32.6 %
	D				*272051*	10298	3288	504	25.3 %
	E					*132570*	4739	1258	12.2 %
	F						*76465*	1614	6.9 %
	G							*30254*	2.7 %
	Total	41238	164989	360688	294738	149337	87368	34369	1132727
	Labels in 2012	3.6 %	14.6 %	31.8 %	26.0 %	13.2 %	7.7 %	3.0 %	100 %
	Improvement	0.0 %	0.2 %	1.3 %	2.0 %	1.5 %	1.0 %	0.4 %	6.3 %

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In 2013, 6.3% of the dwellings (71,436 of 1,132,727) improved to a ‘higher’ label category, whereas 93.7% of the dwelling reports did not change a label category.

TABLE 3.8 Number of dwellings according to energy label in 2013 and 2014 (n=1,384,831)

		2013							
		A	B	C	D	E	F	G	Labels in 2014
2013	A	*67069*	2671	1226	1513	616	417	168	5.3 %
	B		*223356*	16835	4921	2261	1336	369	18.0 %
	C			*428732*	16598	3252	1419	325	32.5 %
	D				*323942*	10090	3107	571	24.4 %
	E					*153562*	5285	1572	11.6 %
	F						*81439*	1820	6.0 %
	G							*30359*	2.2 %
	Total	67069	226027	446793	346974	169781	93003	35184	1384831
	Labels in 2013	4.8 %	16.3 %	32.3 %	25.1 %	12.3 %	6.7 %	2.5 %	100 %
	Improvement	0.0 %	0.2 %	1.3 %	1.7 %	1.2 %	0.8 %	0.3 %	5.5 %

In 2014, 5.5% of the dwellings (76,372 of 1,384,831) improved by at least one label category, whereas 94.5% of the dwelling reports did not change a label category.

Figure 3.4 depicts the energy renovation rates of the non-profit housing stock when different levels of energy improvements are taken into account. The ‘one label step improvement’ rates (blue bar) 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. The rate of improved dwellings to A or B labels ranges from 1.9% (2011) to 3.7% (2012). The ‘A or B label improvement’ is an overlapping category whereas the rest are distinct categories (when summed up they describe the total improved rate). Once more, it is evident that the majority of energy improvements in the non-profit housing sector refer to one label step change. The polynomial trend lines show an increased activity in all types of renovation in 2012 and a slight decrease in 2013 and 2014.

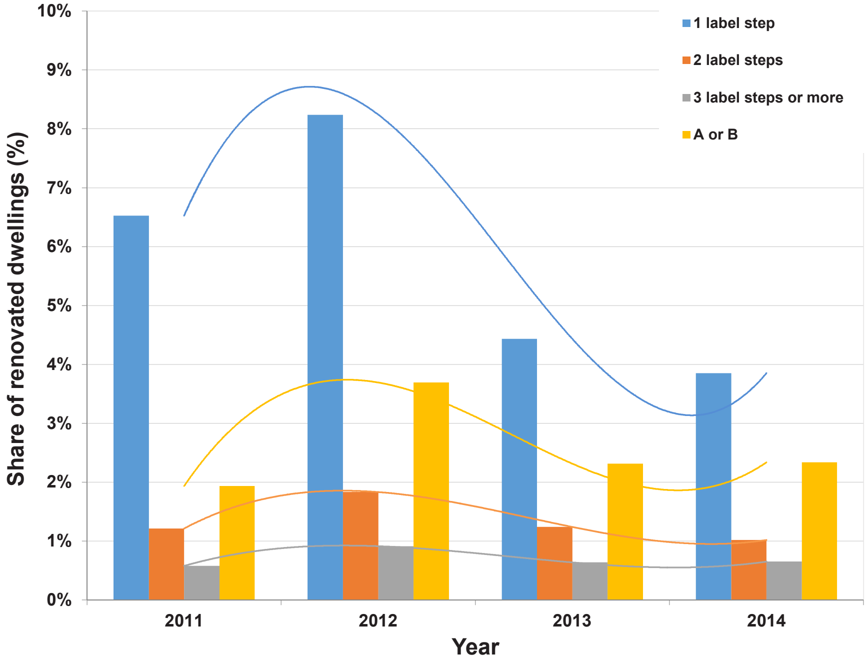

FIGURE 3.4 Energy renovation rates of the non-profit rented housing sector from 2011 to 2014

The data allows us to calculate the deep energy renovation rates (at least three or more label steps) per year. In 2011 the rate was 0.6%, in 2012 it was 0.9%, in 2013 0.6% and in 2014 the rate was 0.6%. The overall deep energy renovation rate for the period 2010 – 2014 was 3.5%. The rates are very low and relatively stable, since 2010, revealing that most of the energy renovations of the social housing stock refer to single improvements or minor renovation works. At the same time, in the Netherlands, the national average annual rate of newly built buildings was 0.6% of the existing residential building stock in 2014 and it has been quite stable since 2010 (Statistics Netherlands 2015; Yücel 2013; Meijer et al. 2009). The demolition rate was 0.15% in 2014 and is also quite stable since 2000 (Statistics Netherlands 2015). These facts highlight the importance of energy renovations and the leading role as an activity in the construction industry in the future.

§ 3.5 Reflection on the SHAERE monitoring system

Big data are used for research in all disciplines the last years. 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 databases, prove to be extremely useful to evaluate policies, project future renovation rates and conclude on best practices for different housing stocks.

As highlighted, one of the strengths of SHAERE is the very large amount of data (2,146,014 dwellings reported at least once from 2010 to 2014), which is more than half of the dwellings of the non-profit housing sector in the Netherlands. The large sample 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. This research was based on the dwellings' physical properties and the reported EI, in order to examine the improvements. Concerning the quality of the 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 for the calculation of the EI 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 Public Housing, for the official energy labels database of the Netherlands, reported that in a sample of 120 labels issued in 2009, 60.8% of the inspected labelled dwellings had an EI that deviated more than 8% (Majcen et al. 2013a; VROM-Inspectie 2009). In 2010, only 26.7% had a different EI (VROM-Inspectie 2010) and in 2011, 16.7% of labels deviated more than 8% in their EI (VROM-Inspectie 2011). In 2013, the inspection was carried out only for office buildings. Hence, there seems to be a trend of improvement, although the studied samples are small (Majcen et al., 2013a). Further research is required to determine the amount of wrongly reported EI values of dwellings. We recommend that input methods be tested and validated in future monitoring systems.

In SHAERE, data with regard to a new reference date are 'simply' added as new records to the existing dataset, meaning that the database must first be restructured to connect the information about a dwelling with regard to several reference dates (Stein et al. 2016; Filippidou & Nieboer 2014). This is a time-consuming yearly procedure. The situation is exacerbated by the fact that, until 2014, individual dwellings did not have an own ID, by which data regarding several reference dates could be coupled (Stein et al., 2016 Filippidou & Nieboer 2014). Until then this was done by creating an encrypted ID variable based on address information (postal codes, street numbers and possible extensions), but although the Dutch postal codes are very refined (on sub-street level), this method is still less reliable than an individual ID. As a result, in future monitoring systems we recommend the use of an ID for the dwellings from the beginning of the system.

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). A pilot would have to be carried out to check this and its applicability.

§ 3.6 Conclusions and policy implications

The main objective of this study was to determine the energy renovation pace in the Dutch non-profit housing sector over the years 2010 - 2014. We presented an analysis of the trends of the energy improvement pace between these years, for both the whole period and also per year. 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.

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. Even though 28.0% of the dwellings have improved (towards a 'higher' energy label category), 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. In the 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 2, 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.

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.

Further research is recommended on the specific measures that have taken place since 2010, and their subsequent impact on the actual energy consumption. As previous research has shown (Guerra Santin et al. 2009; Majcen et al. 2013a, 2013b) it is crucial to study the impact of the energy improvements of the housing stock on the actual energy consumption of the households in the dwellings. 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 actual energy consumption on the other.

Lastly, the use of dynamic monitoring systems consisting of time series big data, like SHAERE, are very effective and suitable for research performed on the topic of energy

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renovations. They can be used to evaluate existing policies and improve future plans. They can also be coupled with other databases, for example actual energy consumption databases, to study the impact of renovations and if the energy consumption decreases.

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4 Energy efficiency measures implemented in the Dutch non-profit housing sector

Note:
The existing housing stock plays a major role in meeting the energy efficiency targets set in EU member states such as the Netherlands. In Chapter 3, 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. The goal of this chapter is to examine the energy efficiency measures currently applied in the sector and their effects on energy performance. We establish a method based on statistical modeling and data analysis of physical properties regarding the energy efficiency, general characteristics and energy performance of 757,614 households. As a result, we provide insight into the energy efficiency measures applied to the existing residential stock. 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. The results show that the goals for this sector will be hard to achieve if the same strategy for renovation is followed.

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Abstract

The existing housing stock plays a major role in meeting the energy efficiency targets set in EU member states such as the Netherlands. The non-profit housing sector in this country dominates the housing market as it represents 31% of the total housing stock. The focus of this paper is to examine the energy efficiency measures that are currently applied in this sector and their effects on the energy performance. The information necessary for the research is drawn from a monitoring system that contains data about the physical state and the energy performance of more than 1.5 million dwellings in the sector. The method followed is based on the statistical modeling and data analysis of physical properties regarding energy efficiency, general dwellings' characteristics and energy performance of 757,614 households. The outcomes of this research provide insight in the energy efficiency measures applied to the existing residential stock. Most of the changes regard the heating and domestic hot water (DHW) systems, and the glazing. The rest of the building envelope elements are not improved at the same frequency. The results show that the goals for this sector will be hard to achieve if the same strategy for renovation is followed.

§ 4.1 Introduction

Worldwide, the residential sector consumes an amount of energy that varies between 16% and 50% of the total , depending on the country (Mata et al. 2010b). Existing buildings account for approximately 40% of the energy consumption in the European Union and are responsible for 30% of the CO2 emissions (Kemeny 2002). The existing housing sector is already playing an important role towards achieving the energy efficiency targets in the European Union (EU) (SER 2013; Ürge-Vorsatz 2007). A large part of this energy consumption comes from the residential sector, as dwellings consume 30% of the energy of the total building stock on average in the EU (Itard and Meijer 2009). This study focuses on the existing housing stock in Europe and specifically the Netherlands. Based on 2009 data, households consume 425 PJ annually, in the Netherlands (Statistics Netherlands 2012).

Existing buildings will dominate the housing stock for the next 50 years based on their life cycle; in the Netherlands the annual rate of newly built buildings is 0.6 of the existing residential building stock in 2014 (Meijer et al. 2009; TNO 2009; Statistics Netherlands 2015).Energy renovations in existing dwellings offer unique opportunities for reducing the energy consumption and greenhouse gas emissions on a national scale in the Netherlands but also on a European and global level. Although there have been initiatives for energy renovations of dwellings in the Netherlands, the assessment and monitoring of these renovations has been lacking. Monitoring the energy improvements of the existing housing stock is necessary and can provide valuable information concerning the technical characteristics and the future potential of the measures applied. This paper investigates what the energy improvement measures in the Dutch non-profit housing sector are over the last years and how they impact the energy performance of the dwellings.

§ 4.1.1 Energy efficiency measures and interpretations of energy renovations

Several measures and energy efficiency policies have been applied both on a European and a national level. In 2008, the Netherlands implemented the EU Energy Performance of Buildings Directive (EPBD). Under this directive, all member states must establish and apply minimum energy performance requirements for new and existing buildings, ensure the certification of building energy performance and require the regular inspection of boilers and air-conditioning systems in buildings (Beuken 2012). The Dutch energy performance measurement system, based on the 'Decree on Energy Performance of Buildings' (Besluit energieprestatie gebouwen – BEG) and the 'Regulation on Energy Performance of Buildings' (Regeling energieprestatie gebouwen – REG), was introduced in 2008. The energy performance of a building is expressed by the Energy Index (EI), which is a figure ranging from ≤0.5 (extremely good performance) to >2.9 (extremely bad performance). The EI is calculated on the basis of the total primary energy demand (Q_{total}). The calculation method of the EI is described in NEN 7120 (published by the Dutch Standardisation Institute) and in ISSO publication 82.3 – ISSO, The Dutch Building Services Knowledge Centre (ISSO 2009). Based on the EI an energy label is assigned to the dwellings. The primary goal of the energy labels is to provide occupants and homeowners with information on the thermal quality of their dwellings. In addition, the theoretical energy use of the dwelling is also mentioned on all Dutch labels issued after January 2010, expressed in kWh of electricity, m3 of gas and GJ of heat, for the dwellings with district heating (Majcen et al. 2013).

The EI is calculated as follows:

$$EI = \frac{Q_{total}}{(155*A_{floor}+106*A_{loss}+9560)}$$

Equation 4.1

The EI is related to the total theoretical energy consumption of a building or a dwelling Q_{total} (MJ), in the nominator, and corrections applied (based on m^2), in the denominator. According to the norm of the calculation, as shown in Equation 4.1, the EI is corrected taking into account the floor area of the dwelling and the corresponding heat transmission areas in order not to disadvantage larger dwellings and those that have greater part of envelope areas adjoined to unheated spaces.

Q_{total} is the modelled characteristic yearly primary energy use of a dwelling adding up the energy for space heating, domestic hot water, additional energy (auxiliary electric energy needed to operate the heating system such as pumps and funs), lighting of communal areas and subtracting the energy generation by photovoltaic systems and/or energy generation by combined heat and power systems assuming a standard use as shown in Equation 4.2 (ISSO 2009). It is possible that the photovoltaic systems contribution is greater than the consumption of the rest of the systems and as a result the Q_{total} can be negative (ISSO 2009). A_{floor} refers to the total heated floor area of the dwelling whereas A_{loss} refers to the transmission heat loss areas in the dwelling such as a cellar (Visscher et al. 2012; ISSO 2009).

$$Q_{total} = Q_{space\ heating} + Q_{water\ heating} + Q_{aux.energy} + Q_{lighting} - Q_{pv} - Q_{cogeneration}$$

Equation 4.2

The Energy Label is based on the calculation of the EI (see Table 4.1). Table 4.1 also depicts the connection of the EI to the energy label and the mean actual primary energy consumption per label category based on a research performed on 200,000 Dutch dwellings (Majcen et al. 2013), since there is no direct connection of the EI and the theoretical energy consumption. Since January 1 2015 the calculation of the EI has changed in the Netherlands and is based on a point system . However, in this study we use the existing calculation method of the EI. This choice is based on the fact that all available data were collected before January 2015, when the new calculation method was not yet in effect. According to the new method for the EI calculation, the impact on the dwellings based on their typology would be different (distinction between single- and multi-family dwellings) (ISSO 2014). In a first sample of 27,500 dwellings, 60% of them maintained the same EI and 34% of them acquired a better or worse EI (ISSO 2014). In addition, the renovation year plays a major role in the new EI and other details that are more precisely calculated. Instead of a number, that is the case with the old method, the dwellings are characterized by a score of points for their energy performance that corresponds to an energy label after the registration to the Netherlands Enterprise Agency (RVO) (ISSO 2014).

TABLE 4.1 Connection of Energy Index with the Energy Label in the Dutch context

ENERGY LABEL	ENERGY INDEX	MEAN ACTUAL PRIMARY ENERGY CONSUMPTION (KWH/M2/YEAR) (MAJCEN ET AL. 2013)
A (A+, A++)	<1.05	138.48
B	1.06 – 1.3	162.08
C	1.31 - 1.6	174.27
D	1.61 - 2.0	195.60
E	2.01 - 2.4	211.55
F	2.41 - 2.9	223.83
G	> 2.9	232.10

In the context of improving the energy efficiency of the housing stock, the term ‘renovation’ is often used. However, there is no clear definition of what an energy renovation is on a global, European or national level. On top of that, there is no definition of the (amount of) improvements that a renovation should include in order to be called like this. For the latter, the European definition refers to either the area that is renovated or the cost of the renovation. A “major renovation” in the EPBD means the renovation of a building where (The European Parliament and the Council 2010):

(a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated; or

(b) more than 25% of the surface of the building envelope undergoes renovation.

This definition does not describe what are the measures that ensure a nearly zero energy consumption of the refurbished dwellings, but rather sets out under what circumstances an energy efficiency renovation should be undertaken. On the national level the situation is similar. Until now, most of the policy measures applied refer to the reduction of the energy consumption and the reduction of specific indicators such as the EI (BZK 2014), but there are no guidelines or definitions of an energy renovation. According to the national plans for the nearly Zero-Energy Buildings (nZEB) implementation in the Netherlands, the definition of large-scale renovations will be developed in more detail in the Building Decree Regulation.

However, this has not been realized yet (NPNZEB_NL 2013). For the aforementioned reasons, in this paper the energy efficiency measures applied on the social housing stock of the Netherlands are going to be identified through individual changes of the dwellings' physical characteristics. We examine every measure individually and then we investigate the number of measures applied in each dwelling. Moreover, we define the energy renovation pace as the amount of dwellings with an upgraded energy performance (at least one energy label step, e.g., from D label to C label) in a specific amount of time (e.g., one year).

§ 4.1.2 Progress in energy efficiency in the non-profit housing sector

Housing tenures differ across Europe and there is no common definition for the non-profit housing sector. However, three common elements are present across European non-profit housing sectors: a mission of general interest, offering affordable housing for the low-income population and the realization of specific targets defined in terms of socio-economic status or the presence of vulnerabilities (Braga and Palvarini 2013).

In the Netherlands, the non-profit housing sector comprises 2.2 million homes, which is 31% of the total housing market (BZK 2013). This is a unique situation as the Netherlands have the highest percentage of non-profit housing in the European Union. The non-profit housing organizations have several goals and criteria to fulfil. Energy savings and sustainability are high on their agenda, especially since 2008 (Aedes

2013). According to the Energy Saving Covenant for the Rental Sector ("Convenant Energiebesparing Huursector"), the current aim of the social housing sector is to achieve an average EI of 1.25 by the end of 2020 (BZK 2012), which is within the bands of label B. The Covenant was signed by, among other stakeholders, Aedes (the umbrella organisation of housing associations), the national tenants' union and the national government. The goal of the agreement means an energy saving of 33% on the theoretical/predicted energy consumption in the period of 2008 to 2021 (CECODHAS Housing Europe 2012). In order to better regulate this subsidised scheme, the Dutch government stated recently that, for the non-profit housing sector, funding from the government will only be provided to the housing associations if they raise the dwelling's energy label by at least three energy label levels (e.g. from D label to A, or from G label to D) (BZK 2014). In 2013 the average EI of the sector was 1.69. At the current rate of energy renovation, in this case the improvement by one label step, which has a mean value of 4% for the last three years, it does not appear that the Covenant's aims will be achieved by the end of 2020 (Filippidou et al. 2014; Majcen et al. 2014, Tigchelaar 2014). The mean value of 4% derives from the turnover of 1,537,554 dwellings in the period 2010-2013 with an improvement of one label step (Filippidou et al. 2014). This rate is considered to be high in comparison with other building stocks. However, it refers to the non-profit housing stock of the Netherlands that acts collectively and has promised to delivered an average EI 1.25, equivalent to an energy label B, by the end of 2020. In addition, the renovation activity measured is considered to be at least one label step improvement.

In a report about the 2012 version of the Energy module of the Dutch national housing survey (Woononderzoek Nederland – WoON), Laurent et al. (2013) state that since 2006 the energy performance increased. However, it was also found that, the energy performance in the non-profit sector was low in comparison to the rest of the residential stock (Tigchelaar and Leidelmeijer 2013). The non-profit sector, therefore, has a large potential for improvement. In addition, Aedes, reports on the progress of the non-profit housing sector each year. In 2014, based on 2013 data and taking into account 60% of the stock, an increase of the energy performance was highlighted in 2013 compared to 2012, 2011 and 2010 data (Aedes 2014). In this report the mean value of the EI is presented along with the energy labels, energy systems and insulation levels distribution. Aedes reported that in 2013 6.2% of the dwellings have had an improvement of the EI. At the same time, the fact of a 4% improvement of the energy performance of the non-profit housing sector is supported (Filippidou et al., 2014; Majcen et al., 2014). Concluding, many measures towards achieving energy efficiency in the non-profit sector in the Netherlands have been realized but, the pace of change is too slow to reach the 2020 energy efficiency goals (Filippidou et al. 2014).

In this paper we identify the specific energy efficiency measures that have been realised, between 2010 and 2013. In order to be able to assess the effect on the energy performance of the measures applied in the non-profit housing sector, an analysis of the changes in all of the energy systems and envelope elements of the dwellings is presented. In the next section the data and methods are presented, followed by the results in the third section and the conclusions and recommendations in the fourth.

§ 4.2 Data and methods

§ 4.2.1 SHAERE database

A complete and detailed assessment of the current efficiency state of the social housing stock in the Netherlands is necessary in order to research the energy savings measures and their effectiveness on the energy performance of the dwellings. In 2008, after the formulation of the earlier covenant on energy saving, Aedes started a monitoring system of the non-profit dwellings called SHAERE ("Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing" – in English: Social Rental 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 social housing sector. It is a collective database in which the majority of the housing associations participate. The database is filled with the software program 'EPA-W', which most of the housing associations (more than three quarters) use for the management of their stock (Majcen et al. 2014).

Since 2010, when the database became operational, housing associations report their stock to Aedes in the beginning of each calendar year, accounting for the previous year (e.g. in January 2014 for 2013). They report the status of their whole dwelling stock at the end of the preceding year.

The database contains the necessary information, per home, to calculate an EI. The data imported include physical characteristics and installations of the dwellings. The data include the U values (thermal transmittance, $W/m^2{\cdot}K$) and Rc-values (measure of thermal resistance, m2·K/W) (ASHRAE 2009) of the envelope elements, estimated energy consumption, expected CO2 emissions, and the EI. Data for 1,448,266 dwellings were available for 2013, representing 60% of the total non-profit housing stock (see Table 4.2).

TABLE 4.2 Number of dwellings reported in SHAERE per year

YEAR OF REPORTING	FREQUENCY	PERCENTAGE OF THE TOTAL NON-PROFIT 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%

This study presents a first analysis of the trends of the energy improvement measures in the social housing stock between 2010 and 2013 in the Netherlands. First, the sample is described and then, based on this description, the method of analysis is presented.

§ 4.2.2 Methods

This study focuses on the dwellings that have been reported more than once (i.e. where data have been inputted by the housing associations in repeated years) in order to pinpoint and to study the energy improvements performed each year). We use longitudinal data to observe the changes of the energy performance of the same dwellings. We observe whether or not the inputted data have changed from 2010 to 2013. We start with the changes in the EI.

Extensive data filtering was required before the start of the data analysis. First, the records for dwellings that were present in the database but contained no information had to be excluded from the analysis. Second, we removed all the potential duplicate cases from the dataset. When reports with exactly the same address, the same EI and reporting year were found, one of the duplicated records was removed. Third, we removed cases with exactly the same address and same reporting year, but different EIs, because it was not possible to select the most recent or correct one.

The following step was to remove the cases lacking data regarding 2010 or 2013. After the filtering, 757,614 dwellings remained, being the number of dwellings reported in both 2010 and 2013. If a deterioration of the EI was observed, we assume this to be an administrative correction. In these cases, the EI for the year before the change has been corrected to the level of the EI afterwards.

§ 4.3 Results

This section presents the results of the analysis. Every table represents a measure to improve the energy performance of the respective dwelling. In total seven measures are taken into account. First, the average EI of the 757,614 dwellings participating in the analysis was calculated (see Figure 4.1).

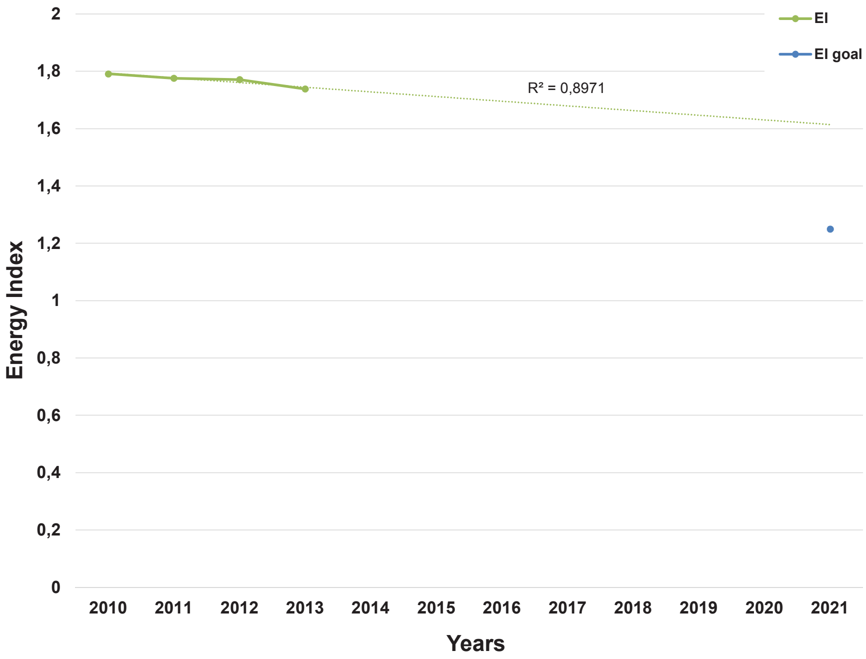

FIGURE 4.1 Development of the EI in the Dutch non-profit housing sector between 2010 and 2013

In 2010 the mean value of the EI was 1.79 and in 2013 1.74 – a drop of 0.05 over three years. The data are normally distributed and the function of the EI for 2010-2013 is approximately linear. As a result , Figure 4.1 depicts the mean EI value for 2010, 2011, 2012, 2013 and the extrapolation of the mean value of the EI if the same pace of energy renovations were to continue. The graph essentially depicts what the energy performance of the non-profit housing stock in the Netherlands would look like if the same type and amount of measures are maintained. The current EI improvement pace is not fast enough to reach the goals. This linear extrapolation indicates that the target for the EI in the national Covenant (namely 1.25) will not be reached by the end of 2020 if this pace continues: the gap would be 0.35, which is nearly the width of an average energy label band. Based on the development of the EI within this period more and "major" energy renovations need to be realized.

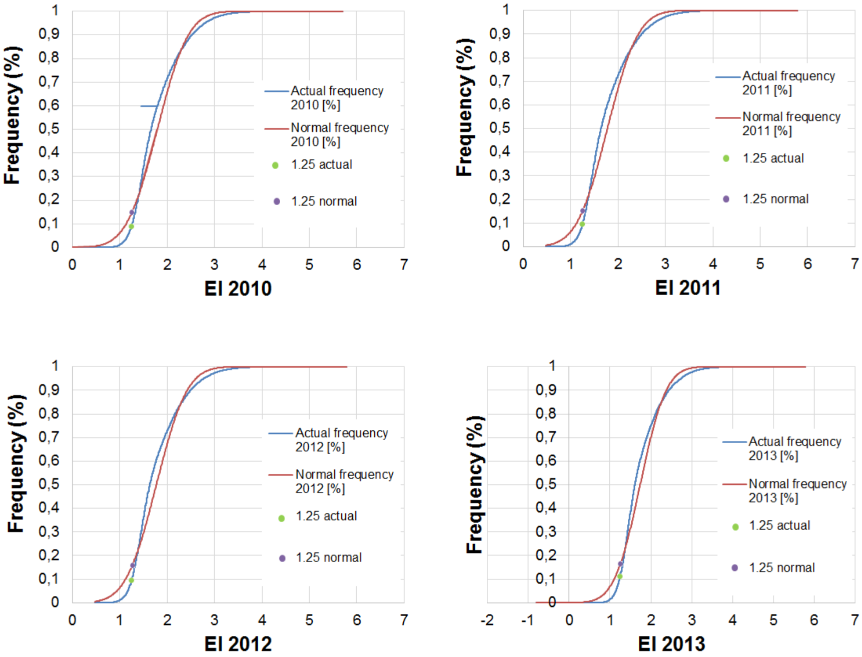

FIGURE 4.2 Evolution of the cumulative distribution function of the EI 2010-2013

In addition to the linear extrapolation of the EI, we also calculate and depict the cumulative distribution function of the EI. In Figure 4.2, starting from the top left, the 2010 cumulative distribution is depicted and continuing to the right and the bottom part of the figure the 2011, 2012 and 2013 functions are shown. Two interesting phenomena are taking place in Figure 4.2. First, we observe that the spread of the EI values does not change when it comes to the larger EI's. This means that the worse performing dwellings do not get renovated or very small changes are only applied.

Second, in the 2013 part (bottom right) for the first time negative values of the EI appear. This on the other hand, depicts dwellings that produce more energy than they consume based on Equation 4.1 and 4.2. The actual probability of a dwelling having an EI of 1.25 in 2010 is 8.8%, in 2011 the probability is 9.1%, in 2012 9.2% and in 2013 the probability rises to 10.9%. The normal probabilities follow a similar pattern (14.5% in 2010, 15.0% in 2011, 15.2% in 2012 and 16.3% in 2013). In order to better understand the improvements leading to this development of the EI, we present the energy efficiency measures of the dwellings reported in 2010 and 2013. Looking at a period of three years reveals the kind of measures that the housing associations choose and which building characteristic is changing the most. In addition we examine the impact of these measures on the EI of the dwellings.

§ 4.3.1 Energy efficiency measures applied in 2010-2013

In this sub-section we present and further examine the actual measures applied between 2010 and 2013. We start with the energy systems and we move on to the building envelope characteristics. Table 4.3 through Table 4.9 present the outcome of the analysis comparing the state of the dwellings in 2010 and in 2013 and thus following the changes in all variables (installation systems, building envelope elements and the EI). On Table 4.3 to Table 4.9 the blank cells represent changes that are impossible (e.g. from a condensing boiler to a gas stove) to happen. They are considered, as administrative corrections and as a result are left blank.

Table 4.3 depicts the change in the heating system in the dwellings that were reported in 2010 and in 2013. The table is best read from the horizontal line where the situation of the first year of report is shown, in this case 2010, to the corresponding vertical side where the situation in 2013 is depicted. In both reference years the heating systems are the same, ranging from a gas stove to a high efficiency boiler to a µCHP system. The diagonal line represents the dwellings whose heating system remained the same these three years.

The number of dwellings with a reported heating system is 757,614. Observing the diagonal of the table, we highlight that the dwellings having a stove (electric or running on gas/oil), high efficiency boilers or heat pumps are the ones that remain the most stable. On the other hand, dwellings with heating systems as the “conventional” boiler with efficiency less than 0.80 tend to change more. 44.6% of the “conventional” boilers were changed in the 3 years of investigation (19,283 in 2010 to 11,044 in 2013).

TABLE 4.3 Percentage of dwellings by type heating system in 2010 compared to 2013 (n=757,614)

		2010									
		Gas/oil stove	Electric stove	"Conventional" boiler (η<0.80)	Improved non-condensing boiler (η= 0.80-0.90)	Condensing boiler (η=0.90-0.925)	Condensing boiler (η=0.925-0.95)	Condensing boiler (η≥ 0.95)	Heat pump	µCHP	Total
2013	Gas/oil stove	72.5							0.0	0.0	21055
	Electric stove	0.0	96.6						0.0	0.0	257
	"Conventional" boiler (η<0.80)	1.2	0.8	55.4							11044
	Improved non-condensing boiler (η= 0.80-0.90)	2.0	0.0	8.9	61.3					6.4	136827
	Condensing boiler (η=0.90-0.925)	0.3	0.0	1.2	0.9	61.5			0.2	0.2	29758
	Condensing boiler (η=0.925-0.95)	0.1	0.0	0.1	0.3	0.8	64.1		0.0	7.5	17309
	Condensing boiler (η≥0.95)	23.7	2.7	33.1	35.6	34.9	34.0	99.3	0.4	3.1	487801
	Heat pump	0.1	0.0	1.3	1.8	2.7	1.9	0.5	99.4		50548
	µCHP	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.0	82.7	3015
	Total	29025	262	19283	219210	44644	25092	374553	43038	2507	757614
	Percentage change	27.5	3.4	44.6	38.7	38.5	35.9	0.7	0.6	17.3	17.26

Note: A blank cell means that either no changes took place or that observed changes are removed, as they are considered administrative corrections. A zero percentage means that no or almost no dwellings changed their heating system.

The table shows that the majority of the dwellings in 2013 have a condensing high efficiency boiler (η≥0.95) and the trend is that the biggest movements from the rest of the energy systems are happening towards the direction of the high efficiency boilers (η ≥0.95), which for the time is the most energy efficient heating system. The largest change is happening from the condensing boilers of 0.90-0.925 and 0.925-0.95 efficiency, where for each category 35% of the dwellings changed their energy system to a condensing high efficiency boiler (η≥0.95). The movement towards a more sustainable energy system such as a heat pump or a µCHP is still not obvious as the percentages range from 0% to 2.7%. On the other hand the local electric stoves are not a frequent choice in the social housing stock. The local gas stoves are changed and in their place high efficiency condensing boilers (η≥0.95) are installed. The total percentage of change of the type of heating system is 17.6% meaning 1 in 5 heating systems is changing in a three year period. On average 5.7% of heating systems are improved per year. The replacement of the heating system is considered as the low-hanging fruit of energy efficiency measures and often, in the Netherlands, is performed under maintenance plans. The older, less efficient boilers are being phased out in a rather short period. In addition, Table 4.3 does not provide any information on how old the heating systems are. As a result, we observe a relatively high turnover in the non-profit housing stock of the Netherlands compared to other housing stocks.

Table 4.4 shows the changes of the domestic hot water system (DHW) in the dwellings that were reported in 2010 and in 2013. As with Table 4.3, the table is best read from the horizontal line where the situation of the first year of report is shown, to the corresponding vertical side where the situation in 2013 is depicted. In both reference years the DHW systems are the same ranging from a tankless gas water heater to a high efficiency combi-boiler to a µCHP system. It is important to highlight at this point that the heating systems and the DHW systems are often combined in the Netherlands. As a result, in many dwellings there is one main system that provides heat for both “sub-systems”. The diagonal line, represents the dwellings whose heating system remained the same during these years.

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TABLE 4.4 Percentage of dwellings by type of domestic hot water system in 2013 compared to 2010 (n=757,614)

		2010									
		Tankless gas water heater	Gas boiler	Electric boiler (<20L)	Conventional” combi-boiler (η<0.80)	Improved non-condensing combi-boiler (η=0.80-0.90)	Condensing combi-boiler (η=0.90-0.95)	District heating	Heat pump	µCHP	Total
2013	Tankless gas water heater	64.1									51381
	Gas boiler	0.3	66.9	3.2	0.2	0.1	0.1	0.1	0.5	0.0	14787
	Electric boiler (<20L)	3.4	3.4	84.2	2.6	0.2	0.2	0.3	0.1	0.0	37400
	Conventional”-combi-boiler” (η<0.80)	0.4	0.3	0.0	59.1			2.8	6.1	0.0	6740
	Improved non-condensing combi-boiler (η=0.80-0.90)	4.3	6.7	2.2	3.5	62.0		0.6	0.3	0.0	117030
	Condensing combi-boiler (η=0.90-0.95)	24.6	14.0	5.6	31.3	36.6	99.4	1.9	20.4	0.0	489394
	District heating	2.2	8.7	4.7	3.3	1.1	0.2	94.2	2.4	0.0	38295
	Heat pump	0.6	0.0	0.0	0.0	0.0	0.2	0.0	70.3	0.0	2585
	µCHP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
	Total	80131	18931	38789	9024	178973	397984	31807	1975	0	757614
	Percentage change	35.9	33.1	15.8	40.9	38.0	0.6	5.8	29.7	0.0	15.5

The number of dwellings with a reported hot water heating system is also 757,614. Starting with the diagonal of Table 4.4, the dwellings that have an electric boiler, a high efficiency boiler or district heating mostly keep this type of generating hot water. Among these types, district heating is not very common. It is used in some cities only for DHW and occasionally for the heating system as the output temperatures are typically not very high.

Conversely, dwellings with DHW systems as the “conventional” or “improved” boiler are relatively often replaced by another system. This is in line with Table 4.3, where the heating systems were shown – a similarity that can be explained by the fact that many dwellings have combined systems for heating and DHW. 40.9% of the “conventional” boilers were changed the last 3 years. As with the heating systems, the popularity of high efficiency boilers (η≥0.95) increased considerably.

A remarkable finding is that from the dwellings that had a heat pump in 2010 20.4% changed to a condensing high efficiency boiler (η≥0.95) in 2013. This finding is counter-intuitive since heat pumps are perceived to increase the energy efficiency of a dwelling. An explanation might be that heat pumps have been found too slow in generating hot water, so that a boiler is installed to tackle this issue. The movement towards a more sustainable energy system such as a µCHP or a heat pump is not obvious as the percentages are 0% and 0.6% respectively. On the other hand the tankless gas water heaters, gas boilers and "conventional" low efficiency boilers are decreasing in the social housing stock and in their place mostly high efficiency condensing boilers (η≥0.95) are installed. The percentage of change for the type of DHW system is 15.5%, close to that of the heating system.

Table 4.5 shows the changes of the ventilation systems of the dwellings that were reported in 2010 and in 2013. As with Table 4.3 and Table 4.4, the table is best read from the horizontal line showing the situation in 2010 to the corresponding vertical side where the situation in 2013 is given. In both reference years the ventilation systems are the same ranging from natural ventilation to mechanical supply and exhaust, centralized and decentralised system (categories such as the heat recovery mechanical ventilation are so rare in the Netherlands that are eliminated from the analysis). The diagonal line, as a consequence represents the dwellings whose ventilation system remained the same for three years. In ventilation, there are not many choices for the residential sector. The majority of the dwellings have either natural or mechanical exhaust ventilation systems. Two main trends emerge in Table 4.5. The first one refers to the dwellings that had natural ventilation in 2010 and mechanical exhaust ventilation was placed in 2013 and the second one refers to the opposite. Another small, in percentage, change is the one of a mechanical supply and exhaust central system to a simpler mechanical exhaust system in 2013. Additionally, due to the fact that almost no mechanical supply and exhaust decentralised ventilation systems were present in the non-profit housing stock, this category was merged with the mechanical exhaust and supply central systems. The total percentage of dwellings with a change in the type of ventilation is 8.7%, much lower that the heating and DHW systems.

TABLE 4.5 Percentage of dwellings by type of ventilation system in 2013 compared to 2010 (n=757,614)

	2010				
		Natural	Mechanical exhaust	Mechanical supply and exhaust. (balanced) central or decentralized	Total
2013	Natural	85.6	3.4	0.0	319934
	Mechanical exhaust	14.3	96.4	2.9	435353
	Mechanical supply and exhaust. (balanced) central	0.1	0.2	97.1	2325
	Mechanical supply and exhaust. (balanced) decentralised	0.0	0.0	0.0	2
	Total	357885	398865	864	757614
	Percentages of change	14.4	3.6	2.9	8.7

Table 4.6 refers to the type of windows (glazing and frame). This is one of the most popular energy saving measures. 757,192 dwellings were analysed as some of them did not have the information for both years (2010 and 2013). The categories of the types of windows are based on the U values that were inputted in SHAERE. The categories were created according to the guidelines of the ISSO 82.1 publication (ISSO 2011) to characterise the types of windows based on their thermal transmittance. In order to extract the U values of the windows, we calculated the mean U value of all windows per dwelling. The categories include single glass windows, double glass, HR+ and HR++ glasses and triple insulation glass.

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TABLE 4.6 Percentage of dwellings by type of windows in 2013 compared to 2010 (n=757,192)

		2010					
		Single glass (U≥4.20)	Double glass (2.85≤U<4.20)	HR+ glass (1.95≤U<2.85)	HR++ glass (1.95≤U<2.85)	Triple insulation glass (U<1.75)	Total
2013	Single glass (U≥4.20)	63.8					32442
	Double glass (2.85≤U<4.20)	17.7	90.6				525488
	HR+ glass (1.95≤U<2.85)	5.6	5.1	95.9			89536
	HR++ glass (1.95≤U<2.85)	12.4	4.3	4.0	99.8		106849
	Triple insulation glass (U<1.75)	0.5	0.1	0.0	0.2	100.0	2877
	Total	50837	570368	59819	74063	2105	757192
	Percentage of change	36.2	9.4	4.1	0.2	0.0	9.89

The diagonal shows the dwellings with unchanged windows. The triple insulation windows remain 100% unchanged. On the other hand 36.2% of the single glazing windows have been replaced in 2010-2013. The majority of the dwellings have double glazing, both in 2010 and in 2013. At the same time, 9.4% of the dwellings with double glazed windows in 2010 changed towards better quality windows in 2010-2013. The dwellings having single glass windows in 2010 changed with a percentage of 36.2% towards mainly double and HR++ windows. Only 0.5% of this 36.2% changed to triple insulation glass. The improvement of the glazing is common in the non-profit housing stock of the Netherlands due to the fact that in the country old uninsulated windows are being replaced on a national scale and is one of the low-hanging fruit of energy measures.

Based on the present results for the type of windows but also on the heating and DHW systems, a trend starts to form. The energy efficiency measures taking place in the non-profit housing sector are focused mostly on doing business-as-usual and mainly maintaining the housing stock. Realising more ambitious energy efficiency measures such as installing a µCHP or triple insulation glass proved to be a rarity. The total percentage of change in the type of windows is almost 10%.

Table 4.7 presents the changes in type of wall insulation. Again, based on the ISSO 82.1 publication (ISSO 2011) different insulation categories were created based on the Rc values of the walls. Taking into account the ISSO 82.1 guidelines, we present a range of no-insulation for the dwellings that were built before the 1970's for example, to extra insulation of an nZEB level. The table shows the changes that were big enough to change a category of insulation. From this variable of the building envelope it is clear that the majority of the non-profit building stock is likely to have been built before the 1970s. For that reason we observe that the majority of the dwellings in 2010 have no wall insulation ($R_c \leq 1.36$) whereas for 2013 the majority of dwellings has insulation ($1.36 < R_c \leq 2.86$).

TABLE 4.7 Percentage of dwellings by type of wall insulation in 2013 compared to 2010 (n=751,807)

		2010					
		No-insulation ($R_c \leq 1.36$)	Insulation ($1.36 < R_c \leq 2.86$)	Good insulation $2.86 < R_c \leq 3.86$)	Very good insulation ($3.86 < R_c \leq 5.36$)	Extra insulation ($R_c > 5.36$)	Total
2013	No-insulation ($R_c \leq 1.36$)	88.3					372661
	Insulation ($1.36 < R_c \leq 2.86$)	11.3	98.9				352338
	Good insulation ($2.86 < R_c \leq 3.86$)	0.2	0.9	98.3			22796
	Very good insulation ($3.86 < R_c \leq 5.36$)	0.1	0.2	1.7	100.0		3545
	Extra insulation ($R_c > 5.36$)	0.1	0.0	0.0	0.0	100.0	467
	Total	421959	308162	19326	2281	79	751807
	Percentage of change	11.7	1.1	1.7	0.0	0.0	7.06

The diagonal shows, as in the previously presented tables, the dwellings with unchanged wall insulation. The very good and extra insulation dwellings remain 100% unchanged and then the non-insulated walls are the ones that change. The majority of the non-insulated dwellings change to the next category which is the insulated walls by 11.3% and only 0.2% to well insulated walls or 0.1% to very well insulated walls. The percentage of change for wall insulation is 7.06%.

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TABLE 4.8 Percentage of dwellings by type of roof insulation in 2013 compared to 2010 (n=456,112)

		2010					
		No-insulation ($R_c \leq 0.39$)	Insulation ($0.39 < R_c \leq 0.72$)	Good insulation ($0.72 < R_c \leq 0.89$)	Very good insulation ($0.89 < R_c \leq 4.00$)	Extra insulation ($R_c > 4.00$)	Total
2013	No-insulation ($R_c \leq 0.39$)	81.6					87133
	Insulation ($0.39 < R_c \leq 0.72$)	1.6	80.5				12303
	Good insulation ($0.72 < R_c \leq 0.89$)	1.8	2.7	79.7			29232
	Very good insulation ($0.89 < R_c \leq 4.00$)	13.8	16.5	19.0	99.6		321935
	Extra insulation ($R_c > 4.00$)	1.2	0.3	1.3	0.4	100.0	5509
	Total	106817	13148	33854	299747	2546	456112
	Percentage of change	18.4	19.5	20.3	0.4	0.0	6.64

Table 4.8 depicts the changes in the level of roof insulation of the dwellings. For the roof insulation 456,112 dwellings out of the 757,614 had data for both 2010 and 2013. On the diagonal the unchanged dwellings are present. Again, the very good or extra insulated dwellings regarding their roof remain almost entirely unchanged. The non-insulated, insulated or good insulated dwellings, move by 13.8%, 16.5% and 19% respectively to very good insulation for the roofs. These percentages are quite large compared to the window or the wall insulation. However, the total percentage of roof insulation change is 6.64% and the sample is smaller. As a result, no definitive results can arise.

Last, Table 4.9 presents the changes of the floor insulation in the dwellings. 469,123 dwellings had information for both years.

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TABLE 4.9 Percentage of dwellings by type of floor insulation in 2013 compared to 2010 (n=469,123)

	2010						
		No-insulation ($R_c \leq 0.32$)	Insulation ($0.32<R_c \leq 0.65$)	Good insulation ($0.65<R_c \leq 2.00$)	Very good insulation ($2.00<R_c \leq 3.50$)	Extra insulation ($R_c >3.50$)	Total
2013	No-insulation ($R_c \leq 0.32$)	88.2					225343
	Insulation ($0.32<R_c \leq 0.65$)	3.1	85.9				52592
	Good insulation ($0.65<R_c \leq 2.00$)	4.7	9.7	94.9			114276
	Very good insulation ($2.00<R_c \leq 3.50$)	3.7	4.0	4.7	97.4		67709
	Extra insulation ($R_c >3.50$)	0.3	0.4	0.4	2.6	100.0	9203
	Total	255600	51970	102545	52661	6347	469123
	Percentage of change	11.8	14.1	5.1	2.6	0.0	9.42

The majority of the dwellings both in 2010 and 2013 have no floor insulation. The diagonal shows that few changes in the type of insulation are happening. The categories for the floor insulation are based on the Rc values of thermal transmittance according to ISSO 82.1 (ISSO 2011). Here as well, the very well and extra insulated dwellings remain 100% unchanged. The rest of the categories (non-insulated, insulated and good insulated) move to well or very well insulated floors. The movements of the floor are quite different than that of the walls where only small steps towards less efficient solutions are taking place. The total percentage of change for the floor is 9.42%, higher than the roof insulation 6.64%.

§ 4.3.2 Number of measures applied and their impact on the energy performance

In this sub-section we report the number of changes per dwelling. The data are presented in the form of the total number of dwellings that have performed one energy efficient measure, two measures, three measures or more. Additionally, we also present the dwellings that had no energy efficiency measure applied and treat them as a control group of dwellings. These changes are allocated to the energy installations and the building envelope elements, presented in the results section. In more detail we consider any improvement of the space heating, DHW, and ventilation systems as a measure. That means that if a dwelling changes a condensing high efficiency boiler to a new condensing high efficiency boiler this would not be perceived as a change since it is not affecting the energy efficiency of the dwelling.

When it comes to the insulation changes of the building envelope elements (windows, walls, floors, roofs) as stated in the results, first a classification scheme was created in order to follow the changes. For every element different classifications were created based on the Rc values reported in the ISSO Publication 82.1 (ISSO 2011) and in accordance to the report on exemplary dwellings in the Netherlands from the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, 2010). In this way we follow and report any change towards a different level of insulation. If we were to track the changes only as positive or negative following just the R_c-value number we would not have at this point an indication of the level of insulation today but merely a count of the positive and negative changes.

We realized the method of the total amount of energy improvements per dwelling by following the changes in each of the eight elements reported and summed them up to a final number. Thus, it was possible to track the dwellings that have performed none, one, two, three or more than three energy efficiency measures. We calculated the mean value of the EI of the dwellings in 2010 and then we repeated the same calculation for the mean value of the EI in 2013. Using longitudinal data (times series of 2010, 2011, 2012 and 2013) enabled the calculation of the impact of the energy efficiency improvements on the average EI.

Table 4.10 shows the percentage of dwellings where energy efficient measures were achieved. 64.5% of the dwellings had no change in three years. For the rest 35.5% the majority of them had one measure performed and only 3.0% had more than three measures implemented. In total, 268,577 dwellings had at least one measure realized.

TABLE 4.10 Percentage of dwellings where energy efficiency measures took place from 2010 to 2013 (n=717,614)

NUMBER OF MEASURES	PERCENTAGE OF DWELLINGS *	AVERAGE EI BEFORE MEASURE (S) WERE EXECUTED	AVERAGE EI AFTER MEASURE (S) WERE EXECUTED	CHANGE OF THE ENERGY INDEX
none	64.5% (489,037)	1.75 (D)	1.73 (D)	0.015
one	15.0% (114,000)	1.78 (D)	1.65 (D)	0.127
two	12.7% (96,066)	1.91 (D)	1.65 (D)	0.257
three	4.7% (35,845)	2.07 (E)	1.66 (D)	0.411
more than three	3.0% (22,666)	2.28 (E)	1.54 (C)	0.739
at least one measure	*35.5% (268,577)*	1.87 (D)	1.60 (C)	0.263

**between brackets the number of dwellings is shown*

The right column shows the impact of the measures on the energy efficiency of the dwellings. The impact is presented in the form of the EI. It is clear that the more the energy efficient solutions applied the more the impact is on the EI. The dwellings that had at least one measure realised achieved a decrease of 0.263 of the EI. We calculated the 0.263 decrease of the EI as a weighted average based on the number of dwellings. A label band is around 0.4 wide. This implies that the energy performance of the dwellings that have undergone an improvement in 2013 was ,on average, slightly more than half a label level higher than in 2010.

Further, Table 4.10 shows a positive correlation between the number of measures and the average EI before the measures are executed (third column). This suggests that less energy-efficient homes are regarded as more in need for improvement. After these improvements, the differences between the average EI are remarkably low (fourth column).

§ 4.4 Discussion

The results presented in the previous section 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 physical characteristics examined: An example is the improvement of a boiler of $\eta=0.80$ to a condensing combi-boiler of $\eta=0.90$-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. 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; Laurent et al. 2012; Majcen et al. 2013) 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.

§ 4.5 Conclusions and recommendations

The goal of this study was to identify 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 this article 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. More or deeper energy renovation measures are required in attain this goals.

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Based on our outcomes, the non-profit housing sector should focus more on the energy efficiency of its dwellings through the implementation of carefully planned energy agendas. This way, 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. In cases were municipal support was offered it resulted in the application of more concrete energy renovation plans by the housing associations.

Last, 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. 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 thus 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.

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

Note:
Energy renovations offer unique opportunities to increase the energy efficiency of the built environment; for the existing housing stock, they are the most important solution. In the previous chapter, an analysis of the energy renovations and their impact on the modelled energy performance of the stock was presented. Usually, the energy savings from renovations are based on modelling calculations. However, recent research has shown that the predicted energy consumption differs greatly from the actual consumption. In this chapter, the effectiveness of energy renovations is re-assessed based on actual consumption data. We connect the data from SHAERE 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 to determine the effectiveness of different measures in terms of actual energy savings. The results reveal the actual energy savings of different efficiency measures, highlighting the significance of the actual energy consumption when a renovation is planned or realized.

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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, 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 use 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 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.

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§ 5.1 Introduction

The existing housing sector plays an important role towards achieving the energy efficiency targets worldwide and in the European Union (EU) (European Commission 2016a; 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 38% of the final energy consumption in the European Union (EU), and are responsible for 36% of the CO2 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 (Balaras et al. 2016; Filippidou et al. 2016; D. 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 (Daša Majcen et al. 2016). Previous research (van den Brom et al. 2017; Balaras et al. 2016; D. Majcen et al. 2013; Sunikka-Blank and 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 and highlight the impact of (combinations of) measures on the dwellings' performance. We analyse the energy saving measures (ESMs) realized and their impact on the actual and predicted energy consumption. In the following background section 5.2 we discuss energy renovation concepts and definitions. Section 5.3 focuses on the data and research methods used. In section 5.4 we present the results of the analysis and in section 5.5 we draw conclusions based on the outcomes of the research.

§ 5.2 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.

The energy savings potential of the existing dwellings is large. In the Netherlands, policy measures have been employed since the last quarter of the 20th century, mainly through building decrees. The energy consumption of new buildings has been regulated since 1975 consisting of limits on transmission losses based on insulation values (Boot 2009). In 1995 these limits were expanded to include the national "EPC" (Energy Performance Coefficient) which is a figure expressing the energy performance of a building depending on the energy consumed for space heating, hot water, lighting, ventilation, humidification and cooling. The energy performance of the existing housing stock is being regulated through energy labels (A to G – most efficient to least efficient), since 2008, when the EPBD was implemented in the Netherlands. The average energy label in 2015 was C (RVO 2015). As the years pass, more dwellings adopt an energy label and thus far 2.9 million have one. The majority of these dwellings belong to the rental sector. Figure 5.1 presents the distribution of the energy labels of the non-profit housing stock for four different years (2010 - 2014). In the first column of the graph (A label), the A+ and A++ labels are also included. It is clear that there is a tendency towards an increasing performance through the years. The labels denoting a relatively inefficient home (D, E, F, and G) show a decline through the years, whereas the 'higher' efficiency labels (A, B, C) show an increase.

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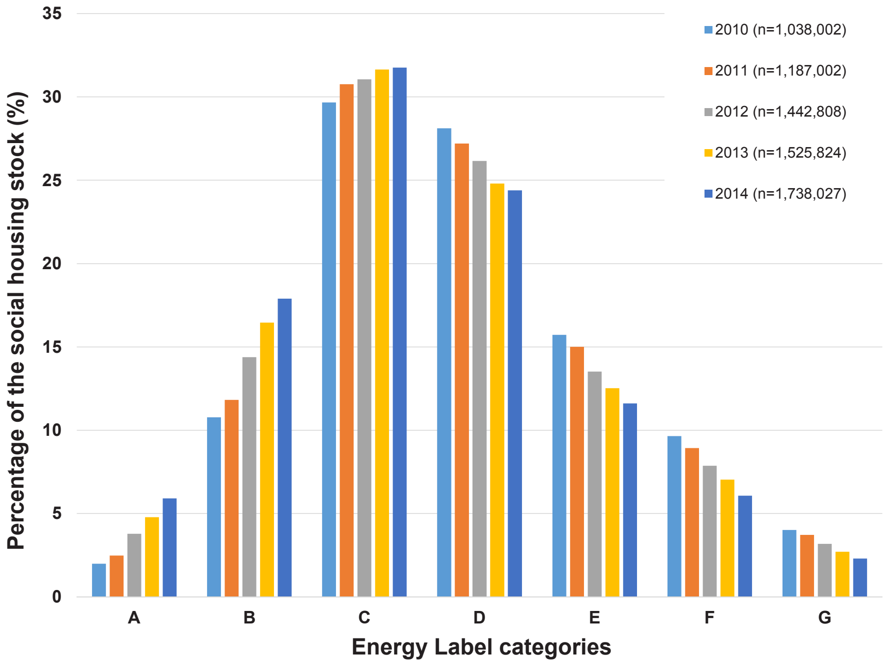

FIGURE 5.1 Energy label distribution in the non-profit housing stock 2010-2014 (Filippidou et al. 2017)

Energy regulations regarding the existing stock are usually less strict than those regarding new buildings, where, as from 2020, nearly zero energy standards must be achieved. Nevertheless, the energy performance of the existing stock is of crucial importance, especially taking into account the low and declining construction rates in the EU (Pombo et al. 2016; Thomsen and van der Flier 2002; Filippidou et al. 2017). Renovating existing buildings is seen as a 'win-win' option for the EU economy (Saheb et al. 2015). However, there are challenges mainly relating to the financing, market uptake and occupant awareness of energy renovations. Further, although there have been various energy renovation actions of dwellings in Europe, the assessment and monitoring of these renovations is lacking.

New buildings and major renovations in the Netherlands are required to meet specific standards e.g. Rc-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.

§ 5.2.1 Non-profit housing sector

The tenure mix of dwellings is an important factor for the ability to renovate regarding both the energy performance and the impact on the pace of energy renovations. The total amount of dwellings in the Netherlands is 7.5 million. The owner occupied sector amounts to 55.8% of the total, whereas the rental sector comprises 43.5% of the total (BZK 2016b). The ownership type is unknown for the remaining 0.7% (BZK 2016b).

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The vast majority of the rental sector belongs to housing associations forming the non-profit housing sector. In this paper, we focus on the Dutch non-profit housing. This sector comprises approximately 2.3 million homes, which adds up to 30% of the total housing market (BZK 2016a). Figures 5.2 and 5.3 present a comparison of the non-profit housing stock and the national housing stock in terms of the building year, first, and the typology of dwellings. When considering the building year, we can observe that the non-profit housing stock is similar to that of the total stock. This is more or less also true when we distinguish single-family and multi-family homes: the non-profit housing stock comprises of 53% multi-family dwellings, the national housing stock of 47%. Figure 5.3 shows, however, that this similarity cannot be stated about the specific type of dwelling.

We examine the non-profit rented housing stock of the Netherlands, also referred to as social housing, where a significant amount of data are available, for three reasons. First, the non-profit housing sector in the Netherlands is the largest in Europe, having a share of 30% of the total stock as mentioned above. This fact advances the research, providing the opportunity to work on a representative sample of the national housing stock, in terms of typology. Second, having such an extensive and representative sample of dwellings is a stepping stone for the provision of statistically significant results. Last, the non-profit housing sector is making decisions about energy efficiency and sustainable solutions collectively and is being subsidised by the state for goals promoting the energy neutrality of the country (Filippidou et al. 2017). Thus, the results of this study can serve as an indication of the energy renovation in the Dutch housing stock, while also considering the differences of the stocks, as mentioned above.

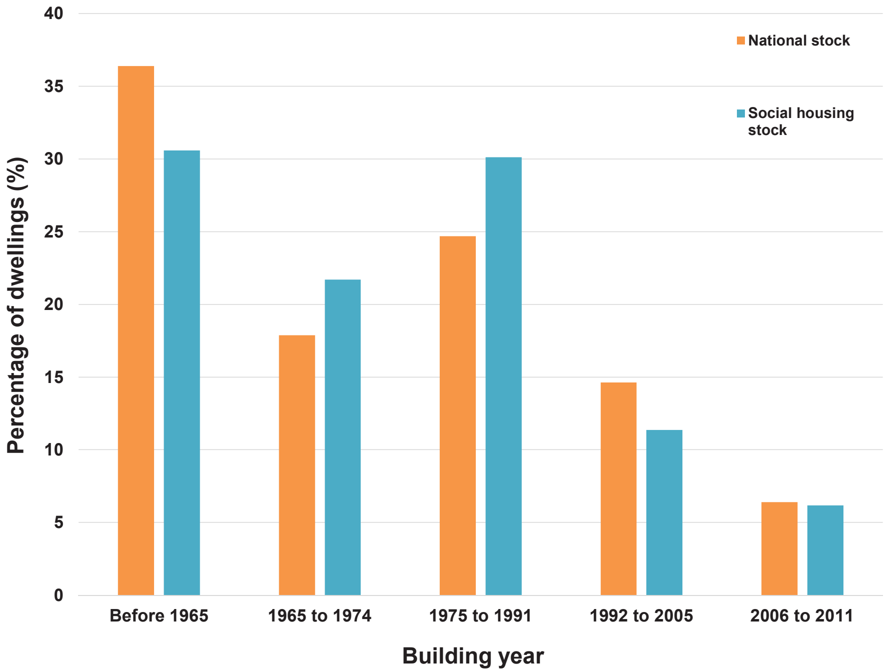

FIGURE 5.2 Comparison of building year cohorts distribution between the national and social housing stock. (source: Agentschap NL 2011 and SHAERE database)

Although no common definition for the non-profit housing sector is used, three elements are shared across the European non-profit social housing sectors: a mission of general interest, affordable housing for the low-income population and realization of specific targets, defined in terms of socio-economic status or the presence of vulnerabilities (Braga and Palvarini 2013). Non-profit housing is typically owned by the public sector; however, there is an increasing trend towards non-public involvement or the privatization of the non-profit housing sector in Europe, as is the case in Ireland, UK, Austria, France, and Denmark (Filippidou et al. 2017). Since the beginning of the 1990s the Dutch non-profit housing sector deviated from government control and public financing and became an independent sector. In the Netherlands, non-profit housing is almost entirely in the hands of private organisations (Elsinga and Wassenberg 2014; Priemus 2013; Kemeny 2002). These organizations can be better described as “hybrid” – they act between government, market and community (Nieboer and Gruis 2016). They have to manage the different and frequently competing interests from each of these three entities (Nieboer and Gruis 2016). The housing organizations have to fulfil several mandatory goals regarding the provision and allocation of homes.

Energy savings and sustainability are prominent on the agenda of the non-profit housing sector, especially since 2008 (Aedes 2016). The main energy efficiency policy for the sector is described in the Energy Saving Covenant for the Rental Sector ("Convenant Energiebesparing Huursector", 2012). The current aim of the non-profit housing sector is to achieve an average energy performance indicator, called Energy Index (EI), of 1.25, corresponding to an energy label B, by the end of 2020 (BZK 2014). The Covenant is a voluntary agreement between Aedes – the umbrella organisation of housing associations – the national tenants union, and the national government. The goal of the agreement corresponds to a reduction of 33% in energy consumption compared to the 2008 levels (BZK 2014). This voluntary agreement is a promising example of policy implementation in organized housing. Agreements like the Covenant could be enforced in communities and other public or private bodies to ensure energy efficiency of housing stocks. However, the application of such agreements is difficult in the owner-occupied housing sector where the owner bears the energy efficiency investment weight alone and is difficult to motivate (Filippidou et al. 2017).

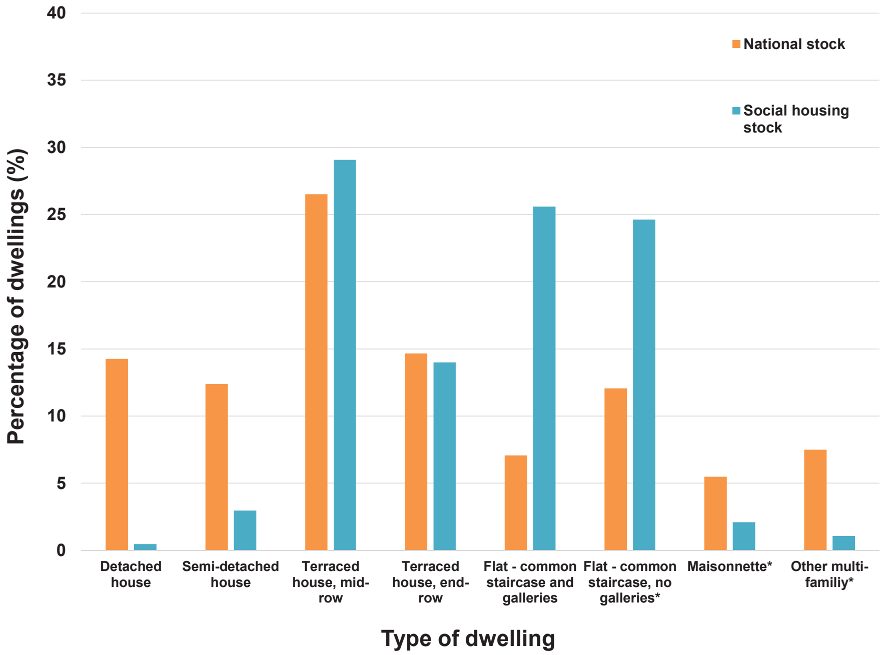

FIGURE 5.3 Comparison of type of dwelling cohorts' distribution between the national and social housing stock. (source: Agentschap NL 2011 and SHAERE database)

§ 5.3 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 2015). 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.

§ 5.3.1 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^{2}K) and R_c-values (thermal resistance, m^{2}K/W) of the envelope elements, the type of installation for heating, 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 5.1 presents the number of dwellings reported in SHAERE every year.

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TABLE 5.1 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	1,374,095	59.7%

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 (Rc-value), roof insulation (R_c-value), façade insulation (R_c-value), and type of glass (U-value).

§ 5.3.2 Methods

§ 5.3.2.1 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 ($<15m^3$ and $>6000m^3$). We also eliminated dwellings with default set values in all variables and with unrealistic useful living area (when $<15m^2$ or $>800m^2$) - 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.

§ 5.3.2.2 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 are presented in Table 5.2 and Table 5.3 (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.

TABLE 5.2 Insulation categories for floor, roof and façade based on the ISSO 82.3 (2009)

CHARACTERIZATION	R_c-VALUE FLOOR m^{2}K/W	R_c-VALUE ROOF m^{2}K/W	R_c-VALUE FAÇADE m^{2}K/W
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 5.3 Window categories based on the ISSO 82.3 (2009)

CHARACTERIZATION	U-VALUE WINDOW W/m^{2}K
Single glass	$U \geq 4.20$
Double glass	$2.85 \leq U < 4.20$
HR+ glass	$1.95 \leq U < 2.85$
HR++ glass	$1.75 \leq U < 1.95$
Triple insulation glass	$U < 1.75$

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.

§ 5.3.2.3 Non-renovated dwellings

As mentioned above, the goal of this paper is to determine the impact of thermal renovation measures on both the predicted and actual energy consumption of the renovated non-profit stock in the Netherlands. However, we need to be certain that an autonomous reduction of energy consumption does not affect the energy savings results of possible energy renovations. For this reason, we also analyse the gas consumption of the non-renovated dwellings. The selection of this "non-renovated group" of dwellings is based on the single "number of ESM" variable when this takes the value 0. The dwellings with 0 energy efficiency measures implemented constitute the non-renovated stock.

§ 5.3.2.4 Actual and predicted energy savings

Consequently, regarding the savings we focus on the dwellings that had 0 or at least one ESM realized – i.e. the renovated stock and the non-renovated. 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 5.1 and 5.2. 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:

$$\text{Savings}_{\text{actual}} = Q_{\text{actual,before}} - Q_{\text{actual,after}} \qquad [\text{kWh/m}^2\text{/year}] \qquad \text{Equation 5.1}$$

$$\text{Savings}_{\text{predicted}} = Q_{\text{predicted,before}} - Q_{\text{predicted,after}} \qquad [\text{kWh/m}^2\text{/year}] \qquad \text{Equation 5.2}$$

where:

$Q_{\text{actual,before}}$: Space heating demand before renovation, Statistics Netherlands
$Q_{\text{actual,after}}$: Space heating demand after renovation, Statistics Netherlands
$Q_{\text{predicted,before}}$: Space heating demand before renovation, calculated according to ISSO 82.3 (ISSO, 2009)
$Q_{\text{predicted,after}}$: Space heating demand after renovation, calculated according to ISSO 82.3 (ISSO, 2009).

This study examines different single ESMs and combinations of ESMs realized in the renovated stock. It also includes the examination of possible savings in the non-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: 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 on both the actual and the predicted energy savings (as dependent variables). In the following section the results of the twofold analysis are presented.

§ 5.4 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 annual energy savings between 2010 and 2014 for the dwellings that had only one ESM realized. We also present the actual and predicted gas consumption of the non-renovated dwelling stock. Furthermore, the effect of various combinations of ESMs on the energy savings is analysed for the dwellings where 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/m^2 and, as a result, are not floor area weighted (for example a dwelling of 500 m^2 weighs the same as a 40 m^2 apartment). 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.

TABLE 5.4 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

The maximum amount of ESMs is 7. Table 5.4 depicts the amount of dwellings and the number of measures applied per dwelling. The first row depicts the non-renovated dwellings with 0 measures applied. This group consists of 384,069 dwellings, which is 59.0% of the sample of this study. 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 5.4). 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 not focus only on the renovated stock and the ESMs that were applied but we also mention the gas consumption differences of the non-renovated stock.

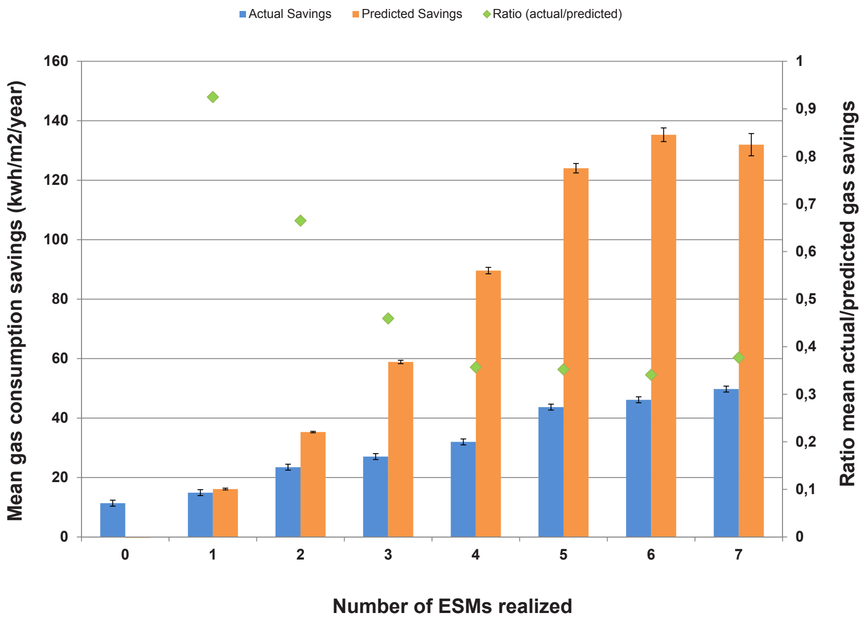

FIGURE 5.4 Mean actual and predicted gas consumption savings based on the number of ESMs realized – including the non-renovated stock (0 ESMs)

Figure 5.4 presents the mean actual and predicted gas savings categorized per number of ESMs and the ratio between mean actual savings and mean predicted savings (except for the 0 ESMs where the predicted savings are 0). 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. The left most column of the graph depicts the autonomous gas savings when no ESM has been performed, i.e. the savings of the non-renovated stock. This result has been reported previously in literature as well (Daša Majcen et al. 2016; Filippidou et al. 2016). It is remarkable that in the period of 2010-2014 there has been a reduction of 11 kWh/m^2/year without any energy renovation taking place. Several reasons can explain why, 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. It is useful to notice that such a reduction in consumption is only visible from the actual savings and not the predicted. The actual savings difference between 0 and 1 ESM applied is very small, below 2 kWh/m^2/year. 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 (van den Brom et al. 2017; D. Majcen et al. 2013) and that is also supported by Figure 5.4 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.

TABLE 5.5 Inventory of ESMs

ESMS	FREQUENCY	RATIO MEAN ACTUAL/PREDICTED SAVINGS
ESM heating system	18036	1.33
ESM DHW system	8878	0.49
ESM heating and DHW systems	63675	0.77
ESM ventilation system	24934	4.87
ESM glazing	16521	0.90
ESM roof insulation	10392	0.46
ESM façade insulation	16182	0.55
ESM floor insulation	14414	1.04

108,131 dwellings (16.6% of the sample) had 1 ESM realized between 2010 and 2014. Table 5.5 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.

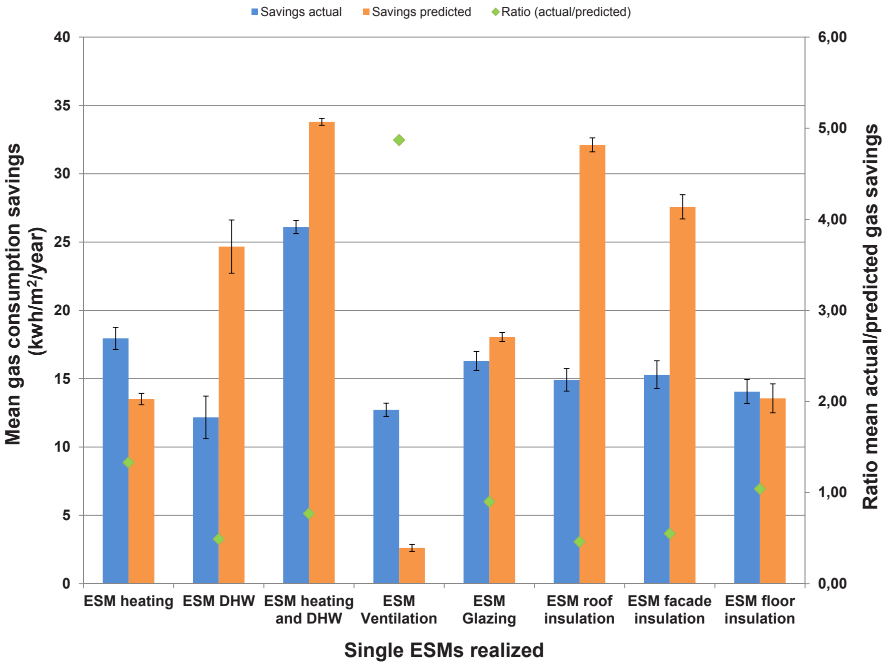

FIGURE 5.5 Mean actual and predicted gas consumption savings for dwellings with single ESMs

Figure 5.5 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 5.5 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 5 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, and 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 5.6 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 5.6 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

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TABLE 5.6 Index of combination of ESMs

Index of combinations of ESMs	COMBINATIONS OF ESMS	FREQUENCY	RATIO MEAN ACTUAL/PREDICTED SAVINGS
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

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.

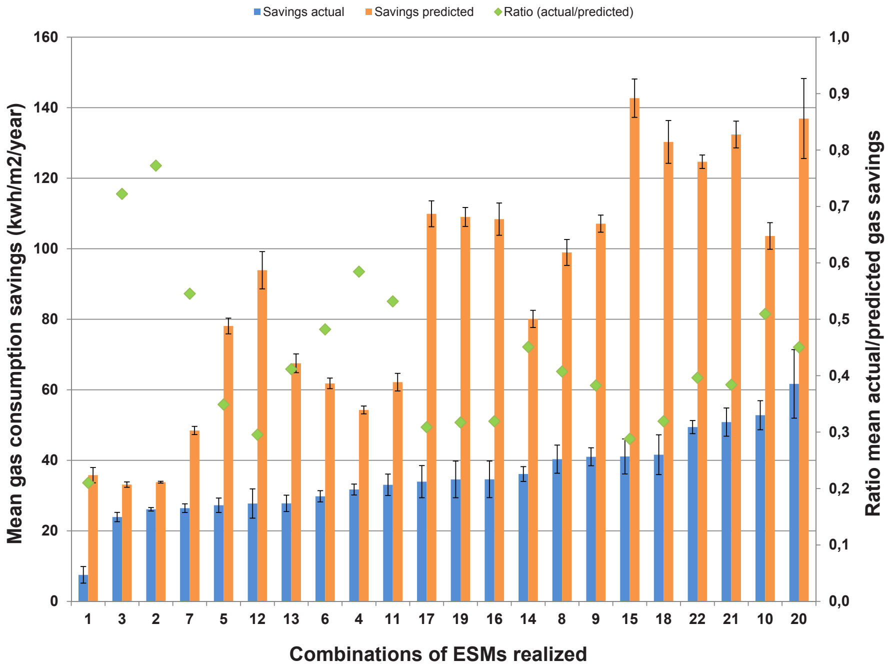

FIGURE 5.6 Actual and predicted gas consumption savings for dwellings with combinations of ESMs realized

The combinations of measures in Figure 5.6 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 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 behaviour 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 5.5). Table 5.6 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 5.6). This may be due to assumed occupant behaviour (including indoor temperature and hours of heating system operation) or wrong predictions of the state of the dwelling before an ESM takes place (van den Brom et al. 2017; Balaras et al. 2016; Daša Majcen et al. 2016; Galvin 2014). Moreover, Table 5.7 and Figure 5.7 are depicting the gap between actual and predicted savings of specific frequent combinations of measures.

TABLE 5.7 Index of frequent specific combinations of ESMs

Index of combinations of ESMs	COMBINATIONS OF ESMS	FREQUENCY	RATIO MEAN ACTUAL/PREDICTED SAVINGS
ESM heating and glazing 01	Improved non-condensing boiler (η= 0.80–0.90) to Condensing boiler (η ≥ 0.95) & double glass to HR+ glass	1532	0.67
ESM heating and glazing 02	Improved non-condensing boiler (η= 0.80–0.90) to Condensing boiler (η ≥ 0.95) & double glass to HR+ glass	1369	0.61
ESM heating and ventilation 01	Condensing boiler (η= 0.90–0.925) to Condensing boiler (η ≥ 0.95) & natural ventilation to mechanical exhaust	5435	0.73
ESM heating and ventilation 02	Condensing boiler (η= 0.925–0.95) to Condensing boiler (η ≥ 0.95) & natural ventilation to mechanical exhaust	524	1.30
ESM heating and façade 01	Improved non-condensing boiler (η= 0.80–0.90) to Condensing boiler (η ≥ 0.95) & no insulation façade to insulation	3462	0.45
ESM heating and façade 02	Condensing boiler (η= 0.90–0.925) to Condensing boiler (η ≥ 0.95) & no insulation façade to insulation	812	0.49

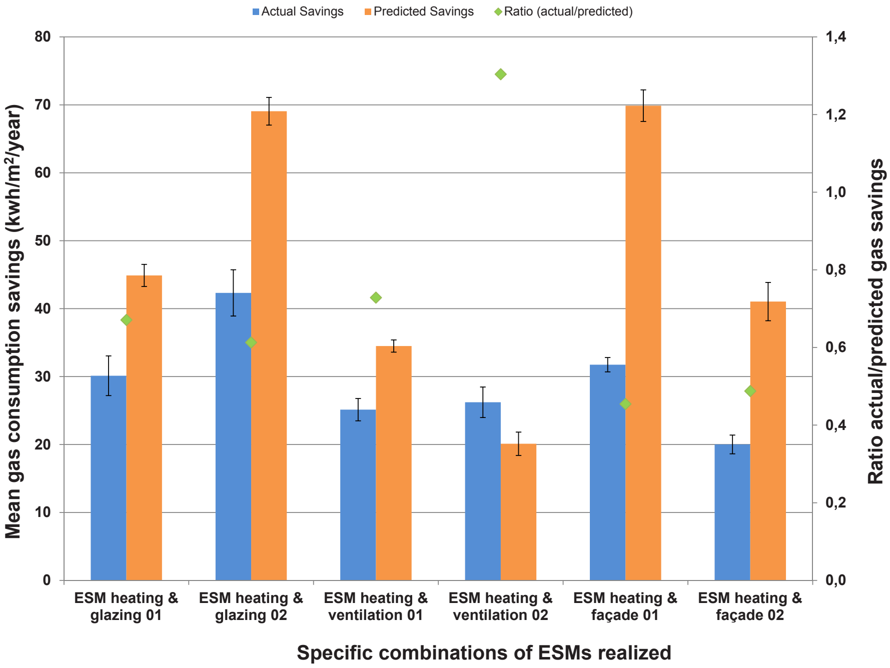

FIGURE 5.7 Actual and predicted gas consumption savings for dwellings highlighting some of the most frequent combinations of ESMs realized

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 5.8 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.

TABLE 5.8 Multivariate linear regression analyses on the actual and predicted savings [kWh/m2/year]

	ACTUAL SAVINGS (R2= 1.6%)				PREDICTED SAVINGS (R2= 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*

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 5.8 – 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/m^2 savings for the heating system and 7.262 kWh/m^2 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 5.8 – 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 5.8 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.

§ 5.5 Conclusions

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

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.

Another important lesson of this paper is the impact that collective agreements, like the Covenant of the non-profit housing sector, can have 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 carried out. Data monitoring and the construction of SHAERE database have a prominent role to that respect. The gathering and analysing of epidemiological data helps track 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.

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 we can 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. Moreover, the connection of this results to policies applied or that will be in force in the future is of great importance.

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6 Energy renovation rates in the Netherlands – comparing long and short term prediction methods

Note:
Chapters 2 to 5 established the background for the energy efficiency state, energy renovations, and these renovations' impact on the predicted and actual heating energy consumption of the housing stock. But can we forecast the renovation rates towards 2050 and beyond? In this chapter, we focus on predicting the energy renovation rates of the non-profit housing stock of the Netherlands. We apply the dynamic building stock model developed in NTNU (Norwegian University of Science and Technology) on the non-profit housing sector for the long term prediction of renovation rates and then compared the results of the empirical SHAERE data. The methods followed in this research represent two different approaches to building monitoring regarding energy renovation rates and energy saving measures. Despite the fact that in the dynamic modelling method the renovation is a probability function and in the statistical method the renovation is an energy saving measure or a group of energy saving measures calculated from a time series dataset – we match the definitions by assigning specific single of energy saving measures or combinations of energy saving measures to renovation cycles (years). The results imply that although ambitious renovation rates are assumed by the EU and other authorities for the future of building stocks, it is highly unlikely that these will be achieved without strict regulations and other incentives.

This paper is a common work of the co-authors that agree that this chapter is part of the thesis. I have designed the research, applied the model to the Dutch non-profit housing stock, compared the empirical results to the modelled and wrote the text. N.H. Sandberg assisted me with the application of the Dutch data to the dynamic building stock model and provided valuable feedback to the text. I.Sartori and H. Brattebø provided us with useful feedback on the research design and results. M.I Vestrum and J.S Næss have provided parts of the text regarding the model and assisted in the application of the model. N. Nieboer provided useful feedback on the text.

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§ 6.1 Introduction

The building sector plays a major role in order to meet the energy saving targets set in the EU and the Netherlands (SER, 2013; ürge-Vorsatz et al., 2007). Existing buildings are responsible for 36% of the CO2 emissions in the European Union (EU) (European Commission, 2008 and 2014). Moreover, among the end use sectors – industry, transport, households, services, fishing, agriculture, forestry and non-specified – households represent one of the most energy intensive sectors consuming 24.8% of the total final energy (European Commission, 2016a; EEA 2017). Two major directives are currently in force, on an EU level, to tackle the issue of energy efficiency improvement of buildings – the Energy Efficiency Directive (EED) and the Energy Performance Buildings Directive (EPBD) (European Parliament, 2010, 2012). Improving the efficiency of the building stock is a central pillar for the carbon reduction goals of the member states (MS) and the EU as a whole.

Energy renovations in existing dwellings offer unique opportunities for reducing the energy consumption and greenhouse gas (GHG) emissions on a national scale in the Netherlands, but also on a European and global level. Due to the long lifespan of buildings, currently existing buildings will constitute a major part of the Dutch housing stock for several decades (Sandberg et al. 2016a). In the Netherlands, it is expected that the renovation activity will be greater than the construction and demolition activity in the future (Sandberg et al. 2016a).

The rate at which energy renovations are realized and the energy performance level achieved after the renovations are crucial factors for an energy-efficient built environment. Energy renovation rates assumed by EU officials and policy makers usually range from 2.5-3% (Stadler et al. 2007; BPIE 2011; European Parliament 2012; Boermans et al. 2012; Dixon et al. 2014). However, at current rates it is claimed that more than 100 years will be needed to renovate the EU building stock (European Commission 2016). Furthermore, the intervention level – how many and what type energy efficiency measures – of the renovations plays an equally significant role to the rate as it can define when the next renovation cycle can occur and the possibility of lock-in effects. The main question addressed in this paper is what the estimated renovation rates for the Dutch housing stock are for different types of renovation, depending on the level of renovation and energy saving measures applied. Answering this question can help evaluate current and previous policies but also shape future ones.

The need for renovations depends greatly on the buildings' age and typology. The characteristics of the building stock are quite different across countries in Europe. In addition, building ownership and the construction sector are naturally fragmented. Research performed so far, has revealed that the majority of building renovations consist of small scale projects and relatively low investments or occur at the natural need of dwellings to be retrofitted (Filippidou et al. 2016; Sandberg et al. 2016; Filippidou et al. 2017). In order to assess and examine the energy renovation measures, how fast or how deep they are being realized, up-to-date monitoring of these activities is required. Moreover, time series monitoring is crucial in order to achieve longitudinal studies that properly report 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.

Moreover, advanced quality information and data are needed to help develop roadmaps and future policies resulting in energy efficient buildings. 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 (Filippidou et al. 2017). In some cases, information gained through the investments on energy renovations are used to calculate the progress. To address the data monitoring issues identified, there is a need for new methods on the estimation of renovation rates that can be used for consistent and scalable analyses of building stocks.

In this paper, we compare two different methods, long and short term, to simulate and assess the energy renovation rate of the Dutch non-profit housing stock. First we apply the dynamic dwelling stock model which has been developed and validated in NTNU, Norway (Sartori et al. 2016). The input parameters are based on statistical information for the development of the non-profit housing stock. Second, we use yearly records gathered centrally and stored in a time series database by housing associations through the energy labelling of their stocks, called SHAERE (Sociale Huursector Audit en Evaluatie van Resultaten Energiebesparing [English: Social Rented Sector Audit and Evaluation of Energy Saving Results]). Ultimately, we are comparing the renovation rates resulting from the dynamic modelling and the analysis of empirical building energy epidemiology data. As a result, we are 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.

This paper is structured as follows. The remaining of section 6.1 sets the background and the second section presents an overview of the data and methods of our research. The third section introduces the results. The fourth section deals with our experiences concerning the dynamic building stock modelling and the longitudinal data analysis using big data. Finally, the fifth section elaborates on policy implications and draws conclusions.

§ 6.1.1 Background

In this study, we focus on the non-profit housing stock of the Netherlands where detailed information about the thermo-physical characteristics and energy installations (heating, domestic hot water [DHW], ventilation, solar systems) is available in the form of time series through the collective SHAERE database. Research

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performed so far, determined the energy renovation pace in the Dutch non-profit housing sector over the years 2010 – 2014, based on the changes of the energy performance after a renovation was performed (Filippidou et al. 2017). The results showed that although a number of energy improvements have been realized, they only resulted in small changes of the energy efficiency of the dwellings. Even though 28.0% of the dwellings have an improved energy performance, only 3.5% had a major renovation (Filippidou et al. 2017). This percentage depicts the cumulative major energy improvement rate of the non-profit housing sector in the Netherlands for a period of four years.

A dynamic dwelling stock model has been developed in NTNU, which can be used to study the long-term development in dwelling stock size and composition has previously been developed and applied in a range of publications (Muller 2006; Bergsdal et al. 2007; Sartori et al. 2008; Hu et al. 2010; Pauliuk et al. 2013; Sandberg et al. 2011; Sandberg and Brattebo 2012; Gallardo et al. 2014; Sandberg et al. 2014; Vasquez et al., 2016, Sandberg et al., 2016 a, b). The core of the model is the population’s need to reside and the main input parameters are the drivers in the system, the population and the number of persons per dwelling. The construction, demolition and renovation activity in the system are outputs from the model, aiming to describe the dynamics of the stock resulting from the changing demand and ageing of the stock. A separate paper explored the sensitivity in model results and conclusions to changes in input parameters (Sandberg et al. 2014). For the case of Norway, they concluded that the most sensitive input parameters (population and lifetime of dwellings) are also the input parameters of the highest uncertainty. However, even when changing these input parameters to extreme and unrealistic values, the main conclusions regarding future renovation rates remained unchanged. The model results and conclusions for the case study of Norway were robust to changes in the input parameters. Renovation rates at levels necessary to achieve policy targets in energy and emission savings seemed unrealistic to be achieved when modelling the “natural” need for renovation (Sandberg et al. 2014).

SHAERE, on the other hand, is a time series database that became operational in 2010. Housing associations report their stock to Aedes at the beginning of each calendar year accounting for the previous year (e.g., in January 2014 reporting for 2013) (Aedes 2017). 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). As a result, SHAERE consists of the actual characteristics and data needed to acquire an energy certificate of all dwellings of the participating housing associations at the end of each calendar year. 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 is a time series database including a

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maximum of five records per dwelling – 2010, 2011, 2012, 2013 and 2014. Analysing the data of the monitoring system we can have empirical results on renovation rates for different renovation cycles based on the type of the renovation measure occurred and the lifetime of the specific components. These results can serve as a reference for the modelling results and help understand the renovation processes of the Dutch non-profit housing sector.

§ 6.1.2 Non-profit housing

The tenure mix of dwellings bears a significant relevance to the ability to renovate regarding both the energy performance and the impact on the pace of energy renovations. The total amount of dwellings in the Netherlands is 7.5 million. The owner occupied sector comprises 55.8% of the total, whereas the rental sector amounts to 43.5% (BZK, 2016b). The ownership type is unknown for the remaining 0.7% (BZK, 2016b). The vast majority of the rental sector belongs to housing associations forming the non-profit housing sector. In this paper, we focus on the Dutch non-profit housing because the sector comprises approximately 2.3 million homes, which adds up to 30% of the total housing market (BZK, 2016a). This is a unique situation, as the Netherlands have the highest percentage of non-profit housing in the EU. The non-profit housing sector can be expected to be a leading example when it comes to energy efficiency goals due to its intrinsic social values.

Moreover, energy savings and sustainability are high on the housing associations' agenda, especially since 2008 (Aedes, 2017). According to the Energy Saving Covenant for the Rental Sector ("Convenant Energiebesparing Huursector"), the current aim of the non-profit housing sector is to achieve an average EI (Energy Index - Dutch energy performance coefficient for existing dwellings) of 1.25 by the end of 2020 (BZK, 2014), which is within the bands of an energy label B. The Covenant was signed by, among other stakeholders, Aedes (the umbrella organisation of housing associations), the national tenants' union and the national government. The goal of the agreement means an energy saving of 33% on the theoretical/predicted energy consumption in the period of 2008 to 2021 (CECODHAS Housing Europe, 2012).

§ 6.1.3 Energy renovations of the Dutch non-profit housing stock

In the Netherlands, the majority of policy measures aim to reduce the energy consumption by increasing the energy performance of buildings through the improvement of the energy labels (BZK, 2014). The energy performance of an existing building is expressed by the EI, which is the figure relating the modelled annual primary energy consumption, the total heated floor area and the heating losses. The EI typically takes values between 0 (extremely good performance) to 4 (extremely bad performance), and is categorised in energy labels (see Section 3).

Although there has been a great deal of research on the energy efficiency and consumption of the housing stock, little has been published on the renovation rates. In a previous publication by the authors the pace of several energy improvement measures is reported – with the majority of dwellings having improved the heating system and the glazing (Filippidou et al. 2016; Filippidou et al. 2017). Even though the energy efficiency policies and initiatives implemented in the Netherlands place it at one of the leading positions of the EU residential sector, there is no evidence of a steady reduction of the gas and electricity consumption compared to the 1990 levels (Majcen et al. 2013). On the contrary, the total energy consumed (gas and electricity) by households increased by 11% from 1990 to 2008 (Majcen et al. 2013). The non-profit sector has a large potential for improvement.

So far, we have identified the specific energy efficiency measures that have been realised, between 2010 and 2013 (Filippidou et al. 2016). In order to be able to assess the effect on the energy performance of the measures applied in the non-profit housing sector, an analysis of the changes in all of the energy systems and envelope elements of the dwellings has been performed. This study focuses on the prediction of the energy renovation rates of the non-profit housing stock applying two different methods. We apply a dynamic building stock model to examine the renovation rates at different renovation cycles (15, 20, 30 and 40 years). We, then, use longitudinal data to observe the changes of the energy performance of the dwellings through SHAERE. We observe whether or not the inputted data have changed from 2010 to 2014. We match different energy renovation measures applied, from 2010 to 2014, based on their life cycle and replacement data to the renovation cycles of the dynamic model to compare the results.

§ 6.2 Methods

First, the dynamic modelling method will be described and then the statistical method based on empirical data will follow (Sandberg et al. 2016; Sartori et al. 2016; Filippidou et al. 2016). A short description of basic functions of the model follows. Further, the input data and assumptions of the model are explained. Moreover, the statistical data analysis approach is explained using SHAERE database.

§ 6.2.1 Dynamic building stock model

The dynamic building stock model used in the analysis is based on the principles of dynamic Material Flow Analysis (MFA). The model can be used to describe long-term dynamic development of a dwelling stock and the stock activities construction, renovation and demolition (Sandberg et al. 2014). The model can be applied for both the total stock and segments of the stock. An outline of the dynamic building stock model is presented in Figure 6.1.

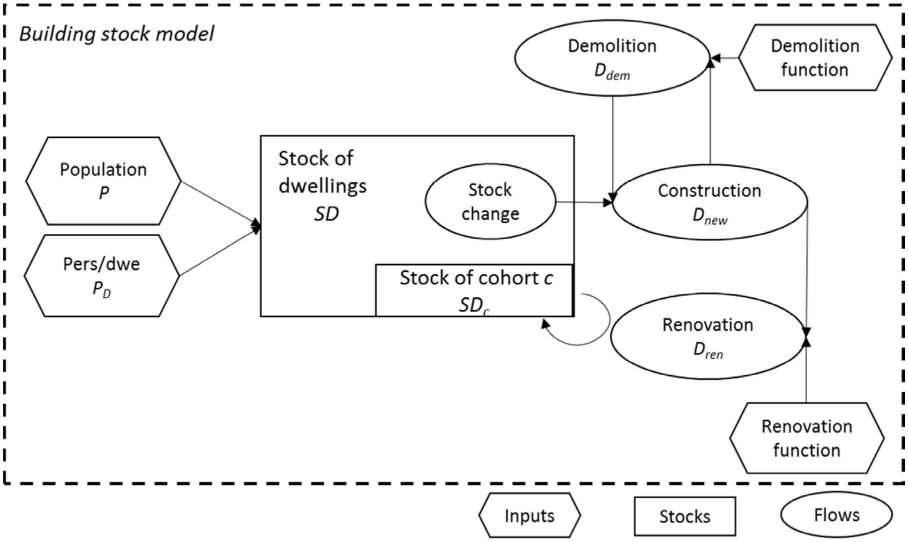

FIGURE 6.1 Conceptual outline of the dynamic building stock model (Sartori et al. 2016)

The model simulates a population's changing demand for dwellings based on the development in the underlying drivers in the system; population *P* and lifestyle which is quantified by the parameter persons per dwelling *PD* (Sandberg et al. 2014). The demand for dwellings in the system *SD* and the change in demand is estimated for each year. A demolition probability function p_{DEM} is applied on construction from previous years to estimate the demolition activity per year D_{dem}. Demolition activity in the model represents both actual demolition and dwellings going out of use. Furthermore, mass balance principles are used to find the sum of the simulated stock change and demolition activity and estimate new construction activity D_{new}.

Yearly renovation activity D_{ren} is estimated by the use of a probability function p_{REN} that aims to describe the activity that is likely to happen due to aging of dwellings and their need of maintenance (Sandberg et al. 2014). A dwelling can be renovated several times during its lifetime, and the renovation cycle R_C is the average time between two renovations of the same type. The model simulates the number of dwellings renovated each year, and this is divided by the stock size to estimate the renovation rate. The renovation rate is therefore an output from the model.

The model can be applied for different renovation cycles representing different types of renovation and the length of the renovation cycle is case specific. Typically, deep renovation activity can be represented by a normal distribution with an average renovation cycle of about 40 years and a standard deviation of 10 years (Sandberg et al. 2016a). A shorter renovation cycle represents more frequent renovation and results in a higher renovation rate, and a longer renovation cycle represents less frequent renovation and results a lower renovation rate.

Construction, demolition and renovation rates are outputs of the model and should be considered as "natural" in the sense that it is a projection of internal dwelling stock dynamics and express the "maintenance" needs and the aging of a given stock (Sartori et al. 2016).

The stock is segmented into cohorts given as different construction periods. The cohorts could for instance represent changes in the prevailing construction technology for different time periods or major socio-economic changes in the system. The model also allows for segmenting the dwelling stock in types and renovation states, which is a good basis for further energy and carbon analysis of the given stock (Sandberg et al. 2011; Sandberg et al. 2014; Sandberg et al. 2016b)

For further details about the model, please refer to Sartori et al. (2016) which includes a detailed description of the model, including the mathematical framework, the algorithm for implementation and in-depth analysis of input and output parameters.

§ 6.2.2 Input data and assumptions of the dynamic model

The input data and assumptions used for the modelling are described here. To avoid short-term fluctuations in the results, non-linear regression is applied to the raw data to make smooth input curves for the input parameters Population P and Persons per dwelling PD.

§ 6.2.2.1 Population

Population statistics, projections and some additional assumptions constitute raw data used for making the smooth input curves for the population. In the Netherlands, population statistics are available for all years since 1804 and projections towards

2060. These projections are calculated by the Statistics Netherlands based on the birth rate, longevity and immigration. Still, for this study we worked with population data for residents of the non-profit housing stock of the Netherlands.

The non-profit housing stock in the Netherlands started as municipal housing for the workers of cities. The first association in cities like Amsterdam started building dwellings for men that had no economic means to live in good quality housing already in 1852. Based on historical sources, we can assume that the start of the non-profit housing coincides with the first Housing Act in 1902, when some data start being available (Schade 1981). Most of these data are gathered from historical documents of municipalities (Haffner et al. 2009, Grinberg 1977). Using the historical data and in continuity references of the percentage of the non-profit housing to the complete housing stock we were able to calculate the population as shown in Figure 6.2.

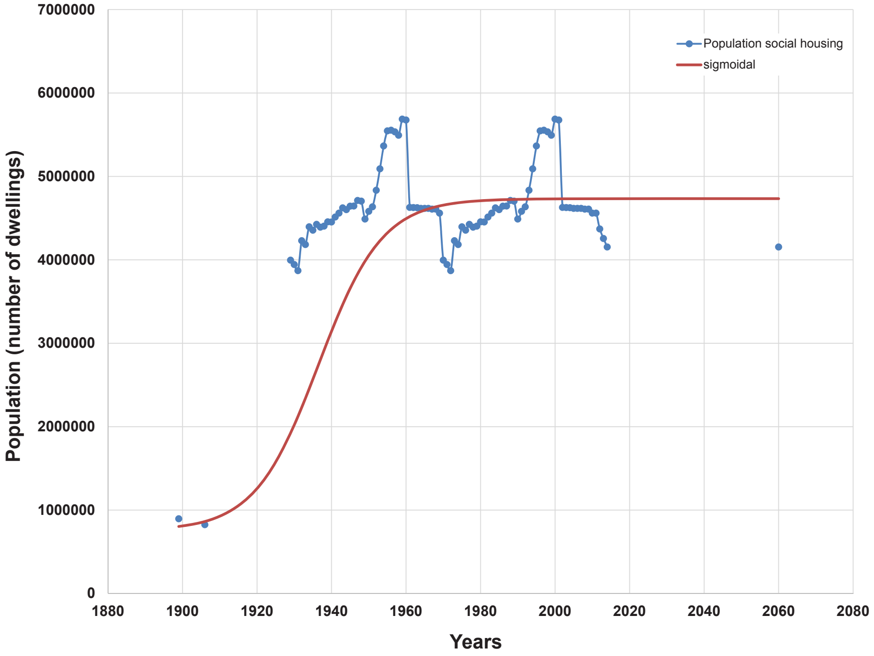

FIGURE 6.2 Development of the population of the non-profit housing stock (sources: Haffner et al. 2009;Schade 1981; Grinberg 1977)

The smooth population curve of the non-profit housing is presented in Figure 6.2. A sigmoidal regression is used due to the fact that the population has increased followed by a period of (possibly expected) decrease and stabilization. The R^2 value of the non-linear regression is 0.68. However, due to luck of continuous data of the population residing in non-profit housing we could not achieve a better fit.

§ 6.2.2.2 Persons per dwelling

The length of the time series available for the parameter number of persons per dwelling PD differs between the complete housing stock of the Netherlands and the non-profit housing. The Netherlands has persons per dwelling statistics available from 1900 to 2014, for every single year since 1960 for the complete housing stock (Statistics Netherlands 2013; Statistics Netherlands 2015a; Statistics Netherlands 2015b; van Harperen 1983; TNO 2009). Additional assumed values for the period 1800-1900 as well as for 2050 and 2100 are included in the regression. For the non-profit housing stock continuous statistics since 1970, from the Dutch Environmental Assessment Agency (PBL), on the number of dwellings are available (PBL 2015). Through historical sources we were able to go back to 1940 (Schade 1981; Grinberg 1977). Three scenarios were tested as shown in Figure 6.3. We tested each one in the model to check the impact on the results. We found out that the model is not susceptible to change in the number of dwellings after 2014. Thus, we chose the Predicted_2 scenario were the non-profit housing stock stabilizes at 25% of the housing market to go on with our analyses.

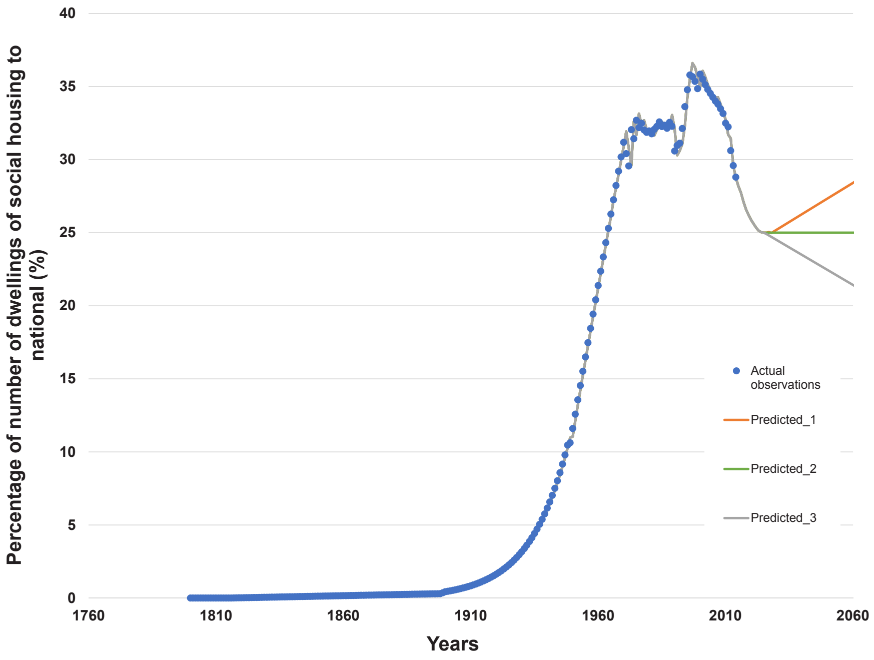

FIGURE 6.3 Development of the number of dwellings of the non-profit housing stock

Based on the number of dwellings and the population residing in the non-profit housing stock we were able to calculate the persons per dwelling historical values. Figure 6.4 depicts the development of the persons per dwelling in the non-profit housing. The polynomial regression with 3 parameters is a good fit with R^2=0.99.

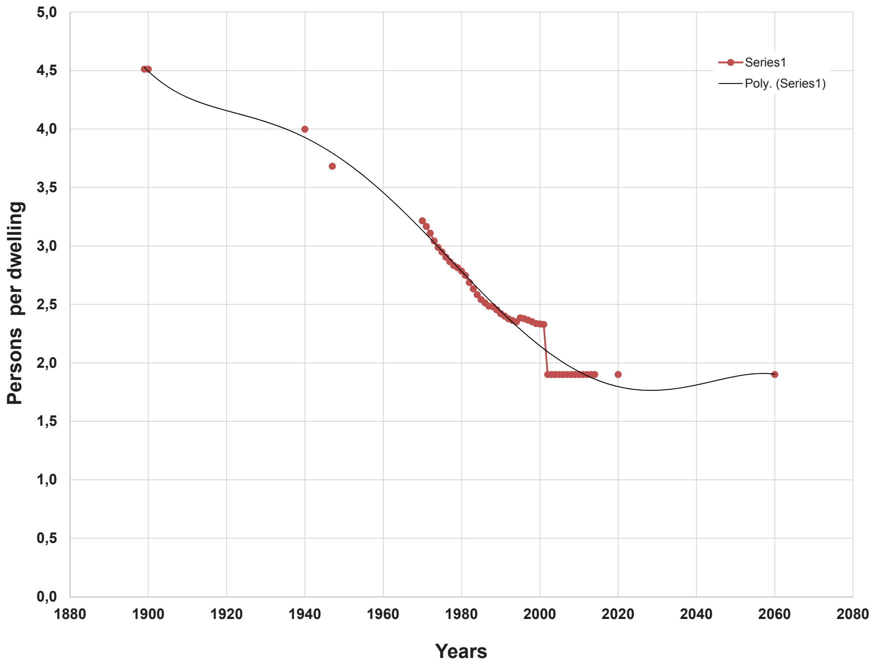

FIGURE 6.4 Development of the persons per dwelling of the non-profit housing stock

§ 6.2.2.3 Dwelling lifetime and renovation parameters

The lifetime probability function is assumed to follow a Weibull distribution defined by the parameters average lifetime per dwelling and the initial period after construction where the probability of demolition is zero, as explained in detail in Sandberget al. (2014) and Sartori, et al. (2016).

The definition of the renovation activity in the model is case-specific. In this case, it will describe the activity in the non-profit housing. An energy saving modernization or energy saving measure (ESM) such as the upgrading of the heating system or the glazing can be thought as having a cycle of 15 and 20 years respectively. We categorize the renovation activity in different cycles. We start with 15 years including ESMs as described above. We then move on to include measures with a cycle 30 years such as the replacement of glazing or the replacement of roof insulation. In this study, we also explore the dynamics of renovations that have the potential for including ESMs that lead to a large decrease in the energy demand – 40 years cycle. The implementation of these measures are costly and not likely to take place if a dwelling is not going through a renovation in any case. Hence, energy efficiency measures could be implemented when the dwelling is renovated due to its “natural” ageing process and need for maintenance and upgrading. In this study, we aim at estimating the total renovation activity resulting from 15 years cycle to 40 years describing the ageing process of the dwelling stock in the non-profit housing in the Netherlands. The 40 years cycle describes the deep renovation of facades and combinations of ESMs commonly estimated to occur in cycles of 40 years. The renovation probability function results from cyclic repetitions of a Normal distribution, as explained in detail in Sandberg et al. (2014) and Sartori et al. (2016).

The lifetime and renovation parameter values for the Netherlands are listed in Table 6.1. The column “Construction period” refers to the parts of the stock the following assumptions are applied to. In principle, the parameter values can differ between dwellings constructed in different years. However, due to limited empirical data available, the same values are assumed for all dwellings regardless of construction year.

TABLE 6.1 Lifetime and renovation parameter values for the Netherlands

COUNTRY	CONSTRUCTION PERIOD	AVERAGE LIFETIME (YEARS)	PERIOD WITHOUT DEMOLITION (after construction – years)	SHARE NEVER DEMOLISHED	RENOVATION CYCLE (YEARS)
Netherlands	All	120	40	3.2%	15 – 30 – 40

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). Table 6.2 depicts the service life of the aforementioned components of the dwellings. By the term service life we mean ‘the period of time during which a building or its parts meet or exceed performance requirements’ (ISO, 2000). The values are typical for Dutch dwellings and were acquired through expert interviews and literature about their maintenance (Straub, 2011 and Straub, 2015). In order to compare the results of the different methods used we are going to depict first the simulated results of the dynamic model and afterwards the empirical results of the statistical analysis. In the 15 years renovation cycle of the model outcomes the ESMs heating, DHW and ventilation are depicted. In the 30 year renovation cycle the glazing and combinations of ESMs, such as 3 or 4 ESMs together are fitted. For the deep renovation cycle of 40 years the insulation of floors, roofs and facades together with combinations of 5 or more ESMs are presented.

TABLE 6.2 Service life of dwelling components (Straub 2011 and Straub 2015)

DWELLING COMPONENT	SERVICE LIFE (YEARS)
Heating system	15
DHW system	15
Ventilation system	15
Glazing	30
Floor insulation	40
Roof insulation	40
Façade insulation	40

§ 6.2.2.4 Cohort definition

Some of the model results are segmented in cohorts. Table 6.3 shows the cohorts as assumed by the model. Cohort 0 represents the initial stock in year 1800 and Cohort 1 the construction of dwellings from 1800 to the end of World War II. Although there are large differences between the dwellings constructed in the early 1800s and in the 1930s, the share of the current stock being constructed before 1945 is limited, and the future possible ESMs are assumed to be of the same types for dwellings constructed in cohort 1. Cohort 2, 3 and 4 represent periods of 35 years where Cohort 2 is the post-war construction from 1946 to 1980, Cohort 3 is the most recent construction from 1980 to 2015 and Cohort 4 is future construction from 2016 to 2050.

TABLE 6.3 Cohort definition

COHORT NUMBER	START YEAR	END YEAR
0	-	1800
1	1801	1945
2	1946	1980
3	1981	2015
4	2016	2050

§ 6.2.3 Building energy epidemiology statistics using SHAERE database

This study includes an inventory of ESMs of the non-profit rented stock in Netherlands from 2010 to 2014 using the depersonalized empirical data collected in SHAERE database. The outcomes are based on a longitudinal analysis of datasets from SHAERE, described in 6.3.2.1.

§ 6.2.3.1 Data in SHAERE and sample selection

SHAERE is the official tool for monitoring the progress in the field of ESMs 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, domestic hot water (DHW) and ventilation and the estimated energy consumption. The data are categorized as variables per dwelling. The initial dataset from SHAERE comprised 2.2 million dwellings containing records from 2010 to 2014. Data filtering was required from the beginning of the analysis. The maximum amount of records per dwelling can be five (2010 - 2014). After the double cases control, 1,752,427 unique dwellings formed the sample. Furthermore, we eliminated dwellings with default set values in all variables and with unrealistic useful living area (when <15m2 or >800m2) - 1,602,391 cases remained. The boundaries are based on the distribution of the living area variables – we exclude outliers and illogical values.

§ 6.2.3.2 Renovation activity

The goal of this paper is to examine the thermal renovation measures of the non-profit stock in the Netherlands and compare the results to those of the dynamic building stock model. Throughout the paper we focus on the renovation activity in the stock. For this reason, we applied the following method in order to estimate the renovation activity from 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 nominal variables. However, in order to identify the improvements of the ESMs, the categorization of the insulation and glazing variables is necessary. The values and boundaries used to distinguish between the levels of insulation are created based on the Dutch ISSO publication 82.3 and are presented in Table 6.4 and Table 6.5 (ISSO, 2009). By creating 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 and compiled to compare with the results of the dynamic model in different renovation cycles.

TABLE 6.4 Insulation categories for floor, roof and façade based on the ISSO 82.3 (2009)

CHARACTERIZATION	R_c-VALUE FLOOR m^2K/W	R_c-VALUE ROOF m^2K/W	R_c-VALUE FAÇADE m^2K/W
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 6.5 Window categories based on the ISSO 82.3 (2009)

CHARACTERIZATION	U-VALUE WINDOW W/m^2K
Single glass	$U \geq 4.20$
Double glass	$2.85 \leq U < 4.20$
HR+ glass	$1.95 \leq U < 2.85$
HR++ glass	$1.75 \leq U < 1.95$
Triple insulation glass	$U < 1.75$

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, meaning that the dwelling belongs to the non-renovated stock, and the maximum is 7, meaning that a complete renovation was realized.

TOC

In the following section we will first present the outcomes of the dynamic model application to the non-profit housing in the Netherlands. Following, the results of the energy epidemiology statistics using SHAERE will be introduced. Despite the fact that SHAERE is a young database and the data are only available for four years, this analysis sheds light to assumed, by policy makers and entities, energy renovation rates and compares with the dynamic model results that have been validated and approach the subject of energy renovation in a different manner.

§ 6.3 Results and discussion

In this part of the paper, graphs of the renovations rates form different cycles (15-30-40 years) are shown based on the results of the dynamic building stock model application to the non-profit housing sector in the Netherlands. Subsequently, we present the results from the time series analysis on renovation rates using SHAERE database. We, then, compare the results and the methods in order to draw conclusions and points of attention in the next section.

Figure 6.5 shows the stock composition in cohorts and how it changes over time according to the model results. Table 6.6 depicts the non-profit dwelling stock composition of cohorts with the data from SHAERE. The simulated share of the stock being constructed before 1945 fits well with the corresponding share of the statistics. The simulated share being constructed from 1946 to 1980 is underestimated by 7.2% whereas the construction from the most recent decades is overestimated. This trend was present in a previous publication where the model was applied in 11 EU countries. The reason for this is, probably, that the model is not able to reproduce short- and medium-term variations in the construction activity that are explained by factors not included in this model, like the post-war construction boom seen in many countries (Sandberg et al. 2016a).

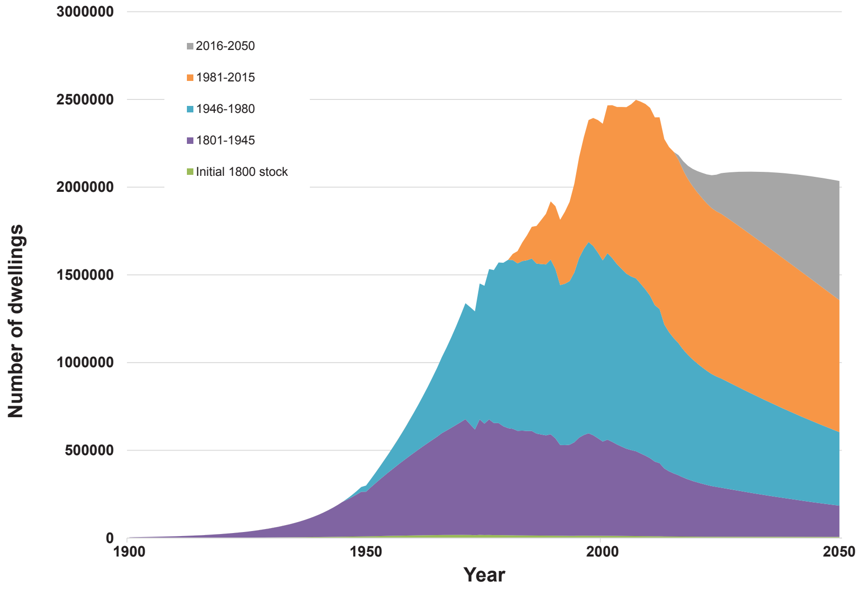

FIGURE 6.5 Simulated dwelling stock composition of the non-profit housing stock in the Netherlands

TABLE 6.6 Comparison of simulated 2011 stock composition with SHAERE data

COHORT NUMBER	START YEAR	END YEAR	STATISTICS (SHAERE 2015)	MODEL RESULTS (2015)	DIFFERENCE (%)
Total			2,189,587 (100%)	1,989,480 (100%)	-
0-1	-	1945	192,602 (8.8%)	143,547 (7.2%)	1.6 %
2	1946	1980	1,142,521(52.2%)	894,639 (45%)	7.2 %
3	1981	2015	854,464 (39%)	951,294 (47.8%)	8.2 %

The simulated development over time in construction, demolition and renovation rates is shown in Figures 6.6, 6.7 and 6.8. The rates are defined as the number of dwellings exposed to the activity in a certain year divided by the total number of dwellings in the stock in the same year. The construction and demolition rates are the same in all three figures, 6.6, 6.7 and 6.8 as the activities are not affected by the renovation cycles. The construction rate was high and increasing, up to 2.5 %, in the period until 1960, due to the strong relative population growth combined with the decrease in number of persons per dwelling. Thereafter, the construction rate has decreased and is expected to keep decreasing to a level of 0.9 % in 2050. This is due to the fact that the construction activity is expected to decrease as a result of the population stabilization. Further, according to the model results, the demolition rate has been rather stable around 0.4-0.5 % and is expected to increase to a level of about 0.7 % by 2050 (see Figures 6.6, 6.7 and 6.8).

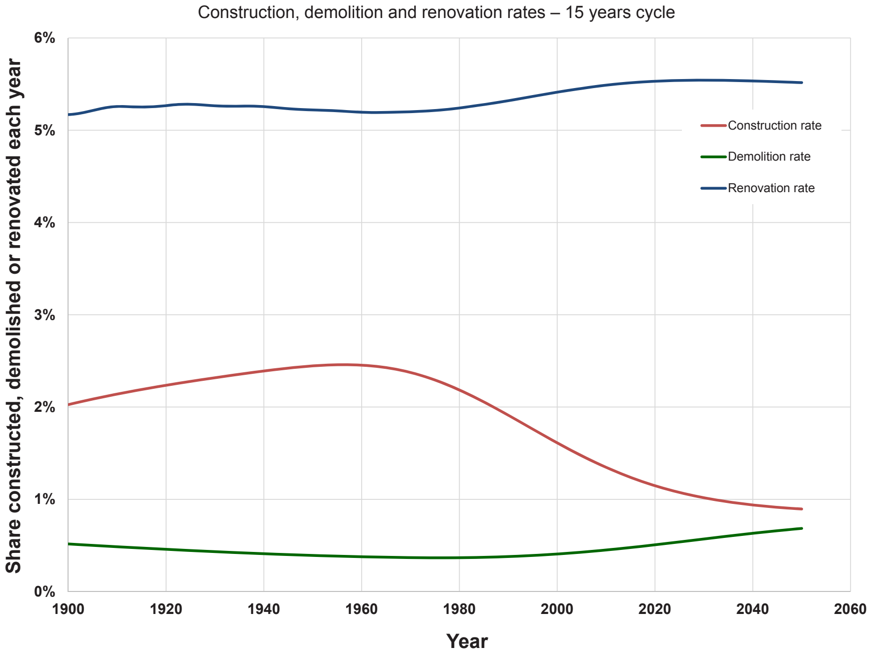

FIGURE 6.6 Construction, demolition and renovation rates, as a percentage of the dwelling stock size in the corresponding year – Renovation cycle 15 years

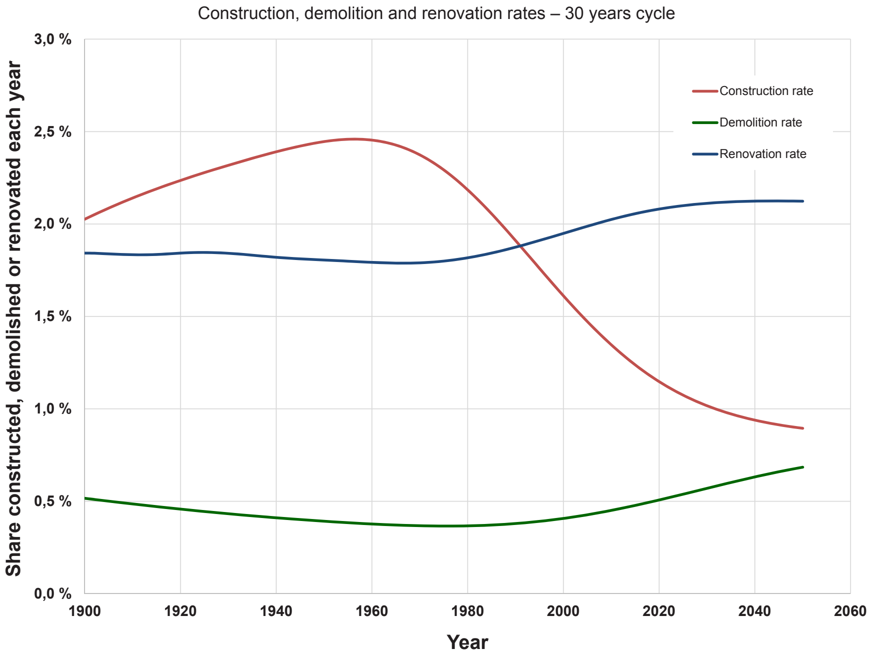

FIGURE 6.7 Construction, demolition and renovation rates, as a percentage of the dwelling stock size in the corresponding year – Renovation cycle 30 years

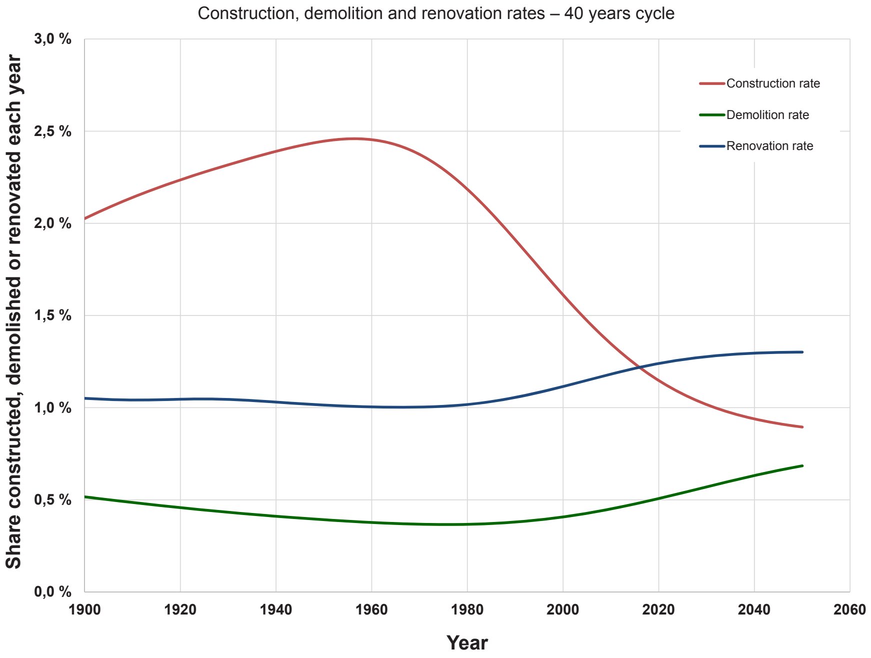

FIGURE 6.8 Figure 6.8: Construction, demolition and renovation rates, as a percentage of the dwelling stock size in the corresponding year – Renovation cycle 40 years

Figure 6.6 depicts the renovation rate when a 15 year renovation cycle is applied. The renovation rate has been rather stable at around 5.1 % and is expected to increase to 5.5 % by 2050. Renovation is expected to be the dominating activity in the system in the coming decades. Figure 6.7 shows the results of the renovation rate when a cycle of 30 years is applied. In this case the rate is stable at 1.8% and is expected to increase to 2.1% in the near future. Following, in Figure 6.8 the deep energy renovation rate is depicted. In this last case, the rate is also stable at 1% and will increase at 1.2% in the years coming. The differences of the rates when different cycles are applied are profound. That is because different levels of renovations are presented in each case. In the next figures, 6.9 and 6.10, the empirical renovation rate results from SHAERE database are presented.

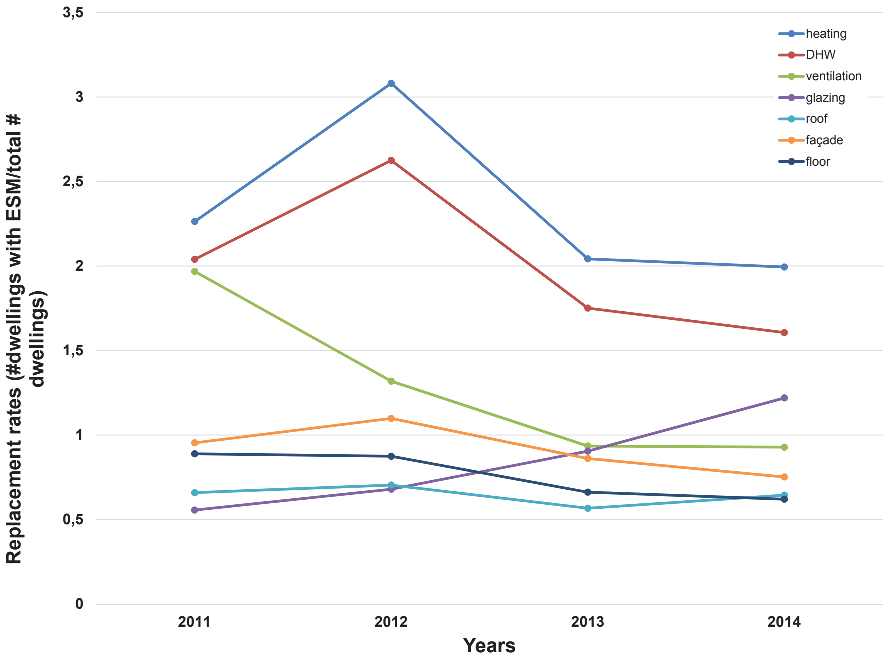

FIGURE 6.9 Replacement rates according to ESMs based on SHAERE

Figure 6.9 depicts the energy renovation rates of the non-profit housing stock when different ESMs are taken into account. The highest replacement or renovation rates concern the heating, DHW and ventilation rates. These are the ESMs that would be depicted in the 15 years renovation cycle of the dynamic model results. If we were to sum these three replacement rates, the result would be around 8% for 2011, 7% in 2012, 4.7% in 2013 and 4.5% in 2014. These empirical results are higher than the simulated renovation rates. However, in this case we rely on detailed information gathered on a collective basis. The ESM glazing has a replacement rate of 0.5% in 2011 and increases gradually to reach 1.2% in 2014. These results are closer to the 30 years renovation cycle of the model in comparison to the 15 year cycle. The floor, roof and façade insulation replacement rates are also depicted in Figure 6.9. These are stable and around 0.5% for all years. If combined together they fit the 40 years renovation cycle shown in Figure 6.8.

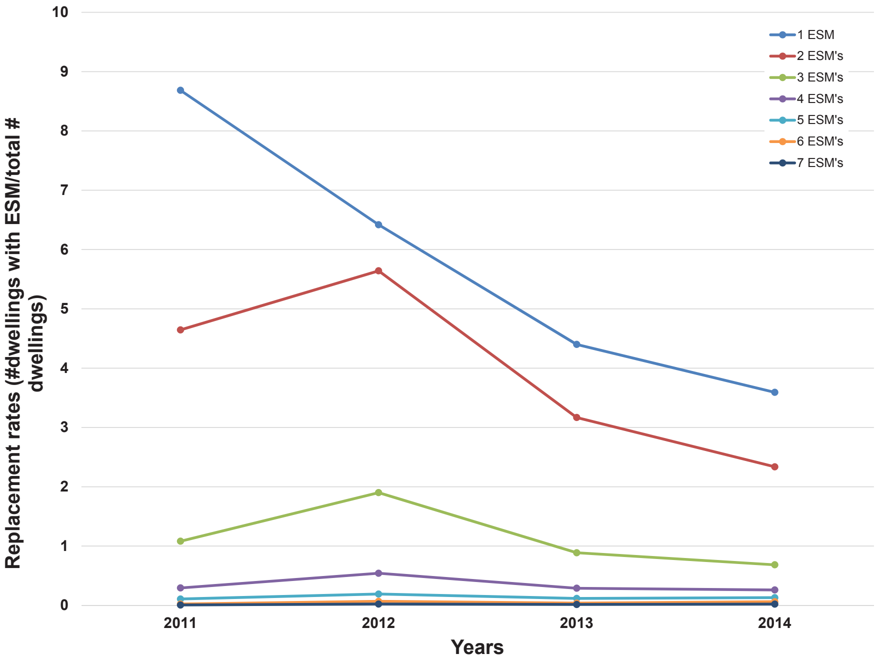

FIGURE 6.10 Replacement rates according to the number of ESMs based on SHAERE

Figure 6.10 depicts the renovation rates according to the number of ESMs applied in the years 2011-2014. If we were to consider a 40 year renovation cycle this would have to be achieved by at least 4 ESMs. If we sum the results of the 4, 5, 6 and 7 ESMs together we result in 1% renovation rate stable for all years. This is in accordance to the simulated results. It seems that the dynamic building stock model is showing better fitted results in longer renovation periods rather than in shorter.

§ 6.4 Conclusions

The 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 paper aimed at introducing different methods of analysis and calculation of renovation rates for the non-profit housing stock of the Netherlands.

We combined two different methods to predict and assess the energy renovation rates of the Dutch non-profit housing stock. The non-profit housing stock is particularly interesting due to its collective nature and, in the Netherlands, due to the higher standards of energy performance agreed and enforced. As a result, the sector is considered a pioneer when it comes to the implementations of ESMs.

According to the simulated results, using the dynamic building stock model developed by Sartori et al., 2015, the renovation rates is 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%. The empirical results show rates at around 1% for the recent years as well. These results are nowhere close to the expected 2-3% used in legislations.

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 way 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.

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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.

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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.

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§ 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.

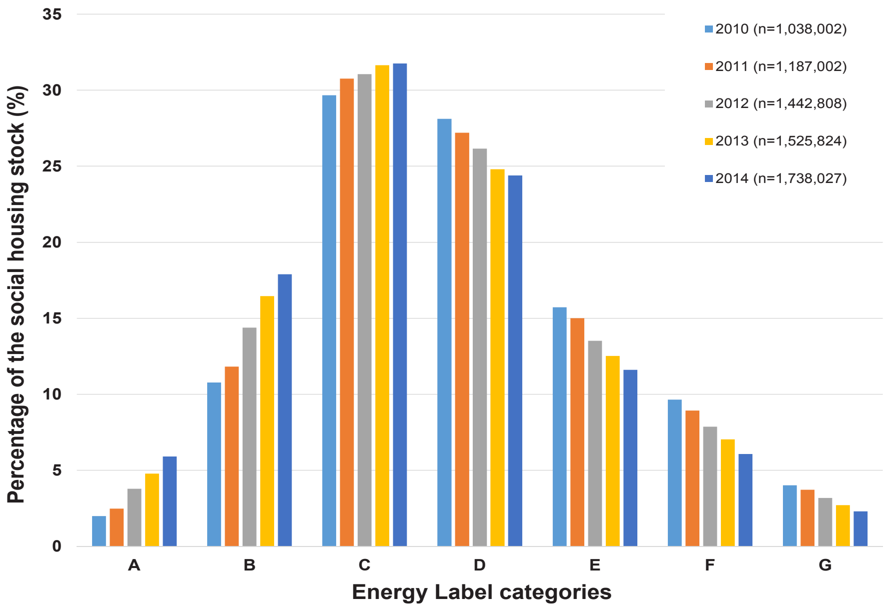

FIGURE 7.1 Distribution of the energy labels of the non-profit rented housing sector in SHAERE database

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 WINDOW 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 ($\eta \geq 0.95$)	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/m^2/year. The mean gas consumption for the Dutch households, as reported by Statistics Netherlands in 2015, is 151.80 kWh/m^2 (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/m^2/year)	119,30 (kWh/m^2/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.

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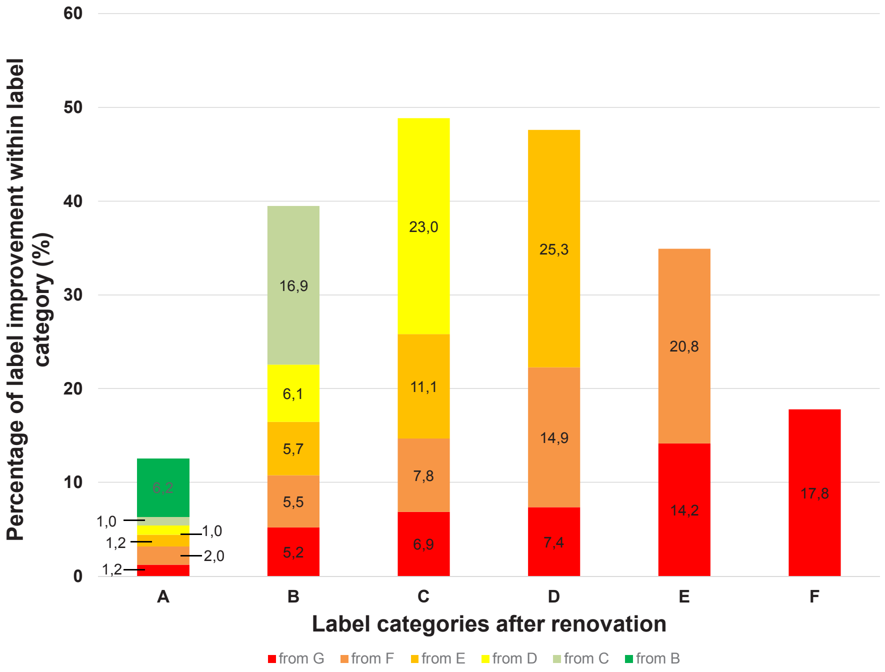

FIGURE 7.2 Improvement of labels of the non-profit rented housing sector from 2010 to 2014

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.

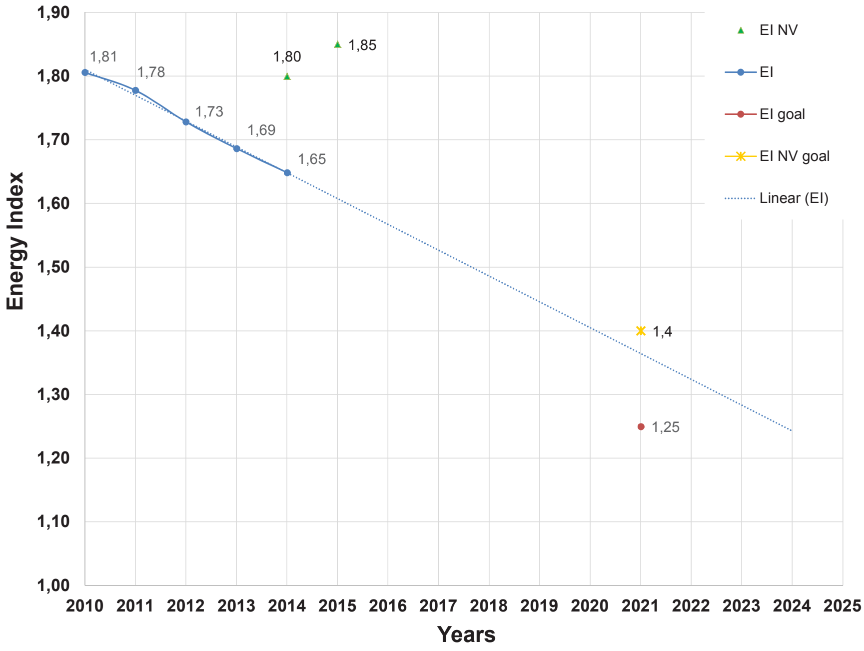

FIGURE 7.3 The Energy Index (EI) development of the non-profit rented housing sector in SHAERE database

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.

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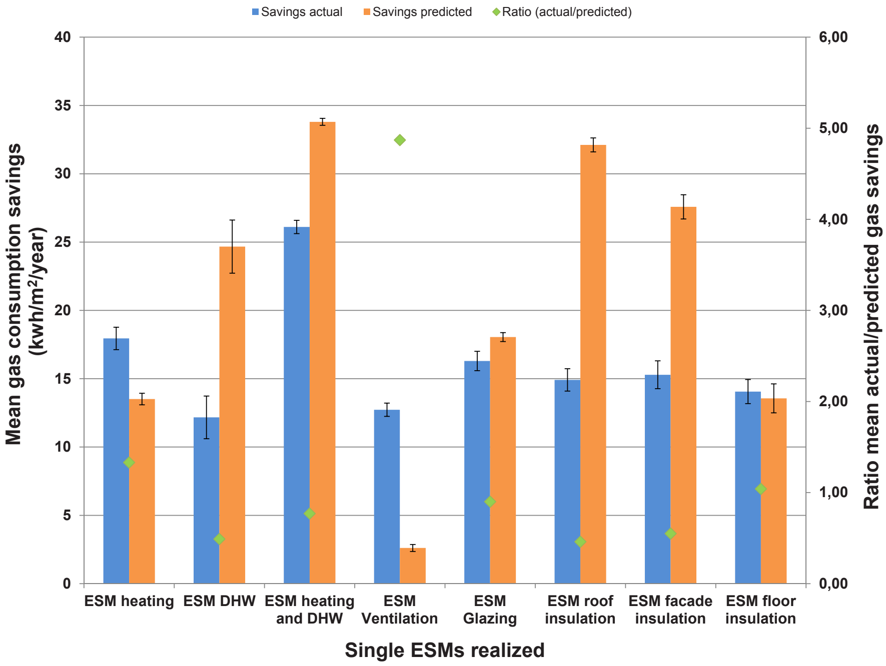

FIGURE 7.4 Mean actual and predicted gas consumption savings for dwellings with single ESMs

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.

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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

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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

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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.

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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

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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.

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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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Appendix A SHAERE monitoring system variables

This appendix presents the tables and variables of the SHAERE monitoring system used in this research.

VARIABLES			SOURCE	COMMENTS
parameters -identification	1	Dwelling ID	SHAERE	8 digit unique number
	2	Street name	SHAERE	Encrypted in continuity
	3	Postcode	SHAERE	Encrypted in continuity
	4	House number	SHAERE	Encrypted in continuity
	5	House number extension	SHAERE	Encrypted in continuity
	6	Status dwelling	SHAERE	Rented /sold /demolished
	7	Housing association name	SHAERE	Encrypted in continuity
parameters -performance	8	EI (Energy Index) current	SHAERE	Current value of EI (in the specific year)
	9	EI registered	SHAERE	Official value of EI
	10	Energy label registered	SHAERE	Official energy label
	11	Registration year	SHAERE	Registration year of the label
	12	CO_2 emissions	SHAERE	Calculated by EPA software based on ISSO 82.3[1] – kg
	13	Theoretical electricity consumption	SHAERE	Calculated by EPA software based on ISSO 82.3[1] – kWh
	14	Theoretical gas consumption	SHAERE	Calculated by EPA software based on ISSO 82.3[1] – MJ
	15	Theoretical heat consumption	SHAERE	Calculated by EPA software based on ISSO 82.3[1] – MJ

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VARIABLES			SOURCE	COMMENTS
parameters - dwelling characteristics	16	Dwelling type	SHAERE	Detached/ Semi-detached/ Terraced mid-row/ Terraced end-row/ Flat with common staircase & galleries/ Flat with common staircase but no galleries/ Maisonette/ Other multi-family
	17	Dwelling sub-type	SHAERE	Only for multi-family dwellings (e.g. middle row)
	18	Net area	SHAERE	m^2
	19	Building type	SHAERE	Light /traditional /heavy
	20	Building year	SHAERE	Existence of default value (1980)
	21	Renovation year	SHAERE	Often not filled in – not compulsory
	22	Mean insulation floor	SHAERE	R_c-value [m^2K/W]
	23	Net floor area	SHAERE	m^2
	24	Mean insulation roof	SHAERE	R_c-value [m^2K/W]
	25	Net roof area	SHAERE	m^2
	26	Mean insulation facades	SHAERE	R_c-value [m^2K/W]
	27	Net heated facade area	SHAERE	m^2
	28	Net facade area (rest)	SHAERE	m^2
	29	Mean insulation windows	SHAERE	U-value (W/m^2K)
	30	Net windows area	SHAERE	m^2
	31	Mean insulation door	SHAERE	R_c-value [m^2K/W]
	32	Net door area	SHAERE	m^2
	33	Envelope insulation	Produced from SHAERE data	R_c-value [m^2K/W]
	34	Net envelope area	Produced from SHAERE data	m^2

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VARIABLES			SOURCE	COMMENTS
parameters - installations	35	Heating system (a)	SHAERE	Collective/individual
	36	Heating system (b)	SHAERE	Gas or oil stove/ Electric stove/ "Conventional" boiler ($\eta<0.80$)/ Improved non-condensing boiler ($\eta=$ 0.80-0.90)/ Condensing boiler ($\eta=$0.90-0.925)/ Condensing boiler ($\eta=$0.925-0.95)/ Condensing boiler ($\eta\geq0.95$) / District heating/ Heat pump/ µCHP
	37	Supply temperature of heating system	SHAERE	High (>55°C)/ Low (35 °C)/ Very low (<35°C)
	38	DHW (Domestic Hot Water) system (a)	SHAERE	Collective/individual
	39	DHW system (b)	SHAERE	Tankless gas water heater/ Gas boiler/ Electric boiler (<20L)/ Conventional "combi-boiler" ($\eta<0.80$)/ Improved non-condensing combi-boiler ($\eta=$0.80-0.90)/ Condensing combi-boiler ($\eta=$0.90-0.95)/ District heating/ Heat pump/ µCHP
	40	Type of heat recovery tap water	SHAERE	Yes/ no, or the efficiency
	41	Ventilation system	SHAERE	Natural/ Mechanical exhaust/ Mechanical supply and exhaust. (balanced) central/ Mechanical supply and exhaust. (balanced) decentralised
	42	Ventilation heat recovery system	SHAERE	Yes/ no, or the efficiency
	43	Photovoltaic system	SHAERE	Amorphous/ Monocrystalline/ Polycrystalline
	44	Photovoltaic system area	SHAERE	m^2
	45	Solar thermal system	SHAERE	Collective/ individual
	46	Solar thermal system area	SHAERE	m^2
META data			**Per dataset**	
1		Date export to SHAERE	SHAERE	
3		Number of dwellings	SHAERE	
4		Date of data registration	SHAERE	

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[1] *ISSO (Dutch Building Services Knowledge Centre). (2009). ISSO 82.3 Formula Structure Publicatie 82.3 Handleiding EPA-W (Formulestructuur). (In Dutch)*

Appendix B Common article EPISCOPE

G Model
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Dynamic building stock modelling: Application to 11 European countries to support the energy efficiency and retrofit ambitions of the EU

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ABSTRACT

A dynamic building stock model is applied to simulate the development of dwelling stocks in 11 European countries, over half of all European dwellings, between 1900 and 2050. The model uses time series of population and number of persons per dwelling, as well as demolition and renovation probability functions that have been derived for each country. The model performs well at simulating the long-term changes in dwelling stock composition and expected annual renovation activities. Despite differences in data collection and reporting, the modelled future trends for construction, demolition and renovation activities lead to similar patterns emerging in all countries. The model estimates future renovation activity due to the stock's need for maintenance as a result of ageing. The simulations show only minor future increases in the renovation rates across all 11 countries to between 0.6–1.6%, falling short of the 2.5–3.0% renovation rates that are assumed in many decarbonisation scenarios. Despite this, 78% of all dwellings could benefit from energy efficiency measures by 2050, either as they are constructed (31%) or undergo deep renovation (47%). However, as no more than one deep renovation cycle is likely on this timeframe, it is crucial to install the most energy efficient measures available at these opportunities.

1. Introduction

Delivering energy efficiency improvements in the building stock is central to published city and national plans to achieve carbon reduction targets across Europe [1,2]. According to a recent EU-JRC report [3], energy renovation is instrumental for reaching the EU2020 goals i.e. reduce GHG by 20%, have 20% of energy from renewables and increase in energy efficiency by 20%. This calls for a common EU renovation plan with a regional approach prioritizing less developed regions. In the EU, feasibility studies, national roadmaps and action plans for energy savings in building stocks commonly assume a significant increase in the renovation rates in order to obtain future energy savings, but the likeliness of reaching these increased rates is rarely evaluated or discussed [4–9].

Understanding and influencing the existing and future dwelling stock is of vital importance as there are significant lock-in risks associated with the long lifespans of buildings and infrastructures

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[10,11]. Consequently, the majority of today's dwellings will still exist in 2050 and beyond [12]. If stringent regulations are not introduced universally and high-standard energy retrofits are assured when buildings are renovated, energy use and corresponding GHG emissions could be 'locked-in' for many decades to come. This lock-in is estimated to lead to a 33% increase in global energy use for buildings by 2050 instead of a decrease of 46% if changes are made [13].

Dwelling stocks were constructed over various periods (cohorts) and segments of the stock to be prioritized for renovation should be identified [14]. Housing stocks are exposed to refurbishment activities during the ageing process, and renovation in the coming decades to a large extent depends on the age composition of the stock and the previous renovation activity.

Throughout Europe, national approaches for the monitoring of the building stock have evolved separately [15]. Information about the progress of the energy performance renovation is required to track the progress of policy implementation. Better information and data are needed to help develop roadmaps in order to achieve more energy efficient buildings [4]. To address the shortcomings and challenges identified there is a need for a new methodology that can be used for consistent and scalable analysis of building stock across multiple countries.

Energy analyses of dwelling stocks are defined by a stock model and an energy model. The stock model describes the development of the stock in terms of size, composition and renovation state, whereas the energy model includes average energy intensities of the various segments of the stock, and assumed savings obtained when dwellings are renovated. Standard linear dwelling stock models commonly assume fixed rates for construction, demolition and renovation activities [16–18] whereas in reality these rates are dynamic, both in the short and long term, and depend upon external drivers as well as the type and age composition of the building stock. The nature of housing supply and the impacts of demands and housing supply is elastic, but an increase in demand in the long term is expected as a result when population increases [19].

In the literature, there are various models and tools to assess energy consumption in dwelling stocks. Kavgic et al. [20] differentiated between top-down and bottom-up approach in stock-level energy consumption modelling. They highlighted the importance of transparency and quantification of inherent uncertainties within any stock model. A range of bottom-up models are used for material, energy or carbon analyses of dwelling stocks, e.g. [21–25]. Meijier et al. [24] also identified serious gaps in the monitoring of the physical residential stock, noting that none of the countries monitored the renovation effects on the housing stock. In material, energy or carbon analyses of building stocks there is often a lack of data on the models' inputs and outputs, as well as the algorithms used that make the reproduction of the results difficult [20,24]. Developing scenarios of future dwelling stock energy demands can unearth such discrepancies, uncertainties, and areas of improvements as well as highlighting the need of more robust data collection [26]. There is a need to quantify and analyze the robustness of key data from retrofitting rates to total stock and its associated assumptions in order to understand the influences of the long-term transformation of the dwelling stock [27].

There is a lack of dwelling stock models that describe the development of the stocks in a good way, and it becomes clear that there is an urgent need to get a more detailed understanding of the long-term dynamic of the dwelling stocks to be able to evaluate the future energy reduction potential. This will lead to a deeper understanding of the dynamics that drive the activities in the system and should be a precondition for a more consistent way to address evolutions of the existing and future building stock and its energy demand. This should also support the previous request for the definition on future practice for the dwelling stock [28].

A dynamic dwelling stock model has been developed through a range of publications and is used to study the long-term development in dwelling stock size and composition with various applications [29–41]. The core of the model is the population's need to reside and the main input parameters are the drivers in the system, the population and the number of persons per dwelling. The construction, demolition and renovation activity in the system are outputs from the model, aiming at describing the dynamics of the stock resulting from the changing demand and ageing of the stock.

A separate paper explored the sensitivity in model results and conclusions to changes in input parameters. For the case of Norway, they concluded that the most sensitive input parameters population and lifetime of dwellings are also the input parameters of highest uncertainty. However, even when changing these input parameters to extreme and unrealistic values, the main conclusions regarding future renovation rates remained unchanged. The model results and conclusions for the case study of Norway were robust to changes in the input parameters. Renovation rates at levels necessary to achieve polity targets in energy and emission savings seemed unrealistic to be achieved when modelling the "natural" need for renovation [38].

The dynamic dwelling stock model is general, though the version focussing on renovation so far has been applied only to Norway [31,37,40]. In the present paper, we apply the same method to analyze the construction, demolition and renovations activities in the dwelling stocks of 11 European countries using consistent definitions and data for all countries, to evaluate how the model fits to other countries and if general conclusions can be made across a range of European countries. The model and algorithm presented in Sartori et al. in this issue [40] are applied to Cyprus, Czech Republic, France, Germany, Great Britain, Greece, Hungary, the Netherlands, Norway, Serbia and Slovenia. For each country the housing stock is modelled with respect to its past evolution and with projections towards 2050.

The key research questions to be addressed are:

- How well does the model represent the long-term historical development in the dwelling stocks of the given European countries?
- What are the differences between the countries in data availability, feasibility of the model, quality of the results and national conclusions to be drawn from the results?
- What general trends are observed and what general conclusions can be made from the comparative analysis of the results from the different countries?
- What is the potential for future development in energy-related renovation of the dwelling stocks in the given European countries and to what extent are these findings in line with the recommendations from Saheb et al. [3] or the assumed renovation rates in traditional scenario models, national roadmaps and action plans [4,6]?

2. Methods

2.1. Overview of the dynamic dwelling stock model

A full description of the model, including the underlying equations and justification, is provided by Sartori et al. in this issue [40]. The key principles and model steps are now summarized to enable understanding of the analysis presented in this paper, while the model equations are presented in Appendix A.

The dynamic dwelling stock model describes the long-term development of the size and age composition of the dwelling stock in a country or region. The conceptual framework of the model is presented in Fig. 1. The core model driver is the population's need

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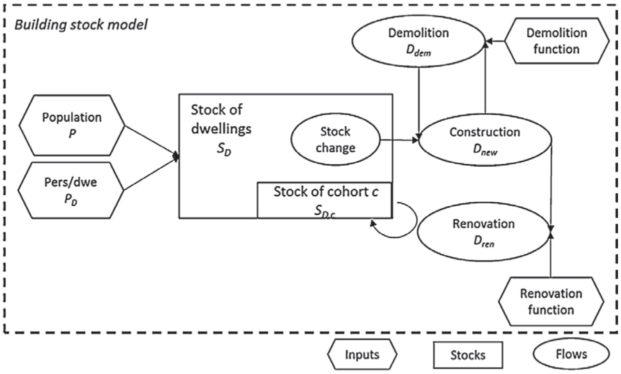

Fig. 1. Conceptual framework of the model.

to reside. Annual demand for dwellings S_D is estimated as the population P divided by the average number of persons per dwelling P_D. The total number of demolished dwellings D_{dem} is estimated each year by applying a demolition probability function on the construction from all previous years. A defined share of the construction from each year is assumed never to be demolished to preserve the national building heritage. Mass balance principles are used to estimate the construction activity D_{new} in year i, that is equal to the sum of new dwellings that are needed in order to replace the demolished ones and meet the change in demand from year i–1 to year i.

Finally, renovation activity D_{ren} in year i is estimated by applying a renovation probability function to the construction from all previous years. The model allows for cyclic repetitions of the renovation probability function, described by the average time between renovations of a certain dwelling, R_C. The cyclic renovation probability function is linked to the lifetime probability function, preventing a dwelling to be demolished shortly after being renovated. The definition of the renovation activity is case-specific and the related renovation cycle should describe the average time between renovations of the defined type.

The model results are the yearly demand for dwellings S_D, construction activity D_{new}, demolition activity D_{dem} and renovation activity D_{ren}, as shown in Fig. 1. Model results are segmented in cohorts (construction periods c) to visualize the stock composition of different cohorts as well as to understand the extent to which different cohorts are exposed to demolition or renovation activity.

2.2. Input data and assumptions

The input data used in this study are summarized in this section. Detailed information about the data sources, assumptions and data processing for each country is presented in Appendix B.

In some of the countries included in the study, the geographical area belonging to the country has changed over time. When this is the case, input data referring to the current territory of the country are collected or estimated by rescaling data from other time periods or from a geographical area not completely corresponding to the current territory of the country. Historical data on number of persons per dwelling is sometimes only available for parts of the territory or a larger area, and this is then assumed to be representative for the geographical area currently belonging to the country. When relevant, this is explained in detail for each country in Appendix B.

Short-term variations in the input time series population P and persons per dwelling P_D result in fluctuations in the model results. This can give the impression that the model captures short-term processes. To avoid this noise in the results, non-linear regression is applied to the raw data to make smooth input curves for population P and persons per dwelling P_D.

2.2.1. Population

Population statistics, projections and some additional assumptions are used to create the smooth input curves for the population. The details of the data availability and data processing for each country are presented in Appendix B. The availability of population data is good in all countries, mainly sourced from census data and population projections from national statistics offices. In some countries, however, like the Czech Republic and Serbia, it is difficult to fit a smooth curve to the raw data due to periods of rapid changes in the population. In the Czech Republic the strong increase in the population in the early 1900s and the subsequent decrease during and after World War II are not well reflected in the smoothed curve. In the case of Serbia the smoothed curve differs notably from the raw data in the recent past and the future.

The smooth population curves are presented in Fig. 2. The non-linear regression function with the best fit was chosen for each country. In countries with a steadily increasing population, a Sigmoidal regression is used. A Gaussian regression is used in the countries where the population has increased followed by a period of (expected future) decrease. The R^2 value of the non-linear regression was larger than 0.95 for all countries. Model projections are most sensitive to the recent past rates of change. For all countries except Cyprus, Czech Republic and Serbia the smooth regression curve shows a very good fit with the raw data for this critical period. For these three exceptions, the poorer fit is considered when analyzing the results.

2.2.2. Persons per dwelling

Historical persons per dwelling data are available from censuses since about 1900 in most of the countries, in Great Britain and Norway since 1800 and in France, Germany and Serbia since about 1950. Future development in P_D is based on assumptions and continuation of trends for each country. When full time series are not

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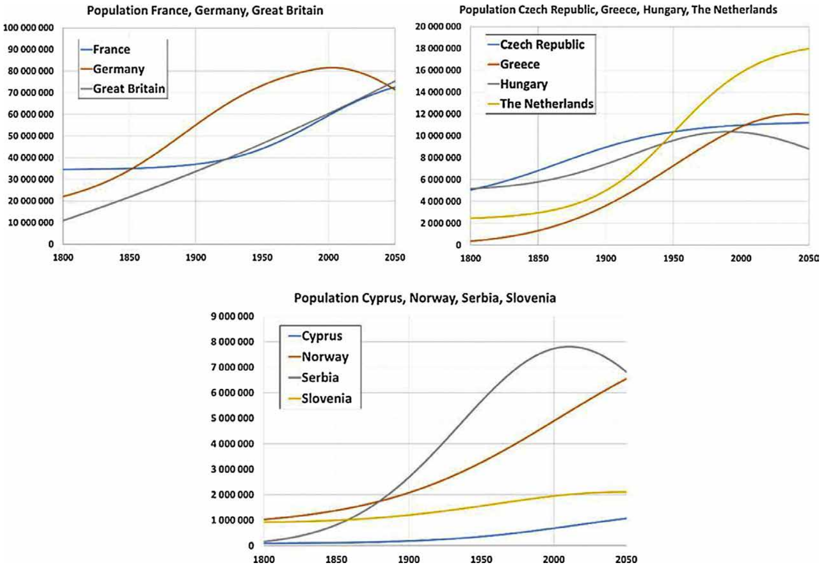

Fig. 2. Development in population (P) in all countries, countries are grouped into three graphs according to population size.

available, additional assumptions are included in the regression to obtain a smooth input curve for the whole period 1800–2050. This is explained in detail for each country in Appendix B.

The smooth P_D curves have the same shape for all countries, although with different starting values. Sigmoidal non-linear regression is used. The shape of the typical curve is exemplified for the case of Great Britain in Fig. 3 together with the raw data used to make the smooth curve. Further, the extreme cases of Serbia and Cyprus are also presented in Fig. 3. Serbia has a high starting value of 6.7 persons per dwelling in 1800. Cyprus is the country with the lowest starting value of 4.1 and the atypical development with a constant level of persons per dwellings from 1800 to 1965 followed by a rapid decrease to a level of 1.9 in 2011. All other countries have a smooth curve with a shape more similar to the curves presented for Great Britain and Serbia, starting at a value of 4.6–5.5 and ending at approximately 2 persons per dwelling in 2050, as shown in Appendix B.

2.2.3. *Dwelling lifetime and renovation parameters*

The lifetime probability function is assumed to follow a Weibull distribution defined by the parameters average lifetime per dwelling and the initial period after construction where the probability of demolition is zero. This is explained in detail in Sandberg et al. [37] and Sartori et al. (this issue) [40], and is consistent with recommendations by Sereda [42]. The country-specific probability function parameters are described in Appendix B.

The definition of the renovation activity in the model is case-specific. An "energy saving modernization" such as changing the heating system or installing a photovoltaic can be thought as having a 20-year cycle or even shorter. In this study though, we explore the dynamics of deeper renovations that have the potential for including energy-efficiency measures that lead to much larger reductions in energy demand. These measures are costly and unlikely to be implemented if a dwelling is not going through a major renovation in any case, perhaps due to its "natural" ageing process, a change of ownership, or the need for maintenance and upgrading. We estimate the total renovation activity resulting from the ageing process of the dwelling stock in each country involved. For most countries, this relates to deep renovation of facades, commonly estimated to occur in cycles of 40 or 50 years. Only in the case of Greece are single measures with a renovation cycle of 30 years are assumed to have a larger contribution to the energy savings than deep renovation of facades. The renovation probability function is assumed to follow a Normal distribution for all countries, as explained in detail in Sandberg et al. [37] and Sartori et al. (in this issue) [40].

The lifetime and renovation parameter values for all countries are listed in Table 1. The column "Construction period" refers to which segments of the stock the assumptions are applied to. In principle, the parameter values can differ between dwellings constructed in different years. However, due to limited empirical data, the same values are assumed for all dwellings regardless of construction year for all countries except Hungary. In the case of Hungary, the initial period without demolition is assumed to decrease for future construction. Further descriptions, references and explanations of the parameter values chosen for each country are given in Appendix B.

2.2.4. *Cohort definition*

Some of the model results will be segmented into cohorts. For easier comparison of the results, the cohorts are defined equally for all countries, as listed in Table 2. Cohort 0 represents the initial stock at the start of the modelling in year 1800, Cohort 1 is

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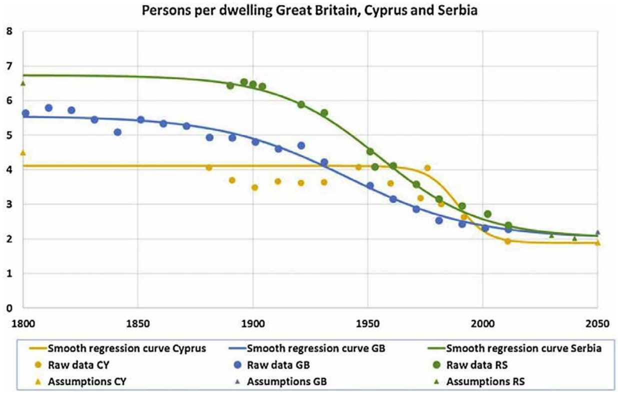

Fig. 3. Evolution in the number of persons per dwelling (P_D) in Great Britain, Cyprus and Serbia.

Table 1
Lifetime and renovation parameter values for all countries.

Country	Construction period	Average Lifetime (years)	Initial period without demolition (years)	Share never demolished	Renovation cycle (years)
Cyprus	All	125	40	5%	40
Czech Republic	All	120	60	5%	40
France	All	125	40	5%	40
Germany	All	125	40	5%	40
Great Britain	All	175	40	10%	40
Greece	All	70	40	5%	30
Hungary	–2015	125	50	5%	40
	2016–	125	40	5%	40
The Netherlands	All	120	40	3%	38
Norway	All	125	40	5%	40
Serbia	All	100	50	5%	50
Slovenia	All	120	40	8%	40

Table 2
Cohort definition.

Cohort number	Start year	End year
0	–	1800
1	1801	1945
2	1946	1980
3	1981	2015
4	2016	2050

the construction from 1801 to the end of World War II. Although there are large differences between the dwellings constructed in the early 1800s and in the 1930s, it is assumed that future renovation technologies, including those for energy-saving purposes, will be similar. The share of the current stock constructed before 1945 is also limited (less than 25% in most of the countries considered here). Cohort 2, 3 and 4 represent periods of 35 years where Cohort 2 is the post-war construction from 1946 to 1980, Cohort 3 is the most recent construction from 1980 to 2015 and Cohort 4 is future construction from 2016 to 2050.

3. Results and discussion

Country-specific detailed results are described in Appendix B. In the following, the results are presented for all countries, or making reference to one or a subset of countries.

3.1. *Dwelling stock size and composition*

The observed historical development of dwelling stock size, measured in terms of the number of dwellings, is used as an input to the model through the parameter persons per dwelling P_D. Nevertheless, the model results are compared with the statistics to ensure that the smoothening of the input curves has not resulted in significant differences between the model results and the statistics. For all 11 countries in this study, there is a good fit, as shown in Table 3 and the related discussion.

In Fig. 4 the modelled dwelling stock size, and composition of cohorts, is presented for all countries for the years 1980, 2015 and 2050. The current stock size varies significantly, from 0.4 million dwellings in Cyprus to 39 million dwellings in Germany. Therefore, all results are normalized against the size of the stock in the respective country in 2015. The total number of million inhabited dwellings in each country in 2015 is shown next to the 2015 bar.

Fig. 4 shows that the size of the dwelling stock has increased in all countries from 1980 to 2015, although at different rates. In all countries except in Cyprus, the number of dwellings in 1980 was 62- 84% of the current stock size. Cyprus has experienced a large recent growth in the dwelling stock and the simulated 1980 stock was only 35% of the current stock size. According to the country-specific comparisons with statistics presented in Appendix B, there was a large increase in the construction activity in the Repub-

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Table 3
Stock composition compared with statistics.

	*Year of comparison		Cohort 0–1 (–1945) % share	Cohort 2 (1946–1980) % share	Cohort 3 (1981–*) % share	Unknown cohort % share	Total % share
Cyprus	2011	Statistical	2.0	23.1	74.8	–	100
		Modelled	11.6	19.8	68.6	–	100
Czech Republic	2011	Statistical	22.0	43.0	32.6	2.3	100
		Modelled	35.2	32.7	32.1	–	100
France	1999	Statistical	32.9	45.7	21.3	–	100
		Modelled	32.7	38.6	28.7	–	100
Germany	2009	Statistical	24.5	43.5	32.0	–	100
		Modelled	31.5	35.5	32.9	–	100
Great Britain	2013	Statistical	36.9	39.8	23.3	–	100
		Modelled	30.0	32.1	37.9	–	100
Greece	2011	Statistical	5.7	49.3	45.0	–	100
		Modelled	8.3	34.3	57.4	–	100
Hungary	2011	Statistical	29.2	40.0	30.8	–	100
		Modelled	30.6	34.6	34.7	–	100
The Netherlands	2012	Statistical	19.5	40.9	39.7	–	100
		Modelled	18.2	37.2	44.6	–	100
Norway	2011	Statistical	16.6	42.7	36.4	4.4	100
		Modelled	22.4	33.5	44.1	–	100
Serbia	2011	Statistical	11.9	52.6	35.5	–	100
		Modelled	15.7	40.9	43.4	–	100
Slovenia	2013	Statistical	21.3	45.0	33.7	–	100
		Modelled	27.6	31.3	41.1	–	100

lic of Cyprus after the Turkish invasion in 1974. This increase is delayed by about 10 years in the simulation, and the real number of dwellings in 1980 was therefore somewhat higher than in the value shown in Fig. 4.

The dwelling stocks are expected to keep growing in all countries except those with decreasing future population projections: Germany, Hungary and Serbia. The expected increase in the stock size in the other countries is 12–25%, except in Cyprus and Norway where the expected increase is about 35%.

A decrease in the length of a certain color in the bars shown in Fig. 4 from one observation year to the next, indicates the simulated demolition of dwellings from the corresponding cohort between the two observation years. A new color shows the new construction in the given period, represented as a new cohort.

In Table 3, the simulated dwelling stock size and composition is compared with the most recent official national statistics on the dwelling stock composition for each country. A common pattern is observed in many of the countries: the stock is composed of a small share of dwellings constructed before 1945 and the model results compare well with these statistics. For most countries, this share is 6–25% of the stock. Exceptions are Great Britain, Hungary and France with shares of the stock being constructed before 1945 of 30–37%. From the larger shares of the stock constructed after 1946, the post-war construction boom in cohort 2 is commonly not fully explained by the model, and the construction from the most recent decades is commonly somewhat overestimated. These discrepancies are expected to lead to corresponding distortions in the model results on renovation activity in the relevant cohorts, but the resulting total renovation activity of the stock is not expected to be significantly affected by this.

3.2. Construction, demolition and renovation activity by country

The simulated construction and demolition activity is compared with statistics for each country in Appendix B. Construction statistics are available in most countries since about 1950–1980. For most countries, the long-term level of construction activity is broadly comparable with reported statistics. A common pattern is however observed in many countries where construction statistics are available: the model tends to underestimate the post-war construction boom between 1950/60–1980/90, and thereafter overestimates the construction activity in the most recent decades. This is also in line with the comparison of the simulated current stock composition with statistics from Table 3. The short- and medium-term variations in construction activity are explained by factors not included in the model, e.g. wider drivers such as economic, climate and unemployment.

Demolition statistics are hardly available, except for in the Czech Republic since 1955 and in some few other countries since about year 2000. The long-term demolition activity seems to be at the right level for the Czech Republic. However, the model results are generally slightly higher than the reported values for 1956–1990, which can be explained by the large number of dwellings destroyed during World War II and therefore not demolished at a later date, when they would have reached their end of life. The consequences of World War II are not captured in the model.

Results for expected annual renovation activity (R_i) in year 2015, 2030 and 2050 are presented for all countries in Fig. 5. The results are normalized against the 2015 total for each country. Fig. 5 shows the development in total renovation activity and its distribution to dwellings constructed in the different cohorts. In all countries except Cyprus, the model forecasts the yearly number of dwellings renovated to increase by 4–18% by 2030 and by 4–41% by 2050, compared with the 2015 rate. Future renovation activity will, to a larger extent, take place in dwellings constructed after 1980, as these dwellings reach an age with increased need for maintenance. The need for renovation of older dwellings will decrease due to the demolition of dwellings in these cohorts.

Cyprus is in a special situation due to the rapid recent and expected future growth in the dwelling stock size. This will lead to an increase in the required future renovation activity to maintain the new building stock. By 2030, the estimated annual number of dwellings needing renovation ($D_{ren,2030}$) is expected to be 70% higher than the current number of dwellings renovated ($D_{ren,2015}$). The increase in renovation will mainly take place in dwellings constructed in the period 1980–2015. By 2050 there will also be some need for renovation of dwellings constructed after 2016, and the total renovation activity is expected to be 85% larger than in 2015.

3.3. Interplay of construction, demolition and renovation

The simulated development in annual rates of construction, demolition and renovation for France, Hungary, Great Britain and Germany is presented in Fig. 6. France and Great Britain

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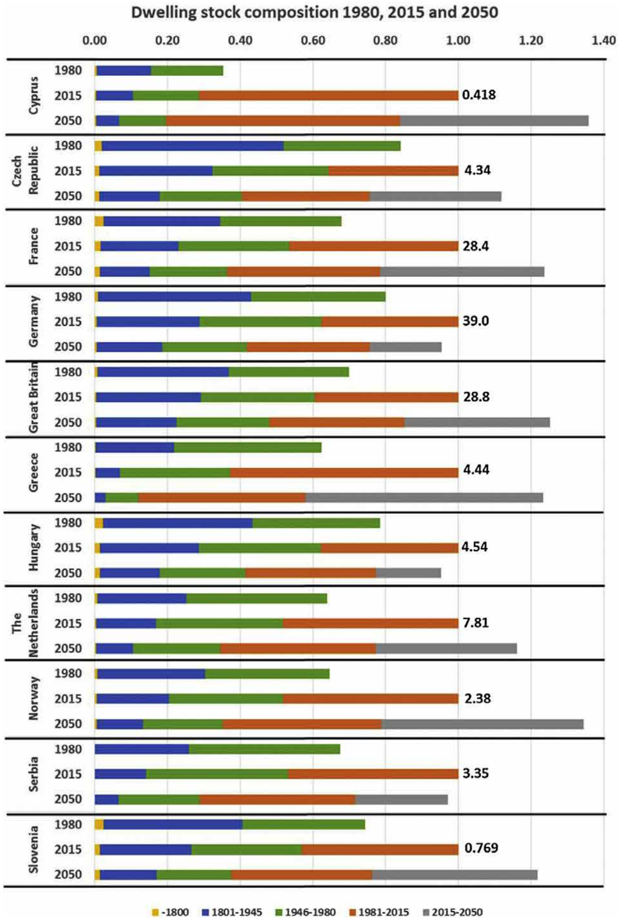

Fig. 4. Normalized dwelling stock composition in all countries in 1980, 2015 and 2050, relative to the 2015 total stock size. The numbers next to the 2015 bars are the number of million dwellings in total in the 2015 stock.

demonstrate a development pattern that is typical of most of the countries with increasing future population, whereas Hungary and Germany demonstrate typical development pattern in countries with expected decreasing population. All rates are defined as the number of dwellings exposed to the activity divided by the total number of dwellings in the stock in the same year.

Most countries in the study follow the same pattern as France and Great Britain: The simulated construction rate was high from 1900 to about 1950–1980. Thereafter there has been a decrease in the construction rate, and the decrease is expected to continue in the future. This is due to slower population growth and saturation of the number of persons per dwelling. Further, the simulated annual demolition rate in most countries has been rather stable at 0.3–0.7% in the past and is expected to remain at the same level or increase slightly to about 1.0% by 2050.

Similarly, in most countries the simulated annual renovation rate has been stable at 1–1.5% and is expected to remain at the same levels or increase slightly towards 2050. Our simulations suggest that renovation will, in most countries, be the dominant activity in

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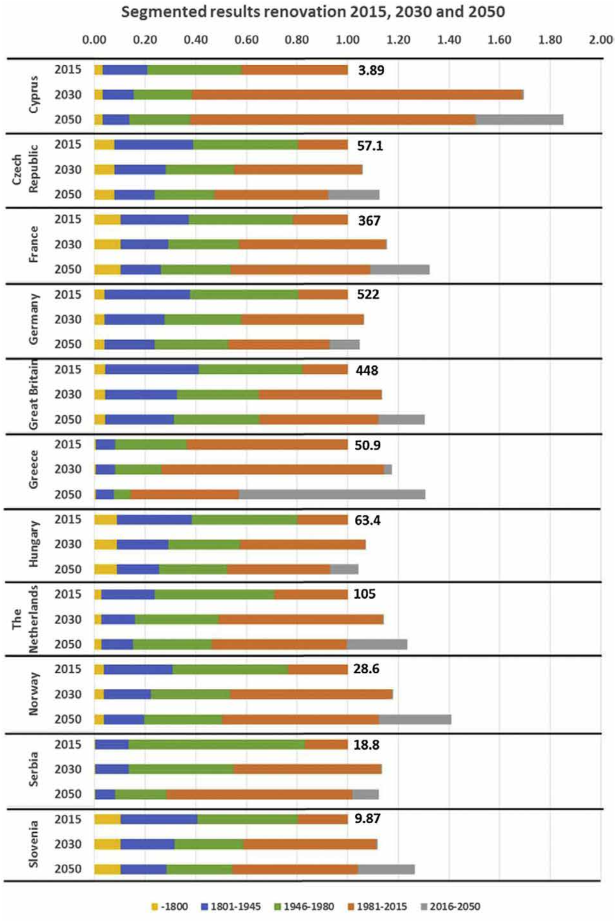

Fig. 5. Segmented results for expected annual renovation activity ($D_{ren,\,i}$) for all countries in 2015, 2030 and 2050, relative to the number of dwellings renovated in 2015 ($D_{ren,\,2015}$). The numbers next to the 2015 bars are the total number of thousand dwellings renovated in 2015.

the system in the future, in terms of number of dwellings exposed to the activity.

In some of the countries, the size of the population has leveled off and is expected to decrease in the future. The construction, demolition and renovation rates follow the pattern shown for Hungary and Germany in Fig. 6, where the annual construction rate has strongly decreased and is expected to fall to about 0.4% by 2050. The simulated annual demolition and renovation rates increase in these countries in the future, as the stock size is decreasing, and the construction rate is expected to be lower than both the demolition and the renovation rates towards 2050.

The simulated construction, demolition and renovation rates for all countries in the years 2015, 2030 and 2050 are listed in Table 4. Minor variations over time are observed in the construction and the demolition rates. The simulated renovation rates, also presented in Fig. 7, are stable through time in all the countries and never exceeds 1.6% in any country. These describe the future expected renovation activity needed for maintenance of the existing stock and may be used to estimate the opportunities to readily introduce

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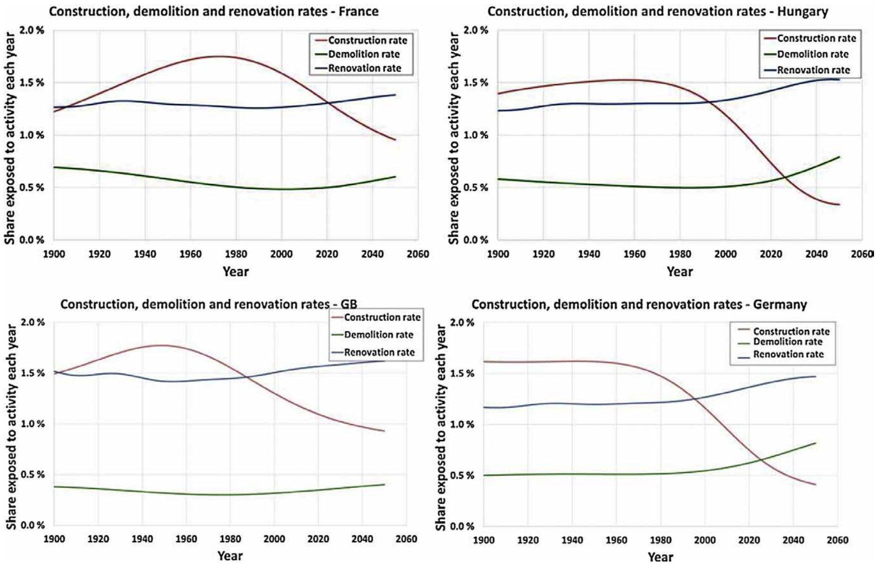

Fig. 6. Development in annual rates of construction, demolition and renovation in France, Hungary and Serbia.

Table 4
Construction, demolition and renovation rates in all countries in 2015, 2030 and 2050. All rates related to the stock size in the same year.

	Construction rate			Demolition rate			Renovation rate		
	2015	2030	2050	2015	2030	2050	2015	2030	2050
Cyprus	1.6%	1.2%	1.2%	0.2%	0.3%	0.5%	0.9%	1.3%	1.3%
Czech Republic	1.0%	1.0%	0.9%	0.6%	0.6%	0.7%	1.3%	1.3%	1.3%
France	1.4%	1.2%	1.0%	0.5%	0.5%	0.6%	1.3%	1.3%	1.4%
Germany	0.8%	0.6%	0.4%	0.6%	0.7%	0.8%	1.3%	1.4%	1.5%
Great Britain	1.1%	0.9%	1.0%	0.3%	0.4%	0.4%	1.6%	1.6%	1.6%
Greece	2.0%	1.7%	1.4%	0.9%	1.0%	1.2%	1.1%	1.2%	1.2%
Hungary	0.9%	0.5%	0.3%	0.5%	0.6%	0.8%	1.4%	1.5%	1.5%
The Netherlands	1.2%	1.0%	0.9%	0.5%	0.6%	0.7%	1.3%	1.4%	1.4%
Norway	1.5%	1.4%	1.2%	0.5%	0.5%	0.6%	1.2%	1.2%	1.3%
Serbia	1.1%	0.7%	0.5%	0.6%	0.8%	1.0%	0.6%	0.6%	0.6%
Slovenia	1.3%	1.2%	1.0%	0.6%	0.6%	0.6%	1.3%	1.3%	1.3%

energy-efficiency measures when dwellings are going through a deep renovation. This is an interesting finding regarding the energy saving potential of the dwelling stock. Scenario analyses and road maps for energy savings commonly assume rapid increases of the renovation rate to levels of 2.5–3% [4–9]. Our analysis shows that the renovation rates resulting from the dwelling stocks' ownership turnover, or need for maintenance, will be far below these levels in all the countries included in this study. Although the renovation process could probably be accelerated by appropriate incentive or investment schemes [43], to achieve a doubling of the renovation rate to meet national targets for reduction of energy consumption and CO_2 emissions will be difficult. Funding schemes should be used to ensure that when dwellings are renovated, high-level energy-efficiency measures are introduced to avoid lock-in effects.

Short- and medium term variations in the rates are not reflected in the model. In the case of Greece, this is clear in the case of the current construction rate. Due to the ongoing turbulence in the Greek economy, the construction industry has come to a halt, and according to the latest statistics available [44,45] the construction rate in 2014 was 0.15%. Such short and medium term variations cannot be explained by this model.

Some studies define the construction, demolition and renovation rates as the number of dwellings exposed to the activity compared to the stock composition in a fixed year [4,37]. A fixed rate then means a constant number of dwellings exposed to the activity each year. In countries with a growing stock, future rates related to the stock size in a fixed year will be higher than if the rates are related to the changing stock size. In countries with a decreasing stock, the corresponding rates are lower. If relating the presented renovation activity to the 2015 dwelling stock size, the resulting 2050 renovation rate will be in the range 1.4–2.0% for all countries except Serbia with 0.7%. So even with this definition, the

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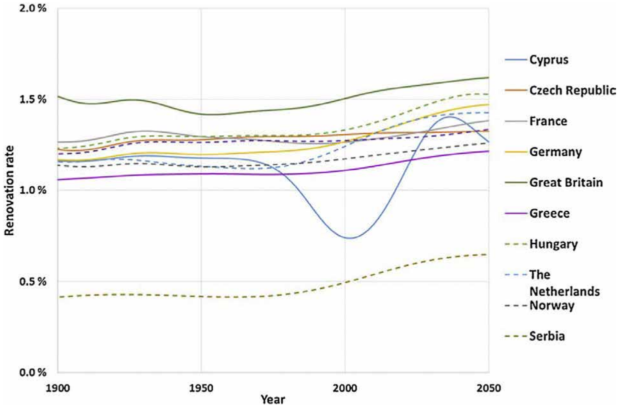

Fig. 7. Simulated renovation rate in all countries 1900–2050.

renovation rate is not likely to reach the level of 2.5–3% by 2050 and in any case not in the near future.

3.4. Applicability and reliability of the model and its results

In this study, a range of input data and assumptions are applied for the analysis of the long-term dynamics of the dwelling stocks in 11 European countries. The presentation of the data and assumptions in Section 2.2 and in Appendix B revealed large differences between the countries. This is mainly due to the large differences in historical development, current situation and expected future development in the countries' population, and probably also due to variations in the factors included in the population projections and estimation of lifetime of dwellings.

Data availability varies between the countries. Some countries do not have data available before 1900, requiring additional estimation steps. This is particularly the case for countries where the national territory changed over time prior to 1900. Later changes in border, e.g. after WWII are better documented and easier to address. The uncertainty caused by the estimation of input data this far back in time has little impact on the model results in the period of highest interest; the recent past and the future development.

The future development of dwelling stocks is strongly related to the expected change in the population in each country. The population projections are taken from the statistical offices, but are still uncertain. Moreover, expected lifetime, fertility rates and migration can be derived using different approaches and assumptions in the different countries. However, these projections provide the best available information on future population growth in the countries studied here. Migration is treated differently in the population projections for the different countries, and this may have significant effects since the future development in the population of European countries will substantially depend on migration policies. The future dwelling stock size and construction rate is highly sensitive to the future size of the population [38]. Further, the demolition rate and hence the construction needed to replace demolished dwellings are sensitive to the assumed lifetime of dwellings. Further, social factors, policies and changing user behavior might also influence the turnover rates of the dwelling stock.

The future renovation towards 2050 will mainly take place in dwellings in the current existing stock. The future renovation rate is therefore less sensitive to future development of the most uncertain input parameters than the future construction and demolition rates.

The most policy-relevant outcome of the presented analysis is the resulting renovation rates. Future construction is expected to be highly energy-efficient, and therefore the future energy savings in the system mainly depend on the improvements of the existing stock. The future energy saving potential in the existing stock should be identified through simulation of likely renovation rates and models showing possible average energy-intensity reductions when a dwelling is renovated. The future renovation rates are little dependent on the highly uncertain inputs, and the resulting renovation rates for all 11 countries turned out to be remarkably similar and stable over time, at levels of 1–1.6% for most countries, as shown in Fig. 7. This, together with the robustness of such results as emerged from the sensitivity analysis in Sandberg et al. [38], indicate that rapid increases of renovation rates to levels of 2.5–3% will be very difficult to obtain.

3.5. Implications for energy efficiency

The dynamic dwellings stock model can be used as a basis for detailed energy analyses of dwelling stocks [41]. Although no full energy analysis is carried out in the present study, the model results indicate the importance of new construction versus renovation of existing dwellings in the dwelling stocks of the various countries towards 2050.

The segmented results presented in Fig. 4 indicate that there are large differences in the importance of the different cohorts and that there is a large difference in the potential for, and necessary strategy to deliver, future energy-demand reductions. Countries with a growing stock have to improve the average energy efficiency of the stock even to keep the future total energy use in the stock at a constant level. In contrast, countries with a decreasing stock will achieve energy savings even if the average energy efficiency does not improve.

Eurostat [46] report 214 million households (dwellings) in 2013 for the EU 28 countries. This study of 124 million dwellings in 10

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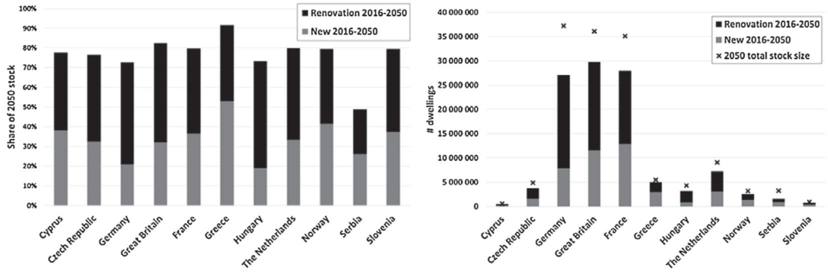

Fig. 8. Number of dwellings constructed or renovated in the period 2016–2050. Left: as percentage of 2050 stock size in each country. Right: absolute number of dwellings.

EU countries and Norway, therefore analyses over half of European housing stock. If the results are representative of the remaining dwelling stock within Europe, the expected low rates of future renovation activity pose a far greater challenge for policy makers seeking to rapidly meet decarbonisation objectives than assumed in current strategies.

The simulated accumulated number of dwellings constructed or renovated in the period 2016–2050 is shown for all countries in Fig. 8 (left) as a portion of the 2050 stock size in the respective country and Fig. 8 (right) as absolute number of dwellings. As each deep renovation and each new construction is an opportunity to implement energy-efficiency measures, this indicates the potential for energy savings in each country. “Renovation 2016–2050” is the sum of the number of dwellings renovated each year in the same period. This does not correspond completely with the numbers of dwellings going through renovation in this period, as a few dwellings will be renovated twice. Within a 40-year cycle, however, only a small proportion will be renovated twice in a 35-year period.

Fig. 8 (left) indicates the shares of the 2050 dwelling stocks that are targetable for energy efficiency measures in the period 2016–2050, either as they are constructed or exposed to deep renovation. In total, this will be 70–80% of the 2050 stock in all countries except Serbia. This means that even though the simulated renovation rates are not expected to increase, there is a large potential for energy efficiency of the dwelling stocks towards 2050. However, as most dwellings are renovated only once in this period, it will be necessary to ensure that the best available energy measures are included when a dwelling undergoes renovation, and to stimulate large-scale introduction of technologies such as heat pumps and photovoltaics.

Fig. 8 (left) further demonstrates how the countries with an expected decreasing population (Germany, Hungary and Serbia) will have a correspondingly low share of new dwellings in 2050. Hence, the largest potential for total energy savings in these countries is through renovation and upgrading of the existing stock. In contrast, countries with a large expected growth in the dwelling stock, like Cyprus, Greece and Norway, will have a high energy-saving potential in the dwellings constructed in the future.

Fig. 8 (right) shows the absolute values of new construction and renovation in the 11 countries, indicating also the total 2050 stock size. As France, Germany and Great Britain contain 77% of the dwellings considered here, accelerated stimulus in these countries would contribute more to achieving a Europe-wide decarbonisation target.

More detailed studies on the energy standard of the dwelling stocks in each of the countries, and their potentials for cost-efficient reductions through introduction of energy-efficiency measures, could be combined with the results from the dynamic dwelling stock model to identify the most cost-effective energy efficiency scheme for housing stocks throughout Europe.

4. Conclusions

A dynamic dwelling stock model is applied to 11 European countries (in alphabetical order): Cyprus, the Czech Republic, France, Germany, Great Britain, Greece, Hungary, the Netherlands, Norway, Serbia and Slovenia. The simulated long-term development in dwelling stock size fits well with the reported statistics for all countries. Despite the differences in data collection and reporting by the different countries, the modelled future trends for the construction, demolition and renovation activities lead to similar patterns emerging in all countries.

The countries included in the study have different expected future development in the size of the population. In some countries, a strong increase is expected, whereas in other countries the population is expected to level off or even decrease. This has large impacts on the simulated future development of the dwelling stock. Countries with large population growth will need high construction activity, and for energy saving matters it is important that the new construction is energy efficient. In countries expecting a lower population growth or decreasing population, the existing stock is of higher importance and energy efficiency achievements are more influenced through renovation of the existing stock.

Overall, the presented analysis shows that despite the differences between the countries included in this study, the model is applicable for all the 11 countries. The model is able to reproduce the current stock size and composition and the long-term dynamics in the system in an acceptable way. Short- and medium-term variations in construction and demolition activities may be explained by factors not included in the model, e.g. wider drivers such as economic, climate and unemployment. Unfortunately, demolition and renovation statistics are rarely available. Better data availability would be useful for model calibration.

The future development in construction and demolition is sensitive to the population input and the lifetime of dwellings parameter, which are highly uncertain. Still, we claim that it is better to include the best available estimates of these important parameters in the study and identify the implications of their uncertainty, rather than using traditional models with fixed construction, demolition and renovation rates that are based on recent trends without discussing their realism and applicability for future analyses.

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We conclude that the model seems to perform reasonably well at simulating the long-term development of changes in dwelling stock composition and expected annual renovation activities. Short- and medium term variations in construction activity are not well captured by the model, as these depend on drivers not represented in the model. However, short- and medium term estimations are not the intended purpose of the model. The general trend observed in most of the countries studied, is that the modelled share of the stock constructed before 1945 shows a good fit with the reported statistics, whereas the post-war construction activity is often underestimated and the construction activity from the most recent decades is consequently overestimated. Although the overall accuracy appears satisfying, caution should be applied when interpreting the segmented results for different cohorts. Additional, or more accurate data, could improve the quality of the segmented results for some of the countries.

A key model output is the renovation rate, which expresses the dwelling stock's need for maintenance due to ageing. The simulations show that only minor increases are expected in the future renovation rate, always within the range from 0.6% to 1.6% towards 2050. Although there are uncertainties in the results, this trend of small incremental changes is consistent across all 11 countries and the results reinforce findings in Sandberg et al. [37,38] that renovation rates at levels of 2.5–3% are unlikely to be achieved through the stock's natural renovation requirements. Furthermore, it shall be noted that the simulated future renovation rate towards 2050 mainly depends on the current stock size and composition and is not significantly sensitive to future development in the input parameters of the model (such as projections on the population development), as shown in the sensitivity analysis [38]. We therefore conclude that the model results on future need for renovation are robust despite the uncertainties in the input parameters.

As future renovation rates are expected to remain close to the current level, it is highly important to make sure that the best available energy-efficiency measures are included when a dwelling is renovated. If European countries are going to follow the recommendations given in the EU-JRC report [3] calling for a common EU renovation plan with a regional approach prioritizing less developed regions, funding and other incentives must be allocated so that energy-efficiency measures are included when dwellings in the less developed regions are renovated, or even to accelerate the renovation process in these countries.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.enbuild.2016.05.100.

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Appendix C The Case of Amsterdam

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Actual Energy Savings of Renovated Dwellings: the Case of Amsterdam

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Abstract

The existing housing stock plays a major role in the realization of the energy efficiency targets. The non-profit housing sector in the Netherlands dominates the housing market as it represents 31% of the total housing stock. In the municipality of Amsterdam, where this share is even 46%, subsidies were given to housing associations between 2011 and 2014 when an energy renovation of their rental property took place and resulted in a better energy performance. The aim of this paper is to examine the impact of thermal renovation on the actual and the predicted energy consumption of the dwellings concerned and to compare both types of consumption. For the non-profit rental dwellings that have undergone renovation in Amsterdam, we use longitudinal data from 2009 to 2013 to examine their actual and predicted gas consumption before and after renovation. The main outcome of the analysis is that in almost all groups of dwellings the gas consumed after renovation decreased significantly. Most of the dwellings had a combination of measures performed and the actual gas consumption savings depend on these combinations. Despite the fact that gas savings after renovation were observed in all dwellings no pattern was found indicating that the better the predicted energy performance achieved, the more actual savings were realized after renovation, but this may be due to the relatively small size of the sample.

Keywords - energy efficiency improvements, monitoring, actual energy consumption, non-profit housing

Introduction

The existing housing sector is already playing an important role towards achieving the energy efficiency targets worldwide and in the European Union (EU) [1] [2]. A large part of this energy consumption comes from the residential sector, as dwellings consume 30% of the energy of the total building stock on average in the EU [3]. The non-profit housing sector in the Netherlands dominates the housing market as it represents 31% of the total housing stock [4]. In the municipality of Amsterdam the share of the non-profit housing reaches 46% [5]. Energy renovations in existing dwellings offer unique opportunities for reducing the energy consumption and greenhouse gas emissions. Monitoring the energy improvements of the existing housing stock is necessary 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 [6].

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 municipality of Amsterdam. The actual savings reveal the true effect of renovations on the reduction of energy consumption. The actual energy also highlights the result of the number and combinations of measures on the dwellings' performance. First we analyze the energy efficiency measures realized and then their impact on the actual and predicted energy consumption. In the following background section 2 we discuss the subsidy scheme of the municipality of Amsterdam and our approach on what comprises an energy renovation. 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 in Amsterdam

In the Municipality of Amsterdam, in the framework of the agreement 'Bouwen aan de Stad II 2011-2014' (in English: "Building the City II 2011-2014") subsidies were given to housing associations when an energy renovation of their rental property took place and resulted in better energy performance [7]. The performance is assessed based on the energy label of the dwellings before and after the renovation took place. Specifically, the subsidy, named 'Bijzondere subsidieverordening verbetering energie-index 2011' (in English: "Special subsidy for the improvement of the energy performance 2011"), is given if at least 2 energy label steps are achieved (e.g. from a G label to at least an E label) [8]. The housing associations can apply for the subsidy when the energy renovation has already taken place and they can do so twice a year, in February and July. The subsidy refers to existing dwellings only, that were renovated after July 2011 and until July 2014 and the new energy label is registered officially to the Netherlands Enterprise Agency (RVO), prior to the application.

For the purpose of this paper we define an energy renovation as the improvement of the energy performance of a dwelling by at least two label steps, following the definition by the subsidy scheme in Amsterdam. In the Netherlands the energy performance

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of a building is expressed by the Energy Index (EI), which is a dimensionless figure, ranging from 0 (extremely good performance) to 4 (extremely bad performance). The calculation method of the EI is described in NEN 7120 [8] and in ISSO publication 82.3 [9]. Based on the EI an energy label is assigned to the dwellings.

Data and Research Methods

This study includes an inventory of energy saving measures of the non-profit rented stock in Amsterdam from July 2011 to the end of 2014. In addition, we examined the effectiveness of these measures based on actual and predicted energy savings. In the Netherlands, 85% of households are heated with natural gas [10]. Thus, for the purposes of this study we focus on the gas consumption data. We used three different datasets to achieve the identification of the measures and examine their effectiveness. In all three datasets an identifier variable for each dwelling is used, comprising of the address, postcode and city, in this case Amsterdam.

First, the official RVO energy label records for the specific renovated dwellings were used. This information was provided by the Rekenkamer Metropool Amsterdam (in English: the audit office of the Amsterdam Metropolitan Region) with the aim of researching the effect of the subsidy scheme on actual energy savings. As a result we were able to have the addresses and some technical characteristics, including the energy label, of the renovated dwellings. 9009 dwellings were present in the dataset from 2011 to 2014.

Second, 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. It is a collective database in which the majority of the housing associations participate [11]. The database includes data from 2010, 2011, 2012, 2013 and 2014 on the performance of the stock in the form of energy labels, without all of them being officially registered at RVO. The analysis is based on longitudinal data using the identifier variable to follow the energy saving measures of the dwellings. SHAERE is much richer than the RVO official energy label database. It includes information on the dwellings' geometry, envelope and installations characteristics and the predicted heating energy consumption based on ISSO publication 82.3 [9]. The data is available before and after the renovations of the stock. In order to identify the energy saving measures we follow seven variables. These include: heating system, domestic hot water system, ventilation system, floor insulation, roof insulation, façade insulation, and type of glass. However, due to the fact that some housing associations provided data only for 2014, and therefore past renovations could not be identified, the sample decreased to 7465 dwellings. When we matched the RVO data to SHAERE 7307 dwellings formed the final sample. This decrease is due to double address reports and missing cases.

Third, we matched the data from RVO and SHAERE databases 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 annual 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 different years of 2009, 2010, 2011, 2012 and 2013. The energy label calculation reported in SHAERE, on the other hand, assumes 2620-heating degree days [9], therefore we applied correction factors to the actual gas consumptions supplied by the Statistics Netherlands.

Data filtering was required from the beginning of the data analysis and especially when we coupled the datasets. In SHAERE we eliminated dwellings with double records, with default set values in all variables and with unrealistic area (when $<15m^2$ or $<700m^2$). Further, we noticed some discrepancies between the RVO and the SHAERE dataset. After testing the distribution of the energy labels for both datasets, we decided to select the dwellings where at least two label steps were achieved after the renovation, based also on the definition by the subsidy scheme. The representativeness of this smaller group of 3207 dwellings was better and in accordance with the official RVO energy labelling dataset. When coupled with the actual gas consumption data from the Statistics Netherlands, more dwellings had to be eliminated because they did not match on the address identifier variable. From the ones that matched several had missing values of gas consumption and were eliminated as well. Also, we had to exclude the dwellings that were renovated in 2013 or in 2014, as the actual gas consumption data are available until 2013. In addition, we removed the dwellings that had unrealistic values of gas consumption ($<15m^3$ and $>6000m^3$). The final sample comprised 819 dwellings. In the following section the results of the two-part analysis will be presented.

Results

First, the results of the energy efficiency measures that took place from July 2011 to the end of 2014 in the non-profit housing stock of Amsterdam will be presented and described. Next, the outcomes of the effect of these measures on the actual and predicted gas savings will be analyzed. In both cases, we will focus on the amount of

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measures performed and the combination of those measures. However, we will also describe briefly the most frequent individual energy efficiency measures.

Energy Efficiency Measures

In this part of the analysis, using the SHAERE and RVO databases, we investigated the energy-saving measures that took place in the non-profit stock of Amsterdam under the aforementioned subsidy scheme [8]. In order to get the subsidy the housing associations needed to improve the performance of the dwellings by at least two energy label steps and to register the new label to RVO.

In the SHAERE database, only 39% of the dwellings had an officially registered label to RVO after the renovation was realized. Of these, only 58% achieved two or more label steps. In 32% of the dwellings no label change was reported. 4475 out of the 7307 cases had information on the space heating systems. 48% of the dwellings (2155 cases) has not undergone any change of the heating system. In 47% of the dwellings (2122 cases) a conventional boiler (η<0.80-0.90) was replaced by a condensing boiler (η≥0.95). Only three boilers were replaced by a heat pump and 149 were replaced by district heating. For the domestic hot water system the facts are similar because in most cases in the Netherlands the two systems are combined. 48% of the dwellings (2180 cases) changed the domestic hot water system. 47% (2094 cases) of those switched to a condensing boiler (η≥0.95). 4474 dwellings had information about the ventilation system. 26% of the dwellings (1181 cases) replaced natural ventilation with mechanical exhaust ventilation. Mechanical supply and exhaust ventilation is rarely used in this sample. The values and boundaries used to distinguish between the levels of insulation derive from the ISSO publication 82.3 and presented in Table 1 and Table 2 [9].

TABLE APP.C.1 Insulation categories for floor, roof and façade based on the ISSO 82.3 [9]

CHARACTERIZATION	R_c VALUE FLOOR [m^2K/W]	R_c VALUE ROOF [m^2K/W]	R_c VALUE FAÇADE [m^2K/W]
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 APP.C.2 Window categories based on the ISSO 82.3 [9]

CHARACTERIZATION	U VALUE WINDOW [W/m²K]
Single glass	U≥4.20
Double glass	2.85≤U<4.20
HR+ glass	1.95≤U<2.85
HR++ glass	1.95≤U<2.85
Triple insulation glass	U<1.75

Only 1600 dwellings had information about the floor insulation. 18% of those (296 cases) had an improvement of the floor insulation. 1948 dwellings had a report for the roof insulation. In 21% of these dwellings (413 cases) the roof insulation was improved. 4465 dwellings had a reported insulation value of the façade. 19% of these (854 cases) improved the façade insulation. However, in the majority of them minimal insulation was placed. On the other hand, the distribution covered by the practice (ISSO 82.3) was weak: there are many small insulation measures realized without the insulation category changing. By refining these categories we showed that 26% of the facades (1160 cases) were somewhat insulated.

4460 dwellings had information about the windows U values. The type of glass is improved in 35% of the dwellings (1573 cases). The glass is usually replaced with HR + or HR ++ glass and sometimes by triple insulation glass. In addition, 207 dwellings added PV cells and 17 a solar boiler for hot water.

We also examined the number of measures realized per dwelling. The maximum amount of energy efficiency measures is, as aforementioned in section 3, 7. Table 3 depicts the amount of dwellings and the number of measures per dwelling. According to SHAERE, when we examine the percentage of dwellings with at least one measure (3250, right column in Table 3), the division is between 1 to 5 measures is flat. In 20% of the dwellings, the measures taken during the renovation are not known. In 35.5% of dwellings no action was taken.

TABLE APP.C.3 Amount of measures per dwelling

AMOUNT OF MEASURES	FREQUENCY	PERCENTAGE	% OF DWELLINGS WITH AT LEAST ONE MEASURE
Not filled in	1459	20.0	
0	2598	35.5	-
1	559	7.7	17.2
2	786	10.8	24.2
3	695	9.5	21.4
4	535	7.3	16.5
5	584	8.0	18.0
6	91	1.2	2.8
Totaal	7307	100	100 (3250)

In Table 4 the most common combinations of measures are indicated. These combinations are not exclusive. The most applicable combination is to improve simultaneously the windows insulation and the heating system: low-hanging fruit. In the municipality of Amsterdam, according to the renovated non-profit housing stock, 17% had one measure implemented, 24% two measures and 59% over two measures. The most common combination of measures is the replacement of the heating system and the glazing.

TABLE APP.C.4 Combinations of measures

PACKAGES OF MEASURES IMPROVING AT LEAST:	FREQUENCY	PERCENTAGE
Heating system and windows	1161	15.9
Heating system and façade	651	8.9
Heating system and roof	374	5.1
Heating system and floor	203	2.8
Heating system and windows and façade	476	6.5
Heating system and windows, façade and roof	111	1.5
Heating system and windows, façade, roof and floor	0	0.0
Façade and roof	200	2.7
Façade and floor	91	1.2
Total	3267	44.7 (7307)

As shown in Table 3 a large number of dwelling reports in SHAERE indicate that no improvement has occurred. The uncertainty of the figures, mentioned above, is large and it seems likely that they give a pessimistic view of the reality. Checks by the Rekenkamer Metropool Amsterdam indicated that the renovations have taken place, but were probably not filled in, or only partially filled in SHAERE. On the other hand, a recent study revealed that the pre-renovation labels, too often, are not properly set (worse than actual), leading to an overly optimistic picture of the completed renovations [12]. So, although we do not have exact data on these biases, it could be that they weigh each other more or less out.

Effectiveness of Measures on the Actual and Predicted Energy Savings

This section, first, discusses the effect of label change on the energy savings. Then, the effect of the amount of energy efficiency measures and the various combinations of measures on the energy savings is analyzed. The average gas consumption in this paper is expressed in m^3/m^2 and as a result is not floor area weighted (for example a dwelling of 500 m^2 weighs the same as a 40 m^2 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 2012 or 2013 data for the post-renovation consumption values. Only the dwellings renovated in 2010, 2011 and 2012 were taken into account.

Groups of dwellings with less than 10 cases could not be exported from the Statistics Netherlands environment for privacy issues and are therefore excluded from the analysis. In all graphs the mean value per group of dwellings is shown. Figure 1, Figure 2 and Figure 3 show the gas consumption before and after renovation in different categories.

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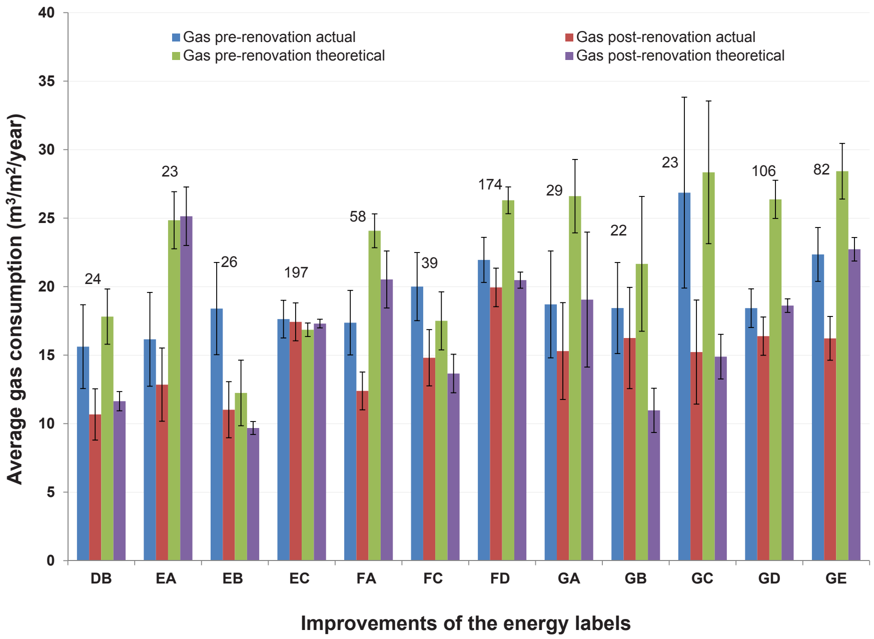

FIGURE APP.C.1 Improvements of the energy labels and the impact on the actual and predicted energy savings. The black lines are the 95% confidence intervals.

In Figure 1 the energy savings are depicted categorized by the energy label steps. The first letter in the name of the category indicates the energy label pre-renovation and the second letter the label post-renovation. For example, category CA includes dwellings that have been renovated from label C to label A. The labels were taken from SHAERE but from the official RVO dataset. The change in gas consumption is shown for both the actual gas consumption and for the predictedgas consumption in all three figures.

It is useful to notice the illogical results of the predicted gas savings in the EA and EC categories: there has been an increase in the predicted gas consumption, which is impossible. This has to do with the findings in section 4.1, where large discrepancies between the labels registered in SHAERE and in RVO were observed. For a large number of the 23 dwellings in category EA, the new label A is not registered in SHAERE. The pre-renovation label E remained in SHAERE along with the corresponding predicted energy consumption. In short, the renovation was not registered in SHAERE. The same seems to happen with the 197 dwellings of category EC.

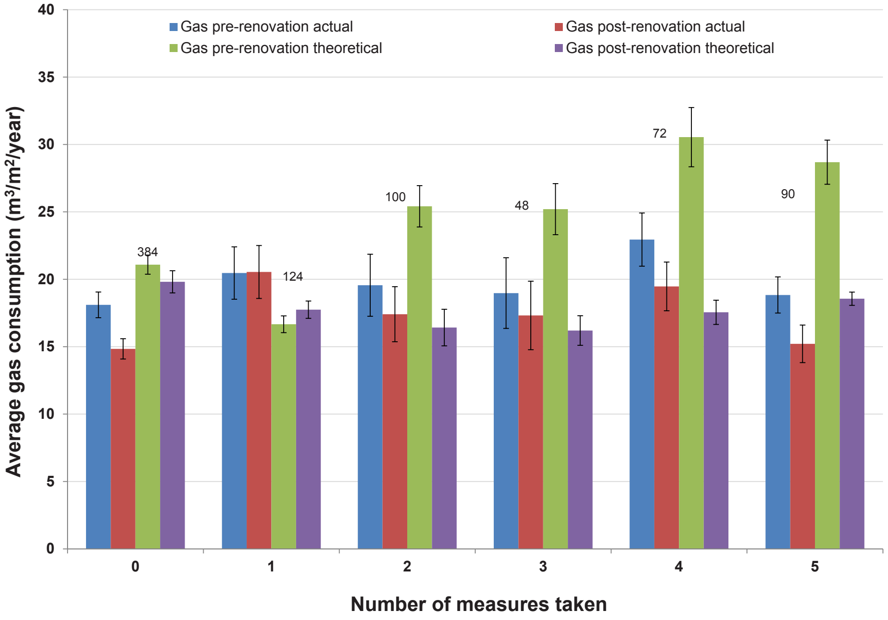

FIGURE APP.C.2 Number of measures realized and the impact on the actual and predicted energy savings.

Figure 2 shows the actual gas savings achieved as a function of the number of renovation measures taken. When only one measure is realized no gas savings are achieved. At the same time, the increase of the theoretical gas consumption highlights the indication that a lot of administrative corrections (meaning that housing associations probably have re-inspected their dwellings and corrected faults from the first inspection) were reported but not actual renovations. When two or three measures take place then the gas consumption decreases proportionally to the number of measures. The largest decrease as expected occurs when 5 measures are realized. Last, when observing the dwellings with no measures taken, according to SHAERE, we see a big reduction of gas consumption. This amount is significantly higher than the autonomous gas reduction of 0.4 m^3/m^2/year which was found in a control group of the non-renovated dwellings in Amsterdam. This indicates that indeed measures were taken, but are not reported in SHAERE.

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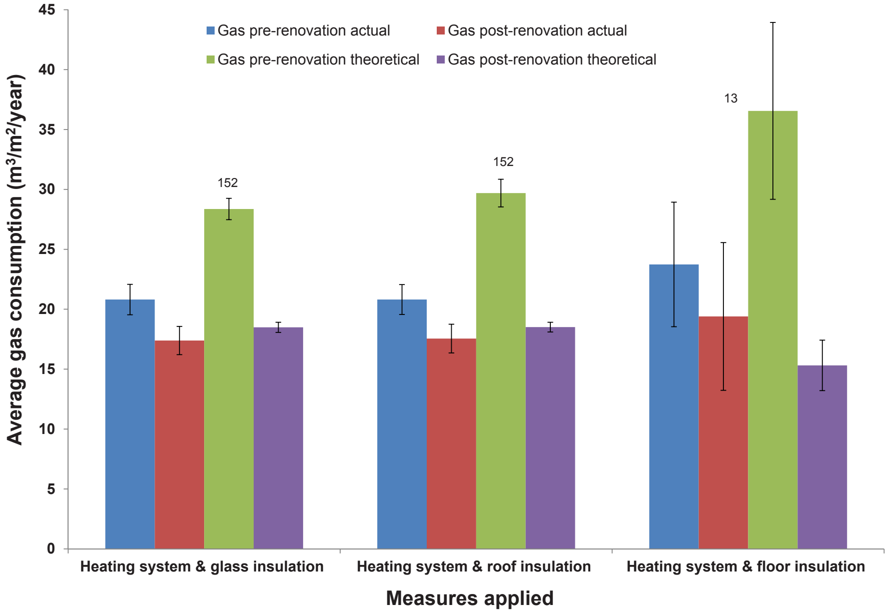

FIGURE APP.C.3 Combinations of measures realized and the impact on the actual and predicted energy savings.

Due to the fact that the majority of the dwellings had at least 2 measures realized we also examined the combinations of (non-exclusive) measures. The three most frequent combinations, with large enough size, are reported in Figure 3. The change of the heating system is present in all three packages of measures. This graph also shows that the predicted gas consumption after renovation is a lot closer to reality, which is in accordance with findings of [6].

Conclusions and Recommendations

The aim of this paper was to examine the impact of thermal renovation measures on the actual and predicted energy consumption of the non-profit housing stock in Amsterdam. This study, first, included an inventory of energy saving measures of the stock from 2011 to 2014. 17% of the dwellings had one measure implemented, 24% two measures and 59% over two measures. The most common combination of measures is the replacement of the heating system and the glazing. However, a large number of dwelling reports in SHAERE indicated that no improvement occurred. The uncertainty of the figures is large and it seems likely that they give a pessimistic view of the reality. As revealed by further interviews with housing associations by the Rekenkamer Metropool Amsterdam and the results of section 4.2, there are indications that the renovations were actually carried out. This fact, though, poses questions about the reliability of databases like SHAERE.

Then, we examined the effectiveness of these measures based on actual and predicted energy savings. The main outcome of the analysis is that in almost all groups of dwellings the gas consumed after renovation decreased significantly. The actual gas savings achieved depend on the number of measures in the sample of the renovated non-profit stock of Amsterdam. Most of the dwellings had a combination of measures performed and the actual gas consumption savings depend on these combinations. Despite the fact that gas savings after renovation were observed all over the sample no pattern was found indicating that the better the predicted energy performance achieved, the more actual energy savings were realized after renovation. However, as indicated by the confidence intervals in the graphics, the sample was too small to be generalized to larger samples.

Monitoring of the existing stock is of great importance to better understand the performance of dwellings and the actual energy savings that can be achieved from renovations. In addition, examining the effect of energy improvements on actual energy consumption is a valuable tool for the creation of successful policies in the future. In order to monitor such detailed processes, the gathering and processing of the data is essential. SHAERE is a useful example of a collective database including, to a big extent, most of the valuable information in order to examine energy renovations of the existing stock. Careful analysis of the data of such collective databases is crucial as this research showed.

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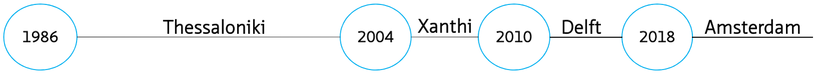
Biographical note

I was born in 1986 in Thessaloniki, Greece. In September of 2004 I moved to Xanthi, Greece, to study Production Engineering & Management at the School of Engineering, Democritus University of Thrace. I wrote my thesis on the energy payback time of photovoltaic parks in Greece. By that time, I knew that I wanted to experience more about the academic world I had just entered. After my graduation in 2010, I decided to pursue a second master's degree in Delft, the Netherlands. This time, I studied Sustainable Energy Technology at Delft University of Technology and received my master's degree in 2013. I wrote my master thesis on the energy performance of smart grid systems. The topic and the experience I had gained, motivated me to apply for a doctoral research position at OTB, TU Delft. That was the start of my research on the energy performance progress of the Dutch housing stock, in October 2013. I concluded my PhD journey in 2018.



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