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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 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.

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## § 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.

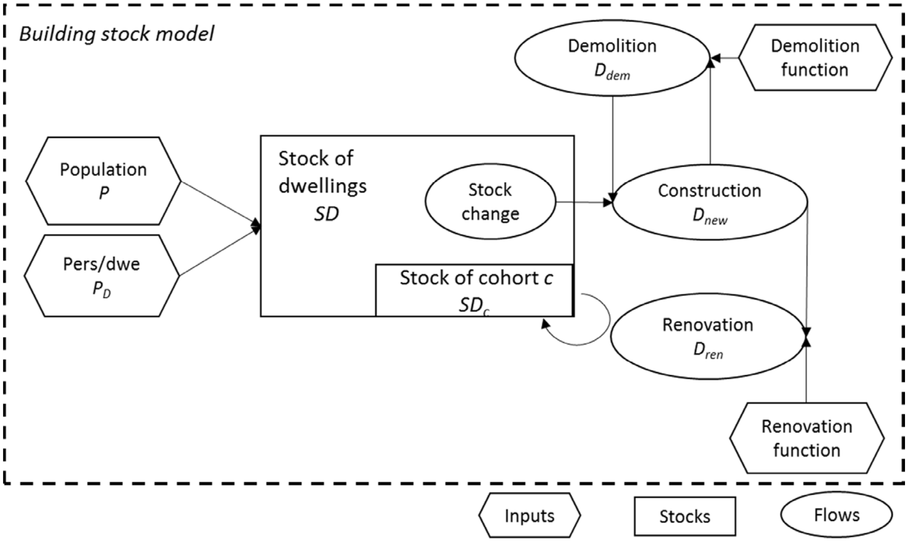

FIGURE 6.1 Conceptual outline of the dynamic building stock model (Sartori et al. 2016)

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.

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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.

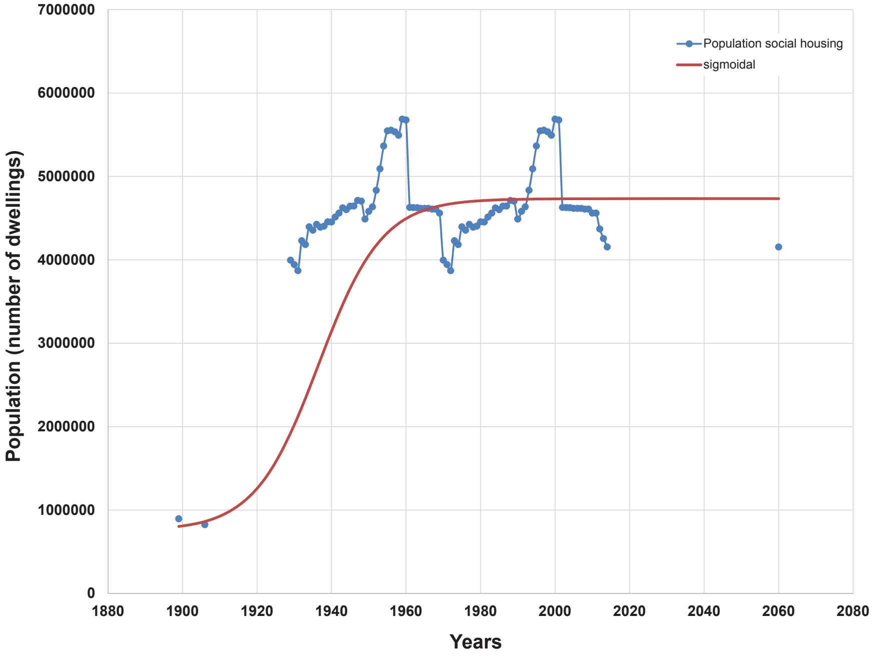

FIGURE 6.2 Development of the population of the non-profit housing stock (sources: Haffner et al. 2009;Schade 1981; Grinberg 1977)

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.

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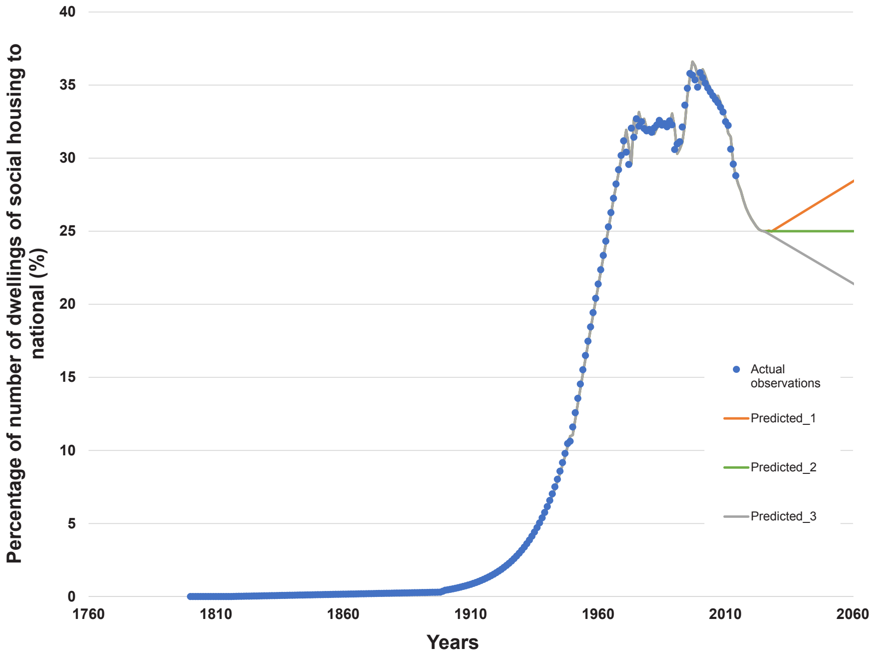

FIGURE 6.3 Development of the number of dwellings of the non-profit housing stock

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.

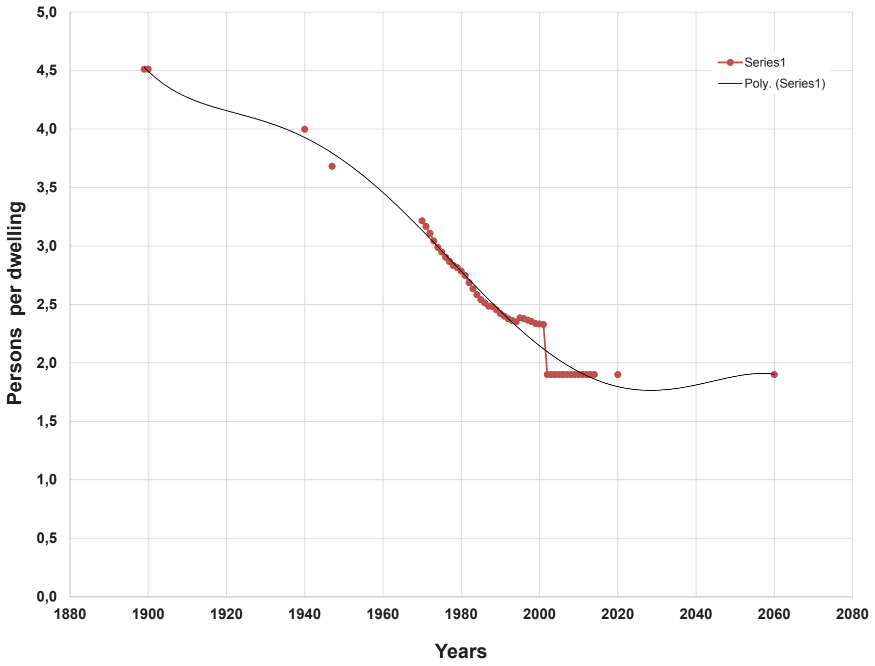

FIGURE 6.4 Development of the persons per dwelling of the non-profit housing stock

## § 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.

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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.

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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).

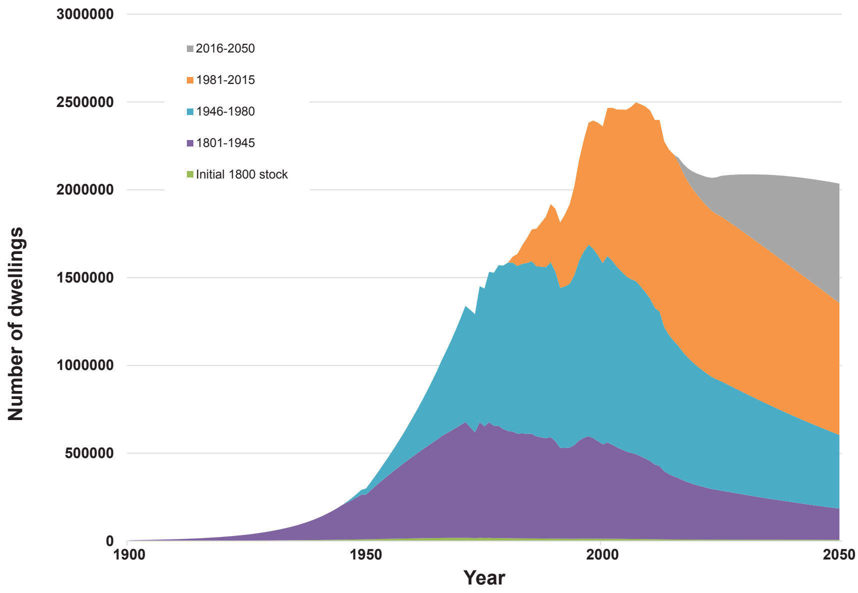

FIGURE 6.5 Simulated dwelling stock composition of the non-profit housing stock in the Netherlands

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).

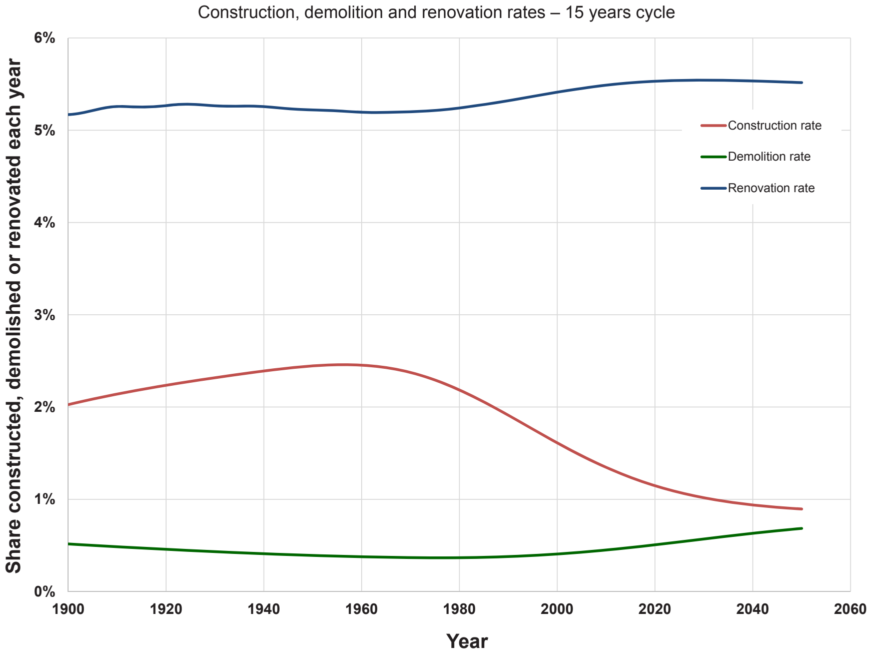

FIGURE 6.6 Construction, demolition and renovation rates, as a percentage of the dwelling stock size in the corresponding year – Renovation cycle 15 years

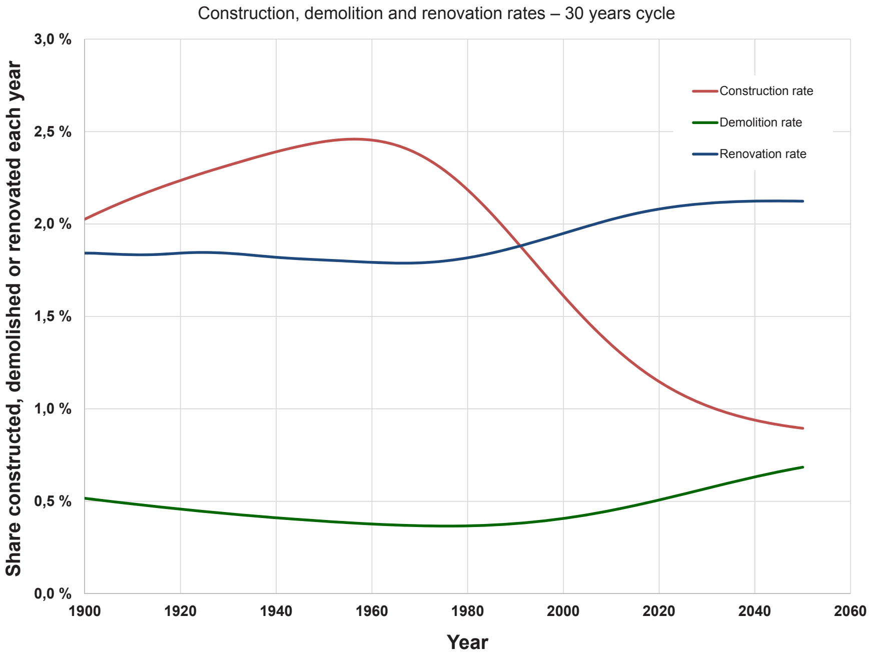

FIGURE 6.7 Construction, demolition and renovation rates, as a percentage of the dwelling stock size in the corresponding year – Renovation cycle 30 years

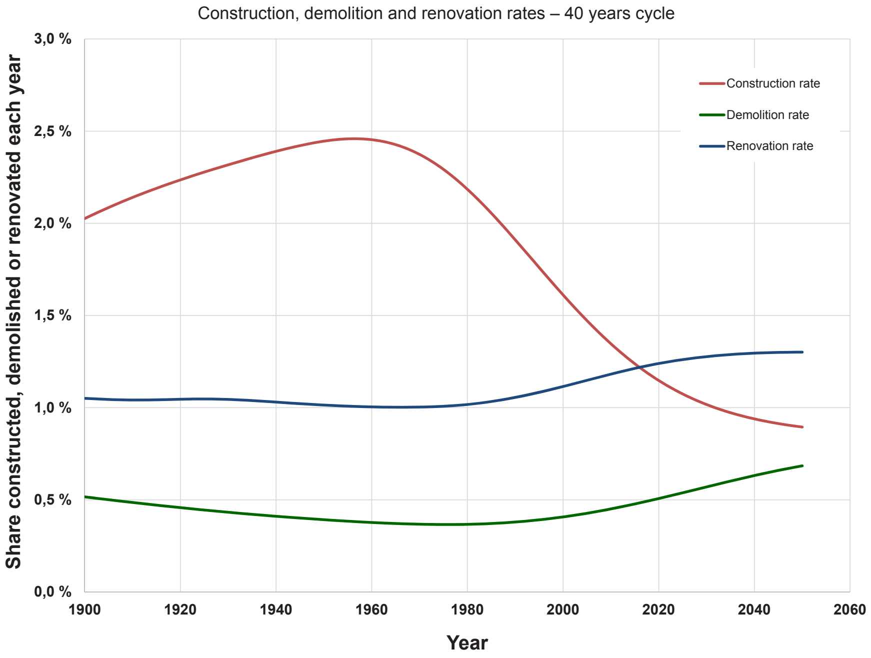

FIGURE 6.8 Figure 6.8: Construction, demolition and renovation rates, as a percentage of the dwelling stock size in the corresponding year – Renovation cycle 40 years

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.

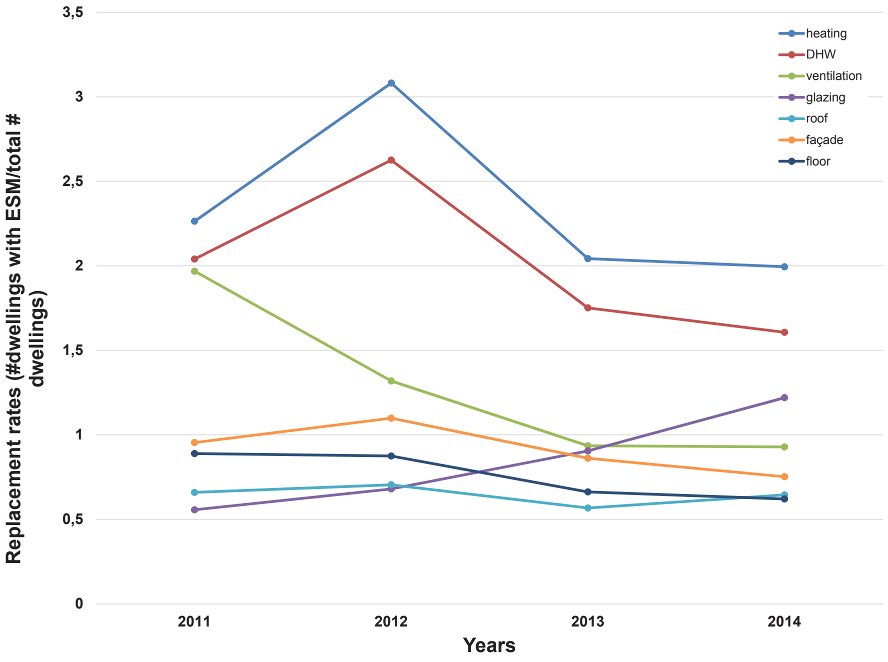

FIGURE 6.9 Replacement rates according to ESMs based on SHAERE

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.

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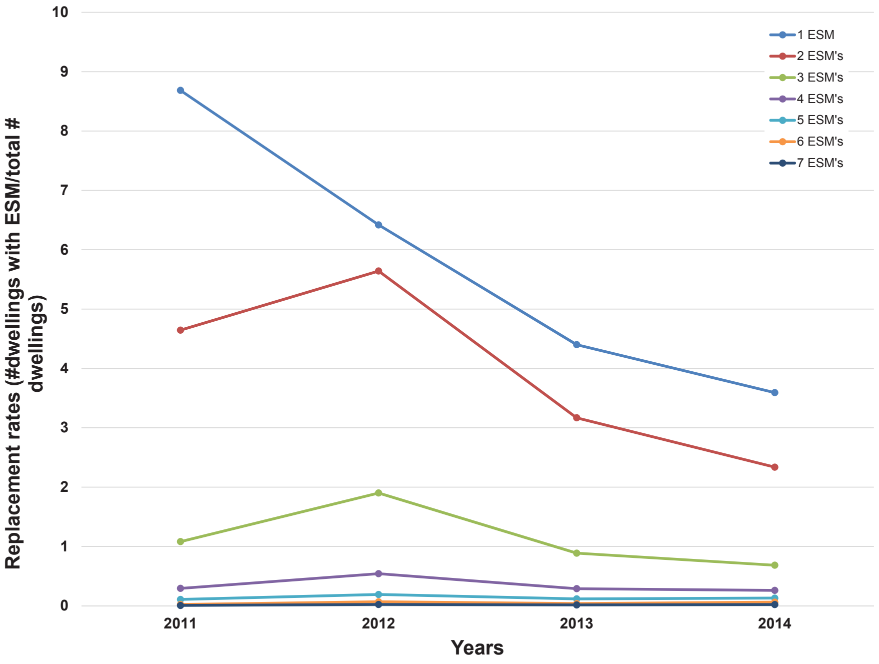

FIGURE 6.10 Replacement rates according to the number of ESMs based on SHAERE

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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