THE ACTUAL PERFORMANCE OF ENERGY RENOVATIONS IN THE DUTCH RESIDENTIAL SECTOR

An Analysis of Measured Energy Performance and Resident Perceptions in Monitored Renovation Projects

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IEBB THEMA 2
DATAGEDREVEN OPTIMALISATIE VAN RENOVATIECONCEPTEN

July 2021

EINDHOVEN UNIVERSITY OF TECHNOLOGY · SAXION HOGESCHOOL · TU Delft

SUMMARY

The Netherlands has seen a rise in energy monitoring campaigns, whereby energy consumption data and data on the perceptions of residents is being gathered to evaluate the performance of the projects.

This report starts with summarizing large scale national studies about the energy renovation performances in the Dutch social housing stock and continued with the analysis of well documented renovation projects. 46 renovation projects representing 4.404 houses projects were analysed, with the goal of developing an understanding of the current state of data collection and monitoring in the Netherlands on the subjects of energy performance and residents' perception.

Current energy models appear to not accurately predict energy savings in dwellings, as a result of not accounting well for occupant behaviour, poorly determined physical characteristics of buildings and issues with the installation and commissioning of systems. Based on data that is currently collected at a housing stock and individual housing level, it is difficult to determine the exact causes of the discrepancies. Better models – digital twins – are therefore needed to predict the actual energy performance of renovation measures in dwellings.

Through this study, it was found that the nature of the data which is gathered varies significantly. For example, some organization gather data on energy performance, some on indoor climate, some on resident preferences and opinions, but none are examining the complete picture. It makes it difficult to comment about which renovation concepts performed specifically well or less well. In most cases where it was documented that renovation concepts outperformed or underperformed compared to expectations, there was insufficient data to determine why this was the case. However, from the point of view of energy performance, many monitored project appeared to perform much better than expected. This may be a direct result of the monitoring and is also surely a result of expressing targeted performance in terms of absolute energy usage instead of energy savings.
Monitoring was generally not at the level that it could be used to diagnostic and solve technical problems in a standardized way, as submetering was often missing.

The desk research also shows that the satisfaction of residents with the renovation process was often monitored, but not to a level allowing for a good understanding of their needs and interactions with the technical systems.
The causes for dissatisfaction were mostly related to residents' dissatisfaction with communication, nuisance, and overall renovation process, especially regarding planning and delays. Residents relocated during the renovation seemed to be more satisfied with the overall process. Participation and involvement were higher when more resources were freed by the housing associations to have residents' opinions heard.

It is also concluded that there is a need for better introduction to the home's systems, better manuals and follow up information and support to the residents after renovation. Not understanding the use or maintenance of the systems can in some cases led to discomfort situations, and to complains about noise from the systems. However, these complaints should not be waved away as being caused by the occupant. It may also be caused by malfunctioning and poor interfaces of the systems themselves.

In the end 13 recommendations about monitoring, analysis, modelling of installations and residents' understanding are formulated

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1. INTRODUCTION

1.1 General

In the Netherlands, a significant amount of final energy consumption is used by households, the majority of which is used for space and water heating. In 2019, the Dutch government introduced a suite of policies and plans to support the transition to a carbon-free built environment via the Climate Plan, the National Energy and Climate Plan (NECP) and the National Climate Agreement (Ministry of Economic Affairs and Climate, 2019).

Approximately 75% of the housing stock required in 2050 already exists today (Visscher, Meijer, Majcen, & Itard, 2016). Therefore, a significant focus will be placed on energy efficiency renovations in the coming years to achieve the national targets. The Dutch government estimates that to achieve 2030 targets, over 50,000 existing homes should be renovated per year, beginning in 2021. By 2030, the rate of energy efficiency renovations should be 200,000 homes per year.

Working toward these objectives, the number of low and zero-energy renovations have accelerated in recent years. Currently, there is not a lot known about how those renovations are really performing, both in terms of energy consumption and the perceptions of residents.

Although many projects report on innovative approaches and techniques for the renovation of residential buildings, for instance through the Topsector Energie Database (Topsector Energie, 2020), few projects report on the actual realized energy efficiency. However, data collection in energy renovations and new net-zero energy housing projects is becoming increasingly common in the building sector to evaluate actual energy performance in energy renovation projects. The gathered data can be utilized for a range of purposes. Table 1 summarizes the uses and opportunities for energy monitoring campaigns.

Table 1. Uses and Opportunities for Monitoring

Use	Opportunity
Scientific research to help develop an understanding about how renovation concepts are performing, how users are behaving, and why. At this level, data is helping to better determine parameters for building models, with the goal of helping to more accurately predict energy saving potential of buildings. With more energy monitoring data, researchers can develop methods to better characterize buildings and estimate energy performance, helping to determine what kind of renovation will lead to optimal outcomes for a building owner.	This is currently the most common application for energy monitoring campaigns in the residential sector. In recent years a significant amount of data has become available from renovation projects, as data gathering becomes increasingly common. Researchers need large quantities of data to help improve methods and models for predicting energy performance, user behaviour, and for understanding why energy consumption and behaviour patterns are occurring.
Energy performance contracts to help evaluate the performance of measures and concepts and to continuously monitor and steer on actual and agreed performance	Currently, data from energy monitoring campaigns is used for developing better energy performance contracts between building owners or energy companies and residents/tenants which are more ethical and tailored to different occupants.
Testing & improving renovation concepts and products to help building owners, contractors, installers and technology companies understand how the renovation concepts are performing. This information can help the parties make better decisions, save money and improve the experience of residents.	It is becoming increasingly common for building owners, contractors, installers and technology companies to gather data (via BMS systems, through resident surveys, etc.). However, very little of the data is being utilized to its full potential for decision making. It is not yet mainstream practice to utilize data for testing and improving products, but there is a significant need and opportunity for this.
Continuous fault detection to help building owners, installers and technology companies with ensuring proper operation of the systems.	It is becoming increasingly common for building owners, contractors, installers and technology companies to gather data through BMS systems in order to ensure proper system operation and remote fault diagnosis. This is becoming more common in non-residential building but is still rarely apply in homes.

1.2 Aim of the Report

This report aims to provide an overview of actual energy performance in energy renovation projects across the Netherlands. It also analyses the difference with predicted energy performance and analyses the perceptions of residents involved in low and zero-energy renovations. It answers questions such as:

- What energy and behavioural data is being gathered through energy monitoring in the residential sector (related to monitoring low and zero-energy buildings/dwellings)?
- How is the data currently being utilized?
- What does the data tell us about actual energy use and resident perceptions?
- How can monitoring be improved to help develop better energy models, and help building owners optimize their investments in energy renovation projects?

1.3 Scope & Methodology

This report provides a representation of the Dutch experience related to actual energy performance in residential energy efficient renovations.

Chapter2 summarizes the outcomes of scientific papers, theses and research analysing the actual energy performances of (renovations in) the Dutch national Building stock in comparison with the expected ones. Most literature is about the social housing building stock and most studies used the energy label database or the SHAERE database from AEDES together with a CBS database containing information on yearly energy consumption at address level. This way more than 85000 houses that underwent a thermal renovation were analysed.

The focus of Chapters 3 and 4 is on thermal energy renovation measures and concepts, including space and water heating and ventilation, that were applied in smaller groups of buildings and where monitoring took place. A focus has been placed on concepts that target a low energy outcome, corresponding approximately to an energy label B or better. It focuses on measures which are based on the use of technologies which are expected to become predominant in the future, including, for example, heat pumps, balanced ventilation, CO2-controlled ventilation. It highlights projects and studies which have been carried out in the recent past (approximately 10 years). It covers renovation projects in both the social and private housing sector across the Netherlands.

The report draws on energy monitoring campaigns, providing a data-driven approach to analysing energy efficiency measures and concepts[1]. Only reports and documents containing specific reference to at least one project and seriously targeting the

[1] Energy monitoring campaigns consist of gathering quantitative and qualitative data about energy efficiency renovation concepts, such as equipment performance, building occupant perceptions, and other external factors that may impact energy consumption and comfort. The data gathered in energy monitoring campaigns can serve to provide insights into the actual efficacy of energy efficiency renovations, as well as how residents are experiencing the renovations. The data can also be used to feed and validated digital twins.

occupants were considered. Information was supplemented through interviews with the project partners (subject matter experts) of the IEBB Theme 2 project.
The information searched for with respect to the energy monitoring campaigns included:

- What building characteristics were reported?
- What aspects of energy performance were considered?
- What aspects of occupancy were considered? In which part of the renovation process?
- What methods of data collection and analysis were used?
- Which data was collected, with which time step and during which period?
- How were other performance aspects (indoor environmental quality (IEQ)) considered?

Renovation projects and energy monitoring campaigns referenced in this report were identified in two ways:

- Through the development of an inventory of monitoring campaigns known by the consortium partners of the IEBB project. From these only the projects with public reports have been used.
- Through desktop research, where on a non-exhaustive search for reports and information about renovation projects where monitoring data (both quantitative and qualitative[2]) was gathered. The report is therefore based on an analysis of existing data, results and publications which have been publicly reported.

The projects were selected based on the public availability of the studies. The renovation also had to target at least energy label B and the reports had to highlight the occupant perspective as well. It includes energy performance data gathered through smart meters and energy bills, as well as occupant data gathered through surveys and interviews. The projects include both social housing and private housing. They are mostly renovation projects, but some new build projects are included for reference.

In total 65 Dutch renovation projects were identified, but because many of them were not well-documented, we ended with 46 projects representing 4.404 houses. From these houses, only 3.695 houses, from 10 different studies, reported on the results and could be accounted for in the analysis of energy performance or user experience. In three projects only, the reports combined all needed information on both energy performance and occupant perspective.
The remaining 709 houses, without reports, have been considered in a short analysis of how data is used (see section 3.3) through non-structured interviews/discussions with the ones processing the data.

[2] Data on quantitative metrics like energy performance, as well as qualitative data related to the behaviour and perceptions of building occupants was gathered.

2. WHAT IS KNOWN ABOUT THE PERFORMANCE OF ENERGY EFFICIENCY RENOVATIONS IN THE DUTCH HOUSING STOCK?

Efforts are underway to improve efficiency and eliminate the use of natural gas in existing residential dwellings for all functions, including space and water heating[3]. Efficient heating and ventilation technologies like heat pumps, balanced ventilation and CO2-controlled ventilation, among others, are being scaled up via energy efficiency renovations to support this.

There is a wide range of thermal energy renovation measures and concepts, each offering varying levels of potential energy-savings. For this report, we define thermal renovations in the following four classifications. This follows a classification of thermal energy renovations defined by (Van den Brom, 2020).

- Single thermal renovation measures: for example, roof insulation, floor insulation, façade insulation, window, heating system, hot water system or ventilation.
- Building insulation: consists of significant improvements to the insulation level of the entire building envelope.
- Building installation: consists of significant improvement to all building installations (heating, domestic hot water, and ventilation).
- Deep renovations: consist of significant improvements in at least three building components that bring them to a level equal to or higher than the current building regulation standards.

How Energy Efficiency Is Currently Calculated

In the Netherlands, energy labels are widely used and accepted as an indicator of a building's energy efficiency. Energy labels are based on the NTA8800 method (Rijksoverheid, 2019), which frames energy efficiency in terms of kWh/m^2 per year. Until July 2020, energy labels were based on an Energy Index calculation, as set out by the European Commission. This index was based on a heat loss and gain calculation, corrected for the floor area of the dwelling and the corresponding heat transmission areas.

Several analyses of energy efficiency in buildings have consistently shown a discrepancy between predicted (or modelled) energy consumption (Van den Brom, 2020) (Majcen, Predicting energy consumption and savings in the housing stock., 2016)

[3] The majority of residential energy consumption is from space and tap water heating. This report therefore places an emphasis on thermal energy renovations focused on improving overall energy performance in buildings.

(Filippidou, 2018) and actual energy consumption. This discrepancy is known as the Energy Performance Gap[4].

This phenomenon exists in both the private sector (Tigchelaar & Leidelmeijer, 2013) and social housing sector (Majcen, Itard, & Visscher, 2013), and is experienced not only on a project scale, but at the scale of the Dutch national housing stock and many other national housing stocks, like France, UK and Denmark (Gram-Hanssen, 2016).

An analysis of 87,513 houses within the Dutch social housing stock, which underwent thermal energy renovations between 2010-2014[5], found that there was an energy performance gap in 97% of dwellings. The performance gap is observed as well with simple measures like glass insulation or wall insulation.

Within the studied dwellings, on average:

- 40% of the renovations were found to have higher energy savings than expected,
- 57% had energy savings that were lower than expected, and
- Only 3% of the renovations had well-predicted results (10% higher or lower than the expected savings).

Figure 1 describes the percentage of overestimated, underestimated and well-predicted energy savings for each renovation measure. The figure illustrates that energy savings are frequently overestimated, and that deep renovations often (81%) result in lower energy savings than expected.

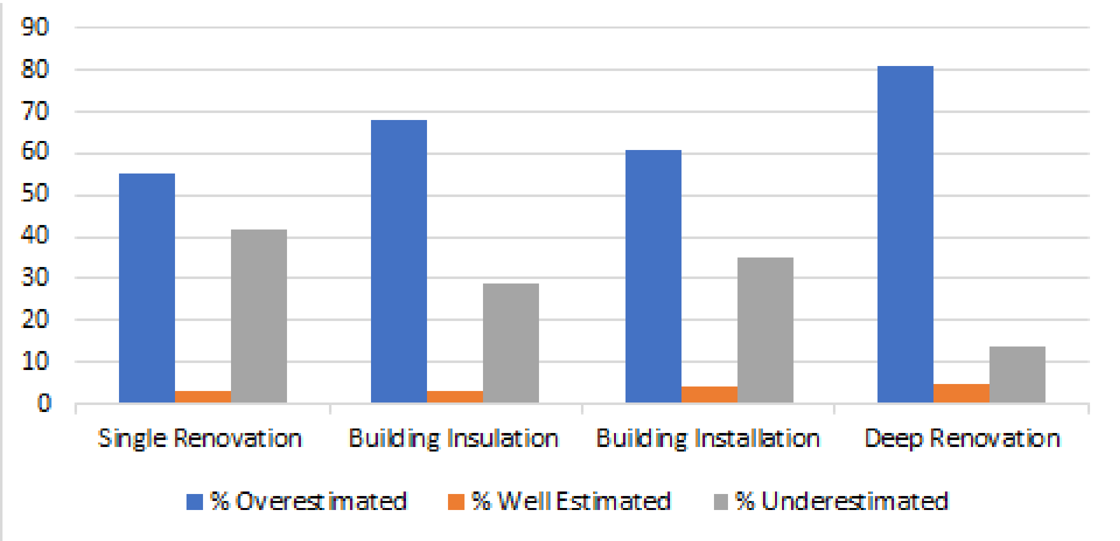


Figure 1. The Percentage of Over-predicted, Well-predicted and Under-predicted Energy Savings for Different Classifications of Energy Renovations Measures (Van den Brom, 2020)

[4] This analysis is based on buildings which were modelled using the Energy Index method, which is no longer in use. While the method for calculating energy labels has improved through the current NTA8800 method, it is expected to result in the same shortcomings, and therefore result in the continued discrepancy between assumed and actual energy consumption.

[5] This sample was selected from a database of over 2 million homes in the AEDES SHAERE and Statistics Netherlands databases.

The same study found that significant differences exist between the average energy savings per energy label for different renovation measures (Van den Brom, 2020).

Figure 2 compares predicted energy savings and actual savings per renovation measure for single measures, and a combination of measures. The number of cases per renovation measure is provided in the figure, and the bars represent the average annual savings in MJ/m^2.

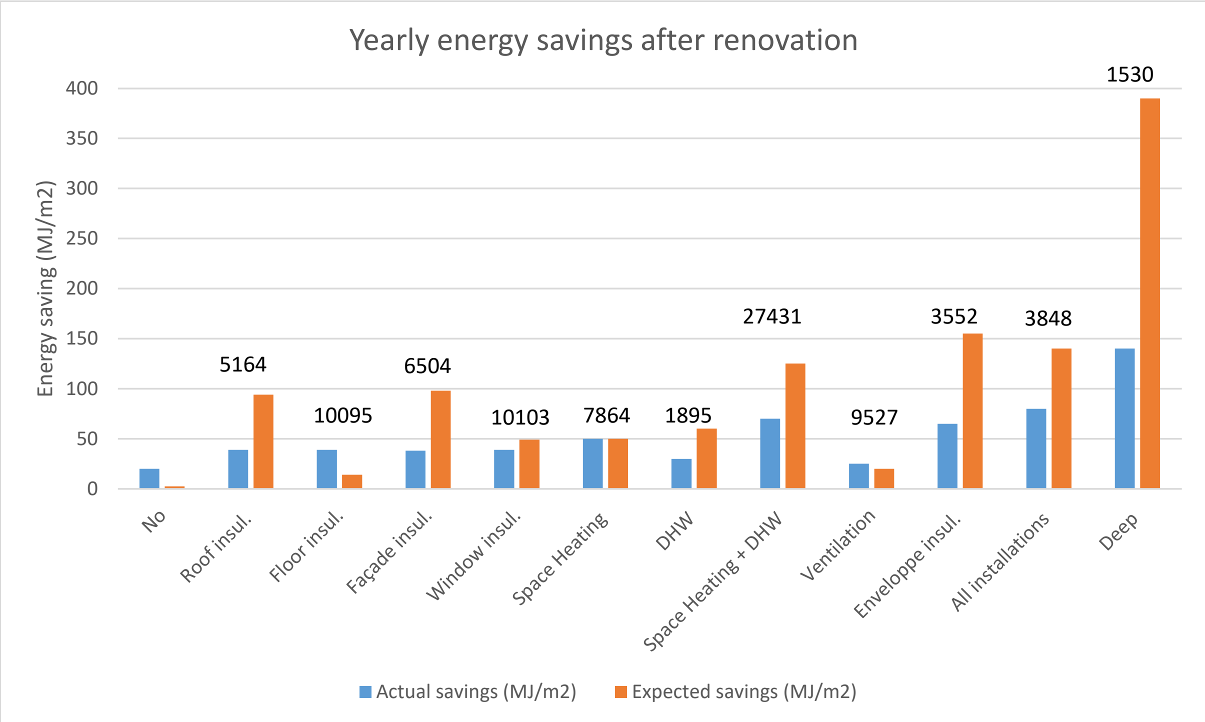


Figure 2. Average Energy Savings in Social [Rented] Housing (Corrected for Degree Days) per Thermal Renovation Measure (Van den Brom, 2020)

It is clear that - except for a few measures like floor insulation, a change in the heating system and change in the ventilation system - the discrepancies are very large, especially for the deep renovations.

Causes of the discrepancy between predicted and actual energy consumption
Research has shown that variances in energy use can be explained by approximately 50% by the user and 50% by building characteristics and external influences (Van den Brom, Hansen, Gram-Hanssen, Meijer, & Visscher, 2019). It is logical then that at individual building level, occupant behaviour plays a strong role in energy consumption. One would, however, expect this effect to be lower at building *stock* level, assuming that variances caused by behaviour would be less apparent because of the large number of households. Figure 2 shows that this is however *not* the case and confirms that energy models do not capture average occupant behaviour.

The discrepancy between predicted and actual energy consumption is a result of:

- Models that do not consider occupant behaviour (number of occupants, ventilation behaviour, temperature settings, use of sun shading, maintenance, and settings of appliances) (Guerra Santin, 2010).
- Models that do not consider external influences accurately enough (shading, or obstructions due to adjoining plots, and the geographic location of the building in the Netherlands).
- Parameters and inputs of the models that cannot be well-determined (like infiltration flow rates or even Rc-values). The estimation of these parameters is time consuming, and therefore costly. However, digital methods based on smart meter data are promising.
- Issues with the systems based on how they are installed and commissioned.

The discrepancies are problematic because they result in inaccurate estimates of expected energy and carbon reductions. This consequently leads to higher-than-expected energy costs and a longer-than-expected payback periods for the party investing in the energy renovations.

Recommendation 1: The correct modelling of expected energy savings after renovations is essential for helping housing associations (and tenants) carry out thermal renovations. Reasons for discrepancies should therefore be researched at a building level, project level and building stock level. This entails a correct estimation of building construction properties before the renovation and a correct estimate of the energy use after renovation. For the estimation of construction properties, digital methods may offer interesting possibilities that should be investigated.

3. THE ACTUAL ENERGY EFFICIENCY OF DWELLINGS AFTER ENERGY EFFICIENCY RENOVATIONS

This chapter contains an inventory of what is known from Dutch renovation projects about the actual realized energy efficiency.

3.1 Description of analysed energy renovation projects

Table 2 contains an overview of energy renovation projects, in which monitoring data or energy bills were used to assess the energetic performance of the renovated dwellings. A precise description of the renovation measures (R_c values, ventilation, air tightness, heating and electricity production) is given in Appendix I[6], and some additional information is also given in section 4.2. In total 8 projects were analysed, representing 3575 dwellings.

Please note that the following terms are used interchangeably: net-zero energy, nul-op-de-meter (NOM), energy-neutral, zero-energy and net zero energy. NOM is the Dutch abbreviation for a house that produces as much renewable energy as it uses yearly on site[7].

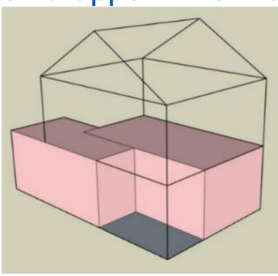
Table 2. Overview of Analysed Energy Renovation Projects, with information on actual energy performance

1	<u>Quickscan Huurderstevredenheid EPV</u> Energetic aim of the renovation: NOM / Net-Zero Energy Housing sector: Social # monitored dwellings: 3,100 Renovation concept used and goal of the monitoring campaign: The aim of this project was to assess social housing tenant's satisfaction with the Energieprestatievergoeding (EPV)[8]. 19 renovation and construction projects involving energy efficient or NOM homes were analysed, two of which included monitoring of the energy use for one year after the renovation. Of the projects analysed, 13 (approximately 450 homes) were NOM new construction or renovation, 6 (approximately 650 homes) were energy-efficient new construction or renovation; 32 (approximately 2,000 homes) were renovations or new construction with energy measures. EPV was usually used in the homes but not all corporations applied it immediately (De Jong & Borger, 2018).

[6] The projects are renovation projects unless otherwise stated.

[7] As an example, a house consuming 5,000 kWh per year for heating and electricity is said to be NOM if 5,000 kWh electricity is produced yearly by solar PV-cells. Positive energy refers to a house that produces *more* renewable energy than it uses yearly on site.

[8] The EPV was introduced in 2016. It allows owners of social housing to request a fee from tenants for (nearly) zero-energy buildings, so that the housing corporation receives a return on the investment. https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels/bestaande-bouw/energieprestatievergoeding

	Public reports about the project: Eindrapport Quickscan Huurderstevredenheid EPV
2	Thermisch Compartimenteren / Thermal Compartmentation Energetic aim of the renovation: NOM / Net-Zero Energy # monitored dwellings: 4 Housing sector: Social Renovation concept used and goal of the monitoring campaign: Two terraced and two end-of-terrace houses constructed in 1955 were renovated according to Thermal Compartmentalization renovation concept, in which insulation, airtightness and ventilation measures are applied to the kitchen and living room. The floor between the living room and bedrooms is also insulated, thereby creating a ‘warm’ and ‘cold’ compartment (Rovers, Struck, & van ‘t Ende, 2020). The aim of the monitoring campaign was to reduce the costs for renovation, whilst reaching net-zero energy (Salemink & Rovers, 2020). Public reports about the project: Compartimenteren woningen met binnen isolatie op maat Compartimenteren woningen met binnen isolatie op maat – aanvulling openbaar eindrapport: monitoring van het energiegebruik over 2020  *Picture: Saxion Hogeschool*
3	Concepten nul op de meter en 80% besparing Monitoring goal: The purpose of the monitoring was to learn from these pioneer projects and share the experiences. Public reports about the project: Final report - Concepten nul op de meter en 80% besparing Resultaten uit monitoring over: Tevreden bewoners
3(a)	Kerkrade Energetic aim of the renovation: 80% reduction in energy use Housing sector: Social # monitored dwellings: 153 Renovation concept used: 153 Social housing dwellings were retrofitted in 10 days with the aim of achieving an 80% reduction in energy use. Methods include new prefab façades, where ventilation ducts were incorporated into the timber frame construction. Prefab roof elements with integrated PV-panels. The toilet, shower and kitchen were not renewed. Gas and electricity were monitored in some houses (Jacobs, Liedelmeijer, Borsboom, van Vliet, & de Jong, 2015).
3(b)	Concepten nul op de meter en 80% besparing - Zorgeloos Wonen Energetic aim of the renovation: 50% reduction in energy use, LEAN[9] Housing sector: Social

[9] LEAN refers to a management strategy which focuses on the elimination of several types of waste, leading to a reduction in operational costs whilst maintaining or improving the quality of the product.

	# monitored dwellings: 115 Renovation concept used: 115 social housing dwellings were retrofitted to label A or A+, with the aim of achieving a 50% reduction in energy use. Renovation measures include new, insulated facades, the insulation of the roof and ground floor, high-performance windows and doors.
4	4. 2nd Skin Demonstrator – Zuid Holland Energetic aim of the renovation: NOM/Net-Zero Energy Housing sector: Social # monitored dwellings: 9 Renovation concept used and monitoring goal: As part of the renovation, the following technologies were implemented: improved insulation, balanced mechanical ventilation with heat recovery, ground source heat pump, low-temperature convectors (cooling possibilities in summer). The project focused on testing user-centered methodologies for monitoring and data analysis, as well as evaluating whether the renovation is really zero-energy. This project also focused on assessing tenant satisfaction and finding aspects to improve in process and the products used. Public reports about the project: Final Report: 2ndSKIN zero energy apartment renovation via an integrated façade approach
5	Tolhuis 1590 - Nijmegen Energetic aim of the renovation: NOM/Net-Zero Energy Housing sector: Social # monitored dwellings: 1 Renovation concept used and goal of the monitoring campaign: The aim of this project was to renovate a 1970s end-of-terrace dwellings to net-zero energy, using the ActiveWarmth electrical wall heating system (De Gemeenschap, n.d.). The monitoring goal was to evaluate the efficacy of the ActiveWarmth electrical wall heating system (Van Goor, 2017). Public reports about the project: Tolhuis Nijmegen Final Report
6	NOM – Zoetermeer Energetic aim of the renovation: NOM/Net-Zero Energy # monitored dwellings: 120 Housing sector: Social Renovation concept used and goal of the monitoring campaign: The purpose of this project is to monitor the energy and comfort performance and to ensure the proper functioning of the energy system. The houses are equipped with the integrated Climate Energy Module (iCEM) of Factory Zero. No survey has been carried out in this project. The research questions addressed in the project are: What is the energy use? What is the energy production? What is the performance of the heat pump? How many hours was the temperature/humidity/CO_2 level outside a comfortable range?

	 *Photo: Baldiri Salcedo Rahola*
7	<u>NOM Renovation - Heerhugowaard</u> Energetic aim of the renovation: NOM/Net-Zero Energy Housing sector: Social # monitored dwellings: 55 Renovation concept used and monitoring goal: A prefabricated facade and roof were placed over the existing homes. The natural gas connection was disconnected, and PV panels were installed at the front and rear to provide as much energy as is (on average) needed for the house and household. The houses kept their connection to the electricity grid (Borsboom, Leidelmeijer, Vliet, de Jong, & Kerkhof, 2016). The purpose of the monitoring was to learn from these pioneer projects and share the experiences. Public reports about the project: NOM-woningrenovatie op weg naar een kwaliteitsproduct. Een inventarisatie van korte termijn verbeter-mogelijkheden Bewonerservaringen En Meetresultaten Uit Nul Op De Meter Woningen In Heerhugowaard
8	<u>NOM Renovation – Tillburg</u> Energetic aim of the renovation: NOM/Net-Zero Energy Housing sector: Social # monitored dwellings: 18 Renovation concept used and goal of the monitoring campaign: This project used a modular building systems Zero on the Meter renovation concept consisting of prefabricated facade elements, a new roof and floor insulation. A balanced ventilation system with heat recovery was used, with a heat pump, boiler, control box, monitoring system and a solar power inverter. The homes did not have a gas connection. Via a website dashboard, it can be seen how much energy is being generated and consumed and whether they are on track for net-zero energy (Borsboom, et al., 2017). Public reports about the project: Bewonerservaringen en meetresultaten Nul op de Meter in Tilburg

3.2 How did the renovations perform?

Table 3 contains an overview of the energy results per project, and the manner in which these were monitored.

Table 3. Monitoring of Energy Use

Project	Energetic aim	Results	Monitoring – energy		Monitoring - other
			Total energy use	Sub-metering	
1. Quickscan Huurderstevredenheid EPV	Net-zero energy	I: 42/46 dwellings are positive energy II: 6/10 dwellings are net-zero or positive energy	Monitoring of energy use over one year.	Electricity consumption and generation. Although not explicitly mentioned, it seems that DHW and SH were monitored separately.	n.a.
2. Thermisch compartimenteren / Thermal Compartmentation	Net-zero energy	A: Positive energy (+1100 kWh) B: Aim not reached (-600 kWh) C: Positive energy (+1500 kWh) D: Positive energy (+800 kWh)	Monitoring of energy use over the year 2020.	Electricity consumption and generation. Heat pump: electricity use, heat delivered to cold compartment, warm compartment and DHW.	One temperature sensor per floor, state contacts
3. Concepten nul op de meter en 80% besparing - Kerkrade	80% reduction in energy use	The energy use for heating is higher than expected. The electricity use for DHW and appliances and ventilation are lower than expected. The electricity generation by PV is lower than expected.	Monitoring of energy use from 18-7-2013 to 12-11-2014.	Electricity consumption and generation. Energy use for DHW and SH were monitored separately. Electricity generation.	n.a
4. 2nd SKIN Demonstrator – South Holland	Net-zero energy	Positive energy due to high yield of PV.	Monitoring of energy use over	Electricity consumption and generation.	Indoor temperature, RH, CO2 and presence.

			two years.		Acceptance, use and evaluation of residents.
5. Tolhuis 1590 - Nijmegen	Net-zero energy	Positive energy (+1300 kWh)	Monitoring of energy use over heating season 2015/2016.	Electricity consumption and generation.	n.a
6. NOM-Zoetermeer	Net-zero energy	Positive energy (+2300kWh)	Monitoring of energy use over the year 2019	Electricity consumption and generation.	Indoor temperature. Temperature, RH, and CO2 of outflow air.
7. NOM renovation - Heerhugowaard	Net-zero energy	46/46 Positive energy in 2015, 42/46 Positive energy in reference climate year	Monitoring of energy use over the year 2015	Daily total electricity consumption, energy use of heat pump, electricity generation.	n.a.
8. NOM renovation - Tilburg	Net-zero energy	8/10 Positive energy in 2015, 6/10 Positive energy in reference climate year	Monitoring of energy use from July 2015 to March 2016	Total electricity consumption, electricity generation, energy use of heat pump.	n.a.

It is noticeable that most projects perform better than expected, being positive energy instead of net-zero energy, also after correction for degree days. The monitoring periods were long enough to ensure a reliable estimation of the yearly energy use.

The higher-than-expected energy performance is surprising in comparison to the results of Chapter 2. (see Figure 2) where it was found that deep renovation generally perform much worse than expected. However, the results in Chapter 2. were obtained for dwellings for which in general no monitoring was applied. It is very well possible that in the eight studies described here, the monitoring has led to actions to restore malfunctioning. It is also possible that because of monitoring and possible energy contracts, additional care was put into the realization of the renovation. But above all, in these projects *the targets are not expressed in terms of energy savings but in terms of achieving net zero energy*.

As can be seen in the more detailed analysis below it seems to happen often that the energy performance of either space heating or hot tap water is lower than expected (at least in 4 of the 8 projects), but this is not seen in the total performance because higher-than-expected solar electricity production makes the house energy positive.

Quickscan huurderstevredenheid EPV

In the first project, the electricity generation was found to exceed the electricity consumption in 42 of the 46 dwellings, after correcting for the use of appliances and ventilation (a standard electricity use of 3000 kWh was used), and in a reference climate year. In one dwelling, more energy was used for domestic hot water (DHW), and in three dwellings more energy was used for space heating.

The second project comprised twenty dwellings, ten of which were monitored and analysed. After correcting for the use of appliances and ventilation, six of these dwellings were found to be net-zero energy or positive energy in a reference climate year. Building installations did not function correctly, causing the electricity use for heating to be higher than expected.

Thermisch compartimenteren / Thermal Compartmentation

For three of the dwellings, it was found that the annual electricity generation exceeded the electricity consumption with approximately 1,100, 1,500 and 800 kWh in a reference climate year (i.e. the energy use in 2020 corrected using the heating degree day method), despite the fact that heat pumps had lower efficiencies than expected. One dwelling had an annual net energy use of approximately 600 kWh per year, which is at least partially the result of a dysfunctional heat pump.

Concepten nul op de meter en 80% besparing - Kerkrade

For a number of the 153 renovated dwellings in Kerkrade, the gas and electricity use were analysed. It was found that both the energy use (for appliances, ventilation, domestic hot water and cooking) and electricity generation were lower than anticipated. The energy use for space heating was higher than expected. The project report speculates that "a possible reason could be that the calculation method for space heating in the EPC was too positive for heat pumps or that the efficiency of the heat pump was different from what was expected."

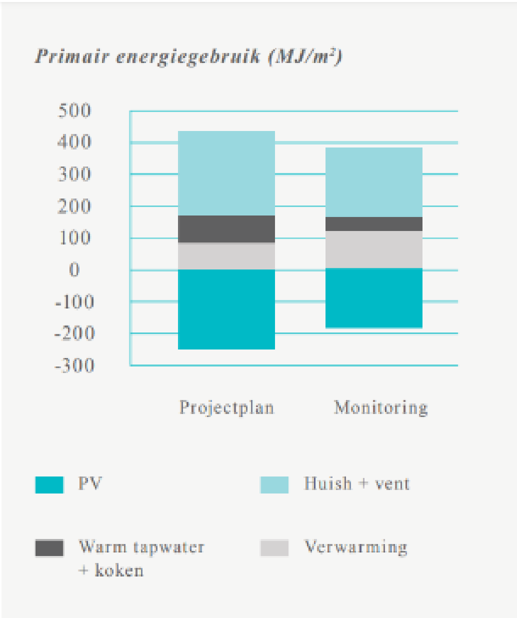


Figure 3. Modelled vs. Actual Energy Consumption and Production - Concepten nul op de meter en 80% besparing – Kerkrade (Jacobs, Liedelmeijer, Borsboom, van Vliet, & de Jong, 2015)

2nd SKIN (Demonstrator)

For the demonstrator project, twelve Simplex buildings were renovated. During the first two years, a net energy surplus was measured due to the high yield of the PV-panels.

Tolhuis 1590

A net energy surplus of 1,300 kWh was measured in the heating season 2015/2016.

NOM-Zoetermeer

The measurements took place on 2019, from 1st January to 31 December. In average there was a yearly surplus of energy of 2300kWh. The houses are equipped in average with 8575Wp (corner houses and in between houses do not have the same number of solar panels). The comfort parameters, temperature, humidity and CO_2 were most part of the time within good comfort range in the winter season. However, high temperature was recorded during the summer season. The houses are well insulated, and they have not been equipped with external shading devices.

NOM renovation Heerhugowaard

The total energy consumption, the electricity generation, and the energy use of the heat pump of 55 buildings was monitored from 1 January 2015 to 22 December 2015. Due to issues with the monitoring systems in 9 of the buildings, the energetic results of 46 dwellings are reported. In 2015, all 46 dwellings were found to be positive energy. In a reference climate year (NEN 5060), 42/46 dwellings would be positive energy. 43/46 dwellings used less energy for DHW than anticipated. 33/46 dwellings used less energy for space heating than anticipated.

- NOM renovation Tilburg

Eighteen buildings were renovated, for ten of which monitoring data of sufficient quality was available.
The total energy consumption, the electricity generation and the energy use of the heat pump was monitored from July 2015 to March 2016. For 2015, 8/10 dwellings were found to be at least net-zero energy. In a reference climate year (NEN 5060), 6/10 dwellings would be at least net-zero energy. The energy use for space hating is higher than anticipated.

3.3 How is data used?

A number of renovation projects identified during the desk study and the inventory from projects owned or known by IEEB-2 partners had to be discarded from the analysis, as monitoring was carried out, but the monitoring data were not analysed or not publicly available. This happened in 902 houses, representing more than 15 projects.

From non-structured interviews and discussions during IEBB partner meetings it seems that it is becoming more common to collect energy data. However, this data is used at a high aggregation level only. While energy meter data are collected, sometimes on monthly basis, sometimes per hour or per15 minute, it seems that only aggregated data is used for yearly performance analysis and sometimes to roughly track malfunctioning in HVAC systems. In general, the largest part of the data is not used and there seems to be a need for methods and standards how to analyse the data. As noted by an interviewee of an organization having collected data before and after renovation, the organization lacks time, capability and workforce to analyse the data. This was even more the case for data relating to occupant preferences and behaviour.

Some companies/organizations are working together with students and teachers at universities of applied sciences to make progress in their analysis. The remarks here were that in few projects a lot is measured, and even used to improve some parts of the system, like heat pumps. But in general, the students were the first ones to make detailed analysis and to find out that sometimes sensors were wrongly placed, or wrongly tagged, or that submetering data needed for the diagnostic of malfunctioning were not present.

Finally, in discussions with two companies selling and installing monitoring equipment for energy and indoor air quality, they both indicated that developments regarding the use and analysis of the data were urgently needed.

3.4 Takeaways & Recommendations

Reported performances

In most of renovation projects reviewed in this report, the energy performance was far above expectation: actual energy consumption was lower than was predicted or expected. However, the targeted performance in these projects was not expressed in terms of energy savings but in terms of being 'net-zero' energy which may also explain the positive outcome. In the projects were space heating or hot tap water energy savings were mentioned, the target was not achieved.

Although the positive results are very promising, it may be useful to realize that more positive results may have been published than negative results. It might also be that in projects where energy monitoring is being carried out, the data help to inform early insights and repairs may be completed if the data shows that things are not performing well, and results may only be reported after adjustments have been made. Additionally knowing that monitoring will take place could influence positively the quality of realization in the studied projects.

Recommendation 2: The fact that a monitoring system is installed and that it is known on beforehand that performance may be analysed might be a driver for better realization practices and quicker diagnosis of (rough) malfunctioning

Recommendation 3: More transparency is needed about underperformance. With more information, researchers, installers and producers can do targeted monitoring and even solve problems on beforehand. It will also help in the development of more accurate energy prediction models.

Recommendation 4: More research/transparency on drivers for excellent performances will be helpful to positively influence the market by making companies and housing associations aware of good practices

Submetering

In the data reported on in the energy monitoring campaigns associated with the renovation projects, it is often not clear why projects are outperforming or underperforming. More data, particularly from sub-meters, is essential for developing an understanding about why buildings are performing the way they do. For example:

- In the Thermal Compartmentation and Heemwonen projects, it was found that in reality, *less* energy is used for DHW, ventilation, lighting and appliances than anticipated.
- In the Thermal Compartmentation project, it was furthermore found that the efficiencies of the heat pumps were lower than expected (i.e. more energy was used for the heat pumps than anticipated).
- In the Quickscan huurderstevredenheid EPV project, monitoring revealed dysfunctional building systems.

Recommendation 5: More sub-metering data should be collected and disclosed by building owners, contractors and/or technology providers. With more sub-metering data, researchers and contractors will be better able to fix as soon as possible malfunctioning. It will also help researchers to explain the differences between the anticipated and actual energy efficiency of a building after renovation in such a way that better predictions can be made.

Recommendation 6: In addition to smart meter data, to be able to steer on the performances and to diagnose malfunctioning, sub-metering data should include:

- Splitting gas use in space heating, domestic hot water (DHW) and cooking
- Splitting electricity use in space heating, DHW, ventilation, cooking and appliances
- Splitting electricity production of PV-cells in on-site energy used, and delivery to grid
- Splitting net electricity use in electricity from grid, from PV-cell and electricity delivered to grid
- Setpoint temperatures of the systems, especially when heat pumps are involved
- Air temperatures

Besides sub-metering, other measurements may explain the difference between the anticipated and actual energy use, for example:

- CO_2 sensors
- Heat pump mode
- Opening of windows and doors
- Occupant presence (measured in the Thermisch compartimenteren / Thermal Compartmentation and 2nd Skin projects)

There is therefore also a need to define which submetering data is needed.

Stakeholders

Stakeholders in the market seem to be in need of data analysis methods. There is a learning need in that area, but the information sources are very scattered. There is a need for standardized methods and to know where to find the right information

Recommendation 7: Develop guidance (booklet/webinars/information) on how to analyse data from smart meters and other meters and which data should be measured to enable fully performing energy and indoor climate equipment.

4. HOW BUILDING OCCUPANTS ARE EXPERIENCING ENERGY EFFICIENCY RENOVATIONS

As mentioned in Chapter 2, a considerable share of the variation in energy use is known to be due to variations in occupant behaviour. Previous research has shown that household composition, heating, cooling and ventilation practices, and lifestyle have a large effect on energy consumption and indoor air quality. These differences can contribute to the performance gap and to uncertainties regarding the financing of renovation projects.

The objective of this chapter is to summarize the existing knowledge regarding the role of the occupants in the success of zero energy and low energy renovation projects in the Netherlands, from a practical perspective, that is: focusing on the practices followed by the construction industry in current renovation projects. The following sections present the results.

4.1 Overview of identified projects

In total, 6 energy renovation projects (14 sub projects, accounting for 3695 houses) were analysed based on information contained in seven public documents, as well as non-public reports and presentations obtained via the project consortium. Table 4 summarises the types and characteristics of projects. The colour codes in Table 4 are used further in the chapter tor refer to the projects as described in the table. Projects 1 (Quickscan Huurderstevredenheid EPV), 3a (NOM-Kerkrade) and 3b (NOM-Zorgeloos wonen) also reported on the energy performance (see Chapter 3). Projects 4 (Heerhugowaard) and 5 (Tilburg) also report on energy performance but not deep enough to be concluded in the analysis.

Table 4. Methods Used in Each of the Projects

1	Quickscan Huurderstevredenheid EPV Energetic aim of the renovation: NOM / Net-Zero Energy Housing sector: Social # monitored dwellings: 3,100 Renovation concept used and goal of the monitoring campaign: The aim of this project was to assess social housing tenant's satisfaction with the Energieprestatievergoeding (EPV). 19 renovation and construction projects involving energy efficient or NOM homes were analysed, two of which included monitoring of the energy use for one year after the renovation. Of the projects analysed, 13 (approximately 450 homes) were NOM new construction or renovation, 6 (approximately 650 homes) were energy-efficient new construction or renovation; 32 (approximately 2,000 homes) were renovations or new construction with energy measures. EPV was usually used in the homes but not all corporations applied it immediately.[15] Public reports about the project: • Eindrapport Quickscan Huurderstevredenheid EPV
2	NOM Renovations & New Builds – Woonbord Energetic aim of the projects: NOM/Net-Zero Energy Monitoring goal: Not known Public reports about the project: • Woonborg en de Energietransitie
2 (a)	NOM Renovation - Roden Housing sector: Social # monitored dwellings: 6 Renovation concept used: Before the renovation, there were problems with draft, damp, limited facilities and no ideal layout (shower room in storage room).
2(b)	NOM Renovation – Padkamp Roden Housing sector: Social # monitored dwellings: 2 Renovation concept used: Unknown
2(c)	NOM Renovation - Roden Housing sector: Social # monitored dwellings: 33 Renovation concept used: Unknown
2(d)	NOM – New Build Holtenweg Vries Housing sector: Social # monitored dwellings: 8 Renovation concept used: Unknown
3	Concepten nul op de meter en 80% besparing Monitoring goal: The purpose of the monitoring was to learn from these pioneer projects and share the experiences. Public reports about the project: • Final report - Concepten nul op de meter en 80% besparing • Resultaten uit monitoring over: Tevreden bewoners

3a	Kerkrade Energetic aim of the renovation: 80% reduction in energy use Housing sector: Social # monitored dwellings: 153 Renovation concept used: 153 Social housing dwellings were retrofitted in 10 days with the aim of achieving an 80% reduction in energy use. Methods include new prefab façades, where ventilation ducts were incorporated into the timber frame construction. Prefab roof elements with integrated PV panels. The toilet, shower and kitchen were not renewed. Gas and electricity were monitored in some houses (Jacobs, Liedelmeijer, Borsboom, van Vliet, & de Jong, 2015).
3b	Concepten nul op de meter en 80% besparing - Zorgeloos Wonen Energetic aim of the renovation: 50% reduction in energy use, LEAN[10] Housing sector: Social # monitored dwellings: 115 Renovation concept used: 115 social housing dwellings were retrofitted to label A or A+, with the aim of achieving a 50% reduction in energy use. Renovation measures include new, insulated facades, the insulation of the roof and ground floor, high-performance windows and doors.
3c	Concepten nul op de meter en 80% besparing - Amsterdamse Buurt - Haarlem Energetic aim of the renovation: Energy label B Housing sector: Social # monitored dwellings: 108 Renovation concept used: 108 social housing dwelling were retrofitted from label F to A and B (37 dwellings) and A+ (71 dwellings), by application of internal wall insulation, high-performance glazing and PV panels.
3d	Concepten nul op de meter en 80% besparing - Energiesprong Montferland Energetic aim of the renovation: Not disclosed Housing sector: Social # monitored dwellings: 61 Renovation concept used: 61 dwellings were demolished and rebuilt. Energy efficiency measures include air source heat pumps, low-temperature underfloor heating and convectors.
3e	Concepten nul op de meter en 80% besparing - RijswijkBuiten Energetic aim of the renovation: NOM New Build Housing sector: Private # monitored dwellings: 5 Renovation concept used: The project was built to NOM standards. Measures include ground-source heat pumps, solar panels, high-efficiency ventilation and a well-insulated shell.
4	NOM Renovation - Heerhugowaard Energetic aim of the renovation: NOM/Net-Zero Energy Housing sector: Social # monitored dwellings: 55

[10] LEAN refers to a management strategy which focuses on the elimination of several types of waste, leading to a reduction in operational costs whilst maintaining or improving the quality of the product.

	Renovation concept used and monitoring goal: A prefabricated facade and roof were placed over the existing homes. The natural gas connection was disconnected and PV panels were installed at the front and rear to provide as much energy as is (on average) needed for the house and household. The houses kept their connection to the electricity grid (Borsboom, Leidelmeijer, Vliet, de Jong, & Kerkhof, 2016). The purpose of the monitoring was to learn from these pioneer projects and share the experiences. Public reports about the project: • NOM-woningrenovatie op weg naar een kwaliteitsproduct. Een inventarisatie van korte termijn verbeter-mogelijkheden • Bewonerservaringen En Meetresultaten Uit Nul Op De Meter Woningen In Heerhugowaard
5	NOM Renovation – Tillburg Energetic aim of the renovation: NOM/Net-Zero Energy Housing sector: Social # monitored dwellings: 18 Renovation concept used and goal of the monitoring campaign: This project used a modular building systems Zero on the Meter renovation concept consisting of prefabricated facade elements, a new roof and floor insulation. A balanced ventilation system with heat recovery was used, with a heat pump, boiler, control box, monitoring system and a solar power inverter. The homes did not have a gas connection. Via a website dashboard, it can be seen how much energy is being generated and consumed and whether they are on track for net-zero energy (Borsboom, et al., 2017). Public reports about the project: • Bewonerservaringen en meetresultaten Nul op de Meter in Tilburg
6	Zen Nieuwbouwwoningen Energetic aim of the renovation: NOM/Net-Zero Energy or Low-Energy Housing sector: Social and private # monitored dwellings: 31 projects and 302 residents engaged Renovation concept used and goal of the monitoring campaign: The purpose of the energy monitoring campaign was to measure the satisfaction of homebuyers, as well as to investigate the experiences of residents of a ZEN home. An extensive survey was carried out in the Spring of 2019 inquiring about: How satisfied are residents with their new-build home? Do they find the home comfortable? How do they experience the energy-efficient measures and systems? Do they understand the systems? Was the information sufficient? What do residents find important? (de Jong, 2019) Public reports about the project: • Woonbelevingsonderzoek Bij Bewoners Van Zen Nieuwbouwwoningen

4.2 What aspects of occupancy were investigated?

The investigation on the role of the occupants in the success of the renovation projects can be categorised according to the phase of the renovation considered and according to the focus on the process or the product.

Different aspects are considered. In relation to the process, we can see the efforts to evaluate the renovation process itself, the residents' participation, and the communication process. In relation to the product, we find a focus on the overall results of the renovation before and during renovation (i.e., the renovated home), the information on itself, and the different outputs of the renovations, that is, the performance of the building in several aspects ((energy) costs, thermal comfort, indoor air quality, noise), and the interaction of the people with the building (the installations). There is also a focus on the quality of the information since residents were also asked whether the information received was understood.

Figure 4 shows an overview of the different occupant related aspects investigated in the projects.

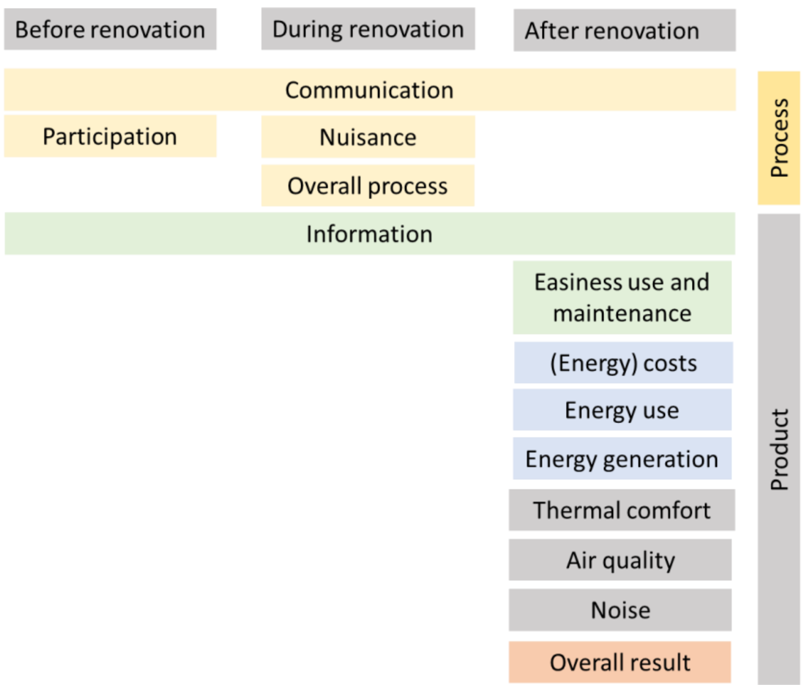


Figure 4. Occupant-related Aspects Investigated in the Projects

4.3 What methods and data were used?

Four types of data collection and analysis methods were found in the projects reviewed in this study: surveys and interviews with residents, building monitoring, interviews with professionals, and desk studies based on previously documented cases. All of the cases in which building monitoring was carried out also included some method to obtain information from the residents (Concepten nul op de meter en 80% besparing, NOM Renovation – Heerhugowaard and NOM – Tillburg), while one project presented the results of a very elaborated residents survey (Zen Nieuwbouwwoningen). Other analyses focused on the review of previous studies (Quickscan Huurderstevredenheid EPV) and interviews with experts in the topic but focusing on the residents' perspective. A number of analyses (here we only present the results of one of them) reported general results on cases, but the methods for data collection or analysis were not documented (project 2, NOM Renovations & New Builds – Woonbord). Table 5 shows the methods for data collection used in each of the reviewed documents. A more detailed explanation of the methods used can be seen in Table 6.

Table 5. Methods used in Each of the Projects

	Data from residents	Building performance	Data from professionals	Other
1			Interviews professionals	Desk study
2	Not reported			
3a-e	Surveys residents.	Monitoring		
4	Interviews residents.	Monitoring	Interviews professionals	
5	Interviews residents	Monitoring		
6	Survey residents			

Table 6. Detailed methods used in Each of the Projects

	Method 1	Method 2
1	Interviews were held with 12 key people from 8 housing corporations involved in the project. A round of discussions was held with employees of the corporations, representatives of residents and experts from housing associations and the rental committee (the total number of people engaged was not disclosed). Discussions with professionals, already documented, about the degree of satisfaction of residents and factors that influence this (communication officers and project leaders of corporations and builders).	Desk study was carried out on the documentation of approximately 50 projects consisting of more than 3,000 homes. Of these, a focus was placed on 19 projects (approximately 1,100 homes) realized from 2014. Numerical results from resident surveys and conversations with residents that have already been documented. This document includes the review of 3a-3b-3c and 5.
2	Not reported	
3a 3b 3c 3d	Surveys capturing the satisfaction of 153 residents was reported in terms of the percentage of people 'agreeing with statement' but not specified which	Monitoring energy use (reported in kwh/year) Also collected: PV yield, Cooling, Heating, Domestic + ventilation, Hot tap water

3e	neighbourhood (data renovation ones). The number of residents who responded to the survey either in general or per project is not explicitly specified. The 153 residents are obtained from a reference to the responses to the satisfaction with systems (n=80 ventilation; n=73 HR-boiler).	Monitoring energy use (reported in kwh/year) and thermostat setting for 5 individual houses (reported per house). Also collected: PV yield, Cooling, Heating, Domestic + ventilation, Hot tap water (reported in average use of 5 houses).
4	Interviews were held with eight providers of NOM renovation concepts. Based on this positioning, the outlined innovation need was tested against the available knowledge from research projects of the TKI, EU-H2020 and IEA-EBC-Annex projects. The research conducted was mainly drawn up from the perception of providers of NOM renovation concepts and from their vision of the users and residents. Interviews were also held with 32 residents (the number of interviews was not explicitly stated).	Monitoring data: supply and feed-in of electricity, electricity use of the heat pump; generation of electricity by the PV panels. (1 January 2015 to 22 December 2015) Analysis included 46 homes. No indoor temperature available.
5	Two months after the renovation - residents of 16 homes interviewed by TIWOS (by telephone). A second round was done after the winter. Residents of 10 homes participated in this.	Monitoring data: supply, return and generation of electricity, electricity use of the heat pump for heating and hot tap water, the electricity use for ventilation and household electricity use. The annual energy consumption is calculated based on this meteorological data for 2015 (KNMI data Gilze Rijen) and for the standard climate year in accordance with appendix A2 of NEN 5060. A dataset has been supplied for 12 homes.
6	Written questionnaire survey to residents of 31 ZEN projects. Via internet also possible. Closed questions, supplemented with a large number of open questions for a better insight into the experiences of the residents. A house-to-house survey was conducted after a second reminder letter. 302 fully completed survey forms were returned. Response rate 21% 72% lived there for 9 months. 14% live in their home between 4 and 8 months, rest for less than 3 months. Some residents who completed the questionnaire had not yet moved in. The answers to the questionnaire were linked to building characteristics: EPC, insulation values, ventilation system, heating system, underfloor heating.	

4.4 Results reported

In this section, the results of the reviewed projects are summarized. The results are presented according to renovation phase and the topic of investigation. More information of the findings per project can be found in Annex II.

4.4.1 Report Highlights

All the projects covered concluded some success on achieving occupants' satisfaction, in comparison to their situation before the renovation or as low/zero energy projects. The satisfaction does not always have to do with energy performance, but has to do with a previous situation, a better indoor quality, upgraded services and exterior look of the dwellings.

In all projects there were some dissatisfied occupants. The causes for dissatisfaction were mostly related to residents not understanding the use or maintenance of the systems (ventilation, low temperature heating) that in some cases led to discomfort situations, and to complains about noise from the systems (heat pump and ventilation system). Where these aspects were investigates, it was concluded that there is a need for better introduction to the home's systems, better manuals and follow up information and support to the residents.

In projects where energy was measured, it was shown that energy targets were usually achieved in average on the overall project. Some residents still used more or less energy than what was specified in the performance contract.

Where the satisfaction with the renovation process was also investigated, it was concluded that in most cases, the residents were not satisfied with the process. In two of the projects, it was also concluded that these issues after delivery could be affecting their satisfaction on a longer term (up to 1 year after completion). Issues affecting this dissatisfaction are extended or changed plans, lack of information, nuisance, lack of trust, and mismanagement of residents' expectations.

One of the reports (which was based on several projects) concluded that the investment costs for NOM renovation are still too high, that not all homes are suitable for this type of renovation, and that there are too many uncertainties associated to the process (costs – not only investment or energy, also maintenance, monitoring--, performance guarantees, etc.).

4.4.2 Before renovation

In the phase before the renovation starts, the aspect that is evaluated is the residents' satisfaction with communication. In addition, several reports focus on the participatory process followed during this phase, and how it affected the rate of acceptance of the renovation. An overview of the projects reporting on these aspects are seen in Table 7.

The main conclusions from both investigations are summarized below. None of the documents reported on the satisfaction of the residents with their homes before the renovation.

Table 7. Overview of the reported aspects before renovation

	1	2	3a	3b	3c	3d	3e	4	5	6
Communication	x	x	x	x	X			X		
Participation		x	x	x	x			x		

Communication

- The main communication dissatisfaction is related to differences in expectations from the residents, for example planning being too optimistic or having a different and much more positive idea on what the house would look like.
- Miscommunication between expectations of residents and contractor (i.e., what is regarded by contractors as a prototype or pilot, the residents understand it as the final solution).

Participation

- Participation is higher when residents are important part of the process, and more resources are dedicated by housing associations to engage them. Residents want to have their opinions heard.

4.4.3 During Renovation

During the renovation process, the aspects that are evaluated are the residents' satisfaction with communication, nuisance, and overall satisfaction with the process (which is of course related to other aspects). An overview of the projects reporting on these aspects are seen in Table 8. The main conclusions of the investigations are summarized below.

Table 8. Overview of the reported aspects during renovation

	1	2	3a	3b	3c	3d	3e	4	5	6
Communication	x		x	x	x				X	
Nuisance	x		?	x	?			x	X	
Overall satisfaction	x	x			x		x	x	x	

Communication

- The main communication dissatisfaction is related to the lack of communication regarding adjustments in the planning or delays.

Nuisance

- Residents that are relocated during construction seem to be more satisfied than those staying in their homes.
- Residents (not relocated) complained about renovations taking much longer than previously communicated.

Overall process

- The satisfaction of residents with the overall process is related to the communication regarding planning, activities and changes, nuisance and problems during the process.

4.4.4 Post Renovation

After the renovation has been completed, the aspects that are evaluated are the residents' satisfaction with communication (after care), quality of information (is it understandable), easiness of use and maintenance of the systems, energy costs, energy use, thermal comfort and indoor air quality, noise and odor complaints, and overall satisfaction with the final product (the renovated home). An overview of the projects reporting on these aspects are seen in Table 9. The fact that in most projects the communication, easiness of use, thermal comfort, indoor air quality and noise are investigated and reported, highlights how important are these aspects for both occupants and builders. The main conclusions of the investigations are summarized below.

Table 9. Overview of the reported aspects after renovation

	1	2	3a	3b	3c	3d	3e	4	5	6
Communication	x		x	x	x	x	x	x	x	X
Quality of information	x		x	x	x			x	x	X
Easiness of use and maintenance	x		x	x		x	x	x		X
Energy costs	x						x	x		X
Energy	x		x			x	x	x		X
Thermal comfort and IAQ	x	x	x	x	x	x	x	x		X
Noise	x		x	x	x	x	x	x		X
Odor			x	x	x	x				
Overall	x	x	x	x	x	x	x	x		x

Communication (follow up)

- The main reported sources of dissatisfaction regarding communication seems to be due to differences in expectation from part of the residents (showroom vs. prototype), the performance contract, and responsibilities for maintenance and malfunctions after the delivery of the house.
- The residents seem to experience the information about installation as complex or too technical. Since information is delivered in short period of time, they are overwhelmed with it. Some expressed to require more personalized information.

Quality of information (understanding)

- Residents in the different projects reported good understanding on how to use the systems from 54% to 79%, depending on the system.
- Residents in the different projects reported good understanding on how to maintain the systems from 20% to 76%, depending on the system.
- It seems that information on the EPV or NOM is not clear enough.

Easiness of use and maintenance

- Two reports state that most residents reported that they knew how to use the systems, but those that do not, are often dissatisfied with their comfort.
- Residents find more difficulties in the control of non-traditional systems such as underfloor heating, convectors or low heating systems. They feel that it cannot be properly regulated, and the heat cannot be felt properly.
- In one project (4), residents had to deal with initial installation problems of the heat pump.
- In two projects 3a and 3b, up to 34% of households have the ventilation on the lowest level. There are complaints about noise, too cool air, and draughts. In two other projects (1 and 6) there were complains about the usability of the ventilation system.

Energy costs

- 41% to 'most' of the homes seem to meet the energy neutrality: residents do not have to pay more or receive money back).
- Satisfaction regarding energy costs is more dependent on the communication with the residents and their expectations.
- The EPV concept seems to be difficult to understand by some residents, and difficult to set up with energy companies.

Energy

- In the document where it was been reported (1, 3e and 5), in most homes, equal or less energy was used than the expected/contracted amount after correcting for weather, use and ventilation (60-90%). In all documents reporting on energy use, it was seen that excess use on heating was compensated by less energy use for DHW or domestic electricity. In average, the projects can be considered energy neutral. One project reported a higher total energy consumption than expected, see also Chapter 2
- In four of the reports, higher energy for heating was used, which was attributed to systems malfunctioning, although in some cases, no monitoring was conducted. One case reported lower energy for heating than expected, which was attributed to the weather conditions (warm year).
- Electricity was lower in projects where active measures were taken to reduce domestic use (3d and 3e).
- In one project efforts were made to determine the origin of the differences on energy use among dwellings. Stating that the thermostat setting, household composition and occupancy were the influencing factors.
- From the documents where it was investigated, two report a higher electricity generation than calculated, and one lower than calculated.

Thermal comfort and air quality

- Most residents are satisfied with indoor climate (67-90%), especially in comparison with previous situation (95%).
- Overheating seems to be a problem in many cases, especially in bedrooms (10 to 44%). Measurements in some projects (3a, 3d, 3e) confirmed the overheating problem.
- In projects with active cooling and an air heat pump to cool the ground floor helps to reduce overheating complaints. However, there were complaints on too cold in the winter and fluctuating temperatures in the summer.

- A small number of residents (5%) suffer from indoor air being too dry.

Noise

- Residents experience less noise from outside, but more noise from neighbours and installations (ventilation system and heat pump).
- The measurements in projects 3b, 3c and 3d confirm the statements from residents.

Overall result (home)

- Residents are mostly satisfied with their homes (78 to 95%)
- Residents appreciate when the exterior of the homes, as well as kitchen and bathrooms are also renovated.
- All documents, where this was investigated (4), report that most residents recognize the advantages (on energy and IEQ) of a NOM or energy efficiency home.

4.5 Takeaways and Recommendations

Satisfaction of residents

The causes for dissatisfaction were mostly related to residents' dissatisfaction with communication, nuisance, and overall renovation process, especially regarding planning and delays. Residents relocated during the renovation seemed to be more satisfied with the overall process. Participation and involvement were higher when more resources were freed by the housing associations to have residents' opinions heard.

It is also concluded that there is a need for better introduction to the home's systems, better manuals and follow up information and support to the residents after renovation. Not understanding the use or maintenance of the systems can in some cases led to discomfort situations, and to complains about noise from the systems. However, these complaints should not be waved away as being caused by the occupant. It may also be caused malfunctioning and poor interfaces of the systems themselves.

Recommendation 8: A clear communication towards the residents about the renovation process is needed to keep the burden low during the renovation.

Recommendation 9: (Long-term) follow up information about the use and maintenance of systems, aimed at residents, is needed. Manuals only are not enough.

Recommendation 10: Take resident's complaints seriously and investigate further possible malfunctioning of components and installations and mismatches with their use.

Satisfaction and opinions vs. measured data

Most reports focus on satisfaction of the residents on different stages of the process (before, during or after), as well as satisfaction on the final result (the product). Several aspects related to building performance are investigated, but with more attention to residents' satisfaction, experiences, and opinions regarding the easiness of use and maintenance of the new installed technologies, as well as perceptions regarding thermal comfort, noise, and air quality. The actual indoor environmental quality such as temperature, CO2 concentration, noise levels, presence of draughts, etc., are often not investigated. Energy is monitored in some projects, which is used to assess whether a project performs within the expectations or the performance contract. However, in cases when higher energy use is demonstrated and some users are dissatisfied, there is rarely the intention, or possibility, to investigate further the reasons for such deviations.

Recommendation 11: Investigation of aspects like residents' satisfaction and experiences is a must, and there is a strong need for monitoring of actual indoor environment quality and energy in order to understand why expected performances are achieved or not; and what makes that residents are satisfied or not.

Qualitative vs. quantitative data collection and analysis

More than half of the reviewed reports focus on qualitative data from interviews and surveys with the residents. In addition, two reports are based on interviews with experts about the residents (second-hand information). The projects that also measured indoor temperatures or setpoint, and/or energy use were able to provide more insight in the performance of the buildings. However, it is difficult to know what exactly causes poor performance (indoor quality / energy use), since information on indoor environmental quality and energy submetering is rarely collected. In the reports, the experts were often able to estimate the cause of the performance gap, which was often attributed to technical malfunctions or poor quality of the construction, see Chapter 3. However, in many instances a non-technical reason could be also attributed to the perception, understanding or satisfaction of the residents regarding the technologies, for example, experiences in a previous home (new users), pre-renovation situation (very high energy bills or very bad indoor quality), previous problems with installations, etc.

In all but one report, the role of occupants' behaviour is not explored. For example, the actual needs and preferences of the residents (e.g. regarding heating setpoint) are not investigated, and there is little reporting on thermostat use, heating setpoints and thermostat setbacks, which are known to have a great influence on comfort and energy use. On the other hand, a great deal of importance if given to the use of ventilations systems, which are also known to be problematic in terms of noise and interaction with the technology.

Recommendation 12: Non-technical reasons for underperformance of systems need to be analysed in a more systematic and standardized way, including resident's experiences and needs before the renovation and their actual needs regarding heating and ventilation setpoints, as well as how they interact with these systems

Recommendation 13: Develop standardized methods for a) analysis of pre-renovation experiences and needs b) actual needs and interaction with systems.

5. CONCLUSIONS AND RECOMMENDATIONS

Alongside the rise of net zero energy renovation projects, the Netherlands has seen a rise in energy monitoring campaigns, whereby energy consumption data and data on the perceptions of residents is being gathered to evaluate the performance of the projects.

This report started with summarizing large scale national studies about the energy renovation performances in the Dutch social housing stock and continued with the analysis of well documented renovation projects. 46 renovation projects representing 4.404 houses projects were analysed, with the goal of developing an understanding of the current state of data collection and monitoring in the Netherlands from multiple perspectives including:

- From a research perspective, regarding how better data can be analysed to support the development of better models that more accurately predict energy consumption in buildings as well as the development of diagnostic methods for underperformances and the development of methods for the analysis of residents' needs, satisfaction, and interaction with the systems.
- From the perspective of housing associations, providing insights on the development of more favourable energy performance contracts, as well as insights on residents' needs and satisfaction with processes and technologies.
- From the perspective of building owners, contractors, and technology providers, regarding ways in which these parties can better understand the performance of specific technologies and installations and how to improve these performances in terms of energy, robustness, ease of use and user satisfaction.
- From the perspective of residents, providing insights into their needs and levels of satisfaction. It should be noted that all projects, except for 2, referred to the social housing sector, and the results may therefore not apply to owner occupied houses. The drivers for satisfaction in owner occupied houses are known to be quite different. However, results concerning interaction with technology can be expected to be easier to generalize.

Current energy models do not accurately predict energy savings in dwellings. The discrepancy between predicted and actual energy consumption is a main result of:

- Models that do not consider occupant behaviour (number of occupants, ventilation behaviour, temperature settings, use of sun shading, maintenance, and settings of appliances)
- Parameters and inputs of the models that cannot be well-determined (like infiltration flow rates or even R_c-values)
- Issues with the systems based on how they are installed and commissioned.

Based on data that is currently collected at a housing stock and individual housing level, it is difficult to determine the exact causes of the discrepancies. Better models – digital twins – are therefore needed to predict the actual energy performance of renovation measures in dwellings. As part of this report, the researchers set out to document how specific renovation concepts performed in practice and what was monitored. Building owners, contractors and technology providers are increasingly gathering data to assess the performance of net zero energy renovation technologies and concepts. Through this study, it was found that the nature of the data which is gathered varies significantly. For example, some organization gather data on energy performance, some on indoor climate, some on resident preferences and opinions, but none are examining the complete picture. It makes it difficult to comment about which renovation concepts performed specifically well or less well. In cases where it was documented that renovation concepts outperformed or underperformed compared to expectations, there was insufficient data to determine why this was the case. However, from the point of view of energy performance, many monitored project appeared to perform much better than expected. This may be a direct result of the monitoring and is also a result of expressing targeted performance in terms of absolute energy usage instead of energy savings.

Monitoring was generally not at the level that it could be used to diagnostic and solve technical problems in a standardized way. The desk research also shows that the satisfaction of residents with the renovation process was often monitored, but not to a level allowing for a good understanding of their needs and interactions with the technical systems.

Following a review of the projects in this report, the following takeaways and recommendations have been developed, addressing either Building and Installation Modelling, Monitoring Needs, Analysis Needs and Residents' Understanding. The recommendations made throughout the report are summarized below and we also have indicated to which of the four categories above the recommendation belongs.

Recommendation 1 (Building and Installation Modelling): A correct modelling of expected energy savings after renovation is a must to convince and help people to carry out thermal renovations. Reasons for discrepancies should be therefore researched at building level, project level and building stock level. This entails a correct estimation of building construction properties before the renovation and a correct estimate of the energy use after renovation. For construction property estimation, digital methods may offer interesting possibilities that should be investigated.

Recommendation 2 (Monitoring Needs): The simple fact that a monitoring system is installed and that it is known on beforehand that performance will be analysed may be a driver for better realization practices and quicker diagnosis of (rough) malfunctioning

Recommendation 3 (Monitoring & Analysis Needs & Building and Installation Modelling): More transparency is needed about underperformance. With more information researchers, installers and producers can do targeted monitoring and even solve problems on beforehand. It will also help in the development of more accurate energy prediction models.

Recommendation 4 (Monitoring & Analysis Needs): More research/transparency on drivers for excellent performances will be helpful to positively influence the market by making companies aware of what works well and creating positive dynamics

Recommendation 5 (Monitoring & Analysis Needs & Building and Installation Modelling): More sub-metering data should be collected and disclosed by building owners, contractors and/or technology providers. With more sub-metering data, researchers and contractors will be better able to fix as soon as possible malfunctioning. It will also help researchers to explain the differences between the anticipated and actual energy efficiency of a building after renovation in such a way that better predictions can be made.

Recommendation 6 (Monitoring Needs): Develop GDPR-proof standards for sub-metering and data collection. In addition to smart meter data, to be able to steer on the performances and to diagnose malfunctioning sub-metering data should include:

- Splitting gas use in space heating, domestic hot water (DHW) and cooking
- Splitting electricity use in space heating, DHW, ventilation, cooking and appliances
- Splitting electricity production of PV-cells in on-site energy used, and delivery to grid
- Splitting net electricity use in electricity from grid, from PV-cell and electricity delivered to grid
- Setpoint temperatures of the systems, especially when heat pumps are involved
- Air temperatures
- CO_2 sensors
- Additional data like comfort parameters (radiant temperature, humidity, air velocity, opening of windows and doors and residence presence may also be useful in future

Recommendation 7 (Analysis needs): Develop guidance (booklet/webinars/information) on how to analyse data from smart meters and other indoor environment meters.

Recommendation 8 (Residents' Understanding): A clear communication towards the residents about the renovation process is needed to keep the burden low during the renovation.

Recommendation 9 (Residents' Understanding): (Long-term) follow up information about the use and maintenance of systems, aimed at residents, is needed. Manuals only are not enough.

Recommendation 10 (Residents' Understanding & Monitoring Needs): Take resident's complaints seriously and investigate further possible malfunctioning of components and installations and mismatches with their use.

Recommendation 11 (Residents' Understanding, Monitoring & Analysis needs): Investigation of aspects like residents' satisfaction and experiences is a must, and there is a strong need for monitoring of actual indoor environment quality and energy in order to understand why expected performances are achieved or not; and what makes that residents are satisfied or not.

Recommendation 12 (Analysis Needs & Building and Installation Modelling): Non-technical reasons for underperformance of systems need to be analysed in a more systematic and standardized way, including resident's experiences and needs before the renovation, and their actual needs regarding heating and ventilation setpoints, as well as how they interact with these systems. This could strongly enrich existing simulation models.

Recommendation 13 (Analysis Needs): Develop standardized methods for a) analysis of pre-renovation experiences and needs b) actual needs and interaction with systems.

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APPENDIX I - RENOVATION MEASURES IMPLEMENTED IN THE ENERGY RENOVATION PROJECTS

Project		Insulation (R_C m² K W^{-1})					Air tightness ($q_{v;10}$ dm^3 s^{-1} m^{-2})	Ventilation	Heat			Electricity gen.
		Roof	Floor	Walls	Glazing	Other			SH gen.	SH rel.	DHW	
1. Quickscan Huurderstevredenheid EPV												
2. Thermisch compartimenteren / Thermal Compartmentation	A and B	- (1.4)	- (0.3)	3.2 (wc) 1.7 (cc)	HR++	Ceiling 5.0	5.15 (wc), 1.07 (cc) 5.77 (wc), 0.68 (cc)	Decentral mechanical ventilation with heat recovery in the warm compartment. Natural ventilation in the cold compartment	High temperature air-water heat pump	Conventional radiators	High temperature air-water heat pump	PV (6400 Wp)
	C and D	- (1.4)	3.5	3.2 (wc) 1.7 (cc)	HR++	Ceiling 5.0	0.65 (wc), 6.9 (cc)	Decentral mechanical ventilation with heat recovery (CO_2 steered) in the warm compartment. Natural ventilation in the cold compartment	Low temperature air-water heat pump	Convector radiators in warm compartment, conventional radiators and infrared panels in cold compartment.	Low temperature air-water heat pump	PV (6400 Wp)
3. Concepten nul op de meter en 80% besparing	Heemwonen Kerkrade	5 - 10			triple		0.41 – 0.51	Mechanical ventilation with heat recovery	HR 107 gas boiler		HR 107 gas boiler	PV (3150 Wp)
	Zorgeloos wonen	4.2 – 5.6			HR++		0.34 – 0.42	Mechanical ventilation with heat recovery	HR 107 gas boiler		HR 107 gas boiler	PV (4650 Wp)
	Amsterdamse buurt	7.5			HR++		5.2	Unknown	HR 107 gas boiler	Convector radiators	HR 107 gas boiler	PV (1730 Wp)
4. 2nd SKIN Demonstrator – South Holland		7.0	3.5	6.0	triple			Balanced mechanical ventilation with heat recovery	Ground source heat pump	Low-temperature convectors (cooling possibilities in summer)	Ground source heat pump	PV (4500 Wp)
5. Tolhuis 1590 - Nijmegen		5.0	3.5	5.0	U = 1.0			Mechanical ventilation with heat recovery	ActiveWarmth electrical wall heating		Heat pump boiler	30 PV panels
6. NOM- Zoetermeer		7.0	4.0	7.0	triple			Mechanical ventilation with heat recovery	Air water heat-pump. Floor heating.		Air-water heat pump	PV (8575 Wp)
7. NOM renovation Heerhugowaard		5,0	4,0	5,0	Triple (U = 0,7)			Mechanical ventilation with heat recovery	Air water heat-pump.			PV (8910 Wp)
8. NOM renovation Tilburg								Mechanical ventilation with heat recovery				

APPENDIX II – DETAILS ON RESIDENT PERCEPTIONS IN THE STUDIED RENOVATION PROJECTS

The colour codes refer to the projects as defined at the begin of chapter 4.

Before renovation

Communication

1	RQ: Satisfaction communication tenant Much too optimistic communication in advance about the planning, in combination with too little or too late communication about adjustment of the planning.
3a	65% (very) satisfied. Less satisfied with info provided during and after, than with info before.
3b	Satisfied with information before, during and after (95% very satisfied)
3c	57% (very) satisfied. Less satisfied with info provided during and after, than with info before.
4	Residents are suspicious of the construction industry, and also have the feeling that their home is technically too complicated. Residents no longer trust information about energy savings and indoor environment. Recommendation: Relief for residents by making performance uniformly visible and create a quality experience based on actual research results and energy data. Model home gave a too positive image because contractor viewed the first house as a prototype, while the residents saw the house as a model home.

Participation

3a	Lots of attention to residents, 70% acceptance was achieved.
3b	Lots of attention to residents, 70% acceptance was achieved.
3c	81% wanted to give input (in layout); lots of attention to residents, 70% acceptance was achieved.

During renovation

Communication

	Communication
1	Dissatisfaction is greatest regarding communication: the (delayed) planning, failure to fulfill agreements and too little information about the activities.
3a	65% (very) satisfied. Less satisfied with info provided during and after, than with info before.
3b	Satisfied with information before, during and after (95% very satisfied)
3c	57% (very) satisfied. Less satisfied with info provided during and after, than with info before.
5	Better communication should have taken place during implementation when things went differently than planned. There was little or no communication about changes in the schedule.

Nuisance

	Communication
1	The potential advantages of the NOM concepts (fast installation – outside of the house), to limit the nuisance for the resident, have not yet been realized in practice.
3b	More satisfied. Lower level of nuisance – they were relocated during renovation.
4	Quite a few people complained about the renovation in an occupied state. Many elderly residents among the residents: more at home, less mobile and often more vulnerable
5	Residents were told at the start that the renovation would take a maximum of 10 days, this turned out to be much longer in practice: 2.5 to 7 months.

Overall process

	Communication
1	The satisfaction of residents scores neither worse nor better than in other projects. The potential advantages of modular (prefab) renovation compared to traditional renovation have yet to prove themselves in practice. Most tenants are satisfied with the process. This degree of satisfaction varies greatly per project. The satisfaction scores in these projects are 57% (108 homes), 61% (153 homes) and 95% (115 homes). In residents' surveys for three NOM projects (approximately 110 homes), residents in two of these gave the process an unsatisfactory mark and in one project they were more than satisfied with this.
2	Implementation (too) drastic for residents; lots of adjustment guidance.
3c	More satisfied, less things going wrong, duration of renovation, relocation.
4	The realization is less positive than the opinion about the result. Almost half especially dissatisfied with the aspect of "planning and design": renovation took longer than was communicated and planned
5	Residents got the idea that the craftsmen were not properly managed. Lack of empathy towards the residents during the implementation. Little account was taken of residents' agendas and an invasion of privacy has been experienced.

Post renovation

Communication (follow up)

	Communication
1	Failure to comply with agreements and lack of clarity about who can be approached in the event of problems. This is particularly annoying for residents in projects in which the entire process, including the supervision of residents, is outsourced to the builder. Communication after delivery can often be improved, especially regarding new installations. The extent to which information about the use and maintenance of installations is perceived as clear varies greatly from project to project. In particular, the information about maintenance is often perceived as unclear. Explanation of measures is often experienced as too technical. In both the traditional renovations with energy measures and NOM / very energy-efficient renovations, residents indicate that they lack more personal information. Regarding the clarity of information about the home, there are major differences between the various technologies (HR boiler, low temperature heating, solar panels, solar boiler, ventilation system), with a distinction between information about use and maintenance.
3a	see before reno
3b	see before reno
3c	see before reno
3e	Information about installations and the performance contract, the residents indicated that they received a lot of information in a short time, so that they did not remember everything. It is not always clear which party is responsible for malfunctions, which means that it sometimes takes a long time before a malfunction is resolved.
4	The need for quality assurance is still there. Residents receive fragmented information about architectural matters and various installation components without cohesion and without an indicator for a healthy home or indoor climate. Residents want a healthy home, but providers are not sure what that is. Recommendations: Gain insight into the health indicators.

	Model home gave a too positive image because contractor viewed the first house as a prototype, while the residents saw the house as a model home.
5	Share of residents less than satisfied with (parts of) the project (first measurement). The assessments of the residents about the implementation of the renovation are not favorable. The average report mark they gave to the total project immediately after completion was 4.8. The dissatisfaction is mainly related to the aspects of "planning" (100% less than satisfied) and "keeping agreements" (80%) Information about the activities 75% less than satisfied
6	Virtually all residents have been informed about the installations in at least one way. Nevertheless, in the perception of the residents, this is not enough. Residents lack a central point of contact, where they can find experts who they can consult with problems and complaints. Residents value oral and written information over information via a website. About 80% of the residents have been informed about the various technical installations. Of the residents who have not received information or are no longer aware of this, a significantly lower proportion knows how to use the relevant system

Quality of information (understanding)

	Quality of information
1	The EPV appears to be difficult to understand for a significant number of tenants. A commonly reported misunderstanding is that residents do not realize that if they pay EPV, they will continue to receive a bill from the energy company. Use: information clear 54% to 79%; Maintenance: information clearly 20% to 76% (with especially large differences between the 3 projects).
2	Older people find NOM-EPV-Monitoring, Energy bundles, Energy supplier difficult to understand.
3a	Majority satisfied but some things not explained well enough. Overall: maintenance not well explain, 1/3 -1/2 did not find the explanation clear Clear use: 54% HR boiler; 75% ventilation; 54% solar panels; 63% solar boiler. Clear maintenance: 46% HR boiler; 2% ventilation; 48% solar panels; 48% solar boiler
3b	Idem + Clear use: 74% HR boiler; 79% ventilation; 76% solar panels. Clear maintenance: 62% HR boiler; 76% ventilation; 57% solar panels; 48% solar boiler
3c	Idem + Clear use: 67% HR boiler; 67% ventilation. Clear maintenance: 46% HR boiler; 20% ventilation; 48% solar panels; 20% solar boiler
4	Information is too complex for residents. Residents ignore the much too complex information, which encourages misuse and causes complaints. Recommendation: Understandable information about the use of a home based on facts without hidden margins. Some residents report that they pay more than before the renovation. This problem is particularly related to the advances requested by the energy suppliers. Energy suppliers seem to be unfamiliar with the NOM concept, because of which they are not always prepared to set the advance to zero. This can still lead to problems in the meantime - especially for target groups who can barely make ends meet.
5	Although it was indicated in advance that software updates would be necessary to get the control regarding heating, ventilation and cooling right (because it is a pilot), several residents complain about the operation of the installations.
6	57% residents feel that they had insufficient explanation about the installations. more information needed about heating, solar panels and ventilation. Daily use of the various systems: not sure whether the system is working properly, not allowed to operate or adjust the system , or no idea how the system works. they would like to know how to limit energy consumption even further.

Easiness of use and maintenance

	Easiness of use and maintenance

1	Tenants have difficulty with the slowness of the heating system. The temperature can only be adjusted gradually. The lack of radiant heat is also mentioned. This is an item especially for less fit residents. Users are relatively critical about the installations, especially the ventilation system. A small group of users experience disadvantages that are inherent to the concept (controllable temperature and lack of radiant heat). They are less satisfied because of overheating in the summer, the controllability of the temperature and the ventilation system. Some also miss the radiant heat.
3a	Resident were asked clarity of information on use and maintenance of HR boiler, ITV, Ventilation, solar panels, and solar boiler. n=44: 32-34% people put ventilation on lower setting (more than in the others); 20%; too cold air in winter; 30% feeling continuous airflow (draughts). But almost half respondents no complaints about ventilation.
3b	Resident were asked clarity of information on use and maintenance of HR boiler, ITV, Ventilation, solar panels, and solar boiler. n=44; 11-16 % ventilation almost always in lower setting because of noise. 41% System too cold in the winter (air) and 20% feeling continuous airflow (draughts). But almost half respondents no complaints about ventilation.
3d	Questions: easiness of use of: Clock thermostat, Sun blinds, CO2 sensor, Underfloor heating, Hot-fill washmashine, boiler, Ventilation living / bedroom, User manual, Cooling system, Ventilation bathroom, Energy display, Ventilation grids, Extractor hood, Convectors upstairs, Heating bathroom. Heating in bathroom and convections above not easy to use. The thermostat, blinds, co2 sensors and floor heating easy to use.
3e	If the installations function properly, the residents are satisfied with them. They say that they do not behave differently in their new home than they did in their previous home. The residents also indicate that they find the comfort in their home (comfortable temperature and sufficient hot water) more important than whether or not achieving Zero on the Meter.
4	Several residents had to deal with start-up problems with installations, in particular with the heat pump.
6	Some residents do not know how to use the installations and - possibly because of this - experience comfort complaints such as dry air, mucous membrane irritations and cold. Residents then wonder whether the systems are working properly and whether they are using them correctly. About 90% of the residents say they know how to operate the various installations Some do not like underfloor heating, because they think it cannot be properly regulated or because the heat cannot be felt properly. Relatively many residents are not very satisfied with the temperature control in their home: Less than half of the residents agree with the statement that the temperature in the home can be properly adjusted in winter. Residents like it when maintenance is arranged. If they want to outsource the maintenance themselves, it is not easy to find a suitable company with expertise.

(Energy) costs

	(Energy) costs
1	For most tenants with EPV, the costs for energy consumption appear to be zero euros or less. This emerges from monitoring data and statements made by those involved. Resident survey shows that 24 out of 40 tenants understand how the EPV really works. 16 tenants are very positive. 4 are decidedly negative.
3e	Satisfied with the energy consumption during the first year and confident of the coming years.
4	This aspect was not systematically asked in the interviews, but it was nevertheless raised regularly (in 12 of the 32 interviews). Some residents report that they pay more than before the renovation. This problem is particularly related to the advances requested by the energy suppliers. Energy suppliers seem to be unfamiliar with the NOM concept, because of which they are not always prepared to set the advance to zero.

	This can still lead to problems in the meantime - especially for target groups who can barely make ends meet.
6	Costs of ZEN homes, takig part in the study, are between - € 50 and € 250 and are on average € 54 per month. The average monthly energy costs are € 47 euros for homes with an EPC of zero or lower and € 82 for a house with an EPC greater than zero. The average monthly amount for energy for NOM homes with an energy performance guarantee is € 31. 41% of the residents of these NOM homes do not pay monthly energy costs or receive money back.

Energy

	Energy
1	Project 1 - 42 of the 46 monitored homes used on average less energy than the 'contract value' based on an average climate year and after correcting for use and ventilation. One house uses more energy for hot tap water and three for heating. The user's influence could not be determined. Project 2 - (+/-20 homes). More electricity was needed for heating than expected due to malfunctioning installations. Ten homes analysed in 2015, 6 reached the 'contract value' of 0 kWh, when correcting for the climate year and ventilation. In the project with EPV, residents were asked about satisfaction with the energy bill. Average of 7.9. In discussion of one project (97 tenants) 11 had to pay extra on balance after one year.
3a	3500 kwh/year electricity. The energy consumption and PV generation are lower than expected. The heating higher than expected. Total gas consumption lower than expected. A possible reason could be that the space heating calculation method in the EPC is too positive for heat pumps or that the efficiency of the heat pump is different than expected. Heating demand (18 GJ per year) is second lowest of projects but slightly lower than expected.
3d	2000 kwh/year electricity (not too high) - active effort has been made to reduce household energy consumption. More energy is used for heating but less for hot tap water. Household energy consumption is lower than expected and PV panels production is higher. Total energy consumption is higher than expected. The calculation for the heat pump (EPC) may be too favorable or the efficiency of the heat pump system may be different. The lower airtightness (more infiltration loss) will lead to higher energy consumption. Heating demand (24GJ/year) highest of all projects and higher than calculated.
3e	Solar panels and HR ventilation, well-insulated and airtight shell (RC = 4.1 m^2K / W). The monitoring shows that the homes are Zero on the Meter on average in the first year. Building-related heat demand (15 GJ per year) is the lowest but it is higher than calculated. 1850 +/- kwh/year of electricity. This project scores best on domestic electricity use because active effort to reduce household energy consumption. Residents are very satisfied with fees for energy-efficient equipment. lThe differences in the net energy consumption between the houses can partly be explained by the thermostat setting. In addition, the monitoring shows that there are considerable differences in household electricity use. In addition to resident behavior, these differences will partly also be related to the composition of households and the degree of presence of residents.
4	Monitoring data: yearly generation, use heating, consumption for hot tap water, household appliances, ventilation, and cooking (domestic + ventilation). 2015 was relatively sunny and had a relatively warm winter. The heat demand was therefore relatively small and there was a relatively large amount of electricity generated by solar panels. In an average climate year in accordance with NEN 5060, the net electricity consumption after correction in 42 of the 46 homes is lower than the contract value.
6	Not measured energy but satisfaction with energy use and costs.

Thermal comfort and air quality

	Thermal comfort and air quality
1	Residents are satisfied with the indoor climate, but overheating is a problem in several cases.

	Three quarters of the residents (n=600) rate the indoor climate as very pleasant (65% to 95%) and experience that the indoor climate has improved. Residents also experience better living comfort: pleasant temperature and no drafts. 10% of the residents experience excessively high indoor temperatures in the summer, especially in the sleeping areas. The ventilation system is rated as satisfactory, but less high than other aspects of the home. This may be due to the noise from the installation, cold air flow or air that is too dry.
2	Cool in the summer - cozy in the winter (new building).
3a	<u>Questions: quality IE after renovation: Humidity (n = 65); Air quality (n = 65); Draft in the house (n = 65); House temperature (n = 36); Winter temperature (n = 29); Summer temperature (n = 29)</u> <u>NOM guarantee: exceeding hours above 26 degrees. % residents per project who experience their home as too hot in the summer</u> <u>% of homes with more than 100 hours of temperature violation. Average number of hours of temperature violation (26.5 ° C). Thermal comfort expressed in temperature exceeding hours and average number of TO hours: (Percentage of homes with an overrun) 100%=300 hrs.</u> Very well insulated, night ventilation and an overhang have been used. More satisfied residents compared to the starting situation, but 34% still think it is too hot in the summer. In the summer, temperature overruns in the bedroom are high. 90% users find indoor environment very pleasant. 95% of the residents- temperature has improved after the renovation compared to a very outdated home. Living room (n=15): % of homes with TO> 100 = 53%. Avg TO hours 35% Bedroom: % homes with TO> 100 = 75%. Avg TO hours 92%
3b	Questions as 3a 67% users find indoor environment very pleasant. 14% residents feel that the air quality in their homes deteriorated. Also, in terms of temperature, some residents experience a decline compared to before the renovation. 23% find it too hot in the summer.
3c	Questions as 3a 90% users find indoor environment very pleasant. 29% residents feel that the air quality in their homes deteriorated. Also, in terms of temperature, some residents experience a decline compared to before the renovation. 44% find it too hot in the summer.
3d	Active cooling with an air heat pump to cool the ground floor. Less isolation than Kerkrade. Top cooling by an air heat pump is used on the ground floor. This translates into a low percentage of residents (25%) that find it too hot in the summer. 67% users find indoor environment very pleasant. 50% find winter temperature too cold and in summer it fluctuates too much; 60% are ok with temperature, 25% too warm in the bedroom in the summer. 20% finds it fluctuates too much in the living room and bedroom. 70% find RH good. Living room (15 homes): % of homes with TO> 100 = 15%. Avg TO hours 25%. Bedroom: % homes with TO>100 - 8%. Avg TO hours 22%.
3e	(n=5) Cooling is used by a ground-based heat pump. Measurements show that the temperature level in the summer is adjustable. Very satisfied with the comfort of the homes. Free cooling with a soil source via the underfloor heating. Average daytime temperature below 25 degrees.
4	At Schatgraven, people were less satisfied with the comfort. Improved comfort (nice and warm, no drafts, less noise from outside) is often mentioned as a positive result.
6	Most residents are satisfied with the comfort and air quality in the home. There are relatively few complaints about drafts, moisture, and mold in ZEN homes. Residents generally recognize the advantages of the installations used, which are unknown and new to most of them.

	Residents of a home with a ground source heat pump appreciate it that the home stays cool in the summer. Some do not like underfloor heating, because they think it cannot be properly regulated or because the heat cannot be felt properly. Relatively many residents are not very satisfied with the temperature control in their home: Less than half of the residents agree with the statement that the temperature in the home can be properly adjusted in winter. Residents of a home with balanced ventilation more often agree with the statement that they live in an above-average comfortable home. A small number of residents (5%) suffer from physical complaints that they think are caused by the indoor air. Almost all these residents also indicate that they suffer from dry air in their homes

Noise

	Noise
1	Residents experience little noise from outside
3a	Percentage of residents per project who experience noise nuisance from the ventilation system in combination with the values of the indicative noise measurements Noise pollution due to ventilation system 16%. Noise level [dB (A)] N/a
3b	As 3a Noise pollution due to ventilation system 21%. Noise level [dB (A)] 34,1 – 40,4
3c	As 3a Noise pollution due to ventilation system 22%. Noise level [dB (A)] 36,1
3d	As 3a Noise pollution due to ventilation system 13%. Noise level [dB (A)] 33,5 - 38,7
3e	Residents mention the noise of the installations as a point of attention, especially that of the heat pump.
4	Complaints about noise are mentioned. There were some complaints about noise nuisance of installations.
6	The most frequently mentioned noise complaints are about sounds from neighbors and from installations. Noise nuisance from the ventilation system, and somewhat less from the heating system, and in particular the heat pump, is relatively often mentioned.

Odor

	Odor
3a	Percentage of residents per project who complain about odors that linger: 7%
3b	Percentage of residents per project who complain about odors that linger: 5%
3c	Percentage of residents per project who complain about odors that linger: 0%
3d	Percentage of residents per project who complain about odors that linger: 13 %

Overall result (home)

1	Tenants are generally very satisfied with their NOM / very energy-efficient home. Insulation and most installations are placed on the outside, so that the living space does not become smaller. Compared to traditional renovation, the substantially renovated exterior is appreciated. If the renovation is accompanied by improvements in the home (bathroom, kitchen, toilet), satisfaction is also high. In five resident surveys of NOM renovations of rental homes in the 2014/2015 period, satisfaction varies between 7.3 and 7.8, on a scale from 1 to 10 (together approximately 150 homes). In report *Satisfied residents* (resident surveys in 2013/2014 of 600 energy-efficient homes), the percentage of satisfied residents in the project with highest satisfaction scores was 95% (115 homes). The percentage of satisfied residents in the project with lowest satisfaction scored was 78% (108 homes).

	If the renovation is accompanied by improvements in the home (bathroom, kitchen, toilet), satisfaction is also high.
2	Residents find NOM-new construction nice to live in.
3a	Most important aspect for (dis)satisfaction is air not being fresh, appearance house, regulation humidity, indoor environment, price/quality and energy costs
3b	Very satisfied with end-result = 95% Most important aspects are: info installations, air freshness, indoor climate, rent price, energy saving home, performance renovation.
3c	Very satisfied with end-result. 78%
3d	7.8 average rate of satisfaction with the new energy efficient home
3e	They say that they do not behave differently in their new home than they did in their previous home. The residents also indicated that they find the comfort in their home (comfortable temperature and sufficient hot water) more important than whether or not achieving Zero on the Meter.
4	They are happy with their new bathroom and kitchen and how beautiful it all looks.
6	<u>Residents indicated how satisfied they are with various aspects of their home in 5 level scale.</u> General satisfaction - highest proportion of satisfaction. More than 80% satisfied with hot water supply and the energy consumption. Slightly less than 80% satisfied with the temperature in the home. A smaller proportion satisfied with the air quality and the noise. Less than half satisfied with the information about the installations. <u>The surveyed residents indicated how satisfied they are with various aspects of their home.</u> Appreciated: light, energy-efficient and above-average comfortable. A large majority agree with statements about comfort: no drafts, and to heat well. More than 30% disagree with statement that installations present never cause noise nuisance. More than a quarter disagree with the statements that it remains nice and cool in the summer in warm weather, and that the temperature in both the living room and the bedrooms can be set as desired in winter. Less than half agree with the statement that the home has a positive effect on health. Large part of the respondents answered this statement "neutrally". Most disagree with the installations present do not cause any noise nuisance.

ACKNOWLEDGEMENTS

This project is executed by the support of the MMIP 3&4 grant from the Netherlands Ministry of Economic Affairs & Climate Policy as well as the Ministry of the Interior and Kingdom Relations.

This report has been developed as part of the *Integrale Energietransitie in Bestaande Bouw Theme 2 - Data-driven Optimization of Renovation Concepts* project. The project is a multi-year, multi-stakeholder program focused on developing affordable and user-friendly renovation concepts for residential buildings. The program consortium is working on innovative solutions for heat conversion and storage, digitization, industrialization concepts, decision-making frameworks, value chain integration and partnership models.

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