The energy-saving potential of social housing tenants in the context of a thermal retrofit

Influencing household energy behavior to reach higher energy saving

Author
M. (Maaike) Bondrager
ID: 0744675

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Eindhoven University of Technology

Graduation committee
Prof. dr. ir. B. de Vries (TU/e)
Dr. Q. Han (TU/e)
Dr. W. J. M. Heijs (TU/e)
Ir. D. J. Noy (Atriensis)

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TU/e Technische Universiteit Eindhoven University of Technology

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Preface

This report is the result of my graduation project on the energy-saving potential of social housing tenants in the context of a thermal retrofit. This master's thesis completes my study Construction Management and Engineering at Eindhoven University of Technology. The project is conducted in collaboration with Atriensis, a consulting company specialized in energy and sustainability for the Dutch housing associations.

I want to thank my graduation committee for their guidance, expertise and time during the research. I learned a lot about thermal retrofits in the social housing sector, but also about conducting scientific research. I enjoyed visiting the different housing associations and I want to thank the interviewees for providing information for my research. I am also thankful for all tenants who made the effort to complete the questionnaire. Thanks to everyone at Atriensis that showed interest in my project and broadened my view on the subject.

Finally, I want to thank my friends, family and my boyfriend for their support by testing the questionnaire and reading parts of the report, but especially for their faith in me during my graduation period!

I hope that you enjoy reading my thesis.

Maaike Bondrager

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Summary

The climate is changing all over the world, because buildings, agriculture, industry and energy production emit more CO_2 than our nature is able to convert to O_2. In Europe, the built environment is responsible for around 40% of the total energy consumption (TNO, 2012). It is therefore important that this sector lowers its energy consumption. Households also need to contribute to this. As one-third of the Dutch households are living in social housing, this sector can help decreasing the energy consumption. Research of SHAERE (2015) shows that although the Dutch social housing dwellings have increased their energy performance on average, the gas consumption of households has barely decreased and the electricity consumption has even increased from 2012 to 2014. This indicates that improving the housing stock to a lower energy index does not automatically lead to more household energy saving.

The theoretical energy saving after retrofitting a dwelling is based on the behavior of an average household composition. Tenants often do not realize that their own behavior differs from this, and that this energy saving will probably not be reached without changing their household energy behavior. When thermal retrofits involve a rent increase, it becomes important for tenants to actually reduce their energy consumption, in order to keep their living costs stable, but preferably lower, than before the thermal retrofit. Behavioral change has a potential to increase this energy saving after a thermal retrofit. The goal of this research is to improve the energy-saving potential of social housing tenants in the context of a thermal retrofit.

A literature study is conducted on energy saving behavior and intervention strategies to influence this household energy behavior. The motivation, opportunity and ability factors at a thermal retrofit that can be influenced in order to reach energy saving behavior are described (Ölander & Thogersen, 1995). Possible intervention strategies and their effectiveness in existing studies are identified (Abrahamse, Steg, Vlek, & Rothengatter, 2005). A thermal retrofit can be seen as opportunity for starting energy saving behavior (Walker, Lowery, & Theobald, 2014). The retrofit often includes new energy systems. Besides the standard instructions, there is a need for tailored instructions in order for the tenants to use the new energy systems energy efficient (Groot, Spiekman, & Opstelten, 2008).

Literature shows that because of a gap between theoretical and actual energy saving, tenants miss out on energy savings between 10 and 30%. This is partly caused by the prebound effect (Sunikka-blank & Galvin, 2012). This can be corrected by the calculation. The energy saving gap that remains after the retrofit can be reduced by improving the behavioral parameters in the calculation, the communication about the applied energy saving measures, and intervention strategies aimed at behavioral change.

A field research is conducted to research the energy-saving potential of Dutch tenants living in a retrofitted dwelling. Seven retrofit projects are researched using three analyses. First, an energy analysis is conducted. The calculated and actual energy consumptions before and after the retrofit are compared with each other at the zip code level. The analyses confirm the gap that is described by existing literature. On average, the tenants of the analyzed zip codes miss out on 10,7% of the calculated energy savings.

Interviews were conducted with the project leaders of the seven projects. The current retrofit process is mainly focused on convincing tenants to participate in the thermal retrofit. A rent increase is presented as a percentage of the calculated energy saving by the retrofit. There is barely communication aimed at the influence that tenants' behavior can have on this energy saving. The interviewees see an opportunity for improving the communication after the retrofit, aimed at instructing the tenants in a clear and simple way how to use their energy systems. Some are not convinced that helping tenants with their energy saving behavior is also part of the responsibility of the housing association.

A questionnaire was send to the tenants of retrofit projects as third analysis in the field research. Five most promising intervention strategies to influence tenant' energy saving behavior in the context of a thermal retrofit were identified: feedback, commitment with goal setting, reward, instructions for the energy systems and free products. The preferences of the tenants towards these strategies were tested by a discrete choice experiment. Questions about the motivation and ability factors in the context of a retrofit were also included. A response rate of 15,7% was reached with 147 respondents. The respondent characteristics showed that in terms of age, household composition and household income, the respondent group did not represent the target group (Dutch social housing sector). The average respondent can be described as an elderly tenant, living in a two-person household without children, with an average household income. The respondent group has little knowledge about their energy saving, while the main motivation for participating in the retrofit was cost saving. The results from the discrete choice experiment showed that for this respondent group, individual intervention strategies are preferred over collective strategies. Also, a brochure with instructions on energy systems was preferred over a visit from an energy specialist.

The conclusion of this research is that there are mismatches between the different aspects in the context of a thermal retrofit. The calculated energy saving is often different from the actual energy saving of tenants after a thermal retrofit. This has effect on both the tenants and the housing association that invested in the retrofit. The tenants save less energy than expected, and therefore the rent increase has a higher impact on their total living costs. The investment in the retrofit by the housing association is less effective than expected. These mismatches can be reduced when housing associations start monitoring the energy consumptions of the housing stock. This gives them more insight in the effectiveness in the retrofit. The calculation of the energy saving can also be improved by this, which leads to a fairer rent increase for the tenants.

There is also a mismatch between the housing association and the tenants. After the retrofit is completed, there is no or little communication aimed at stimulating energy saving behavior of these tenants, while the retrofit seems an opportunity to start energy saving behavior. Tenants also need tailored information about the correct use of the energy systems. This mismatch can be reduced by a more tailored and simple communication between a housing association and its tenants. It should be considered which energy saving systems are applied at the retrofit, and how dependent the effectiveness of these systems is on household behavior. Tailored instructions about the efficient use of the system will increase the energy-saving potential of the tenants. Together, this can improve the energy-saving potential of in the context of a thermal retrofit.

Samenvatting

Het klimaat verandert wereldwijd doordat gebouwen, landbouw, industrie en de energieproductie meer CO_2 uitstoten dan dat onze natuur O_2 kan aanmaken. In Europa is de gebouwde omgeving verantwoordelijk voor circa 40% van het totale energieverbruik (TNO, 2012). Daarom is het belangrijk dat deze sector zijn energieverbruik verlaagt. Huishoudens moeten hier ook aan bijdragen. Eén-derde van de Nederlandse huishoudens woont in een sociale huurwoning. Deze sector kan bijdragen aan het verlagen van het energieverbruik. Onderzoek van SHAERE (2015) laat zien dat ondanks dat de gemiddelde energie index van de Nederlandse sociale huurwoningen is gedaald, het gasverbruik van de huishoudens nauwelijks is gedaald, en het elektriciteitsverbruik zelfs is gestegen tussen 2012 en 2014. Dit laat zien dat het verbeteren van de woningvoorraad niet automatisch tot energiebesparing in de huishoudens leidt.

De berekende energiebesparing na een energetische ingreep is gebaseerd op het gedrag van een gemiddeld huishouden. Bewoners realiseren zich vaak niet dat hun gedrag hiervan afwijkt, waardoor de berekende energiebesparing waarschijnlijk niet gehaald wordt zonder gedragsverandering. Als er een huurverhoging gevraagd wordt voor de energetische ingreep, wordt het nog belangrijker voor de bewoner om het energieverbruik te verlagen. Zo kunnen de woonlasten gelijk, of nog liever lager, gehouden worden dan voor de energetische ingreep. Er is potentie voor gedragsverandering van sociale huurders om de energiebesparing te verhogen bij een energetische ingreep. Het doel van dit onderzoek is het verbeteren van het energiebesparingspotentieel van bewoners tijdens en na een energetische ingreep.

Een literatuurstudie is uitgevoerd naar energiebesparend gedrag en interventiestrategieën om dit gedrag te beïnvloeden. Belangrijke motivatie-, kans- en haalbaarheidsfactoren tijdens een energetische ingreep voor een hogere energiebesparing zijn geïdentificeerd (Ölander & Thogersen, 1995). Mogelijke interventiestrategieën en hun effectiviteit volgens bestaande literatuur zijn onderzocht (Abrahamse et al., 2005). Een energetische ingreep kan gezien worden als aanleiding om energiebesparend gedrag te starten (Walker et al., 2014). De ingreep bevat meestal nieuwe energiesystemen. Bewoners hebben duidelijke uitleg nodig, alleen dan kunnen ze deze systemen zo energie-efficiënt mogelijk gebruiken.

Bestaande literatuur laat zien dat door een verschil in de theoretische en werkelijke energiebesparing, bewoners tussen de 10 en 30 procent energiebesparing mislopen. Dit komt deels door het “prebound” effect, waarvoor gecorrigeerd kan worden in de berekening. Het verschil tussen theoretisch en werkelijk wat nog overblijft, kan verkleind worden door gedragsparameters in de berekening te verbeteren, door verbeterde communicatie over de energie systemen en door interventie strategieën gericht op gedragsverandering.

Het energiebesparingspotentieel van Nederlandse sociale huurders is onderzocht door middel van een veldonderzoek. Zeven renovatieprojecten zijn onderzocht waarbij drie analyses zijn uitgevoerd. Als eerste is het energieverbruik geanalyseerd. De berekende en werkelijke energieverbruiken voor en na de energetische ingreep zijn met elkaar vergeleken op postcodeniveau. De beschreven effecten in de literatuur zijn herkend in de resultaten van het veldonderzoek. Gemiddeld genomen lopen deze bewoners 10,7% van de berekende besparing mis.

De projectleiders van de zeven projecten zijn geïnterviewd. Het huidige proces is voornamelijk gericht op het overtuigen van de bewoners om in te stemmen met de energetische ingreep. Bewoners krijgen een huurverhoging, berekend als percentage van de berekende energiebesparing door de energetische ingreep. Er wordt nauwelijks aandacht besteed vanuit de woningcorporatie aan de invloed dat bewonersgedrag kan hebben op de hoogte van de energiebesparing van een huishouden. De geïnterviewden zien potentie in het verbeteren van de communicatie na de ingreep, gericht op duidelijke instructie over het gebruik van de energiesystemen. Niet alle geinterviewden zijn ervan overtuigd dat het stimuleren van het energiebesparingsgedrag bij bewoners de verantwoordelijkheid is voor de woningcorporatie.

Als laatste onderdeel is er een enquête verstuurd naar de bewoners van renovatieprojecten. De vijf meest belovende interventiestrategieën om bewonersgedrag te beïnvloeden bij een energetische ingreep zijn bepaald door de literatuur en de interviews: feedback, besparingsdoel vaststellen, instructie voor de energie systemen, een beloning en een energie-bespaar box. De voorkeuren van de bewoners voor deze strategieën zijn getest door middel van een discrete keuze experiment. Vragen over de motivatie en gedragsfactoren bij een renovatie zijn ook toegevoegd. 147 respondenten hebben de enquête ingevuld, een respons van 15,7%. Voor leeftijd, huishoudenssamenstelling en huishoudeninkomen is de respons niet representatief voor de populatie (Nederlandse sociale huursector). De gemiddelde respondent kan omschreven worden als een oudere bewoner die in een tweepersoonshuishouden woont en een gemiddeld huishoudensinkomen heeft. De respondenten hebben weinig kennis over hun energiebesparing, terwijl de voornaamste motivatie voor meedoen met de energetische ingreep kostenbesparing was. De resultaten van het keuze experiment laat zien dat individuele interventiestrategieën voorkeur hebben boven collectieve strategieën. Een brochure met instructies over de energiesystemen heeft de voorkeur boven een bezoek van een energiespecialist die instructies geeft.

De conclusie van dit onderzoek is dat de verschillende aspecten van een energetische ingreep niet overeen komen met elkaar. De berekende energiebesparing is vaak groter dan de werkelijke besparing. Dit heeft gevolgen voor zowel de bewoners als de woningcorporatie. De bewoners besparen minder dan verwacht, waardoor de huurverhoging een hogere impact op hun woonlasten heeft. De investering van de woningcorporatie is minder effectief dan verwacht. Dit kan verbeterd worden wanneer woningcorporaties het energieverbruik van hun woningvoorraad gaan monitoren. Het geeft hen meer inzicht in het effect dat de investering heeft. Daarnaast kan de berekening van de energiebesparing hiermee verbeterd worden, zodat de bewoners een eerlijkere huurverhoging krijgen.

Er is ook een "mismatch" in de communicatie van woningcorporatie naar bewoners. Bewoners worden nauwelijks geholpen bij energie besparen, terwijl een energetische ingreep een goede kans lijkt voor het starten van energiebesparingsinitiatieven. Bewoners hebben simpele, duidelijke instructies nodig om de energiesystemen in hun huis efficiënt te gebruiken. Er is een betere communicatie vanuit de woningcorporatie nodig. Afhankelijk van de invloed van bewonersgedrag op de toegepaste energiesystemen, moet er gepaste informatie gegeven worden aan de bewoners. Op deze manier kan het energiebesparingspotentiaal van bewoners bij een energetische ingreep vergroot worden.

Abstract

The Dutch social housing sector needs to decrease its energy consumption. Housing associations invest in thermal retrofits, to reach a lower energy index and energy saving for the tenants. The theoretical energy saving is often larger than the actual energy saving. Charging a rent increase based on the theoretical energy saving is disadvantageous for the tenants. This research focuses on how the energy-saving potential of social housing tenants in the context of a thermal retrofit can be improved.

Seven Dutch social housing retrofits are analyzed on three different aspects. First, the calculated energy savings are compared to the actual energy savings. Results show that these tenants miss out on 10,7% of energy savings. This is partly caused by the “prebound” effect, which can be corrected by the calculation. The energy saving gap that remains has a potential to be reduced by energy saving behavior. The current retrofit process focuses on convincing tenants to participate in the retrofit. The influence that tenant’ behavior can have on the calculated energy saving is barely explained. Based on the literature and interviews, five promising intervention strategies to stimulate energy saving behavior after the thermal retrofit are found.

A questionnaire was send to the tenants, including a discrete choice experiment to derive the preferences of the tenants towards the proposed intervention strategies. Results show that individual intervention strategies are preferred over collective strategies. A brochure with simple and tailored instructions on the energy systems is preferred the most.

The results show mismatches between the three researched aspects of a retrofit. Reducing these mismatches will lead to a higher energy-saving potential for the tenants. Housing associations need to monitor the energy consumption of their housing stock, this leads to more insight in the effectiveness of the investment and a fairer rent increase. The communication between the housing association and the tenant can be improved by focusing more on explaining the influence of household behavior, using the retrofit as starting point for intervention strategies aimed at changing this behavior and provide clear instructions about the energy systems installed at the retrofit.

1. Introduction

The climate is changing all over the world, because buildings, agriculture, industry and energy production emit more CO_2 than our nature is able to convert to O_2. The earth's temperature is rising, and this has major effects on the rising sea level and the extinction of plant- and animal species. It is necessary to create a circular economy and a low-carbon emissions economy to reduce the global warming to a maximum of 2 degrees Celsius. World leaders have agreed on this decrease of temperature. This can be achieved by replacing fossil fuels with renewable energy and by reducing the need for energy (Minister voor Wonen en Rijksdienst, 2014; Ministerie van Infrastructuur en Milieu, 2013). In Europe, the built environment is responsible for around 40% of the total energy consumption (TNO, 2012). Therefore it is important that this sector lowers its energy consumption. Households also need to contribute to this.

1.1 Housing associations and regulation

One-third of the Dutch households are living in social housing. This means that the 381 housing associations together own approximately 2,4 million dwellings (Aedes, 2014b). Core business of housing associations is to build, rent and manage social housing for their target group, which are households with a yearly income below €34.911 (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2015). In June 2012, the Dutch parties in the rental sector have agreed on a covenant (Hazeu, Kamminga, Laurier, & Spies, 2012). In this rental covenant it is agreed that the housing stock of housing associations must have an average energy index of 1,25 (which equals an energy label B) by the end of 2020 (Minister voor Wonen en Rijksdienst, 2014). This corresponds to an energy saving of the building-related energy consumption of 33% from 2008 to 2020. The average energy-index of the social housing sector has decreased since 2010. In 2014, almost 130.000 social housing dwellings have improved their energy label (SHAERE, 2015). Research shows that from 2010 to 2014 the energy index decreased from 1,82 to 1,65. It is expected that at this pace, this value will be around 1,35 instead of 1,25 at the end of 2020. Annually more dwellings must be improved to reach this goal (SHAERE, 2015).

Housing associations have a tight budget due to the economic situation of the past years and new regulation from the Dutch government. That makes it a challenge to improve the housing stock. According to their core business, the associations have to keep their dwellings affordable for their target group. Retrofitting a dwelling increases its value, which will be calculated through in the rent. Now that energy costs become a bigger part of the living costs, housing associations must be more involved with the energy consumption of their tenants. There are housing associations that apply the "Woonlastenwaarborg" (living costs guarantee) at a retrofit. This means that they guarantee their tenants that their living costs will decrease after a retrofit. When they charge a part of the retrofit costs to the tenants by a rent increase, they guarantee that this rent increase is lower than the decrease in energy costs. When it turns out that the households' average living costs have not decreased, the housing association will pay the difference and adjust the rent increase (Woonbond, 2014). When applying these kinds of methods, it becomes more important for the housing associations that tenants reach these energy savings. They need to find a balance between the affordability and the quality of their housing stock (Aedes, 2015).

1.2 Thermal retrofit

Improving the existing dwellings to achieve a higher energy index is referred to in this study as a (thermal) retrofit. Installing or placing a system or material (such as insulation) to an existing dwelling, with the purpose of improving the energy efficiency of the dwelling, is called a thermal retrofit. The context of this research is thermal retrofits commissioned by housing associations. A thermal retrofit consists of applying several energy saving measures to the existing dwellings. There are active and passive energy savings measures. Active measures require energy-related systems to be added to the dwelling. Common systems are balanced ventilation, central heating systems and PV panels. These active measures improve the energy efficiency of the dwelling or they provide renewable energy. Passive measures are improvements by insulating the building envelope, which reduces the energy demand of the dwelling because of the lower heating demand. The energy-saving potential of active measures are more dependent of the tenants' behavior than the energy-saving potential of passive measures (TNO, 2012). In this study the dwellings after the thermal retrofit will be referred to as energy improved dwellings or (thermally) retrofitted dwellings. Within the current housing stock of the Dutch housing associations, more dwellings are being retrofitted than there are new build. The new housing regulation also makes it more difficult for associations to build new dwellings (Aedes, 2015). There are great differences in the size of a thermal retrofit. Some only include applying passive measures, while other dwellings are retrofitted into energy neutral dwellings. Energy neutral dwellings are dwellings that produce as much energy as is consumed by the residents. In order to achieve this, more energy systems need to be applied. Retrofits that only apply passive measures will not reach the energy indexes that will be needed in the future. Eventually, renewable energy must become the standard because gas is finite.

Housing associations pay much attention to the communication with the tenants before a retrofit. This communication is mainly aimed at convincing the tenants to agree with the retrofit. However there seems to be a lack of communication afterwards, when the retrofit is completed. This can lead to a lack of energy saving after the retrofit (Breukers, Summeren, & Mourik, 2014).

1.3 Household behavior

The effectiveness of energy saving measures depends on tenants' household energy behavior. When a retrofitted dwelling is used in the right way, it reaches a much higher energy-saving potential. However, household behavior may be dependent on habitual behavior of the residents (Heijs, 1999). Even if they are aware and have knowledge of the importance of reducing carbon dioxide emissions, changing household behavior in order to contribute to this reduction proves to be difficult.

A dwelling with a low energy index does not necessarily mean that the actual energy consumption of this household is low as well. In order to reach higher energy savings residents need to contribute to this by changing their behavior. A lot of research has been conducted on the effectiveness of different intervention strategies for changing household behavior in order to reduce the energy consumption. In the Netherlands, the government and other parties have set up multiple energy saving campaigns, with mixed energy saving results. "Beter Peter" is one of these campaigns. This was an interactive energy saving program developed by "Milieu Centraal", "de Nederlandse Woonbond" and Aedes aimed at tenants. Tenants could register for free and receive personal advice on how they could save energy in their dwelling. Such initiatives have disappeared after a few years. Parties have stopped investing due to lack of interest and energy saving results from the tenants.

1.4 Household behavior and thermal retrofits

Instead of the individual energy saving initiatives such as “Beter Peter”, as mentioned in the previous paragraph, it might be easier to stimulate residents to save energy by connecting saving initiatives to an event such as a thermal retrofit. This seems promising, because a retrofit causes a change in context and this can create the opportunity for residents to adopt new energy saving behavior in the household (Maréchal, 2010). This is further explained in chapter 2. As mentioned before, the saving potential of a retrofit also depends on the tenants’ behavior. A retrofit is initiated by the housing association, not by the tenants themselves. Therefore awareness about the needed change in energy consumption might be missing for the tenants, which is something that is usually present when you decide to do a retrofit yourself.

When a housing association invests in a retrofit of their dwellings, this often involves a rent increase for the tenants of these dwellings. This increase is often calculated as a percentage (e.g. 50%) of the calculated energy savings the tenants will supposedly gain by this retrofit. In this way the housing association earns a part of the investment back. The calculated energy savings are mainly based on the characteristics of the dwelling. Because of differences in household energy behavior, not every household reaches these calculated savings. As said before, residents need to adapt their behavior in their retrofitted dwelling in order to reach their highest energy savings. The communication after the retrofit can be instrumental to trigger these tenants to save more energy.

1.5 Atriensis

This research project is carried out in cooperation with the consulting company Atriensis. Atriensis is specialized in energy and sustainability for the Dutch housing associations. Atriensis provides advice in the field of energy policies, energy labels, and thermal retrofits. Within this research, the company provided retrofit projects from different housing associations across the country and knowledge suited for this research.

1.6 Problem definition

Research of SHAERE (2015) shows that although the Dutch social housing dwellings have increased their energy performance on average, the gas consumption of households has barely decreased and the electricity consumption has even increased from 2012 to 2014. This indicates that improving the housing stock to a lower energy index does not automatically lead to more household energy saving. Behavioral change has a potential to increase this energy saving. When housing associations retrofit their housing stock, this retrofit can be used as a trigger for tenants to become aware of the change in behavior that is needed in order to reach a higher energy saving.

The theoretical energy savings are based on the behavior of an average household composition. Tenants often do not realize that their own behavior differs from this, and that the theoretical energy saving will probably not be reached without changing their household behavior, especially when new energy systems are installed. Tenants may not understand the functioning of these energy systems in their improved dwelling (Groot et al., 2008). When retrofits involve a rent increase, it becomes important for the tenant to actually reduce their energy consumption in order to keep their living costs stable, but preferably lower, than before the thermal retrofit.

1.6.1 Research questions

The research question of this project is:

How can the energy-saving potential of social housing tenants in the context of a thermal retrofit be improved?

There are four sub-questions formulated, which will be answered in order to answer the main research question.

1. What does energy-related household behavior consist of and which methods are known to influence this behavior for the purpose of energy saving?
2. How much on average do tenants miss out on energy savings after a thermal retrofit..
    a. ..according to the literature?
    b. ..according to the field research?
3. What is the current process for thermal retrofits in the social housing sector and is there space for intervention strategies after these projects, aimed at behavioral change?
4. Can a thermal retrofit serve as a trigger for energy saving behavior for tenants and which intervention strategies are preferred according to tenants?

1.6.2 Research design

The research design is illustrated in figure 1.1. The first phase of this research is aimed at gaining insight in the existing studies that are related to the subject of this study. A lot of research is conducted on energy-related household behavior and how this can be influenced. A literature review is therefore the best method to collect and process this data and answer the first sub-question. Question 2a will also be answered by a literature study: the existing theory about calculating the theoretical household energy consumption is studied.

To answer the second, third and last sub-question, a field research will be conducted on Dutch social housing retrofits to support the literature and investigate the retrofit process in the Dutch social housing sector. Seven comparable retrofits of different associations are selected and approached by Atriensis for cooperation with this research.

Question 2b investigates the available household energy consumption data of the retrofits of the field research, to explore the gap between the theoretical and actual energy savings after a retrofit. The theory found for question 2a will be compared to this field research. The theoretical energy consumptions are calculated by Atriensis. These will be compared to the available data of actual energy consumptions of the grid operators. Several criteria will be formulated in order to get a reliable comparison. The answers on questions 2a and 2b will be able to show whether the retrofit process actually results in the energy saving that has been calculated. If there is a gap between the consumptions this will be the potential of higher energy savings that can be achieved by behavioral change of tenants after a retrofit.

The third sub-question will be answered by interviewing each project leader of the retrofit projects. This will give insight in the current retrofit process including the communication towards the tenants and the potential of changing tenants' behavior after such a retrofit, according to the housing associations.

The last part of the project is also part of the field research. Beside information about the retrofit process, it is also important to obtain information about the experience of the tenants and their preferred intervention strategies after the retrofit. After all, it is the tenant who needs to be influenced when behavioral change is desirable. Due to the scope and timeframe of this research, it is not possible to test which intervention strategies are the most effective on tenants after a retrofit. It is only possible to ask tenants which information they received and what intervention strategies they would prefer after a thermal retrofit, in order to save more energy. A quantitative research is used, because using a good quantitative research the results can be generalized to a larger population. A questionnaire is a fast way to reach many tenants, and therefore it is suited for this phase. The variables for the questionnaire will be selected from the literature study and the information obtained from the project leaders in the field research. A part of the questionnaire will be aimed at finding preferences towards the selected intervention strategies to change household behavior. Respondents receive information about these intervention strategies and a discrete choice experiment is used to derive these preferences. With this method the relative importance of attributes can be derived from the results (Oppewal & Timmermans, 1993). The discrete choice analysis has been used before on comparable research on energy-saving measures (Nieuwenhijsen, 2010; Spank, 2013). When the four sub-questions are answered by the different phases in the study, the main research question can be answered.

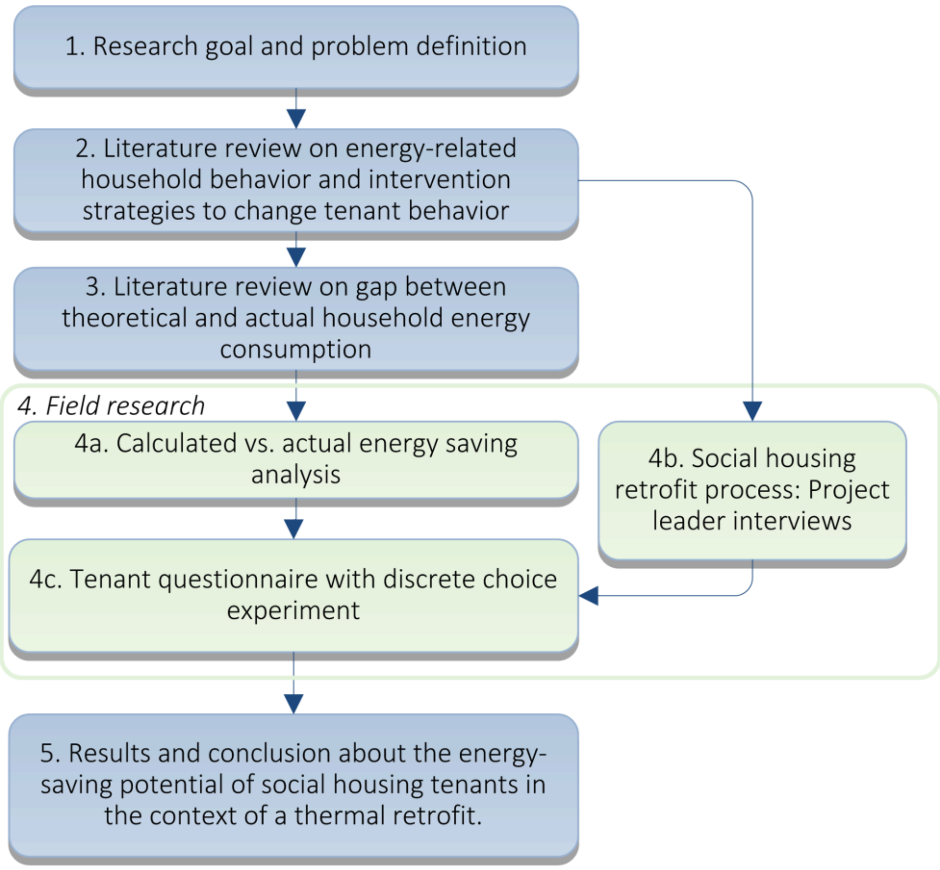

Figure 1.1: Research design

1.7 Reading guide

In chapter 2, energy-related household behavior and how energy saving behavior can be influenced using intervention strategies is described. Chapter 3 describes the difference in theoretical and actual energy consumption and how the calculation of the theoretical energy saving can be improved. The design and goal of the field research is described in chapter 4, including the methodologies of the three analyses as part of the field research. Chapter 5 explains the analysis and results of the comparison between calculated and actual energy savings at a thermal retrofit. The project leader interviews are presented in chapter 6. This chapter ends with the identification of the variables for the discrete choice experiment. Chapter 7 presents the design, analysis and results of the tenant questionnaire including the discrete choice experiment. Chapter 8 discusses the results of chapter 5, 6 and 7. The final conclusions are presented in chapter 9, together with the recommendations and evaluations.

Table 1.1 shows the glossary with the most important definitions used in this research.

Table 1.1: Glossary

Term	Definition
Energy index	A number that indicates the energy performance of a dwelling. The energy index is determined by 150 features of a dwelling. The lower the number, the better the energy performance of the dwelling. The energy index is taken into account in the determination of the maximum rent price.
Energy label	A letter that indicates the energy performance of a dwelling. It is indicated at a scale from A to G, where dwellings with an A-label are most energy efficient. The energy label is based on 10 features of a dwelling.
Energy saving measures	The measures as part of a retrofit that improve the energy performance of a dwelling. Energy saving measures can be passive or active. Active measures are dependent on household behavior and passive measures are not dependent on household behavior.
Grid operator	The operator of the electricity and gas grid. There are ten operators responsible for the Dutch energy grid.
Housing association	An organization that builds, rents and manages social housing for households with a yearly income below €34.911.
Standard year consumption (SJV)	The expected year consumption of dwellings at standardized conditions and based on a normalized year. It is published by the grid operators and used to determine the monthly energy costs of household.
Thermal retrofit	Improving existing dwellings by applying energy saving measures to achieve a higher energy index.
Woonlastenwaarborg	A guarantee of the housing association to their tenants that their rent increase will be lower than the decrease in energy costs on the average of the retrofit complex.

2. Energy saving behavior

This chapter gives insight in a selection of the existing research on household energy savings and how this can be stimulated. Its purpose is to answer the question: *Which methods are known to clarify the functioning of the energy improved dwelling, and which methods are known to influence tenants' behavior for the purpose of energy savings?* Saving energy in itself is not behavior, it is a consequence of behavior (Martiskainen, 2007). The focus of this chapter lies on behavior related to direct energy consumption in the householdFpref situation. This is also related to habitual and routine behavior, for example related to lights, thermostat settings and other daily activities at home. Looking at household energy consumption, a distinction can be made between building-related and user-related energy consumption. Building-related energy consumption defines all energy related to the heating, damping, cooling, ventilation, hot water and lighting. All other energy consumption is defined as user-related energy consumption, which on average increases because of a growing number of appliances per household. Despite the used term, users do have an influence on the building-related energy consumption. For example, they can influence the thermostat and ventilation settings (TNO, 2012).

2.1 Energy-related household behavior

Campaigns started by governments and other institutions to promote household energy saving have not led to large reductions of the household energy consumption. Many consumers are aware of the climate change and related energy issues, but it seems hard to translate this into a behavioral change within their own household. There are several factors of household behavior that make behavioral change difficult for residents. The next paragraph explains why.

2.1.1 Factors of energy behavior

In order to reach higher energy savings in the residential sector, residents need to change their energy-related household behavior. Much research on behavior related to household energy consumption use models that are based on rational behavior. Rational behavior assumes that consumers weigh the expected costs and benefits of different actions and choose the actions that are most beneficial or least costly to them. In order to make such a rational choice, the consumer needs information on the possible actions (Martiskainen, 2007). If household energy behavior was based on this rational behavior, residents would see the benefits of energy saving for their living costs and for the environment. However, there are several factors as part of energy behavior that counteract rational behavior and therefore energy behavior cannot be explained by rational behavior alone. The most important factors as part of household energy behavior in this context are knowledge, motivation, feedback and habits.

When residents do not have enough knowledge about energy-saving household behavior and the benefits that it would have, they cannot make a rational choice for this “right” behavior. This knowledge can refer to general knowledge about the impact of CO_2 emissions on the earth's temperature (e.g. why would they adopt energy saving behavior), but it can also refer to knowledge about the correct use of the energy systems in the dwelling (e.g. how can they adopt energy saving behavior) (Groot, Spiekman, & Opstelten, 2008).

Secondly, when residents lack motivation for energy saving behavior, this behavior will not be adopted by these residents. For example, comfort is often very important for residents. The living room needs to be at a comfortable temperature. Household routines are based on convenience. Residents are often not motivated to adopt energy saving behavior, because they feel that they need to cut back on comfort or convenience when applying this behavior (Walker et al., 2014).

Another factor of energy behavior that prevents rational behavior is a lack of feedback on the current behavior. When residents do not receive feedback on their current household behavior, they will not see the (negative) consequences resulting from their behavior (Lehman & Geller, 2005). Therefore this lack of feedback can hold back behavioral change into energy saving behavior.

The last factor of household energy behavior that will be explained is habitual behavior. Household energy behavior can exist of habitual actions and habitual behavior contradicts rational behavior (Heijs, 1999; Maréchal, 2009). Habits, in the context of this research, are defined as (a range of) behaviors learned through reinforced repetition of a behavior, in a particular situation and in response to a particular cue. Habitual behavior can be preceded by unconscious as well as conscious behavioral choices and can occur in a more or less automatic manner (Heijs, 1999). Maréchal (2009) defines a habit as 'behavior that takes the form of repetitive actions performed with minimum thinking' (Maréchal, 2009), and therefore suggest that a habit is only preceded by (mostly) unconscious choices. The distinction between conscious and unconscious choices that 'start' the habit can be interesting for the effect of an intervention strategy. An example of habitual behavior in the household situation can be that the late night news is the cue for a household member to turn down the thermostat and go to sleep (habit). Habitual behavior is frequently occurring in consumers' daily lives and thus at home. Many of these habitual behaviors during the day are related to household energy consumption. In his article, Maréchal (2010) highlights the importance that habits need to be understood in order to design effective intervention strategies aimed at changing these habits. There is no intervention strategy that will affect every habit (Heijs, 1999). It is difficult to study habitual behavior and changes due to strategies, because self-reported behavior may not represent the true behavior.

The next paragraph will explain how these different factors of household energy behavior can be influenced, in order to change this behavior into an energy saving behavior.

2.1.2 Influencing behavior

There are two types of energy saving behavior that are expected to occur after certain intervention strategies. These are curtailment behavior and investment behavior (Han, Nieuwenhijsen, de Vries, Blokhuis, & Schaefer, 2013). Curtailment behavior is a decrease of the energy consumption by a change in behavior, while investment (or efficiency) behavior is a decrease of the energy consumption by investing in the quality of the dwelling and in energy efficient appliances. Lehman & Geller (2005) suggest to concentrate on investment instead of curtailment behavior, to reach highest energy savings on the long term. They argue that investment behavior requires a one-time action, while curtailment behavior requires repetition in order to change behavior and that requires higher costs. Within the social housing sector, investment behavior by tenants is not that relevant, because they often do not have the authority (or the money) to invest in sustainable changes in the dwelling such as retrofits. They do have control over purchasing energy efficient appliances or light bulbs as investment behavior, but this has a smaller effect on energy saving. In this context, the retrofit is the investment behavior by the housing association, and the energy saving can be enlarged by complementing this investment behavior with curtailment behavior at the level of the tenants. Curtailment behavior is therefore the behavior that is most relevant in the context of this research.

Energy behavior, as explained in the previous paragraph, can be influenced by macro-level factors and by micro-level factors. Macro-level factors can be defined by the TEDIC factors: technological developments, economic growth, demographic factors, institutional factors and cultural developments (Abrahamse et al., 2005). These factors are aimed at changing the context by financial rewards or laws, to make the behavior relatively more attractive. The micro-level factors are influenced by these macro-level factors. Motivational factors, abilities and opportunities are micro-level factors. Most intervention strategies aim at changing these factors rather than the macro-level factors. There are many models developed that represent behavior from different theoretical perspectives. Ölander & Thogersen (1995) have designed the MOA-model, representing the micro-level factors Motivation, Ability and Opportunity. The model is illustrated in figure 2.1. The model shows that the presence of motivation to achieve certain (change in) behavior, can only result in this behavior when the ability to behave is present, and the right opportunity has occurred.

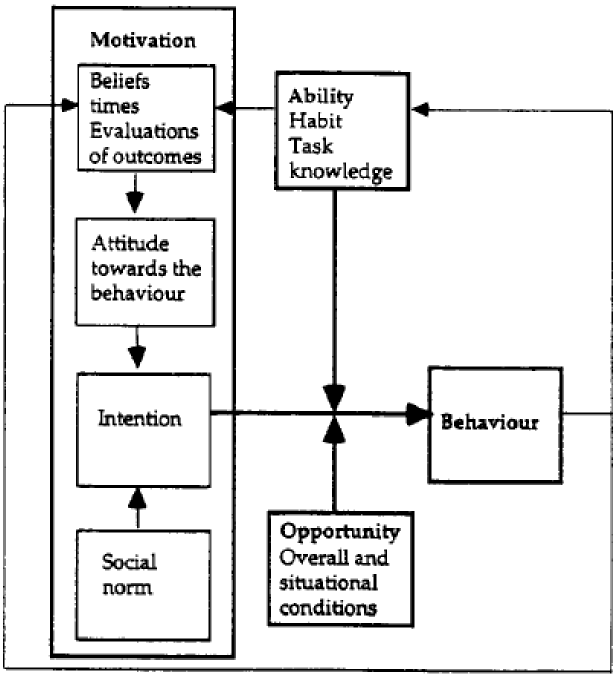

Figure 2.1: The Motivation-Opportnities-Abilities model (Ölander & Thogersen, 1995)

In this context, the model can be used to search for the most promising intervention strategies. The role of the factors and how they can be influenced to reach a change in the energy-related household behavior is researched. The motivation, ability and opportunity factors after a thermal retrofit in the social housing sector are discussed next.

Motivation
According to the MOA model in figure 2.1, motivation towards a behavior exists of peoples' beliefs, evaluations of outcomes, attitude towards the behavior, the social norm and the intention towards changing behavior. The intention is influenced by the attitude towards the behavior and by social norms. The motivation in this model is based on Fishbein and Ajzen's Theory of Reasoned Action (Madden, Ellen, & Ajzen, 1992). Beliefs about a certain behavior can change because of experiences. This is illustrated by the feedback arrows from behavior back to beliefs. If expectations change soon after starting the behavior, the arrow goes straight back to beliefs. The feedback arrow via ability means that the task or activity has become easier or quicker by learning, and therefore the beliefs about it have changed.

Residents can be unaware of the connection between the increasing emissions of carbon dioxide, and their individual behavior that can change to reduce this (Vassileva & Campillo, 2014). They might have beliefs that carbon dioxide emissions need to be reduced, but the attitude towards a behavior in their household to reach this is lacking. Hayles & Dean (2015) interviewed social housing tenants about climate change and found that when people feel strongly about climate change, they do not automatically act on this issue. In other words, "just because you think something is important does not necessarily make you live in a way to reduce the negative effects contributing to that phenomena." (Hayles & Dean, 2015, p. 43). Moreover, consumers are often not interested in consuming energy, but in the functions and conveniences that energy can provide when it comes to energy systems. Fulfilling these needs is important, not the energy it costs to fulfill it (Ellegård & Palm, 2011).

Residents' motivation for adopting pro-environmental behavior is the subject of multiple studies. Saving money seems the most important factor for the majority of the respondents and the environmental aspect seems less important for residents (Elsharkawy & Rutherford, 2015; Walker, Lowery, & Theobald, 2014). Questionnaire results on the energy behavior of two groups from a research of Vassileva & Campillo (2014) also showed that saving money is most important for residents. This motivation seems to increase as the average income decreases. Many housing associations use lower energy costs and a positive effect on the environment as 'selling points' for their retrofit plans. However, according to Abdalla (2013) it is often the comfort of the dwelling that tenants appreciate the most afterwards. Van de Werff (2015) states that value conflicts are often occurring when behavioral change is stimulated. Residents may be motivated to live more environment friendly, however they believe the associated behaviors are less profitable, less pleasurable, or take more time or effort to do so (Steg, Bolderdijk, Keizer, & Perlaviciute, 2014). In other words, there is a value conflict between 'doing the right thing' and missing out on time, money or fun. It is important to reduce this value conflict, in order to change the attitude towards the behavior. Reducing the value conflict is possible by making the pro-environmental actions beneficial for them.

Another factor that influences the motivation towards energy friendly household behavior is the convenience of technology (Walker et al., 2014). When an energy use practice is quicker or easier to perform than the previous practice, residents will probably have a positive attitude towards this new practice. Switching off appliances or lights are practices that residents will be more likely to do if the switch is easy to access and the appliance needs little start up time after it has been switched off. This also applies to a new heating system in the dwelling: when the display is easy to use, residents will change the temperature settings more often. This probably leads to a more energy efficient use. Groot, Spiekman, & Opstelten (2008) mention that this convenience in the household can be increased by coaching on routines. Focusing on reducing the time constraints by more energy saving behavior in the routines will increase convenience and therefore residents will be more willing to adapt to energy saving behavior. Social norms are also important when it comes to energy saving behavior. In this context, social norms about saving energy can be strengthened by the neighborhood. When the whole neighborhood has agreed upon the retrofit, the neighbors can decide together to behave more environmental friendly to increase this potential of energy savings.

Opportunity

Opportunity as a micro-level factor is a precondition for the performance of the behavior. It depends on situational variables (Ölander & Thogersen, 1995). For example, when someone wants to reduce his car usage, but there is no alternative routing by train or bus and it is too far to take the bike, the situational conditions are not appropriate to apply this behavior.

The thermal retrofit can be viewed as an opportunity for the tenants to change their household energy behavior. The event of the dwelling becoming more energy efficient is a positive situational condition for creating awareness for energy saving by tenants. Maréchal (2010) conducted a research on different aspects of habits, related to the energy consumption by residents. One aspect is the “habits-disturbed-due-to-context-change” theory. It suspects that the occurrence of residents moving, which is a change of context, can be viewed as a “window of opportunity” related to changing energy consuming habits. This will not results in a direct or automatic change of habits, but it can create an opportunity for new habits to replace the old ones. It is a more specific theory aimed at household energy saving based on the “downstream-plus-context-change” theory of Verplanken & Wood (2006), aimed at unconscious habits in the health and transportation field. The specified theory of Maréchal, (2009) on energy consumption of residents is likely to work when it is not possible for habits to be conducted in the same way due to the new context. The cue for the habit may have disappeared or the actions as part of the habit cannot be executed the same way in the new dwelling. For example, a new heating system with a different interface requires different actions from the resident in order to change the temperature. While the habit must be changed in order to reach the same goal, the residents have the opportunity to create a more energy friendly habit.

Walker, Lowery, & Theobald (2014) mention the theory of Verplanken & Wood (2006) in their research on energy-related behavior changes at a social housing retrofit. They argue that during a retrofit, “the changes in the fabric of the home and energy-related technologies provide scope for destabilizing contexts and altering the image of the energy use practice” (Walker, Lowery, & Theobald, p. 113, 2014). In other words, the household routine can be disrupted because of the changes in the dwelling and that creates an opportunity for new routines to emerge in relation to the household energy behavior. However, the functioning of this theory strongly depends on the size and type of the retrofit. Intensive retrofits with advanced energy systems and/or where tenants need to leave their dwelling for a few days can relate to this theory. A retrofit where residents do not have to leave their dwelling because of the small changes will not result in a strong ‘change of context’. Also, not all household routines will be disrupted because of a context change. For example, residents will probably not wash their clothes at lower temperatures after the retrofit, because this routine is not disrupted by the retrofit. However, when a different ventilation system is installed, a new routine needs to be created in order to reach the same goal (ventilate the dwelling). If at that moment some guidance about energy efficiency is reached to the tenants, the opportunity is created for an energy saving behavioral change.

Ability
In the MOA model, the ability is seen as a component that can be operationalized into two components: habit and task knowledge (Ölander & Thogersen, 1995). If a person is motivated to reduce his energy consumption, the lack of knowledge to do so and/or the habitual behavior in the household can prevent him to perform the energy saving behavior. Habitual behaviors are triggered by specific cues and are difficult to change. Therefore this component needs attention when stimulating behavioral change. Habitual behavior is already discussed in paragraph 2.1.1. Task knowledge is another part of the ability factor and is very important in the context of a social housing retrofit. As mentioned before, retrofits come in different sizes. The 'basic' way of a thermal retrofit is insulating the building envelope of the dwelling, and improving the ventilation of the dwelling. On top of that, there are additional energy systems that can be placed in the dwelling, for example a heat pump, sun boiler or a high efficient heating boiler. These appliances need to be controlled by the user, and research show that this often leads to wrong use of the system. There is a lack of knowledge by the user. This problem is especially relevant in the social housing sector, because the tenants did not choose the energy saving measures that will be installed. If this would have been the case, there would have already been a basis of knowledge about the measures. Agentschap NL (2012) wrote an information brochure for Dutch professionals about energy in the housing sector and residential needs. The ventilation system is mentioned as the biggest risk factor in energy efficient housing. Residents often have complaints about comfort, user convenience, user control and noise. According to this article, the resident wants their dwelling to be self-explaining. The influence of the user on the energy consumption can be restricted by applying robust measures and robust systems. Robust measures are the orientation of the dwelling and insulating the building envelope: users cannot influence the effect these measures have on the energy consumption. Robust systems are systems where the impact of the tenants related to the energy consumption is minimal. Examples are PV panels and a shower with Heat Recovery Unit (HRU). The more guidance there is needed for using an energy system, the more vulnerable the system is for residents (Egmond, 2010; TNO, 2012).

Research on system use shows that people often do not use their systems properly. This leads to energy wasting behavior such as opening windows when it is hot, instead of turning the thermostat down. It is however not only the user that should become aware of how to use their systems, but the designers and builders should also be aware of how they can design the system robust and user-friendly (TNO, 2012). The technical world meets the world of the end-user at the control of the system, and thus emphasis should lay on the design of the user interface of these control systems (Groot et al., 2008). When energy systems are designed without involving its future users, it leads to a gap between the designers and the residents who use the systems. For example, the base temperature when designing home appliances is 20-21 degrees Celsius, but according to research, 56% of the residents likes a room temperature higher than 21 degrees Celsius (Abdalla, 2013). These households can experience the thermostat as not working properly, whilst it does, only for the parameters it is designed upon. This 'mismatch' in expectations also has to do with residents' experiences taken from their old situation. This mainly applies to heating and hot water. The research even showed that the longer residents have had the new system, the stronger they felt it delivered too little capacity. Some residents had already moved because of the dissatisfaction.

Problems like these can probably be reduced in the design phase. In the design phase of the retrofit the housing association can help their tenants by discussing with the contractor which system is ‘self-evident’ enough. The tenants should only need a minimal amount of guidance before using it the right, energy-efficient way. The disadvantage is that this probably will not be the cheapest option. “Bewoners ontmoeten bouwers (tenants meet builders)” is a project that studied three thermal retrofits in the Netherlands. The aim was to find a successful alignment in the process and in the communication between builders and users, and users and building (systems). From interviews with tenants it became clear that they would appreciate more attention and guidance after the project was finished. This would not only be positive for the satisfaction of the tenants, but it is very useful to check whether the control and maintenance of the systems are understood by its users. A visit after the retrofit, or a brochure with additional guidance can ensure that the systems are used properly and energy efficient by the tenants (Breukers et al., 2014). When they understand what changed in comparison to their old situation in terms of the systems, they can adapt their behavior in a way that suits the new situation. This seems more useful than providing information beforehand, when the system is not used in practice yet.

Using the presented literature about thermal retrofits and energy saving behavior, an adapted version of the MOA model of (Ölander & Thogersen, 1995) is created for the context of a thermal retrofit in the social housing sector. It is based on the discussed motivation, ability and opportunity factors in this context. The model is shown in figure 2.2.

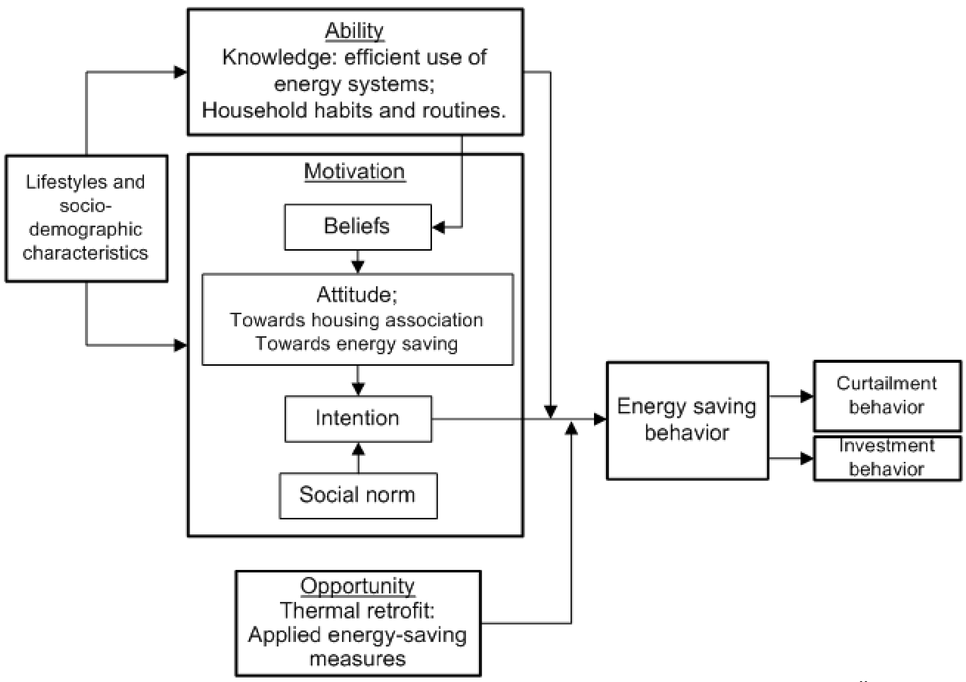

Figure 2.2: Energy saving model after a social housing retrofit (based on MOA model (Ölander & Thogersen, 1995)

This model is adapted in order to clarify the situation of a thermal retrofit. It can be used for this research to identify the intervention strategies that are needed to influence these factors in order to stimulate the energy saving behavior. “Behavior” in the MOA-model of (Ölander & Thogersen, 1995) is in figure 2.2 specified as energy saving behavior, which can result in curtailment and investment behavior. As mentioned before, curtailment behavior is more relevant in this context than investment behavior and this is illustrated by the size of the box. Another addition to the original model are the lifestyles and socio-demographic characteristics. People’s education level and lifestyle have influence on their ability and motivation (Han et al., 2013). The tenants’ characteristics in the retrofit neighborhood can be identified in order to estimate their motivation and ability towards energy saving behavior. The attitude towards a retrofit consists of two parts: the attitude towards the housing association and the attitude towards energy saving. The image of the housing association is often not very positive. In order to motivate the tenants at this retrofit, the image must improve. The attitude towards energy saving can probably be influenced more easily. The opportunity is defined as the thermal retrofit and the applied energy-saving measures. This moment creates awareness, which influences the attitude and beliefs of tenants towards energy saving behavior. The knowledge as part of ability is defined as knowledge about the use of the energy systems. This is the main factor of knowledge at the retrofit, as it can make great differences in the energy saving before and after the retrofit. Routines and habits are common in households and are of great importance when trying to change a behavior.

In paragraph 2.2 the intervention strategies are explained, and in chapter 6 the current retrofit process is explained by a field research. This information together can improve this theoretical model by adding the most promising intervention strategies that can influence energy saving behavior in the context of a thermal retrofit. This model will be used for the questionnaire design.

2.1.3 The rebound effect

Retrofitting a dwelling involves a risk: the occurrence of rebound effects. The increased energy efficiency of the dwelling can lead to a negative behavioral change of the resident: the rebound effect. This is a response effect of the residents to the efficiency improvements of a dwelling. After the retrofit the energy consumption of the household decreases, and knowing this, the residents feel that they can consume this saved energy (or money) in a different way. Therefore a rebound effect increases the household energy demand, which will partially offset the energy efficiency gains by the retrofit. It is difficult to identify a rebound effect. According to the existing literature, two main types can be distinguished. The first type is the direct rebound effect, which is the increased energy consumption after the thermal retrofit. Consumers will take longer showers and set a higher indoor temperature, because they know they consume less energy due to the retrofit. The other effect is the indirect rebound effect. This effect is that residents buy energy appliances when their energy consumption has decreased. For example, consumers buy a dish washer because they reduced their energy consumption (Aydin, Kok, & Brounen, 2014). The rebound effect is not limited to household activities: An indirect rebound effect can also occur by a holiday flight to a resort of the saved money by the retrofit. The rebound effect is often indicated as the ratio between the theoretical savings by energy efficiency and the realized savings. When the expectation is that 50% of the energy is saved, but in reality only 10% is saved, the rebound effect is 80% (Adrians, 2010). Research of Aydin shows that the rebound effect occurs at 41% of tenants and 27% of home owners. Moreover, according to this research this effect is higher among the tenants with low income. This is remarkable, because it is expected that households with a low income tend to think careful about every euro they spend. This might be explained by another approach of the rebound effect. A rebound effect is not always to blame to the tenant. For example, when tenants first had to use a geyser for hot water and now have their hot water coupled to the heating system, opening the tap will result in a stronger water stream than before the retrofit. They consume more water, but this is not a rebound effect that can be influenced by stimulating energy saving behavior.

Adrians (2010) conducted a research on different household behaviors of residents that moved to a low-energy dwelling. The goal of this research was to find behaviors that indicate the presence of rebound effects. Twenty-one households were included in the research. Behaviors of these households that have increased and thus indicated a rebound effect were often linked to heating.

2.2 Intervention Strategies

Many researchers have identified strategies for encouraging voluntary behavioral change. As mentioned in the previous paragraphs, there are different kinds of behaviors and habits that are relevant for household energy saving. Therefore different kinds of interventions are needed. However, this research is not aimed at one specific kind of behavior, but at the household behavior in general, to reduce the overall household energy consumption.

There are various ways of categorizing the strategies for changing household energy behavior, called ‘intervention strategies’. Abrahamse, Steg, Vlek, & Rothengatter (2005) conducted a literature review on studies on intervention strategies. They categorized the intervention strategies as antecedent or consequence strategies and this classification will also be used in this review. The meaning of these types are explained in paragraph 2.2.1 and 2.2.2. Han, Nieuwenhijsen, de Vries, Blokhuis, & Schaefer (2013) added structural interventions as a third type, which are strategies executed by a government (for example subsidies). Structural interventions can be effective for households to save energy, but in the social housing sector these interventions will not affect households directly so these interventions will not be discussed in this research. Figure 2.3 shows a clear overview of the intervention strategies relevant in the context of a thermal retrofit by housing associations, based on a more extensive tree structure of Nieuwenhuijsen (2010). In the next paragraphs, the antecedent and consequence strategies are explained, and the relevance on the thermal retrofit is discussed.

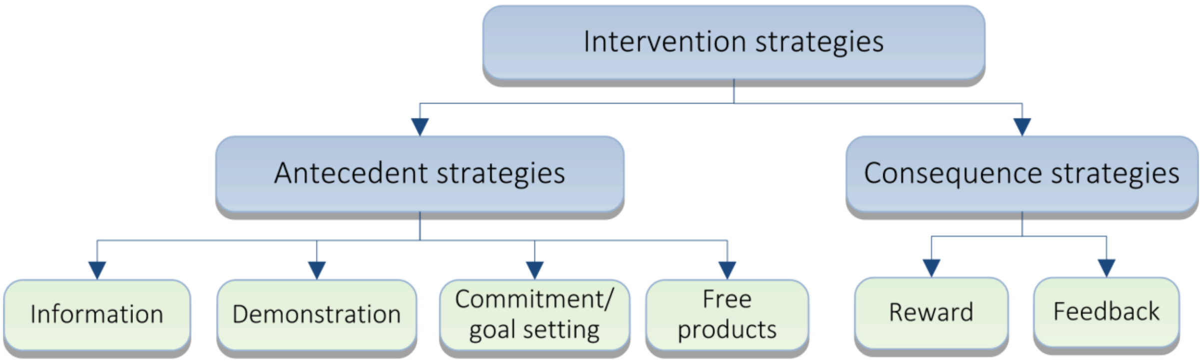

Figure 2.3: Intervention strategies, adjusted from figure 4.2 in Nieuwenhuijsen (2010)

2.2.1 Antecedent Strategies

Antecedent strategies are aimed at influencing factors of energy saving before the behavior starts. For example, providing information about energy saving measures can increase knowledge of households and therefore can result in energy savings. The main types of antecedent strategies will be explained first.

Information is an important intervention strategy. It was already mentioned by explaining the MOA-model of (Ölander & Thogersen, 1995) in paragraph 2.1.2, that residents need to increase their knowledge in order to change their behavior. Information is a broad concept. It can be communicated in many ways. In their daily lives, people receive enough mass information about how to save energy and about the importance of reducing the energy consumption. However, they need more tailored information that they can use in their specific situation (Martiskainen, 2007). Information by an energy specialist seems effective because of the two-way interaction: residents could ask questions about their specific situation. According to a questionnaire among residents, Elsharkawy & Rutherford (2015) found that the majority preferred to have energy advice communicated through leaflets and booklets instead of communicated by a person. Simple, innovative and informative brochures should be designed as appropriate to the specific needs of target groups. When a standard brochure is designed, it is only a small effort to rewrite a brochure to fit the next thermal retrofit. Other ways of providing information are by mass media or prompts. Mass media means large campaigns aimed at a large target group, on TV or by posters. This has not proved to be effective for household energy saving behavior. A prompt is information on the individual level. This can be a short message located where the behavior needs to be performed (Lehman & Geller, 2005). This can be an attractive intervention when the target behavior is relatively easy to perform.

It has been examined by multiple studies that only providing information occasionally is not enough to change household energy behavior, but this information can function as a “basis” for other intervention strategies (Heijs, 2006; Martiskainen, 2008). For example, residents who were repeatedly exposed to information campaigns achieved better results at an energy saving event than residents who were not exposed to such campaigns (Kang, Cho, & Kim, 2012). The more tailored the information is at the behavior and the residents, the more promising it is for changing energy behavior (McKenzie-Mohr, 2000).

Demonstration as an intervention strategy can be on a small scale, for example neighbors who save energy (e.g. PV panels on roof), or companies that promote their sustainable way of doing business. Demonstration can also appear as a model dwelling where energy saving measures are installed, so that residents can see for themselves what these measures look like and how they work.

Commitment and goal setting are often combined antecedent strategies. Households can be given a certain goal of an energy saving percentage and commit to this goal. This can be a written or oral promise (Abrahamse et al, 2005). It is easier to commit to a promised fixed goal, than to promise to just reduce the households’ energy consumption. Resident can commit to a goal in various ways and with various people. In the context of a retrofit, it might be stimulating to commit to an energy saving goal together with the neighborhood that is being retrofitted. It can also be stimulating enough for a family to commit to a goal within their household. Before the retrofit, a calculated energy saving percentage is often presented to the tenants. This percentage is based on the energy saving measures that will be applied. As said before, the calculation is based on the average household situation and therefore not all households will automatically reach this saving percentage. Therefore, this percentage can be used as the "goal" that the tenants can commit to. This way they might become aware that this percentage is not automatically reached, and it seems an easy goal because the energy saving measures will take care of a part of the saving. Commitment strategies have been effective on the long term in several studies (see Abrahamse et al (2005), Appendix Tabel A1).

Another type of intervention strategy is "free products": tenants can be handed an *energy saving box* to stimulate their energy saving behavior. Depending on the applied measures in a retrofitted dwelling, a free energy saving box can be handed out to help the tenants save more energy by small adaptations. It can be a prolongation of the awareness that the changes by the retrofit can create for the tenants. Products that are suited in this context are a shower timer, a "standby killer" (a socket with an on/off switch to 'kill' stand-by devices) and LED bulbs. Using these products requires minimal action, but it reduces the energy consumption and can encourage tenants to buy more energy efficient appliances.

2.2.2 Consequence strategies

Consequence strategies are meant to influence energy saving after the behavior occurred. For example, giving households feedback about their behavior that led (or did not led) to energy saving. This feedback is a consequence of the behavior and it may encourage households to reduce their energy consumption. Feedback and rewards are the two main consequence strategies (Abrahamse et al., 2005).

Providing *feedback* is a promising tool when it comes to reducing the energy consumption in households. Feedback can influence energy behavior of households, because they can associate certain outcomes with their behavior (Abrahamse et al, 2005). Feedback can make the consequences of behavior clearer and therefore increases the occurrence of behavioral change corresponding with the consequences (Lehman & Geller, 2005). Research has been conducted to optimize the frequency and form of feedback. Vassileva, Odlare, Wallin, & Dahlquist (2012) studied the impact of consumers' feedback preferences on the electricity consumption in Sweden. Electricity consumption data for apartments and houses has been analyzed for a period of four years, as well as possible household socio-economic factors. Results from their survey show that web-based feedback is most preferred among this group, compared to a display or to bills. However, using an electronic device (display) for providing feedback on household energy consumption seems more effective than other types, because there is no delay between the action and the feedback. The devices can be placed in all areas in the home. Therefore households can correct their behavior immediately. These developments have led to a two-way interaction instead of a one-way direction in the energy consumption, which is positive for the energy-saving potential (Midden, Mccalley, Ham, & Zaalberg, 2008).

Savings from feedback will always vary according to the technology under consideration. Due to the fast evolutions in technology many types of feedback are available. For example, disaggregated feedback seems very promising, where residents can see a distinction between different appliances on their display. This makes them very aware of the actions of one single appliance (Darby, 2006). Feedback on a display also does not have to be complex. Showing a happy or sad face when behavior has a positive or negative effect on the energy consumption is an example of a simple, but very clear, feedback tool (Abdalla, 2013). Feedback is an intervention strategy that has shown to be effective on the long term according to several studies (see Abrahamse et al (2005), Appendix Tabel A1).

The other consequence strategy is *rewarding* energy saving behavior. When rewards are promised for reaching certain energy savings, this often has a positive effect on the motivation of households. A reward can be combined with a set goal or it can be contingent with the amount of energy that is saved after a certain period (Abrahamse et al, 2005). A reward seems an effective intervention strategy, it can be a ´fun´ way to motivate residents to reduce their energy consumption. The disadvantage is that often, after the reward is given, the effect goes away. Lehman & Geller (2005) suggest improving these reward-based interventions, for example by optimizing the length of the period and combining it with clear (tailored) information. The calculated energy saving presented to the tenants before a retrofit can be used as the fixed amount a reward is given. This seems easy to reach for the tenants, but at the same time will make them aware this saving will not be achieved without behavioral change.

2.3 No one size fits all

Multiple studies note that residents have different lifestyles and needs, so there is no “one size fits all” strategy. Effective interventions should thus be tailored to the characteristics of the resident groups (Abrahamse et al., 2005). Vassileva et al. (2014) state that these different needs should be investigated repeatedly, because preferences and new technologies are evolving fast. The age of respondents is also important to take into consideration. Age has a curvilinear relationship with saving behavior. This means that middle age households are most often involved in energy saving behavior and young and elderly households are less involved in it (L. G. Berry & Brown, 1988). As the elderly are the most rapidly growing age segment, they need to be considered as important group for influencing energy saving behaviors. It seems a difficult target group. Research from Vine, Barnes, Mills, & Ritschard (1989) found that most elderly tenants felt that they were already using the minimal amount of energy. Therefore they claimed to be unable to save more energy without it resulting in a negative impact. It is also mentioned that trust in the organization is very important, especially for the older tenants (Berry & Schweitzer, 1991).

Because of these different household characteristics combining different interventions can be more effective. Multiple interventions can trigger a larger group of households with different characteristics. However, some intervention strategies are more logical to combine than others. Abrahamse, Steg, Vlek, & Rothengatter (2007) used different combinations to examine whether it would result in changes in direct and indirect energy use, changes in energy-related behaviors and changes in behavioral antecedents. They combined tailored information, goal setting (5%) and tailored feedback. The result was that households that received this combination of interventions reached the energy-saving goal. It encouraged households to start adopting various energy-saving options and increased their knowledge on energy saving.

Ben & Steemers (2014) suggest that integrative retrofit strategies have to be developed by combining both building technologies (different sizes of retrofitting) and behavioral change to achieve a higher efficiency. Their research showed that different 'levels' in energy behaviors of residents affect the energy efficiency potential of retrofitting listed housing. Residents have different lifestyles and needs and therefore different potentials to save energy after a retrofit. Residents that have a low-energy behavior do not realize great energy savings, despite the size of the retrofit.

In their review, Abrahamse et al (2005) made an overview of a number of studies, including the short- and long-term effects on behavioral change. Only a few studies measured long term effects and most of the outcomes were that the saving effect was not maintained (see Abrahamse et al (2005), Appendix Tabel A1). The saving effects of strategies combined with feedback or commitment and goal setting tend to maintain longer.

Research on the effectiveness of intervention strategies on energy saving behavior is time consuming and can take years. When there is not enough time to test the effectiveness of these strategies, it is possible to ask residents about their preferences towards intervention strategies. This can be applied using a discrete choice experiment as part of a questionnaire. Finding tenants' preferences by the discrete choice method has been used in other research about household energy behavior and retrofits conducted in a small time frame (Nieuwenhijsen, 2010; Spank, 2013). Using a discrete choice experiment can derive the relative importance of a group of residents towards the different intervention strategies, by presenting the residents 'profiles' to choose from (Oppewal & Timmermans, 1993).

2.4 Conclusion

This chapter has the purpose of answering the sub-question: *Which methods are known to influence tenants' behavior for the purpose of energy savings, and which methods are known to clarify the functioning of the energy improved dwelling?*

Behavior in relation to household energy saving and possible strategies and opportunities to reduce the household energy consumption by influencing tenants' knowledge and habits in the household situation have been explained in this chapter. The behavioral model of (Ölander & Thogersen, 1995) distinguishes three micro-level factors that are influenced by energy behavior: Motivation, opportunity and ability. Most intervention strategies are aimed at changing these micro-level factors. In order to get a clear overview of the factors that can be influenced in order to reach an energy saving behavior for social housing tenants after a thermal retrofit, the MOA model is adapted to this context (figure 2.2). Energy saving behavior can be divided in curtailment and investment behavior. For this research the curtailment behavior is more important than the investment behavior. The investment of retrofitting the dwellings is already made by the housing association. Curtailment behavior of the tenants after this investment behavior has a potential of increasing the energy saving. Residents have different characteristics and lifestyles and this affects their motivation and ability to change behavior (Han et al., 2013).

Intervention strategies that can influence the MOA factors are divided in antecedent and consequence strategies (Abrahamse et al., 2005). The main antecedent strategies are information, demonstration, free products and commitment to a goal. The main consequent strategies are feedback and reward. There is no strategy that has effect on every tenant, so a combination of strategies seems more effective. There is no 'one size fits all', which also implies that before applying intervention strategies it is important to get to know the target group.

The moment of the retrofit can be a trigger for tenants to become aware of their energy behavior. Tenants' knowledge of the energy systems that are applied at a retrofit is often low. It is important that tenants use their energy systems correctly in order to use the energy-saving potential of the dwelling (TNO, 2012). This can be improved in the design phase: placing user friendly devices and robust measures (Groot et al., 2008). It can also be improved by guiding the tenants. A brochure with tailored instructions or a visit from an energy specialist can increase tenants' knowledge about the use of their energy systems (Breukers et al., 2014).

In order to find the most promising intervention strategies in the context of a social housing retrofit, more information is needed from the current processes and experiences in the Dutch social housing sector. This cannot be derived from the literature. A field research on different retrofits in the Netherlands would provide this information. This is explained in chapter 4 and 6. When the most promising intervention strategies are derived from the literature and the field research, the preferences of the tenants towards these intervention strategies after a retrofit are derived using a discrete choice experiment. This is explained in chapter 7. First, it is important to find out how much tenants miss out on energy savings after a retrofit, and if this be reduced by influencing tenants' energy saving behavior. This is discussed in the next chapter.

3. The theoretical household energy consumption

The purpose of this chapter is to answer the second research question using the existing literature. The question to be answered is: *How much on average do tenants miss out on energy savings after a thermal retrofit according to the literature?*

After their dwelling is thermally retrofitted, tenants' energy consumption will decrease because of the improved energy performance of the dwelling. The energy cost savings by the retrofit is presented by the housing association in advance in order to convince the tenants to participate in the retrofit. However, there often seems to be a gap between the calculated and actual amount of energy saved after a thermal retrofit. The reasons for the occurrence of this gap, and different methods to calculate the theoretical energy consumption are explained based on the existing literature. Next, it is explained how housing association can monitor the energy consumption data of their tenants and why this is very useful.

Theoretical and actual household energy consumption of dwellings have been studied in order to understand the reason for the differences that occur. In these studies only the gas consumption is included in these comparisons. The electricity consumption depends more on household appliances than the building systems. It is difficult to separate the building related electricity consumption from the electricity consumption by household appliances in the energy bills of households Therefore a good comparison cannot be made in research when including the electricity consumption (Aydin et al., 2014; Daša Majcen, Itard, & Visscher, 2013). The fact that the electricity consumption is not included in the calculation of the energy saving does not mean that there is no saving potential in the electricity consumption of households.

3.1 Theoretical versus actual energy consumption

Research on differences in the theoretical and actual energy consumption found that the worse a dwelling is thermally (high energy index), the more economically the occupants tend to behave with respect to their space heating. This is clearly illustrated by a large-scale research on approximately 200.000 dwellings. The result of this study is shown in figure 3.1.

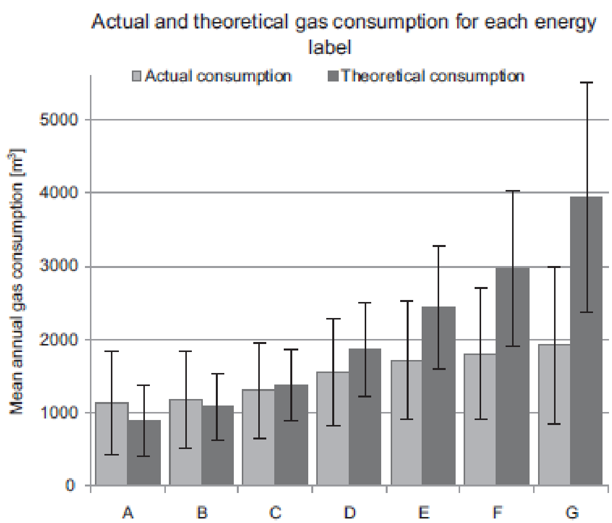

Figure 3.1: Gas consumption in dwellings across label categories with ±1 std. deviation (D. Majcen et al., 2013)

The energy labels with the theoretical energy consumptions of these dwellings were compared with the actual energy consumptions (D. Majcen, Itard, & Visscher, 2013). The figure shows that dwellings with a low energy label, on the left, consume less energy than calculated, while the calculated energy consumption of a high energy label is much higher than the actual consumption. It is therefore likely that in the context of a thermal retrofit the theoretical and actual consumption before (e.g. label E) are further apart than they are after the retrofit (e.g. label B), because the energy index (label) is lower and therefore the values are better calculated according to the results of this study. This gap between theoretical and actual energy consumption has consequences for the reliability of the calculated energy savings for occupants after a thermal retrofit.

Multiple studies have searched for an average percentage of the difference in theoretical and actual consumption. A study from 2005 examined this in the context of saving potentials at thermal retrofits (Bartiaux & Gram-Hanssen, 2005). The authors also found that an energy-saving potential can be much lower in reality when the used theoretical energy consumption is higher than the actual consumption. The difference can amount to 20-30% of the energy savings gained through a general average rebound effect (Haas & Biermayr, 2000) or 10-30% for space heating (A. Greening, Greene, & Difiglio, 2000). According to Majcen et al., (2013), the theoretical calculation of the total heating energy consumption can deviate approximately 35-40% from the actual consumption. Ben & Steemers (2014) compared different sizes of a retrofit of listed housing and found that the differences in calculated and actual saving could vary from 10% at a low retrofit level, to 30% at the maximum retrofit level. They also defined three different levels of energy behavior, which can also cause differences of energy savings that ranges up to 62-86% in listed housing. This research was based on a small sample size. Sunikka-blank & Galvin (2012) examined the calculated energy performance ratings of 3400 German dwellings, and plotted it against the actual measured consumption. They found that on average occupants consume 30% less heating energy than the calculated rating. They have researched this problem about energy saving after thermal retrofits further and introduced a new term; the pre-bound effect. The meaning of this term is illustrated in figure 3.2.

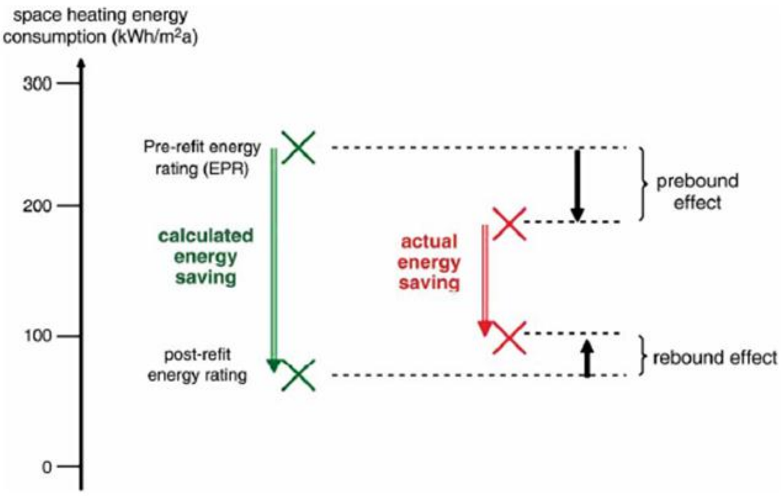

Figure 3.2: The pre- and post-retrofit heating energy consumption of calculated and actual energy saving (Sunikka-blank & Galvin, 2012)

The figure shows the calculated energy savings on the left. This is often presented to the tenants before the start of the retrofit. However, the actual situation may be the situation illustrated on the right in the figure: a smaller arrow that represents a smaller energy saving. The actual pre-retrofit energy consumption of a household is often lower than calculated. This is called the “prebound effect” and partly leads to wrong energy saving calculations.

Sunikka-blank & Galvin (2012) explains that the prebound effect can be due to a fault in the calculations, but that it is probable that a part of it is due to diversity in the heating pattern. In a poorly insulated dwelling occupants may automatically adapt their behavior. They tend to consume less energy because they are aware of the bad energy performance of their dwelling (Ben & Steemers, 2014). Above that, unoccupied rooms are not always heated. That makes the average indoor temperature lower than the average temperature used in a theoretical model. But when the dwelling is retrofitted more rooms in the dwelling can and will be used. This results in a higher average indoor temperature because of the improved energy performance of the whole dwelling. This decreases the difference in energy consumption before and after a thermal retrofit (Bartiaux & Gram-Hanssen, 2005).

The arrow in figure 3.2 shows that the retrofit actually results in a lower energy saving than calculated, because tenants cannot save the energy that they do not consume. Beside the prebound effect, figure 3.2 also shows a mismatch in the energy consumption after the retrofit. The authors of the article called it the rebound effect. This is the effect that has already been discussed in paragraph 2.1.3. Using this term, the authors suggest that the illustrated difference after the retrofit in actual and theoretical energy consumption is only caused by this rebound effect. Although this can be one of the causes, there are other factors that can explain the difference in the energy consumption after the retrofit. Therefore, in this research the gap between theoretical and actual energy consumption after the retrofit will not be referred to as the rebound effect. The possible causes of this gap beside the rebound effect will be elaborated.

First, it can be explained by the calculation. It is difficult to include household behavior into the energy consumption calculation. There are different behavioral parameters that are part of household behavior. Daša Majcen et al. (2013) researched the influence of indoor temperature, number of occupants, internal heat gains and ventilation rate. Their sensitivity analysis of these factors showed that the average indoor temperature had a large influence on the theoretical gas consumption, as well as the ventilation rate. The number of occupants and the internal heat load also had an influence, but on a smaller scale.

Secondly, the size of the difference between calculated and actual energy savings can depend on the applied energy saving measures during the retrofit. As discussed in paragraph 1.2, there are active and passive (or: robust) measures. Tenant behavior can influence active measures (e.g. ventilation, heating) more than passive measures (e.g. insulation). The more robust a measure is, the less effect tenant behavior has on the energy-saving potential of the measure. A retrofit that includes many passive and robust measures is less dependent on household behavior and thus the calculation of the energy saving will probably be closer to the actual energy saving than a retrofit that includes many active measures.

Related to the applied measures, the communication from the housing associations towards the tenants can affect the actual saving compared with the calculated saving. When active measures are applied, it will make a difference whether or not the tenant knows how to use these measures efficiently (Groot et al., 2008). Tenants can also be stimulated to start living more energy efficient, as discussed in chapter 2.

3.2 Reducing tenants' living costs by thermal retrofits

When Dutch housing associations plan a thermal retrofit for a complex (cluster of dwellings), they request the current energy indexes of these dwellings. Based on these indexes, they can determine the right energy-saving measures to decrease the energy index to the desired level. A lower energy index will results in a decrease of the energy consumption of the tenants and therefore their energy costs. Coupled to the energy indexes, theoretical energy consumptions before and after the thermal retrofit are calculated. The calculated decrease depends mainly on the energy saving measures that are applied.

A thermal retrofit will need an investment from the housing association. Often a part of this investment is charged to the tenants by a rent increase. The majority of housing associations do not base this rent increase on the investment costs of the retrofit, but they base it on a percentage of the calculated decrease of the dwellings' energy consumption. This is recommended by the covenant rental sector in order to decrease the living costs of tenants (Atriensis, 2015a; Hazeu et al., 2012). That is why they do not charge 100% of the calculated energy savings, but a lower percentage. This way, in theory the living costs of the tenants will still decrease. The term "in theory" illustrates that tenants cannot assume that they will save this presented amount of energy. The household energy consumption depends on other factors, especially behavior, but behavior is difficult to model into this calculation. The next paragraph will elaborate on this.

3.3 Calculation of the energy consumption

The energy index can be calculated using software, for example VABI Assets Energy according to the 'Energieprestatie Woningen' (ISSO, 2014). This software calculates the energy index of a dwelling according to its building characteristics. Coupled to this energy index, the energy consumption of the dwelling is calculated. As explained in paragraph 3.1, behavioral parameters are difficult to include in the calculation. The calculation is corrected by some standardized parameters, e.g. the length of the heating season. There is also assumption for the average household size, which is coupled to the user surface of the dwelling. For example, the average household size for a user surface between the 50 and 75 square meters is 2,2 persons. As mentioned before, the indoor temperature of the dwelling is probably causing a great part of the difference between the theoretical and actual energy consumption of dwellings. The indoor temperature is used as an average of all rooms in the dwelling and is set on 16,5 degree Celsius. This value was the same before and after the thermal retrofit. However, to correct for the rebound effect (higher comfort level so set the indoor temperature higher), the Woonbond has advised to use 17 degree Celsius as the temperature after the thermal retrofit. There are more parameters (e.g. income classes, education, age of possible children) that can be used in the software to get a more accurate consumption of each dwelling (Vabi, 2015). However, this is a time consuming process and for large retrofit projects it is not practical.

3.3.1 Actual energy consumption from grid operators

Housing associations can request the energy consumptions of their dwellings from their local grid operator. A grid operator is the operator of the energy grid. In the Netherlands there are ten operators responsible for the energy grid. Because of privacy reasons, the energy consumptions are available for the owner of the dwelling in clusters of minimum 5 dwellings. Each operator has its own prices for requesting the data. Since July 2015, all Dutch grid operators present the energy consumption data of their clients on their websites for free, clustered at the 'zip code-6' level. The reason for publishing these data for free is to stimulate innovation (endinet.nl/opendata). This means that everyone can check the gas and energy consumptions of each zip code in the Netherlands. According to Atriensis it is a good source for energy saving projects. It is an accessible method to get insight in the energy consumption of neighborhoods (Atriensis, 2015b). For small assignments or quick scans of the effect of energy saving actions these data can be used to compare the energy consumption over the past years.

These energy consumptions provided by the grid operators are not exactly the actual used consumptions of the dwellings. It is the SJV, 'standard year consumption', which means that it is the expected year consumption of the household at standardized conditions and based on a normalized year (Endinet, 2015b). It is based on the actual consumptions of the previous years. It is corrected for the climate and therefore not reliable on strong or soft winters. Every year can be compared with each other, but it is not the same consumption as the tenants see on their annual bill.

Paying for the energy consumption has more advantages for big companies such as housing associations. The biggest advantage of paying for the energy consumption data is that the clusters can be determined by the housing association itself. The zip code clusters of the free consumption data often do not exactly match the dwellings that are owned by a housing association. It also takes time to figure out which zip codes match the dwellings of the housing association.

3.3.2 Correcting the calculated energy saving

At the start of the communication process, many housing associations want to determine the rent increase based on the calculated energy saving. Knowing that the theoretical energy consumptions often differ from the actual energy consumptions, there are possibilities to correct the calculation of the theoretical consumption. This is possible when the actual energy consumptions of the dwellings are available.

The theoretical energy consumption before the retrofit is compared to the actual energy consumption, derived from the grid operator. If this shows a difference in theoretical and actual consumption in the before situation, Atriensis corrects the calculated energy saving costs by the ratio between theoretical and actual consumption. Therefore it is assumed by Atriensis that the saving percentage of the energy saving measures is not dependent on the "start value" the calculation is based on. This assumption is not necessary, because the actual energy consumption is known and can be used in the calculation. This would result in a more reliable the calculation of the energy saving. This is what Atriensis calls "fitting"; the parameters in the calculation model are changed (predominantly the indoor temperature) in order to get the actual energy consumption as a starting point for the calculation. When calculated this way, there will be no prebound effect as discussed in paragraph 3.1. This is illustrated in figure 3.3 and 3.4. If the energy saving percentage indeed does not depend on the start value of the calculation, the situation in figure 3.4 would occur. This is the situation that Atriensis is assuming in current calculations. The gap that is now occurring after the retrofit can be reduced in several ways as already discussed in paragraph 3.1

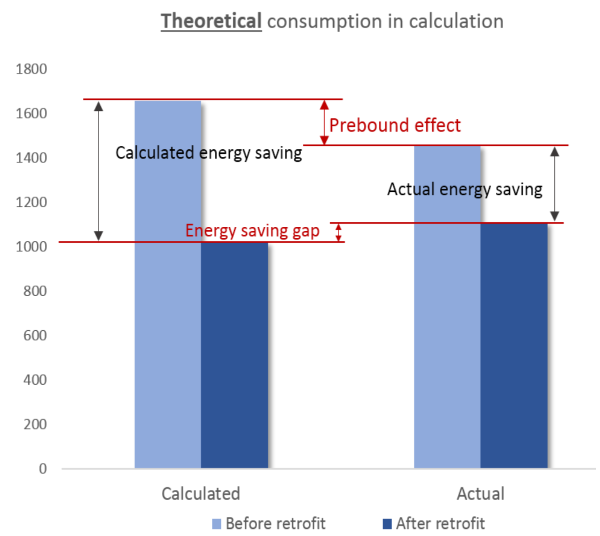

Figure 3.3: Using theoretical consumption in calculation

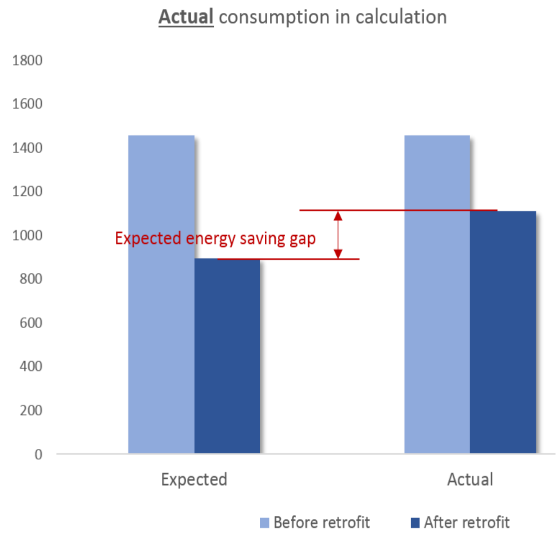

Figure 3.4: Using actual consumption in calculation

It is not a disadvantage that the actual energy consumptions are only available in clusters when it is used to calculate a rent increase percentage. It would not be fair to use the energy consumption at the dwelling-level, because a neighbor of an old tenant has to consume less energy to reach the heating temperature than a neighbor next to a vacant dwelling. Charging a higher rent increase to the neighbor of the vacant dwelling is unfair.

3.4 Monitoring the energy consumption at retrofits

When housing associations request the energy consumptions from their dwellings by the grid operator, they can monitor their complexes before and after a retrofit. Without monitoring, the association cannot know whether the calculated energy savings were reached by the tenants. It is impossible to improve the retrofit process when there is no feedback on the effectiveness of the tenants' energy consumptions. Moreover, it seems illogical to present a theoretical saving and charging a rent increase based on this theoretical saving, but not monitor whether this saving is reached. The means for monitoring are available for housing associations and it does not have to be expensive, as discussed in paragraph 3.3.1.

Monitoring energy consumption of the housing stock makes it possible for housing associations to show tenants the potential of a retrofit by showing the results of already retrofitted complexes. It can also be used to explain the difference in energy saving of different clusters. Strategies can also be determined by monitoring the energy consumption: if consumptions stay high after a retrofit there can be decided that additional strategies are needed for that complex.

3.5 Conclusion

The aim of this chapter was to answer the research question '*How much on average do tenants miss out on energy savings after a thermal retrofit according to the existing literature?'*.

Studies show that the energy consumption of a dwelling is not easy to predict, because energy consumption is not only dependent on the characteristics of the dwelling. The worse the energy performance of a dwelling, the worse the calculation of the energy consumption is (Daša Majcen et al., 2013). The theoretical energy consumption is too high, because occupants tend to behave more economically aware in these dwellings. Studies on energy saving after a retrofit acknowledge the problem that calculated savings are often not realistic enough and that leads to wrong calculations on the payback period and rent increase.

Sunikka-blank & Galvin (2012) have introduced the "prebound effect". This is the effect that the theoretical energy consumption before a retrofit is higher than the actual consumption and therefore occupants are assumed to save energy that they never used in the first place. This causes an extra effect on the difference in energy savings besides the known rebound effect. The prebound effect can be corrected when calculating the energy saving. The before consumptions, theoretical and actual, are known beforehand, therefore this difference can be corrected by the housing associations before calculating the rent increase. In current projects Atriensis uses the SJV to compare the calculated consumption to the actual consumption. The calculated energy saving is corrected by the ratio between calculated and actual consumption before the retrofit. However, this does not solve the prebound effect entirely: it would be more accurate to calculate the energy saving based on the actual energy consumption instead of the calculated energy consumption.

Studies on the influence of behavioral parameters on the household energy consumption led to an improvement of energy consumption calculations in the past years (Bartiaux & Gram-Hanssen, 2005). The problem is that the more parameters are included in the calculation, the more time consuming it becomes to calculate the energy consumption of a dwelling; especially when these parameters are very specific and difficult to find out for each dwelling. The average indoor temperature seems to influence the dwellings' energy consumption the most of all parameters that can cause differences between calculated and actual energy consumption.

The answer to the research question is that on average, tenants miss out on energy savings at a range between 10 and 30% of energy saving because of the difference in calculated and actual energy saving (Bartiaux & Gram-Hanssen, 2005; Ben & Steemers, 2014; Daša Majcen et al., 2013). This effect is partly being corrected in current energy consumption calculations, but this could be more accurate. Since July 2015, all Dutch grid operators have published the energy consumptions of households clustered per zip codes for free. For housing associations, these data can be useful to monitor the energy consumption of their dwellings in an accessible and cheap way. They can decide whether additional guidance is needed, based on the actual energy consumptions of the complex after the retrofit compared with the calculated values. When a budget is available, it is recommended to request the energy consumptions against payment, because the clusters can be determined by the housing association and this will provide more insight in the retrofitted projects. This will also lead to more accurate energy saving calculations.

4. Field research design

The previous chapters gave insight in the existing literature relevant for this research. This chapter will explain the field research and the methodologies as the 4th step in the research design in figure 1.1 in chapter 1. The field research consists of three parts. First, it is examined whether the difference in actual and theoretical energy saving mentioned in the literature is also occurring in Dutch thermal retrofits in the social housing sector, to see the relevance of changing household energy behavior after a retrofit. Next, the intervention strategies for changing this behavior, found in the literature, will be selected for the context of this study. In order to do this, the current process of a thermal retrofit by Dutch housing associations need to be examined. Last, tenants' opinion about energy saving after a thermal retrofit and the selected strategies will be conducted. All these steps are conducted using a field research. The problem focus, goal, project criteria and process of the field research are explained in this chapter. Next the methodologies for the analyses will be explained.

4.1 Problem focus

Household have great potential to lower their energy consumption and contribute to the reduction of carbon dioxide emissions. The moment of a retrofit has a potential to function as a trigger for tenants to start energy saving behavior, using intervention strategies aimed at changing behavior. Literature shows that there is often a gap between the calculated energy savings after a retrofit, and the actual amount of savings. This field research will find whether this gap is occurring and how this gap can be reduced. Before starting a social housing retrofit, there is much communication between the housing association and the tenants about why they should participate in the project. There seems little attention paid to the tenants after the retrofit. However, it seems that tenants need more information about the changes in their dwelling. Literature shows that many energy systems are not understood by its users, and this results in an inefficient use of the system. Housing associations base their rent increase on the theoretical energy saving and this can result in unjustified rent increases if tenants do not reach this calculated value. The focus for this field research lies on retrofits in the social housing sector in the Netherlands. To represent this group, different retrofit projects across the Netherlands are selected for this research. This is explained in paragraph 4.3.

4.2 Field research goal

The field research has different goals. Several retrofit projects will be examined from different point of views. First, the calculated and actual energy consumptions of the retrofit projects are analyzed. The goal is to see if the gap between calculated and actual consumptions found in the literature is occurring in the Dutch social housing sector. If it is, this will reinforce the importance to stimulate behavioral change at such retrofits. Next, the goal is to learn about the current process of these retrofit projects. The project leaders will be asked about the communication before, during and after the process and how they charge (and explain) a rent increase. Last, based on the conducted interviews and the findings in the literature, the variables important for stimulating energy saving behavior are identified, and tested in the tenant questionnaire. The goal of the questionnaire is to find if there have occurred behavioral changes due to the retrofit, and to ask their about the preference towards the selected intervention strategies. Some results will be analyzed by comparing the housing associations with each other. These results might be explained by the different approaches used at the retrofits (derived from the interviews). Together this will result in answers to the second, third and fourth research question from paragraph 1.6.1.

4.3 Project criteria

The following criteria are used to select the complexes from the housing associations that are used for the analyses. Each complex:

1. is executed based on an advice report from Atriensis;
2. has at least 50 reasonable identical retrofitted dwellings (1 or 2 types);
3. has an individual central heating system;
4. has been retrofitted in the period of 2011/2012/2013;
5. is located at a different municipality and belongs to a different housing association.

The first criterion makes sure that there is enough information available about the complex. An advice report includes characteristics of the dwellings of the complex, calculations of the investment costs and calculated energy saving costs based on the proposed energy saving measures. The second criterion is chosen because a smaller project does not represent the average size of a retrofit at a housing association and thus cannot represent an advice for the total social housing stock in the Netherlands. The third criterion is chosen, because changes in the energy consumption can be analyzed on the smallest scale possible. Next to that, tenants with an individual heating system have more influence on their heating behavior. The fourth criterion ensures that there is enough known about the retrofit. It is recent enough, but it is not too recent, so that enough can be said about the results and the energy savings after the thermal retrofit. The last criterion has been added, so the approaches of different associations throughout the country are researched, and they are not influenced by for example the same municipality. Table 4.1 shows the selected retrofit projects used for the analyses. Appendix A shows more information about the applied measures and change in energy index of each retrofit.

Table 4.1: Characteristics of projects used in this research

Housing association (city)	Total no. of dwellings	City of complex	Year of retrofit	No. of dwellings	No. of participating dwellings
Rhiant (Hendrik Ido Ambacht)	1.800	Hendrik Ido Ambacht	2012	71	26
Urbanus (Belfeld)	800	Belfeld	2013/ 2014	58	58
Standvast Wonen (Nijmegen)	8.900	Nijmegen	2010	148	115
GroenWest (Woerden)	12.000	Montfoort	2013	52	52
Omnia Wonen (Harderwijk)	7.000	Nunspeet	2013	65	61
Qua Wonen (Bergambacht)	8.700	Bergambacht	2012/ 2013	117	117
'thuis (Eindhoven)	10.000	Eindhoven	2012	64	51

4.4. Process

Seven housing associations with a complex that met the criteria in paragraph 4.3 were selected out of the clients of Atriensis. The differentiated sample of retrofits is presented in table 4.1. In appendix A, an extensive version of this table is attached including the interview information. As soon as the project leaders agreed to participate in this research, an interview was planned at their office. The design of the interview is explained in paragraph 5.2. Initially, six complexes were selected. However after the conducted interview with the project leader of Rhiant, it became clear that only 26 of the 71 dwellings participated in the retrofit. This did not met the first criteria, so an additional complex was searched. Rhiant is not excluded from the research (the interview was already conducted), however the complex was not useful for the energy analysis. The seventh complex that was added to the research belongs to the housing association Qua Wonen.

The results from each interview, together with the information from the literature review, was used for designing the questionnaire. The tenants are asked about their energy related behavior, and their preferences towards the selected intervention strategies. This will be done using a discrete choice experiment. An operationalization scheme of the variables was constructed and the questionnaire was designed. The questionnaire was revised multiple times before it was send to the project leaders for approval, and then to the tenants.

Parallel to this process, criteria were set up for the energy consumption data in order to analyze if the calculated savings for these complexes were reached on average by the tenants. The methodologies of these analyses are explained in the next paragraph. Then, chapter 5 shows the data collection and analysis and results of the energy consumption analysis. Chapter 6 explains the data collection, data analysis and results of the project leader interviews and the identification of the variables for the tenants' questionnaire. Next, chapter 7 explains the collection, analysis and results of the questionnaire including the discrete choice experiment. Chapter 8 will discuss all the results derived from this field research.

4.5 Methodologies

4.5.1 Calculated versus actual energy saving

Chapter 3 has discussed the gap between the calculated energy savings, calculated using the housing characteristics, and the actual energy savings that a household reaches after the retrofit. To find out whether this gap between calculated and actual energy savings is also present at current Dutch social housing retrofits that have been studied, an analysis will be made using Excel. This is step 4a in the research design in figure 1.1. The calculated savings are derived from Atriensis and the actual savings are derived from the grid operator websites. This is explained in the data collection in paragraph 6.1. In order to compare these two data sets, some criteria and assumptions need to be made, presented in paragraph 6.2. The calculated and actual energy savings will be analyzed using Excel, presented in a diagram. The advice report also contains information about the investment costs for retrofitting a dwelling and the rent increase that will be applied. This will be used to compare the payback period and the actual savings the tenants reached including the rent increase. The criteria and assumptions that are made for the analysis are presented in chapter 5, and then the data analysis and results are presented.

4.5.2 Project leader interviews

Step 4b in the research design in figure 1.1 are the interviews conducted with the project leaders of the projects in table 4.1. The main goal for interviewing the project leaders of the complexes is to understand the process of the retrofits and what guidance or strategies are applied in the different complexes. Next to that, information about the calculated energy savings and how this was explained to the tenants was clarified. A semi-structured interview was conducted. In appendix B, the basic questions used for the interview are presented. Depending on the situation, extra questions were asked. Before conducting each interview, the advice report of Atriensis for that retrofit was read for some pre-knowledge about the project. . In order to generate the input for the next stage of the research (questionnaire), the interviews were conducted before designing the questionnaire. The interviewed persons are included in appendix A. It was a semi-structured interview: based on the answer more questions were asked in order to receive as much knowledge as needed. The sub-question to be answered is*: What is the current process for thermal retrofits of housing associations and is there space for interventions after these projects, aimed at behavioral change?* The literature on intervention strategies and energy saving behavior can complement the information from the interviews. This information together can identify the variables for the questionnaire and add this to the theoretical energy saving behavior model.

4.5.3 Tenant questionnaire

The third part of the field research is deriving information about tenants' behavior and preferences towards intervention strategies in the context of a social housing retrofit. This is illustrated as the tenant questionnaire as part 4c in the research design in figure 1.1. A quantitative method is the best method to investigate the aspects on a large group of tenants. A questionnaire will be send to the tenants that live in the researched retrofits in table 4.1. The questionnaire variables will be identified by the literature and project leader interviews. It will be recognized which housing association each respondent belong to, in order to compare the differences between the housing associations.

Socio demographic variables

The socio demographic variables will be included in the questionnaire, to examine whether the respondents represent the target group; tenants of the social housing sector.

Micro level factors

The tenant questionnaire will include questions about the micro level factors. Most of these questions will be analyzed for each housing association separately. This way, the results might be better explained by the information derived from the conducted interviews. There is tested whether the tenants are satisfied about the quality of the received information and the motivation for participating in the retrofit. There will also be questions about energy saving knowledge and the occurrence of behavioral changes by the retrofit. The exact questions will be based on the theoretical energy saving behavior model that will follow from the project leader interviews.

Discrete choice experiment

In order to investigate the preference of the tenants in receiving guidance by different intervention strategies, a discrete choice experiment is used. This method is explained more in detail.

A discrete analysis is often used to derive relative importance of attributes by presenting 'profiles' to the respondents (Oppewal & Timmermans, 1993). The discrete choice analysis has been used on comparable research on energy-saving measures (Nieuwenhuijsen, 2010; Spank, 2013). Using this method, the tenants' preferences towards sorts of stimulation of saving energy after a thermal retrofit will be found by deriving the relative importance of attributes from the results (Oppewal & Timmermans, 1993). Asking tenants directly which intervention strategy is most preferred, will not give a reliable answer. It is important that tenants answer the question in the right context by using the right information.

There are three types of methodologies within the discrete analysis. This is illustrated in figure 4.1. The type that is most appropriate for a research is depending among others on the number of attributes. A distinction can be made between revealed and stated methods. The respondents have experienced the retrofit of their dwelling, thus it is possible to conduct the revealed method. However, (through the interviews) it is already known what kind of help they have received and the purpose of this experiment is to discover the needed and preferred help within these projects. Therefore the stated method will be used. There is a difference between preference and choice. The preference method makes the respondents evaluate the profiles one by one, and the choice method makes the respondents choose the best option between profiles. Choice and thus the decompositional choice method is preferred, because choosing an option is more representative of the actual process of selecting. Also, it provides the 'no-choice' option that respondents can choose if they would not choose any of the presented profiles. This method is also known as the discrete choice method. The experiment design is explained in paragraph 7.2.

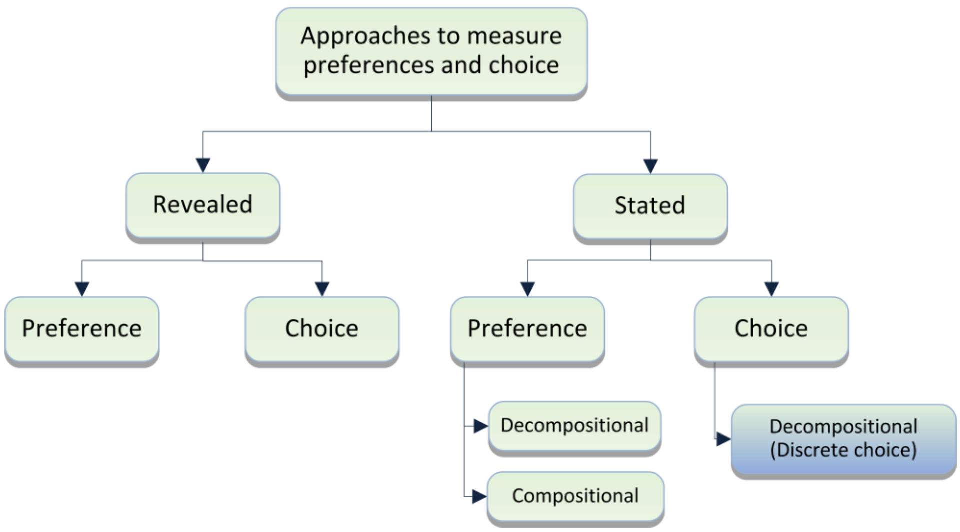

Figure 4.1: Adjusted choice analysis schema from Kemperman (2000)

Sample Size

In the Netherlands, housing associations own 2,4 million social rent dwellings. Yearly, more than 20.000 of these dwellings are being thermally retrofitted (Aedes, 2014b). This means that the target group for this research, dwellings that will be retrofitted, is very large. The needed number of respondents for the questionnaire hardly depends on the size of the population (target group), especially when the population is above 20.000.

However, sample sizes in discrete analysis is dependent on the variables of the experiment instead of the population size it represents. Within the conjoint analysis, a discrete choice experiment is a relatively inefficient method in the number of attributes each respondent can rate.
There is a rule of thumb of Orme (2010) that can determine the desired number of respondents for these experiments, this is showed in equation 4.1 and 4.2:

$$n > \frac{500 \cdot C}{t \cdot a} \qquad (4.1) \qquad\qquad n > \frac{500 \cdot 6}{14 \cdot 2} \qquad (4.2)$$

n = number of respondents
t = number of choice sets (tasks)
a = number of alternatives per task (not including the none alternative)
c = number of analysis cells.

For this experiment, each respondent completes 14 tasks with 2 alternatives and a 'no choice' option. The number of analysis cells when considering interaction effects, represents the largest product of levels of any two attributes, which is 6. When only the main effects are considered, c is equal to the largest number of levels for any attribute, which is 3. That makes the number of desired respondents *n* more than 107 respondents.
A second formula to calculate the sample size is used to check the respondent number in equation 4.3 and 4.4 (Cochran, 1977).

$$n = \frac{z^2 \cdot p(1-p)}{a^2} \qquad (4.3) \qquad\qquad n = \frac{1{,}96^2 \cdot 0{,}3(1-0{,}3)}{0{,}05^2} \qquad (4.4)$$

n = the number of respondents needed
p = chance of filling in
z = standard deviation with reliability percentage (1,96 for a 95% reliability)
a = Margin error of 5%

The outcome of this formula is *n* is 323 respondents. There is a big difference between the outcomes of these formulas. According to Orme (2010), for a robust quantitative research where one does not intend to compare sub-groups, at least 300 respondents are required (Orme, 2010). That suggests the second formula is more reliable.

The number of households belonging to the researched projects is 477, as shown in table 4.1. This is higher than the desired respondents, but the respondent rate should also be taken into account as equation 4.4 shows. To reach 323 respondents as a response rate of 30%, the questionnaire should be send to 1070 respondents. Therefore besides these households, some other retrofit projects from the same housing associations are also included in the sample. This results in a total of 934 tenants that will receive a questionnaire. The social housing sector has an average mutation of 8% per year (Aedes, 2014a). This means that every year, 8% of the tenants is moving to another dwelling. The retrofits took place a few years ago, therefore a number of tenants that receive the questionnaire will have not experienced the retrofit. This means that they cannot answer the questions of part 1, but they can answer the other two parts. This is mentioned in the letter and questionnaire.

4.6 Conclusion

For this research, 7 retrofit projects of 7 housing associations are approached. These projects are analyzed at three different levels. The goal is to answer three research questions, each by one analysis. The methodologies are explained. The calculated energy saving will be compared to the actual energy saving after these retrofits using the data from Atriensis and from the grid operators. This will show whether there is a gap between the calculated and actual values. From each project, the project leader will be interviewed about the current retrofit process. There will also be examined whether there is space for intervention strategies to stimulate energy saving behavior after the retrofit. In order to find information about energy saving by the tenants, a questionnaire will be designed and send to the tenants of retrofit projects of these housing associations. A discrete choice experiment will be designed as part of the questionnaire, to find the preferences of tenants towards the possible intervention strategies after a social housing retrofit.

This chapter explained the methodologies of the three field research analyses. The next chapters will present the data collection, data analysis, results and conclusion of each of the analyses.

5. Calculated versus actual energy saving

The methodology of the analyses of the calculated and actual energy consumptions before and after the retrofit is explained in paragraph 5.4.1. This chapter contains the data collection, analysis and the results. This is step 4a in the research design in figure 1.1.

5.1 Data collection

The energy consumption data from each retrofit project in table 4.1 were collected from each advice report of Atriensis (calculated consumption) and the website of the grid operators (actual consumption). The advice report of Atriensis includes calculated energy consumptions before and after the retrofit, depending on the applied measures. This is calculated for each dwelling, based on its building characteristics. It is split into gas consumption (water and heating) and help electricity (the electricity for the energy systems). The actual energy savings are derived from the websites of the grid operators of the housing associations. These are available for each year (from 2008 to present) on a zip code level, in SJV (standard year consumption). This is explained in chapter 3.2.2. How these two different datasets are compared is explained in the next paragraph.

5.2 Data analysis

The analysis is done at the 6-zip code level; due to privacy reasons the individual consumptions are not available. To make the analysis as reliable as possible, the zip codes that do not meet the criteria in table 5.1 are excluded from this analysis.

Table 5.1: Criteria for the zip codes of the grid operator database used for this analysis

1	The zip code only consist of dwellings of the studied complex
2	All dwellings of criteria 1 were included in the retrofit
3	There are no large deviations in the data such as “0”

The analysis will only include the gas consumptions. Although it can be interesting to compare the electricity consumption due to a change in household behavior, the available data differ too much from each other to make a comparison. In the calculated consumption for electricity only the ‘help electricity, the electricity needed for the building systems, is included. In the SJV database, there is no distinction between ‘help electricity’ and appliance electricity. The gas consumptions from the calculations from the advice report are called “calculated consumptions’ and the SJV gas consumptions from the grid operators are called “actual consumptions” in this analysis. The assumptions for the gas consumption analysis are shown in table 5.2.

Tabel 5.2: Assumptions for the analysis

1	The calculated “before” consumption is compared with the actual consumption of 2 years before the year of retrofit
2	The calculated “after” consumption is compared with the actual consumption of 3 years after the year of retrofit
3	The degree days are calculated the same for both data sets

Following the defined criteria and assumptions, 10 zip codes from the studied projects were analyzed. From 5 out of 7 housing associations, at least 1 analysis could be made. No comparison could be made of zip codes belonging to the complex of GroenWest and Rhiant.

As mentioned before, the number of dwellings of Rhiant was too low to make an analysis. The project of GroenWest included enough retrofitted dwelling, however it turned out that they were scattered over multiple zip codes, always including other dwellings that did not belong to the retrofit project. The averages of the calculated energy consumptions of the dwellings in these zip codes are calculated, in order to make the comparison on the same level. Next, they are combined in an excel sheet in order to create a diagram that shows the difference in m^3 gas consumption savings per year for the average dwelling in the zip code. The second part of this analysis is that the consumptions are translated into energy savings in euros, using the gas price of the year the calculation was made. This can be coupled to the investment costs of the associations, and the difference in effectiveness of the retrofit can be shown by a change in the (theoretical) payback period. When a table is called "calculated", the data is derived from the advice report of Atriensis. When it is called "presented", these data is derived from a brochure that is presented to the tenants of the complex. The diagrams and calculations are shown and discussed in the next paragraph. The results are compared with the applied measures by the retrofit. These are shown in appendix A.

5.3 Results

The figures show the before and after gas consumption per year, calculated and actual values are shown next to each other. The difference in these columns represents the energy saving after the retrofit. The tables 5.3 – 5.7 include the used data to calculate the calculated and actual cost saving and payback times.

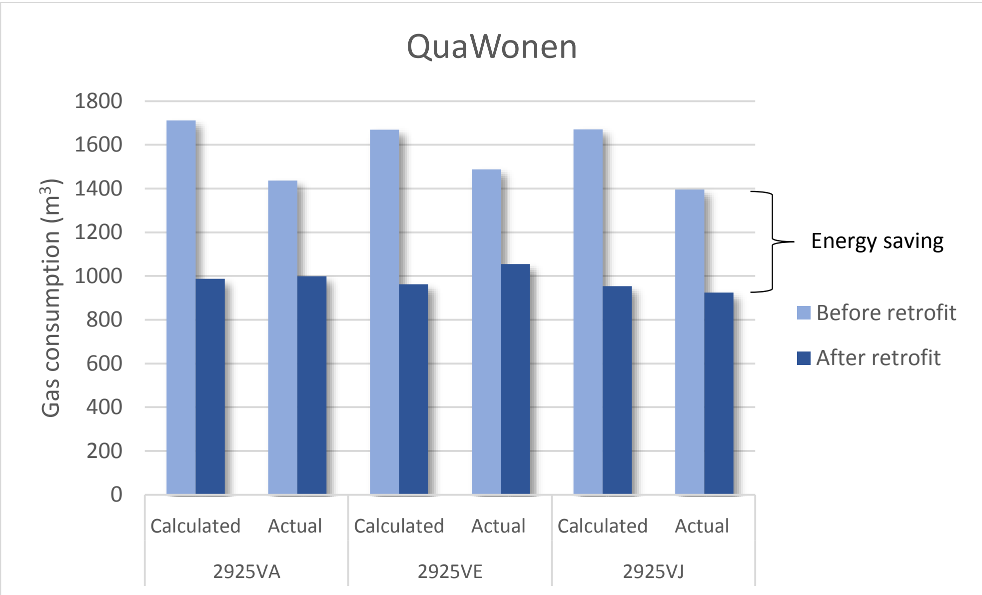

Figure 5.1: Calculated and actual saving of the zip codes of Qua Wonen (Atriensis, 2011d; Stedin, 2015)

Table 5.3: Calculation for zip code 2925VJ (Atriensis, 2011d)

Gas price (euro/m³)	0,66		**Calculated**	**Actual**
Investment average dwelling (€)	8.840	**Saving of average dwelling (€)**	469	310
Rent increase (16,67%) (€)	78	**Payback period (year)**	19	28
		Saving – Rent increase (€)	391	232

Three zip codes of Qua Wonen were analyzed and presented in figure 5.1. The calculated saving percentage were around 43%. The prebound effect occurred, as can be seen by the higher calculated values. The calculated savings are all lower than calculated. For example, zip code 2925VJ reached a saving percentage of 33,7%. Because of the low percentage of rent increase (16,7%), the tenants of this zip code will save according to this calculation €232 per year instead of the expected €391.

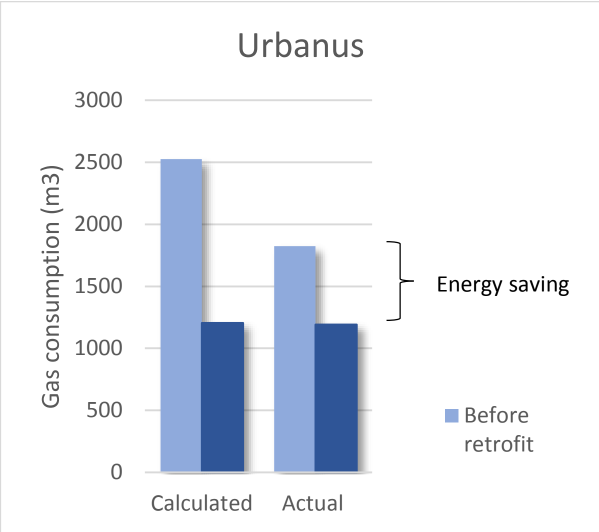

Figure 5.2: Calculated and actual saving of zip code 5951BG (Atriensis, 2011a; Enexis, 2015)

Table 5.4 Calculation for Urbanus (Atriensis, 2011a)

Gas price (euro/m³)	0,72
Investment average dwelling (€)	6278
Rent increase (50%) (€)	445

Table 5.5 Comparison for Urbanus (Atriensis, 2011a)

	Calculated	Actual
Saving average dwelling (€)	890	454
Payback period (year)	7	14
Saving - Rent increase (€)	445	9

Zip code 5951BG of Urbanus in figure 5.2 illustrates that a saving percentage of 52,3% is calculated, but a saving percentage of 34,6% is reached. A rent increase of 50% is charged to the tenants. The large difference in calculated and actual saving leads to a small energy saving of €9 per year instead of the expected €445 according to the calculation.

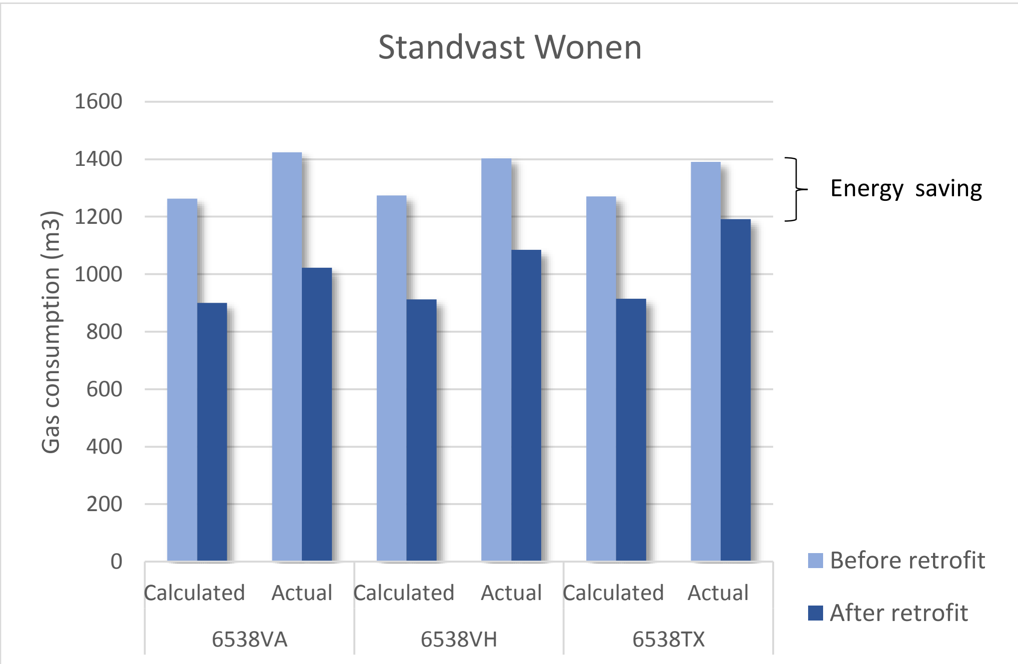

Figure 5.3 Calculated and actual saving of zip codes of Standvast Wonen (Atriensis, 2010; Liander, 2015)

Table 5.6 Calculation for zip code 5638VA (Atriensis, 2010)

Gas price (euro/m^3)	0,67		Presented	Actual
Investment average dwelling (€)	7.389	Saving of average dwelling (€)	241	269
Rent increase (50%) (€)	126	Payback period (year)	31	27
		Saving - Rent increase (€)	115	143

Three zip codes of Standvast Wonen could be analyzed. The graph in figure 5.3 shows that the calculated energy consumptions before the retrofit are higher than the actual consumption before. This is the opposite of the prebound effect. The energy saving percentages of 6538VA and 6538VH are close to the actual energy saving percentages. For example, for zip code 6538VA a saving percentage of 28,7% is calculated and a saving percentage of 28,2% is reached. A rent increase of 50% is charged to the tenants. The saving of an average dwelling and the rent increase presented on the brochure for the tenants is lower than the calculation for this zip code. According to this calculation, the tenants of zip code 6538VA have saved more than was expected.

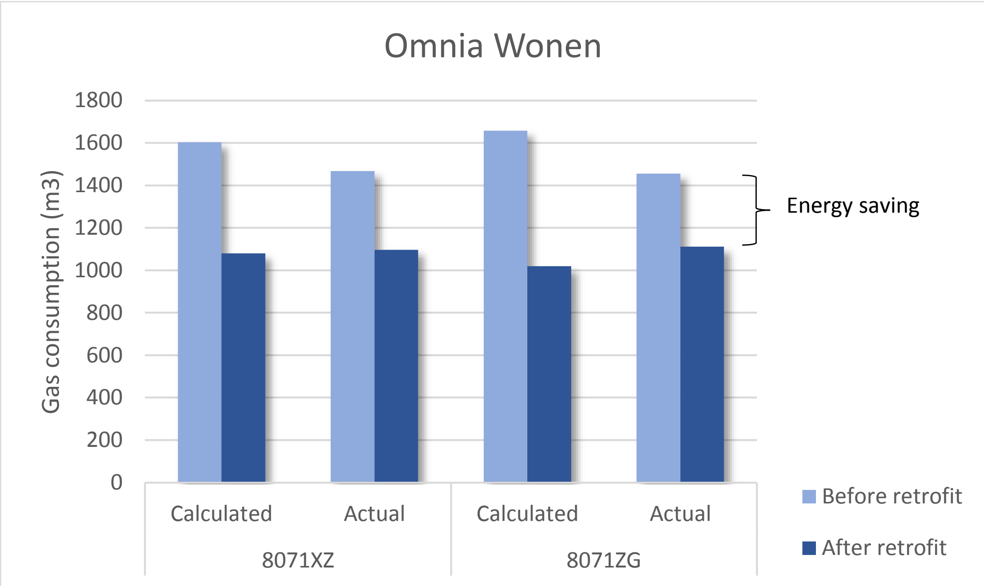

Figure 5.4: Calculated and actual saving of zip code 8071ZG (OW) (Atriensis, 2011b; Liander, 2015)

Table 5.7: Calculation for zip code 8071ZG (Atriensis, 2011b)

Gas price (euro/m^3)	0,72		Calculated	Actual
Investment average dwelling (€)	5.243	~~Saving of average dwelling~~	~~383~~	~~268~~
~~Rent increase (75%) (€)~~	~~287~~	2/3 saving of aver. dwelling	255	268
2/3 of rent increase (75%) (€)	191	Payback period (year)	14	20
		Saving – Rent increase (€)	96	79

Two zip codes of Omnia Wonen are analyzed. The calculated and actual energy consumptions differ before and after the retrofit. This leads to a smaller actual saving percentage than expected. Zip code 8071ZG of Omnia Wonen in figure 5.4 shows that a saving percentage of 35,9% is calculated, but a saving percentage of 23,6% is reached. A rent increase of 75% is charged to the tenants. The advice report mentions that before calculating the rent increase of 75%, the calculation energy savings are reduced with 1/3. This is decided based on the difference before the retrofit in calculated and actual energy consumptions (the prebound effect). This results in a saving of €79, which is close to the calculated €96. If there was no reduction made for the calculated energy saving, tenants of these zip code would have increased their living costs with €19.

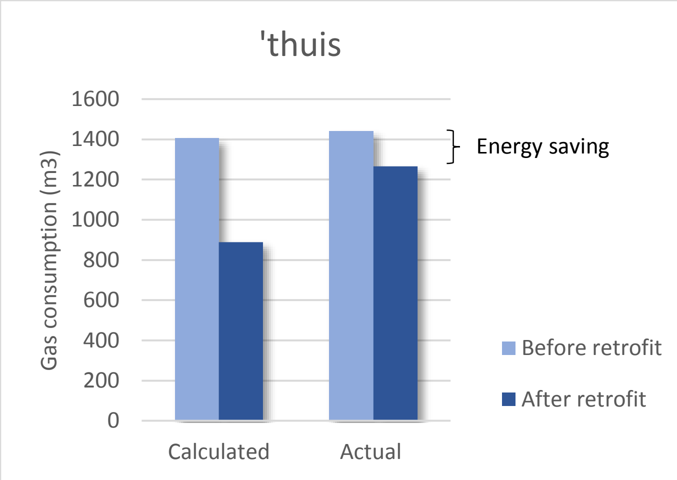

Figure 5.5: Calculated and actual savings of zip code 3417TD (Atriensis, 2011c; Endinet, 2015a)

The tenants of zip code 3417TD of housing association 'thuis saved 12,1% instead of the calculated 36,8% as illustrated in figure 5.5. According to the brochure, 'thuis charged a rent increase of maximum €175. This is almost half of the rent increase based on the calculation for this zip code, which is €343. It is unknown where this correction was based on, because figure 5.5 does not show the occurrence of a prebound effect. It is also not known which rent increase is charged to the tenants of this zip code, therefore there is no comparison for this housing association.

5.3.1 Calculated and actual energy consumptions

The tenants of Urbanus and Qua Wonen have reached on average the calculated energy consumption after the retrofit. However, the energy consumption before the retrofit is calculated higher than the actual average consumption before the retrofit. This results in a great difference in the energy saving percentage. The differences in calculated and actual energy saving percentages are shown in table 5.8. The percentages of OW and T are left out, because the energy saving was corrected and the tenants did not miss out as much as was calculated. The table shows that on average, for these zip codes, the tenants have missed out on 10,7% of energy saving.

Table 5.8: differences in calculated and actual energy saving percentages

Zip code	SW VA	SW VH	SW TX	QW VA	QW VE	QW VJ	U	Average
Calculated saving %	28,7	28,4	28	42,3	42,3	43	52,3	-
Actual saving %	28,2	22,7	14,3	27,7	29,2	33,7	34,6	-
Difference	0,5	5,7	13,7	14,6	13,1	9,3	17,7	10,7

The zip codes of Standvast Wonen in figure 5.3 show that the calculated energy consumptions before the retrofit are calculated lower than the actual energy consumption before the retrofit. This is the opposite effect compared to the other observed zip codes. Even though the calculated and actual consumptions do not match, the tenants of zip code 6538VA have reached the calculated energy savings (only on a different level). These tenants have, on average, saved as much energy as expected.

5.3.2 Rent increase and cost saving

Figure 5.1 and table 5.3 show that despite the mismatch in calculated and actual energy consumption before the retrofit, the tenants of zip code 2925VJ have an average saving cost per year of 232 euros. This is due to the low rent increase percentage of 16,67% that Qua Wonen charged at this retrofit.

The tenants of Omnia Wonen and ‘thuis received a rent increase of 75% of the savings, but both projects decided to correct the calculated energy saving. This probably “saved” these tenants from an increase in their living costs. Some tenants of Standvast Wonen have saved as much as was calculated, therefore the applied rent increase results in a costs saving of 50% of the calculated and reached energy savings. The tenants of Urbanus, shown in figure 5.3, received a rent increase of 50% of the calculated energy consumption savings. This results in an average energy saving costs per year of 9 euros, instead of the calculated 445 euros based on the calculated energy savings.

5.3.3 Payback period

The payback period is included in the tables, because it shows the effectiveness of the retrofit investment. It is calculated by dividing the investment cost for the average dwelling in the complex by the energy cost saving of the average dwelling. At a social housing retrofit, the payback period is a theoretical value. The investment for the retrofit is paid by the housing association, while the energy costs of their tenants decrease because of this retrofit. A part of the investment will flow back to the associations when a rent increase is applied, but this is not included in the shown payback period.

The payback period of Standvast Wonen is the only one that is actually lower than calculated. The payback periods of the other housing associations is shown to be higher than calculated. This means that the effect of the investment is lower than was expected. The actual payback period has increased, because the investment costs are the same, but the average energy costs saving is lower than calculated. For example, the payback period of this zip code of Urbanus (table 5.4 and 5.5) is twice as long as calculated.

5.3.4 Applied measures

Appendix A shows the applied measures and the improvement of the energy label of each retrofit project. The results show differences between the projects in the reached savings compared to the actual savings. These differences are partly caused by the applied measures and the label step, as discussed in chapter 3.

The most notable energy saving measure is the sun boiler applied at Standvast Wonen. This is a robust measure: it is little dependent on household behavior. Robust measures will result in energy saving and figure 5.3 shows that tenants of these zip codes have reached on average a high energy saving. Moreover, the label before retrofit was C, which means that the dwellings did not have a bad energy performance prior to the retrofit. The higher the energy label, the better the prediction of the actual energy consumption is (Daša Majcen et al., 2013). This explains the absence of the prebound effect in figure 5.3.

The other extreme example is the retrofit of Urbanus in figure 5.2. The dwellings had a bad energy performance of label F prior to the retrofit. Several robust measures were applied to reach energy label B. This figure illustrates the literature that states that a high energy label leads to a high prebound effect (Sunikka-blank & Galvin, 2012). The calculated energy saving before the retrofit is much higher than the actual energy saving.

5.4 Conclusion

The calculated and actual energy consumption before and after the retrofit of the projects are compared. Several criteria were used to make the comparison as reliable as possible. The research question *"How much on average do tenants miss out on energy savings after a thermal retrofit according to the analyzed projects?"* can be answered.

The analyses show that the majority of the researched zip codes has not reached the calculated saving percentage 3 years after the retrofit. Six of the ten diagrams show the effect of a higher calculated energy consumption before the retrofit. Thus, the prebound effect of Sunikka-blank & Galvin (2012) (explained in chapter 3) seem to have occurred in these zip codes. The theoretical consumption seem to differ more from the actual consumption when the dwellings have a high energy label. This effect also reflects the findings in the literature. The results show that this leads to a lower cost saving for the tenants than expected, because the calculation for the rent increase is based on saving energy that the tenants did not consume prior to the retrofit. It seems more worrying when the calculated savings are lower than the actual savings *after* the retrofit. These effects are less evident in the analyses. However, when there is a prebound effect, it also affects the outcome of the savings after the retrofit. After all, the saving potential is still present despite the higher starting point in the calculation.

Of the analyzed projects, 'thuis and Omnia Wonen have chosen to reduce the calculated energy saving before calculating the rent increase. This is applied to correct for the difference in calculated and actual consumptions. If this was not applied, the rent increase of both associations would have led to higher living costs for the tenants according to the calculations. Both associations used a rent increase percentage of 75%, which might be the reason for the careful interpretation of the calculated saving.

When a housing association considers a retrofit project, the costs and benefits are well considered. Every euro spend on a dwelling, is expected to be earned back in some way (here: partly by the tenants). It is of their concern to know how effective the applied measures have been. The results show that most of the analyzed zip codes have not reached the calculated energy savings. Therefore, the (theoretical) payback period is longer than expected. This is a signal to the housing association that the applied retrofit has a smaller effect than was expected.

According to these analyzed zip codes, the answer on the research question is that the tenants have missed out on average 10,7% of energy savings (table 5.8). This is at the lower side of the range of 10-30% found in the literature, but it is still a large deviation between calculated and actual energy saving. Because of the differences in rent increase, tenants have experienced this differently in their living costs. The percentage is partly caused by the prebound effect. Tenants cannot save what they did not consume before the retrofit. However, it is explained that when the calculation corrects the prebound effect, it will most likely results in a higher gap between calculated and energy saving after the retrofit. This effect is explained in chapter 3 and illustrated in figure 3.3 and 3.4.

As explained in chapter 3, this effect has potential to be reduced by different actions. The applied measures already explained some differences in the reached energy savings. The communication between the housing associations and the tenants can also play a role in reducing this gap. This will be examined in the next chapter, where the interviews with the project leaders are presented.

6. Current retrofit process

The methodology for deriving information about the current retrofit process is explained in paragraph 4.5.3. This chapter will explain the data collection and analysis, and the results from the interviews with the project leaders of the retrofit projects. This belongs to step 4b in the research design in figure 1.1.

6.1 Data collection

As shown in table 4.1, seven retrofit complexes from seven different housing associations are selected for this research. The project leaders of these projects were approached for an interview at their office. From all seven projects, the advice report from Atriensis was read first. Then the interviews were conducted and recorded at the office of the housing associations. Each interview took approximately one hour. The questions of the interviews are based on the missing information after the literature study.

6.2 Data analysis

The recorded interviews were typed out and structured according to the standard questions. When all interviews were conducted, an excel sheet was created of the answers in order to compare them with each other. Based on this document, comparisons and similarities were explored between the retrofit processes of the housing associations. The most important and relevant results are discussed in the next paragraph, divided in 5 subjects. The interviews will clarify the current retrofit process in the Dutch social housing sector. Comparing the literature to this retrofit process leads to the identification of the variables relevant to a social housing retrofit. These variables will be used as input for the tenants' questionnaire.

6.3 Results

6.3.1 Motivation for thermal retrofit

All housing associations have the same motivation for the thermal retrofit. When a complex needed major maintenance, Atriensis was given the task of identifying the possible improvements on the energy performance of complex. A complex is the term for a cluster of dwellings (mostly built in the same period) used by housing associations. Housing associations state in their policy that their housing stock will reach a certain energy performance, and therefore they need to retrofit complexes. Sometimes additional renovation was optional, for example tenants could also choose for a new kitchen or bathroom. The energy improvements of these complexes were also aimed at lowering the living costs of the tenants. A couple of years ago the prognosis was that the energy prices would rise extensively. This was a good reason for the associations to start these projects, and relatively easy to explain to the tenants why they should participate.

6.3.2 Participation of tenant

The associations differ in opinion about participation of the tenants. Of course, everyone strives for 100% participation. Some (3) have applied the `70% rule`; when 70% of the tenants agreed to the thermal retrofit, the association may execute it on the entire complex. Most of the associations (4) rather not use this rule. Although they also strive for maximum participation, it does not fit their policy to force tenants to participate in a project that includes a rent increase. Omnia Wonen had a special reason for this. Their complex had a great variation in energy labels, and therefore the rent increase per dwelling for this thermal retrofit would differ too. In that situation, it was not fair that tenants who receive a rather low rent increase could decide that other tenants also need to participate, when they will pay a much higher rent increase.

6.3.3 Communication before retrofit

Every association charged a rent increase, based on the calculated theoretical energy savings. Most associations charge 50% (4) or 75% (2) of the calculated energy savings as rent increase for the tenants. Qua Wonen charged 16,7% of the calculated energy savings to their tenants. Their argument is that applying such a low percentage, they can guarantee their tenants that their living costs will decrease despite the rent increase. In this way they do not need to worry about the effect of tenants' behavior on their energy consumption, despite the guarantee on the lower living cost.

The arguments for applying an individual rent increase or a collective rent increase differ per association. An individual rent increase means that every tenant receives a rent increase based on the properties of their own dwelling. A collective rent increase means that the housing associations calculates the rent increase based on the average calculated energy savings of the complex. Every tenant receives the same rent increase. Some associations argue that tenants want to pay for what they get, while other associations have experienced that it is hard to understand for a tenants why he pays more than its neighbor. At four of the studied retrofits the tenants received a personal rent increase. At the other three retrofits the average saving and rent increase of the complex was presented and charged to all tenants. It is remarkable that one association that charged an individual rent increase, added that they would not have done this again because of the difficulties experienced by explaining it to the tenants. Another association, who charged an average rent increase to everyone, applies an individual rent increase in their current projects. They did not experience the collective rent increase as fair towards the tenants.

All associations, except for Urbanus, have organized a collective meeting with the tenants as the first communication about the energy saving measures. Urbanus skips the collective meeting and immediately visits each tenants personally. They have bad experiences with the collective meetings; only a few tenants can set the mood for such a meeting, which is not convenient when they are against the retrofit.

An important subject of the collective meeting is the calculation of the rent increase. The time that is spent to explain this theoretical calculation differ per association. Some associations want their tenants to understand how this theoretical energy saving percentage needs to be interpreted. For example, they explain that the average dwelling and average household size (2,2 persons) does not exist, and therefore the presented energy saving percentage might not be reached by everyone. Some also mention the basic tricks on how to lower the energy consumption. This attention for household behavior is not always included in these presentations about the rent increase and energy savings. After the collective meeting, tenants receive the information in a brochure or letter, and they can decide before a certain date to participate or not. When a low percentage has agreed, calls or visitations are planned to convince the other tenants to participate. Some interviewees mentioned that tenants often have a negative perception of the housing association; therefore they put much effort in developing the strategy to convince the tenants to participate. Because of this the strategies to reach maximum participation are all quite standard and well conceived.

6.3.4 Communication after completion

There is little attention for the communication towards their tenants once the project is completed. The majority of the associations indicate that this is something that can and needs improvement, also because their tenants have indicated this. The bigger (longer, more impact) the size of the retrofit, the more tenants would appreciate a closure. Next to that, guidance is often needed for the new home, even when the tenants might not realize this. Some associations have experienced this, mostly about the ventilation and the heating, because insulating the dwelling means that a different approach of heating the dwelling is needed. Table 6.1 shows the information provided and strategies applied by the housing associations before and after the retrofit according to the interviewees.

Table 6.1: Applied communication and intervention strategies of each housing association

Housing association	Communication and intervention strategies
GroenWest (GW)	- Collective meeting (before) - Simple instructions for ventilation - No explanation about the influence of household behavior
Omnia Wonen (OW)	- Two collective meetings (before) - Extensive explanation about household energy behavior energy saving - Standard and simple instructions for energy systems - Standard energy saving tips - Explanation about the influence of household behavior
Qua Wonen (QW)	- Collective meeting (before) - Model dwelling (after participation) - Standard instructions for energy systems - No explanation about the influence of household behavior
Rhiant (R)	- Extensive brochure (before) - Collective meeting (before) - Minimal explanation about the influence of household behavior
Standvast Wonen (SW)	- Short brochure (before) - Collective meeting (before) - Standard instructions sun boiler and ventilation (after) - Standard energy saving tips (after) - Probably some explanation about the influence of household behavior
‘thuis (T)	- Extensive brochure (before) - Collective meeting at model dwelling (before) - Energy saving tips (before) - Tailored instructions for energy systems - Explanation about the influence of household behavior
Urbanus (U)	- Short brochure (before) - Technical and communicative employee visited the tenants (before) - No explanation about the influence of household behavior

Tenants of association ‘thuis reached several documents, including tailored instructions-tips (hints) for their dwelling. According to the project leader providing these documents is not standard for their thermal retrofits. It was applied in this project, because of previous projects where tenants did not use their ventilation properly. They admit that it would be useful to adapt this tailored document to all complexes that will be thermally retrofitted, but there is no time available for that. One retrofit included a sun boiler, which is an unknown system for the tenants. These tenants also only received the ‘standard’ instructions, delivered with the boiler. The association indicates that looking back, it would have been wise to write tailored and simple instructions for this system. They received complaints and there were problems with the system afterwards. At another association, the energy company placed ‘smart meters’ in the dwellings of the complex. This was not part of this thermal retrofit, however this did create some enthusiasm of some tenants, but after a while this disappeared. None of the associations have asked the tenants afterwards whether they reached the calculated energy savings. The majority has sent some sort of survey for feedback, but this was mostly about the retrofit process, send a few months after completion.

6.3.5 Helping tenants save energy

The project leaders were asked whether they thought helping tenants to save energy is a task for the housing association. Three project leaders answered yes, and four answered that it was a task, but not anymore. They had various reasons for their answers. The associations that answered no, have all tried certain energy saving programs a few years ago, which did not become a success by lack of motivation of the tenants.

Five associations recognize the opportunity to improve the communication and guidance after such a project. Urbanus sees opportunity in sending an energy consult a few months after completion, to help the tenants remember how to cope with their dwelling and how to keep their energy costs low. Others see opportunity in more personalized and simple instructions and possibly some tips for energy savings. They mentioned it might help against the rebound effect. It is in their interest if it helps tenants to maintain their low living costs. Groenwest mentions that it would be good to remind tenants of their influence on their energy costs, but they feel it is not an added value to combine this with a thermal retrofit. They have a few of these projects a year, so you would not reach that many tenants by only helping them after a thermal retrofit. ‘thuis is working with ‘Climate coaches’. These are tenants who followed a course on energy savings, and they visit neighborhoods to encourage people to save energy.

Almost all associations have tried energy saving programs in the past. Often mentioned programs are ‘Beter Peter’ and ‘Energieloket’, saving programs developed for residents by the government and additional parties. These were not successful for these associations and do not exist anymore. It made Rhiant and Qua Wonen state that housing associations should stick with their core business, and household behavior is not something they should interfere with. Tenants are not interested in that kind of information from the associations, which is what they have learned from these programs. They can help the tenants by making their dwelling more energy efficient, the rest is up to them.

6.3.6 Identification of variables for the discrete choice experiment

Chapter 2 has given insight in household energy behavior, and the existing intervention strategies to influence energy saving behavior. The interviews with project leaders of Dutch social housing retrofits have clarified the current process of these retrofits. There seems a potential for stimulating tenants to change their behavior after the retrofit, in order to reach more energy saving. Most of the interviewed housing associations do not monitor the energy consumptions of their retrofitted dwellings, so it is unknown whether these retrofits have reached the calculated energy saving.

Based on the previous chapters, the most promising intervention strategies for this situation will be explained. The theoretical energy saving behavior model for a social housing retrofit in figure 2.2 can be complemented with these strategies. These will be used as input for the tenant questionnaire as variables for the discrete choice experiment.

In order to increase knowledge, but also motivation, tenants must know something about the importance of reducing the overall energy consumption and reducing carbon dioxide emissions. It is often used as basis for other intervention strategies (Heijs, 2006; Martiskainen, 2008). The majority of the interviewees has organized a collective meeting before the retrofit where it is briefly explained why they need to improve their housing stock. Therefore, for this research it will be assumed that general information about the importance of reducing the energy consumption is already given to the tenants before the retrofit.

According to the literature, there is often no clarity about the usage and maintenance of applied energy systems in the dwelling (Groot et al., 2008). The standard instructions are too complex to understand for the average resident, so it is suggested to give simple instructions, adjusted to the knowledge level of the resident. This will increase the comfort and it helps them to save energy, because the correct use is the most energy efficient use of the system (Breukers et al., 2014). This is very relevant in the context of a thermal retrofit in the social housing sector. The majority of the interviewed project leaders have handed their tenants instructions about the energy systems at the retrofit, some were standard and some tailored. It is also possible to give the tenants instructions by sending an energy specialist to the households. This has the advantage that tenants can ask questions and thus it has an interactive aspect. Especially as the size of the retrofit increases, knowledge on the new energy systems is required in order to reach energy saving behavior. Therefore, instruction for energy systems is one intervention strategy that is selected for this context.

The literature about household energy consumption has showed that it is hard to predict, and behavioral aspects are difficult to consider in this calculation. Literature has also shown that the calculated savings are often larger than the actual savings (Bartiaux & Gram-Hanssen, 2005). The energy analyses of these retrofits have shown that these differences still exist in the Dutch retrofit projects. This can be used in a positive way by using intervention strategies reward and commitment with goal setting. It can be emphasized that this calculated energy savings is not reached by only the retrofit, but behavioral changes are needed from the tenants. Tenants can be convinced to save energy by committing to an energy saving goal, for example this theoretical energy savings. They can also be promised a reward when this goal is reached. Especially because the interviews learned that tenants receive a rent increase as a percentage of the calculated energy savings after the thermal retrofit. It is charged after the retrofit, while tenants will not notice the decrease in energy costs until the next billing. Therefore, this rent increase may function as awareness and trigger for saving money by saving energy. When a reward or commitment to a goal is used as an intervention strategy, tenants may feel that they do save money by adopting energy saving behavior.

As mentioned before, there is often at least one collective meeting where the housing associations inform the neighbors about the retrofit plan. Such a meeting can bring the neighbors closer to each other, if the atmosphere of the meeting is positive. It can therefore be an opportunity for intervention strategies that require social norms (Breukers et al., 2014). Collective strategies such as comparative feedback or collective commitment to a goal have potential of succeeding in this context. Comparative feedback allows tenants to compare their energy consumption to the neighborhood in order to motivate each other to save more energy. A collective commitment means that the neighbors together commit to a certain goal and motivate each other to reach this goal together.

Some intervention strategies need a clear starting point, for example feedback, commitment to a goal and reward need some explanation and rules before starting. Depending on the social characteristics of the neighborhood, commitment and feedback strategies can be applied on the household level or together with the neighborhood. The retrofit suits as a starting point for energy saving intervention strategies. The association can also give tenants an energy saving box with free products (e.g. shower timer, power killer) that can help them to start applying new energy saving behaviors. It can positively influence the attitude towards saving energy (and towards the association), and it can influence the creation of new routines by using the products.

Some combinations of interventions have been more effective in realizing energy savings in households, than presenting these interventions on their own. These interventions 'interact' with each other; residents respond more positively (or negatively) on the combination of two interventions, than they would on the individual intervention strategy (Abrahamse et al., 2005). It is easier to commit to a goal, when a reward is promised when reaching this goal. Feedback is also very easy and more effective to combine with other strategies. Next to reward and commitment with goal setting (Abrahamse et al., 2007), Heijs (2006) mentions that including a prediction of the amount of energy savings will increase the effect of feedback. Since the interviewees all showed their tenants the calculated energy savings, feedback can be a promising intervention strategy after a retrofit.

The mentioned intervention strategies suitable in this context are now added to the theoretical energy saving behavior model. The adjusted model is shown in figure 6.1.

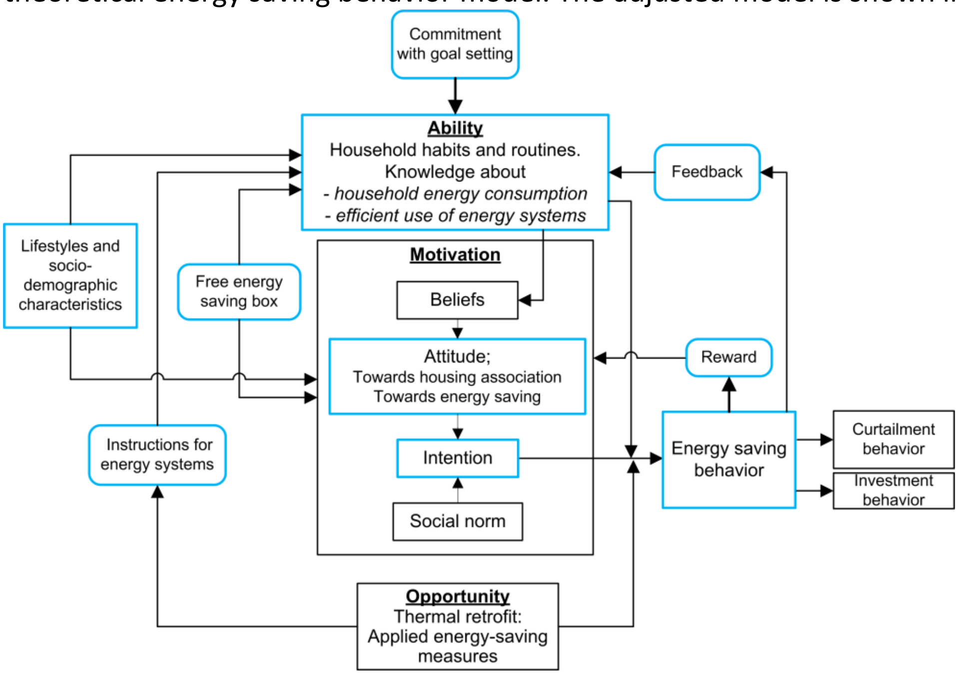

Figure 6.1: The energy saving model for this research: the context of a social housing retrofit

This model captures the intervention strategies that seem most promising to help tenants save energy after a thermal retrofit. The model shows which micro level factor can be influenced by which intervention strategy. The instructions of the dwelling will depend on the applied energy-saving measures, and it will increase tenants' knowledge. Giving the tenants a free energy saving box can both influence the motivation and the ability of the tenants. It can influence the habitual behavior (for example with a shower timer), and it can influence the attitude towards energy saving behavior. Commitment to a saving goal can influence tenants' intention to adapt an energy saving behavior, and their attitude and social norms towards energy saving behavior. Receiving feedback on a certain behavior will increase knowledge about it, and can change certain routines in the household, if a saving effect is noticed from a new behavior. Receiving a reward from an energy saving goal can lead to a positive attitude towards energy saving behavior.

Some variables or aspects of a variable from this theoretical model will be tested by the questionnaire for tenants that are living in an energy improved dwelling. These are indicated in blue in figure 6.1. The preferences of the tenants towards the intervention strategies will be tested. The socio-demographic characteristics of the tenants are included in the questionnaire, to test the representation of the respondent group. Some of the aspects of the micro level factors will be included in the questionnaire. The knowledge of the tenants about their own energy consumption will tested as well as the attitude and intention towards the participation in the retrofit is tested. Several energy saving behaviors after the retrofit are tested in the questionnaire. The effects that the intervention strategies have on the micro level factors cannot be tested by a questionnaire, so the arrows are only based on the literature. In the next chapter, the variables, methodology, data analysis and results of the tenant questionnaire are explained.

6.4 Conclusion

The question to be answered in this chapter is: *What is the current process for thermal retrofits in the social housing sector and is there space for intervention strategies after these projects, aimed at behavioral change?* The current process for a thermal retrofit of housing association complexes, as learned from these 7 interviews, can be summarized as follows.

Almost all of the communication towards the tenants is aimed at convincing them to participate in the project. Therefore almost all communication is centered before the retrofit. After some years of experience in organizing retrofits, this communication seems optimized and results in acceptable scores in terms of tenant participation and satisfaction. The most difficult part about convincing the tenants is the rent increase. Most associations cannot execute a retrofit without charging a rent increase. They base this rent increase on the calculated energy saving. This can be based on the individual calculation or the average calculation of the energy saving, where everyone pays the same rent increase. The opinions differ about which method is most fair and clear for the tenants.

Communication after the completion of the project is far from a priority for all associations. The project where most effort was put in the communication afterwards, claimed that this was not usual for retrofits. However, the majority agrees that more communication after completion would be useful and wished by tenants. Instructions for the dwelling and the systems seem useful by everyone, but not all associations think other energy saving strategies are necessary.

Except for the sun boilers placed at the complex of Standvast Wonen, the studied retrofits did not include very advanced energy systems. Tailored instruction will become more important when more complicated systems such as PV panels, heat pumps and other innovative systems are installed as part of a thermal retrofit. This will probably occur more in the future, when a higher energy index will be required and the 'basic' measures are already applied.

Based on these interviews there can be concluded that there is space for the associations to influence tenants' behavior after a thermal retrofit. Not every association sees the importance of aiming specifically at energy saving measures, but helping tenants with the usage of their dwelling and new systems is recognized as a positive addition to the communication towards tenants. From the information out of these interviews together with the literature about energy behavior, the variables that are important for this context are identified and illustrated in an energy saving model in figure 6.1. Five intervention strategies are most promising in this situation, to influence the motivation and ability of the tenants. Some of the variables from the model will be tested in the next phase for the field research: the tenant questionnaire.

7. Tenant questionnaire

Paragraph 4.5.3 explained the methodology for the tenant questionnaire as part 5c of the research design in figure 1.1. The previous chapter resulted in the identification of the important variables for energy saving behavior in the context of a thermal retrofit. This chapter will operationalize the variables that will be tested in the questionnaire. Next, the data collection and analysis is explained. Last, the questionnaire results are presented.

7.1 Questionnaire design

As a result of the project leader interview combined with the literature, the questionnaire variables are identified in paragraph 6.3.6. They are visualized in the model in figure 6.1. As indicated in blue, (parts of) the following variables in figure 6.1 will be examined in the questionnaire:

- Socio demographic factors;
- Motivation;
- Knowledge;
- Preference towards intervention strategies;
- Energy saving behavior.

The purpose of these different variables need to be explained and then translated into measurable questions, to make sure that the output of the questionnaire matches the purpose of the questions. Variables can be ‘simple’, which means that by asking one question it is measured what is required. There are also ‘complex’ variables, where multiple questions are needed to measure the variable (Adrians, 2010). In appendix C, the operationalization scheme of all variables is presented. It contains the variables, the topics that it belongs to, the question that results in the right data, and the measurement level of the question.

The answer of the first and last part of the questionnaire were analyzed using SPSS. This is a statistical program and is often used for analyzing data.

7.1.1 Socio demographic factors

The socio demographic are included in the questionnaire to test if the respondents represent the target group. They can be operationalized as ‘simple’ variables. The measurement level was chosen carefully. For example, the household income was asked on an ordinal scale, instead of ratio. Writing down the income is often a greater barrier than choosing from a range.

7.1.2 Motivation

A micro level factor that will be measured in the questionnaire is motivation of participating in the retrofit. The main motivations for participating in a retrofit as mentioned in the literature are comfort, cost saving and the environment. These will be asked to the tenants using the Analytical Hierarchy Process. This decision support tool is developed by Saaty and it determines the relative importance of a set of criteria using pair-wise comparison (Saaty, 1987). This will give insight in the weighing of tenants’ decision. Figure 7.1 shows the question. The purpose for this question is to derive the most important motivation of this respondent group. Intervention strategies can be selected that trigger this motivation.

12. What is your most important motivation for participating in the thermal retrofit?						
a. Primarily for the cost saving	O	O	O	O	O	Primarily for the environment
b. Primarily for the cost saving	O	O	O	O	O	Primarily for the comfort
c. Primarily for the environment	O	O	O	O	O	Primarily for the comfort

Figure 7.1: Question about motivation for participation in the thermal retrofit

7.1.3 Knowledge

The energy-related knowledge of the tenants is measured by a question about their energy consumption. Before the start of the retrofit, all tenants received a theoretical energy saving. Their knowledge about their own energy consumption is tested by asking them if this energy saving was reached in their own household. This will be asked by a multiple choice question. The purpose of this question is to compare tenants' knowledge of the different retrofit projects with each other. The differences can be explained by the different approaches of each of the housing associations.

In order to make this question more reliable, two questions about change of situation are included in the questionnaire. Tenants are asked whether they invested in energy appliances and in changed to the dwellings after the retrofit. These changes can have influence on the energy consumption, and in this way the tenants that invested can be excluded from the energy saving knowledge.

7.1.4 Energy saving behavior

From the interviews with the project leaders of the retrofits, the communication process of each retrofit is known. Whether this communication might have led to changes in certain household behaviors can be derived from the questionnaire. A change in behavior can be measured by asking about performing several energy-related household routines, before and after the retrofit. One of the used questions is shown in figure 7.2.

1. How often do you use the windows in the living room for ventilation?	
Before the retrofit	*After the retrofit*
1) Always	1) Always
2) Almost always	2) Almost always
3) Sometimes	3) Sometimes
4) Rarely	4) Rarely
5) Never	5) Never
6) Not applicable	6) Not applicable

Figure 7.2: Question about an energy saving behavior

As found in the literature, energy saving behavior can be divided in curtailment behavior and investment behavior. This research mainly focuses on curtailment behavior related to the household energy consumption, but investment behavior is also included as part of energy saving behavior. Curtailment behavior is measured by questions about the settings and use of the thermostat, ventilation and shower. Asking the same question for the situation before and after the thermal retrofit will make clear whether tenants have adapted some of their behaviors after the retrofit.

The preference of tenants toward intervention strategies is tested in two ways in this research. First, the satisfaction about the received information about the dwelling and rent increase is asked. Second, because tenants did not receive those intervention strategies that are found in the literature, a discrete choice experiment is applied to find the preferences towards all strategies, after including information about the possible strategies.

7.1.5 Satisfaction

The questionnaire also includes questions about the satisfaction about the quality of the received information, specified with regard to the process and the rent increase based on the energy saving. This can also be compared to the information given by the housing association to the tenants.

7.1.6 Preferences of intervention strategies

The intervention strategies which are most promising in this situation for the tenants to reduce their energy consumption are chosen to be the attributes for the discrete choice experiment. These are the intervention strategies identified in paragraph 6.3.6 and illustrated in figure 6.1:

- Feedback
- Commitment with goal setting
- Instructions for energy systems
- Reward
- Free energy saving box

Feedback

Two kinds of feedback have been chosen as most promising at a retrofit. One kind of feedback is continuous feedback. A display will be installed in the dwelling, where different kind of information can be presented on this display such as the overall consumption in kWh or in euros. Tenants can check this display whenever they want, it gives continuous information about their energy consumption. The other option is comparative feedback, between their household and the whole neighborhood. In the questionnaire, 'continuous' is changed to 'individual', to make the distinction more clear to the tenants.

Commitment with goal setting

Commitment with goal setting can occur at the individual level: the goal is set by the residents themselves and for themselves. The other option is to set a goal at the collective level: the retrofitted neighborhood commits to a goal that is determined collectively, and they commit to it together. To make it easier to understand for the respondents, this variable is renamed into 'energy saving-goal'.

Instructions for energy systems

The instructions for energy systems can be written, in a flyer or brochure specifically made for the thermal retrofit, or it can be communicated personally, by an energy specialist or someone from the housing association.

Reward

A reward can be promised to tenants when they achieve the calculated energy saving presented at the retrofit. In this experiment, there are no different levels of reward used because the calculated energy saving percentage differs per complex.

Free energy saving box

Depending on the applied energy saving measures in the retrofitted dwelling, tenants will be handed an energy saving box to stimulate their energy saving behavior. To make it easier to understand for the respondents, this variable is renamed into ‘energy saving-kit’.

Each choice can contain a different number of attributes. Thus, three of the attributes consist of 3 levels, and two only 2 levels. This is shown in an overview in table 7.1.

Table 7.1: attributes and corresponding levels in the discrete choice experiment

	Attributes	Levels
1	Feedback	- Individual - Compared to the neighborhood - Not included
2	Energy saving-goal	- Individual - Together with the neighborhood - Not included
3	Reward	- Included - Not included
4	Instructions for energy systems	- Brochure - Energy expert - Not included
5	Energy saving box	- Included - Not included

Composition rule

In this choice-based experiment, all main effects of the attributes will be measured. There are also some 'interactions’ of interventions that will be measured, as some interventions seem more effective when combined with each other than on its own (Abrahamse et al., 2007). This effect can be measured in the experiment and is called the first-order interaction effect. As mentioned in paragraph 6.3.6, ‘feedback’ combined with ‘energy saving goal’, ‘feedback’ combined with ‘reward’ and ‘energy saving-goal’ combined with ‘reward’ are the most promising combinations. These interactions are shown in table 7.2. The other possible interactions between attributes are less promising or even not studied, and therefore are assumed negligible in this experiment.

Table 7.2: Interaction effects that will be measured in the experiment

Interaction effects between attributes	
1 Feedback	2 Energy saving-goal
1 Feedback	3 Reward
2 Energy saving-goal	3 Reward

A standard discrete choice design is shown as a table, presenting two profiles to the respondents and a third ‘none’ option. Each of the used attributes and levels are explained on the page prior to the experiment. A standard question design for the discrete choice experiment is a table with the included levels in each profile. However, this was found to be unclear and difficult by the test respondents. Therefore another lay-out is used. The profiles are defines as sentences, describing the situation. This makes it easier to read, than a table with abstract words. Figure 7.3 shows the example question used in the questionnaire:

Example question: Which approach would convince you the most to save more energy?

a) You receive an energy saving-kit and you can compare your energy consumption to that from the neighborhood.
b) You agree upon an energy saving-goal with your family (household) and an energy expert visits your home to explain about the efficient use of your dwelling.
c) Neither

Figure 7.3: Example question from the questionnaire

3 of the 5 attributes include 3 levels and 2 include 2 levels. There are 3 first-order interactions that need to be included in the design of the experiment. The full factorial design contains all these interactions. The number of combinations in the full factorial design is defined by "$\text{attributes}^{\text{levels}}$" . For this experiment this means that there are 3^3 x 2^2 108 possible combinations that respondents need to evaluate. This is a too large amount to present to the respondents. Research have showed that respondents are able to complete up to 30 choice tasks, but after that point the quality of the data may come into question (Hair, Black, Babin, & Anderson, 2007). This questionnaire will include more questions than only the discrete experiment, thus the choice tasks must stay at a reasonable amount. The amount of profiles can be reduced into a subset. This must be done in a manner to preserve the orthogonality (no correlation among levels of an attribute) and balanced design aspect (each level in a factor appears the same number of times). A fractional factorial design is a suited way to create a subset (Hair et al., 2007). To construct the design, the catalog of experimental plans of (Hahn & Shapiro, 1966) is used. For an experiment with 5 attributes that consist of two 2-level and three 3-level attributes, a subset of 27 profiles is required. These profiles can be found in appendix E. 14 random choice sets can be constructed from these profiles, where respondents can choose between two profiles or the 'no-choice' option. There are 4 different designs of 14 choice-sets distributed among the tenants, to increase the reliability of the experiment.

7.1.7 Final design

The questionnaire was divided in three parts. The first part contained the energy saving behavior questions, the motivation and knowledge questions and the satisfaction about the received information and strategies. The second part was the discrete choice experiment and the third part contained the socio demographic questions.

The questionnaire was designed as an offline paper version. This was chosen instead of an online version, because not all e-mail addresses of the respondents were not known. Moreover, it was expected that a substantial part of the tenants were elderly and not own a computer. The complete questionnaire is shown in appendix E. The questionnaire took approximately 15 minutes to fill in. It was decided that for a higher response it might be better to also create an online version of the questionnaire. The Berg Enquête System[1] was used for this design. A link to this questionnaire was included in the guiding letter. It can be recognized by the questionnaire which housing association each respondent belong to, in order to compare the differences between the housing associations for several questions.

7.2 Data collection

The questionnaire was send by post to the tenants of the retrofit projects in table 4.1 and additional projects, shown in appendix F. The guiding letter included a link to the online version of the questionnaire and was send on behalf of the TU/e and myself. The majority of

[1] https://vragen20.ddss.nl/intro/contact

the associations gave permission to include their logo in the letter. This was meant to enlarge the willingness to respond. One of the associations have send the questionnaire on behalf of themselves and send the completed questionnaires back to me.
The questionnaire was distributed to 934 tenants in week 51 of 2015, and a reminder was send by e-mail in week 2 of 2016. Not all housing associations approved to send this reminder, and not all e-mail addresses are known. Therefore the reminder did not reach the whole group of tenants.

141 tenants filled in the questionnaire: 10 online and 137 on paper. A response rate of 15,7% is reached. The response of each housing association is included in appendix F. Table 7.3 shows the respondents for each of the three parts of the questionnaire. The 14 tenants that did not complete part 1 did not live in their dwelling when the renovation was executed. The response percentage could probably be higher, if the reminder was send to all tenants instead of the tenants with e-mail addresses. The time of the year and the length of the questionnaire can also be explanations for the response rate.

Table 7.3 Sample group

	Written	Online	Total	%
Finished total	137	10	147	15,7
Completed part 1	122	8	130	13,9
Completed part 2	49	6	55	5,9
Completed part 3	132	10	142	15,2

Table 7.4: Response of the choice experiment

Sample	Included	Excluded	% Included
1	14	22	38,9
2	16	22	42,1
3	12	14	46,2
4	8	19	29,6

For the analysis of part 2 it was defined that respondents who answered 10 times or less the same option in the discrete choice experiment are included in the analysis. This resulted in 55 respondents that could be included in the analysis of part 2. This is a remarkable low number of respondents. Many respondents skipped part 2, the discrete choice experiment in the questionnaire and others choose the same option (mainly c) too consistent. As explained in the previous paragraph, the 27 profiles were distributed in the questionnaires in 4 random choice sets of 14 questions. The percentage of completed and consistent results of each of these 4 samples was compared in table 7.4, to find out whether one of these samples contained too difficult choice sets. The percentages indicates that sample 4 included some difficult choice sets. This sample includes some questions where the two options include almost the same variable and that might have hold back some respondents. Figure 7.4 shows an example of a choice set from sample 4, where the options might have been too similar.
Some respondents indicated that they did not need energy saving interventions, because they already lived energy efficient.

9. Which approach would convince you the most to save more energy?

a. You agree upon an energy saving-goal with the neighborhood. You can get insight in your energy consumption by a display or app and you receive an energy-saving kit. When you reach the saving goal, you get a reward.
b. You agree upon an energy saving-goal with the neighborhood. You can get insight in your energy consumption by a display or app. An energy expert visits your home to explain about the efficient use of your dwelling and you receive an energy-saving kit. When you reach the saving goal, you get a reward.
c. Neither

Figure 7.4: Question from questionnaire-sample 4 with almost similar options

7.3 Data analysis

7.3.1 Socio demographic factors

The questions about the socio demographic factors are analyzed using SPSS. This is a statistical program and is often used for analyzing data. The characteristics of the total social housing sector are calculated back to the number of respondents in the questionnaire. The chi square goodness of fit test is used to determine whether the distribution of the respondents follows the known distribution of the target group (Dutch social housing tenants) (Laerd statistics, 2013). The chi square is calculated by equation 7.1.

$$\chi^2 = \sum \frac{(O-E)^2}{E} \qquad (7.1)$$

χ^2 = Chi square
O = observed frequencies (respondents)
E = expected frequencies (social housing sector)

The null hypothesis is that the respondents' characteristics are equally divided as the characteristics of the Dutch social housing sector. When the p-value of the chi square test is <0.05, at an alpha of 0.05 the null hypothesis is rejected (Montgomery & Runger, 2011). A chi square value of 0 means that the respondent group is identically distributed as the target group.

7.3.2 Motivation factors

The AHP method is used to analyze the motivation of participating in the retrofit. First, the inconsistent answers will be excluded from the analysis. Then, the answers of all respondents together are recoded into a reciprocal matrix using Excel and this will lead to a priority vector for each motivation (Saaty, 1987).

7.3.3 Knowledge

The tenants knowledge is asked by a multiple choice question and this will be analyzed by SPSS, by counting the answers and display it in a graph. This question will be analyzed for all respondents together and for each housing association separately. The respondents that made investments that might have led to a change in energy consumption are excluded from this analysis. The results of each housing association can be compared with each other and explained by the approach of the housing association retrieved from the interviews.

7.3.4 Behavioral change

The before and after questions about the household behavior will also be analyzed in SPSS. The analyses of these questions will be performed with the paired t-test. Only the answers that are on the same scale can be used. At several questions, the respondents could choose for option 6: "not applicable". Respondents who answered this were excluded from that question, because this option does not have the same scale as the other options. This also accounts for the option "I don't" in the first question. All questions can be viewed in the questionnaire shown in appendix E. The test analyzes the differences between the answers before and after the retrofit. When the mean of the differences is zero, there is no difference in behavior. This test assumes that the differences are approximately normally distributed

(Montgomery & Runger, 2011). The results will be analyzed for all respondents and for each housing association separately.

7.3.5 Satisfaction

The satisfaction about the received information is asked on a 5-point scale and the results will be compared of each housing association. The results will be shown as a boxplot, in order to see the variance in the satisfaction.

7.3.6 Discrete choice experiment

The results of the discrete choice experiment will be analyzed in order to find the respondents' preferences for the presented and explained energy saving interventions after the retrofit. The analysis will be done in NLOGIT. This statistical program is specialized in choice experiments. The output will be analyzed using the following methods.

Random Utility Theory

In order to analyze the data of discrete choice experiment, the random utility theory is often used to find the probability that individuals choose a certain alternative. It is represented by equation (4.5). The utility is formed by an observed and an unobserved component:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \qquad (7.2)$$

U_{ni} = The utility that decision maker *n* will derive from 'choosing/receiving' alternative *i.*
V_{ni} = the observed component
ε_{ni} = the unobserved component, the "error" component

This theory uses the assumption that decision maker *n* will choose alternative *i* if and only if $U_{ni} \geq U_{nj}$ for all $j \neq i$ (Train, 2002). In this research, the utilities are not calculated at the individual level, therefore the "n" in the formula will be left out. Each alternative is based on a different combination of attributes and their levels. Therefore, the observed component (V_i) of the utility for an alternative is the summation of the utilities of the attributes. The observed component of the utility associated with alternative *i*, V_i, is typically defined as a function of *k* variables, x_{ik}, with associated preference weights, such that:

$$V_i = \beta x_{ik} \qquad (7.3)$$

V_i = the observed component
X_{ik} = vector of k attributes describing alternative i
β = the weight (or parameter) associated with attribute x_{ik}

Effect coding

The vector of the attribute describing attribute 1 (feedback), 2 (commitment) and 4 (instructions) needs to represent 3 levels. In order to make a functioning utility equation, these attributes need to be recoded into 2 (number of levels – 1) variables using effect coding. The recoding of the attributes is represented in table 7.5, 7.6 and 7.7.

Table 7.5: Effect coding for variable Feedback

Attribute level \ Variable	Feedb1	Feedb2
Individual	1	0
Comparative	0	1
Not included	-1	-1

Table 7.6: Effect coding for variable Commitment

Attribute level \ Variable	Comm1	Comm2
Individual	1	0
Neighborhood	0	1
Not included	-1	-1

Table 7.7 Effect coding for variable Instructions

Attribute level \ Variable	Instr1	Instr2
Brochure	1	0
Energy specialist	0	1
Not included	-1	-1

For the attributes reward and energy saving box, there are only two levels, -1 means 'not included' and 1 means 'included'. Now that the attributes are recoded, the formula for the utility of a certain profile in this analysis is expressed as follows:

$$U_i = \beta_0 + \beta_{feedb1}x_{feedb1} + \beta_{feedb2}x_{feedb2} + \beta_{comm1}x_{comm2} + \beta_{comm2}x_{comm2} + \beta_{rew}x_{rew} + \beta_{instr1}x_{instr2} + \beta_{box}x_{box} + \beta_{12}x_{feedb}\,x_{comm} + \beta_{13}x_{feedb}x_{rew} + \beta_{23}x_{comm}x_{rew} + \varepsilon \qquad (7.4)$$

U_i = The utility is derived from 'choosing/receiving' alternative *i*.
β_0 = a parameter not associated with any of the observed and measured attributes
ε = the unobserved component, the "error" component

The β coefficients represent the weights of the attributes (x_i) in table 7.1 and the weight of the interaction effects (x_ix_i) between the attributes in table 7.2. A positive β means that the attribute has a positive influence when the respondents make a choice, a negative β means a dislike towards this attribute on the choices made. Because the use of effect coding, the results will contain only two of the three levels and one of the two levels of the attributes. As mentioned before, the values of the levels are equal to 0 per attribute. Therefore the missing value can be calculated and the results must be interpreted relative to the other level (Hensher, Rose, & Greene, 2015). In order to say something about the importance of the attributes, the relative importance of the attributes can be calculated. This is done by adding up the absolute difference of the highest and lowest part worth value for each attribute, and then relatively compare them, so that an importance in percentages is presented (Spank, 2013).

Goodness of fit

In order to see if the model is predicting the values better than the null model, the goodness of fit is calculated. The R-squared value and the likelihood value indicate the goodness of fit of the model. The R-square is a value between 0 and 1. A good predicting model has a value around 0,2. It is calculated with the following equation (Hensher et al., 2015):

$$R^2 = 1 - \frac{LL_{estimated\ model}}{LL_0} \qquad (7.5)$$

Multinomial logit model

The multinomial logit model is the most widely applied model in discrete choice analysis to predict the probability that a choice alternative will be chosen, based on the independent variables. In this research, the 'importance' of the attributes will be derived using this equation on the data from the questionnaires. It is shown in equation 4.9 (Train, 2002).

$$P(i\backslash A) = \frac{e^{V_i}}{\sum_{j\in A} e^{V_j}} \qquad (7.6)$$

P(i\ A) = probability that alternative *i* is chosen from choice set *A*;
Vi = structural utility of alternative *i*;
$\sum_{j\in A} e^{V_j}$ = the sum of the structural utilities of alternative *j* in choice set *A*

In this choice experiment, choice set A contains 3 choices. Every respondent will see 14 choice sets, and make 14 choices. Calculating the probability for each of the choice sets results in the utilities of the attributes.

7.4 Questionnaire results

The questionnaire results are analyzed for all respondents together. Some results are more interesting when comparing the respondents of the different housing associations with each other. The different approaches of the housing associations at the retrofits as shown in table 6.1 are used to find explanations for differences between the respondents of the housing associations. The results will be discussed using the abbreviations of the housing associations as indicated in table 6.1.

7.4.1 Socio demographic factors

The socio demographic characteristics of the respondents were analyzed with the chi square goodness of fit test in table 7.8, in order to see if they represent the target group: tenants of the social housing sector. Because of the difference in response size, the socio demographic characteristics of the discrete choice respondents are also tested with the chi square test. These results are shown in table 7.9. The "O" is the observed value: the respondents of the questionnaire. The "E" is the expected value: the characteristics of the social housing sector from Aedes that are calculated back to the number of respondents of this questionnaire (Aedes, 2012).

Table 7.8: Social demographic characteristics of all respondents

Characteristics	%	O	E	$(O-E)^2$ / E	Chi square
Age (years) n = 140					
0-45	7,9	11	44	25,2	χ^2 = 36.9 df = 2 p value = 0.000
45-65	45,7	64	48	5,1	
65+	46,4	65	47	6,6	
Household composition n = 140					
One person	32,1	45	69	8	χ^2 = 39,9 df = 3 p value = 0.000
1 adult with child(ren)	12,9	18	17	0,1	
2 adults with child(ren)	8,6	12	20	3,2	
2 adults no children	46,4	65	34	28,3	
Household income (netto/month) n = 106					
Less than €1500	39,6	42	27	9,0	χ^2 = 21.9 df = 2 p value = 0.000
€1500 - €2500	49,1	52	47	0,5	
€2.500 - €3.500	11,3	12	32	12,5	

Table 7.8 shows that for these characteristics all p values are <0,05. This means that the null hypothesis that the distribution of the respondents follows the known distribution of the target group is rejected. It means that for the age, household composition and household income the respondents are not representative for the target group. The higher the value of χ^2, the less representative the distribution is. The $\frac{(O-E)^2}{E}$ column shows how each category contributes to the chi square. The higher this value, the worse the representation. This shows that the age group 25-45 years is underrepresented and the ages from 45 and older are slightly overrepresented. The household composition '2 adults no children' is overrepresented. The low income group is overrepresented and the high income group is underrepresented.

The chi square test of the discrete choice respondents in table 7.9 shows that they represent the target group better than the total respondents: the chi square values are closer to zero and the p value is closer to 0,05. It is however still not representing the target group. The age group 45-65 is still overrepresented, while the 65+ category is better represented. The household composition and income situation are similar to the total respondent characteristics, but less extreme.

Table 7.9: Social demographic characteristics of the Discrete Choice respondents

Characteristics	%	O	E	$(O-E)^2 / E$	Chi square
Age (years) n = 55					χ^2 = 21.4 df =2 p value = 0.000
0-45	12,7	7	18	6,3	
45-65	63,6	35	19	13,6	
65+	23,6	13	19	1,7	
Household composition n = 55					χ^2 = 12,0 df = 3 p value = 0.007
One person	29,1	16	27	4,6	
1 adult with child(ren)	18,1	10	7	1,7	
2 adults with	12,7	7	8	0,1	
2 adults no children	40,0	22	13	5,6	
Household income (netto/month) n = 43					χ^2 = 8.6 df = 2 p value = 0.014
Less than €1500	41,9	18	11	4,9	
€1500 - €2500	44,2	19	19	0,0	
More than €2.500	10,9	6	13	3,8	

Based on the results in table 7.8 and 7.9, the results of the questionnaire should be interpreted carefully. The conclusions based on this questionnaire will be partly aimed at the older tenant segment.

A comparison with the target group could not be made for all socio demographic characteristics that were included in the questionnaire. The percentages and counts of the other characteristics are shown in table 7.10 for all respondents and 7.11 for the discrete choice respondents.

The average age of all respondents is 63 years. The average age of the discrete choice respondents is 57. The percentage retired respondents is very high for all respondents, but in the discrete choice experiment a lower percentage is retired and a higher percentage is working more than 12 hours a week.

Table 7.10: characteristics all respondents

Education level (n=138)	%	N
None	2,2	3
Primary school	10,9	15
Lower secondary school	23,9	33
Higher secondary school	3,6	5
Lower vocational	11,6	16
Secondary vocational	29,7	41
Higher vocational/University	18,1	25
Working situation (n=154)	**%**	**N**
Job <12 hours	1,3	2
Job ≥12 hours	26,6	41
Entrepreneur	4,5	7
House wife/man	9,1	14
Unemployed	6,5	10
(partly) disabled	5,8	9
Retired	44,8	69
Other (sick, volunteering)	1,3	2
Average age		63
Average age living in dwelling		27

Table 7.11: Characteristics discrete choice respondents

Education level (n=55)	%	N
None	1,8	1
Primary school	7,3	4
Lower secondary school	20	11
Higher secondary school	1,8	1
Lower vocational	9,1	5
Secondary vocational	38,2	21
Higher vocational/University	21,8	12
Working situation (n=58)	**%**	**N**
Job <12 hours	3,4	2
Job ≥12 hours	36,2	21
Entrepreneur	3,4	2
House wife/man	5,2	3
Unemployed	10,3	6
(partly) disabled	12,1	7
Retired	29,3	17
Other (sick, volunteering)	0	0
Average age		57
Average age living in dwelling		21

7.4.2 Motivation factors

The respondents were asked if they willingly participated in the renovation, since some of the projects used the “70%” rule. Only 6 of the respondents did not agree, and 15 respondents agreed after doubting. 97 respondents agreed to the retrofit. The 112 respondents that agreed were asked what their motivations were for agreeing with the retrofit, by the question shown in figure 7.1. Using analytical hierarchy process (AHP), the importance of each motivation of the tenants was calculated. Excluding the inconsistent answers left 78 respondents for the calculation. The priority vector was calculated, which resulted in the relative weights of the three motivations. The results are shown in Table 7.12.

Table 7.12: Priority vector of motivations

Motivation	Priority
Cost savings	0,430
Environment	0,287
Comfort	0,283

The meaning of these priority vectors is the importance factor tenants have given to the three variables. Energy cost savings is on average the most important motivation with 43 percent. Because these are relative weights, it should be interpreted as follows: energy cost savings is found approximately 1,5 (43,0/28,7) times more important than the environment, even as comfort (43,0/28,3).

7.4.3 Knowledge

The tenants were asked whether their energy consumption has decreased according to the calculated energy savings. Figure 7.5 shows the answers of all respondents and the answers of the respondents of each housing association separately. The largest group of all respondents with 37,6% is unaware of their savings. 24,8% of the respondents have saved energy, but a smaller amount than was calculated. 10,9% claim that they have an equal energy consumption as before the retrofit, which means that this group has not saved energy despite the thermal retrofit. 19,8% of the tenants have saved as much as calculated, and 5,9% even saved more energy.

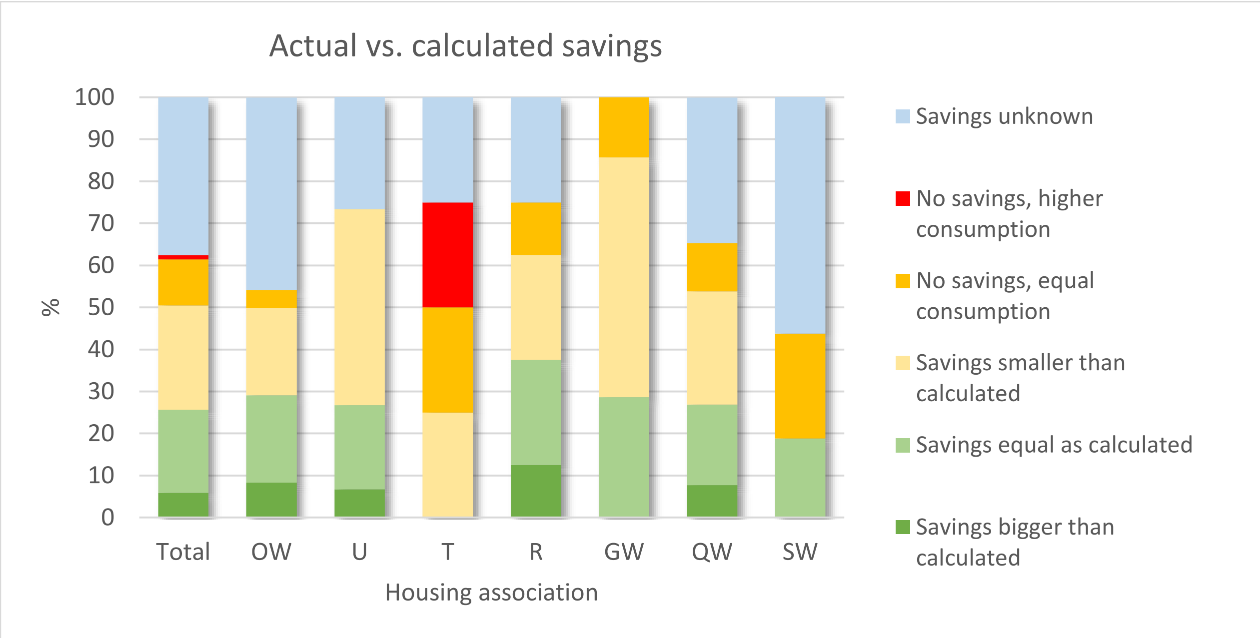

Figure 7.5: Actual vs calculated savings

Energy saving knowledge

Looking at the answers of each housing association separately, it shows that tenants of OW and SW are least aware of their energy consumption. For OW, it is known that part of the project ended in 2015, therefore some tenants cannot know their energy saving. When all tenants of OW are excluded from this question, the tenants that are unaware of their energy saving still form the largest group with 28,6%. The project leaders were asked whether attention was paid to the influence of household behavior on the presented energy saving. This is shown in table 6.1. The brochure of SW did not mention it, but according to the interviewee it is probably mentioned at the collective meeting. Tenants of QW did not receive explanation about the effect of household behavior, because their rent increase was only 16,7% of the calculated savings. This can explain the low knowledge of these respondents. Comparing all housing associations with each other, the differences in results cannot be explained by the use of an explanation about the influence of household behavior in table 6.1.

Energy saving amount

Tenants of GW and U have the highest percentages of respondents that have saved energy after the retrofit, including the answer ‘saving smaller than calculated’. Respondents of R reached the highest percentage of tenants that saved equal or more than the calculated savings. Table 6.1 shows that tenants of R received guidance on the heating behavior and ventilation for a lower energy consumption. GW and U tenants received no specific information about saving energy. Therefore the results on energy saving of these respondents cannot be explained by the received information according to the housing associations in table 6.1.

7.4.4 Behavioral change

The respondents were asked for 8 different actions what their behavior before and after the retrofit was. The questions were asked as shown in figure 7.3. These answers are analyzed using the paired t-test. The differences in results of each variable were approximately normally distributed, thus the test could be performed. The paired t-test shows if there are significant changes in behavior before and after the retrofit, and whether these changes are positive or negative.

The significance of changes in behavior after the retrofit were analyzed for all respondents and the results are shown in table 7.13. This table shows that two behaviors are significantly different before and after the retrofit. The thermostat settings show the greatest change in the before and after situation. This is shown by the mean in the table: the mean of the difference is 0.214. The mean of the difference in choosing a green label when buying appliances is 0.161. Both means are positive. As can be seen, the difference is defined by "after minus before". Thus, the behavior after the retrofit has a mean that increased with 0,214 and thus a positive change has occurred. It means that a significant group of the respondents has changed the moment of turning the thermostat down before going to sleep to an earlier moment, compared to the moment before the retrofit. This is an energy saving behavior.

A positive change has also occurred at the behavior 'choosing a green label'. The mean of this variable has increased with 0.161. This means that a significant group of respondents now (after the retrofit) chooses more often for buying an appliance with a green energy label than before the retrofit.

Table 7.13: Paired t-test on eight behaviors before and after retrofit

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	**Thermostat settings b – a**	**,214**	**,641**	**,059**	**,096**	**,331**	**3,606**	**116**	**,000**
Pair 2	Radiator unused rooms b - a	,108	,780	,068	-,028	,243	1,574	129	,118
Pair 3	Ventilation grids b - a	,117	,911	,090	-,061	,294	1,298	102	,197
Pair 4	Window living room b - a	-,064	,870	,083	-,228	,101	-,767	109	,445
Pair 5	Window bed room b - a	-,016	,395	,035	-,084	,053	-,446	128	,656
Pair 6	Shower time b - a	,054	,439	,039	-,022	,131	1,405	128	,162
Pair 7	Shower frequency b - a	-,016	,217	,019	-,054	,022	-,815	127	,416
Pair 8	**Green label appliances b - a**	**,161**	**,554**	**,051**	**,060**	**,262**	**3,156**	**117**	**,002**

The results are also analyzed for each housing association separately. This is shown in appendix G. This shows a significance change for the thermostat settings at R and QW. The results of OW shows a significant negative change in ventilating the living rooms with windows. This is probably caused by the placement of ventilation grids in the living room at the thermal retrofit. There is no association that has a significant change at choosing a green label when buying appliances.

According to table 6.1, the tenants of R received a brochure with extended information about the project and about the expected energy saving. Tenants of QW could visit the model dwelling and received standard instructions for the systems. These are no clear stimulations that can explain the energy saving behaviors found in this analysis. Tenants of other associations also received some sort of intervention strategy, but for these respondents it did not result in significant behavior changes of the tested behaviors. Therefore the differences between the respondents cannot be explained by the different approaches of the housing associations in table 6.1.

7.4.5 Satisfaction

The respondents were asked whether they were satisfied about the quality of the received information about the retrofit and the received information about the rent increase and energy saving. It was asked on a scale from 1 to 5, where 1 was very satisfied and 5 very dissatisfied. The boxplots in figure 7.6 and 7.7 show the answers of the respondents per housing association. The thickness of the boxplot show the amount of respondents of each association.

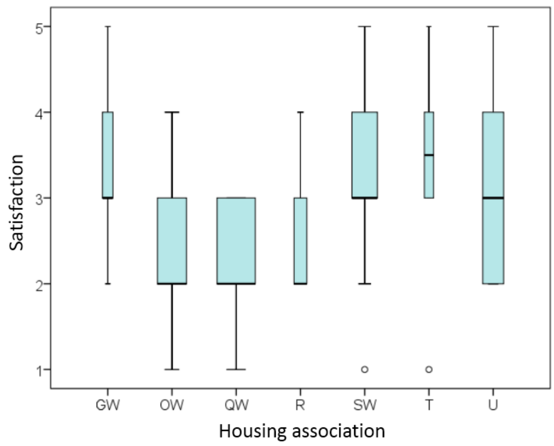

Figure 7.6: Satisfaction of rent increase information

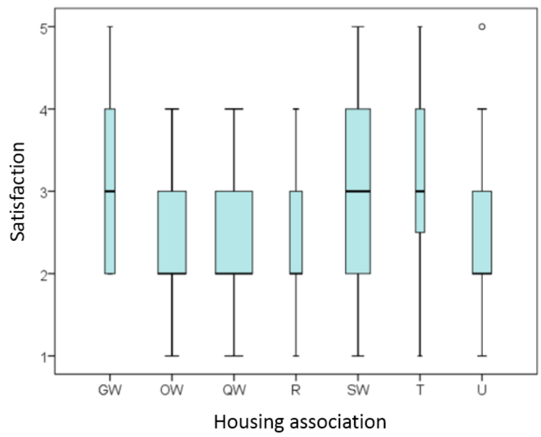

Figure 7.7: Satisfaction of general retrofit information

Respondents of QW, OW and R seem satisfied about the received information about both subjects. Table 6.1 shows that QW did not reach their tenants that much information or intervention strategies. OW and R reached their tenants more extensive information, which seems appreciated by the tenants. Respondents of GW, T and SW are least satisfied. The dissatisfaction of tenants of SW seems to be caused by lack of information about the sun boiler according to some remarks in the questionnaire.

The respondents were also asked whether they have missed information after the completion of the retrofit and 22,4% of all respondents indicated that they did. Besides stating that there was no information given at all, some respondents wished to receive information about the actual reached savings and some remarks were aimed at technical issues about the sun boiler of SW. This association had the highest percentage of respondents that indicated a need for information after completion. Lack of information afterwards caused some problems at that retrofit project. From other associations there were also few tenants that indicated that they would have liked more instructions of the systems. Beside the sun boiler applied at SW, the applied systems at other associations were not that complicated.

7.4.6 Preferences towards intervention strategies

The choices of the 55 respondents in part 2, the discrete choice experiment, are analyzed using NLOGIT. The respondents' characteristics of these 55 respondents are analyzed separately. It shows that the average age of the discrete choice respondents is 57. This is 5 years younger than the average age of the total respondents. The household composition is also more in balance than it is for the total respondents. The chi squares are shown in table 7.9. In appendix E the used profiles and choice set are included. A multinomial logit regression is used to derive the preferences of the tenants towards the presented attributes and levels in the choice sets

Model fitting

The log likelihood of the model is smaller than the log likelihood of the constant, which means that the designed model predicts better than the constant model. This is shown in table 7.14. The pseudo R-squared statistics is 0,900 (adjusted R-squared 0,0821). The bigger this number, the better the model is predicting. A good model has a value around 0,2. Based on this value, is not a good predicting model. It was tried to obtain a higher R-squared value by deleting the non-significant variables, however including all variables the model seemed most suitable for predicting the model.

Table 7.14: Goodness of fit

Pseudo R-squared	LL(0)	LL(β)
0,900	-831,4176	-756,61682

The multinomial logit model output is shown in appendix H. None of the tested interaction effects are significant in this model. All main effect are at least 90% significant, and therefore the results are shown from a significance of 90% and higher. The variables with a significance of 90% are visualized by a lighter color in the diagrams, the dark blue variables are significant at the 95% and 99% level. Figure 7.8, 7.9 an 7.10 show the coefficients of the 3-level variables that NLOGIT has calculated. The levels must be interpreted relative to each other. When the preference β is approaching 0, it has a low influence on the choice made.

Energy saving goal

Respondents dislike goal setting with the neighborhood the most, compared with individual goal setting and no goal setting. They also prefer no goal over setting an individual goal.

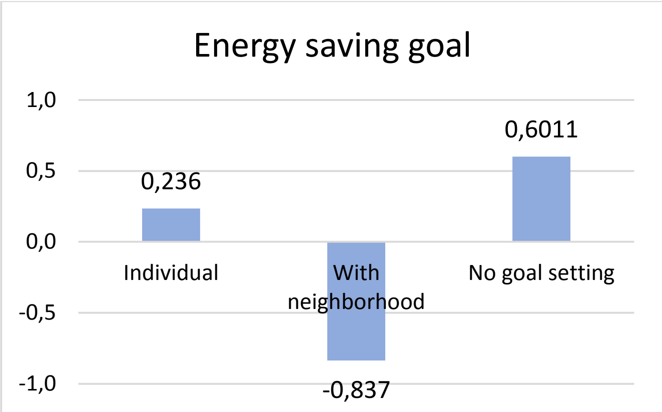

Figure 7.8: Preferences of each level of the attribute energy saving goal

Feedback

Regarding feedback, respondents also are less willing to compare their feedback with the neighborhood. They prefer individual feedback over no feedback.

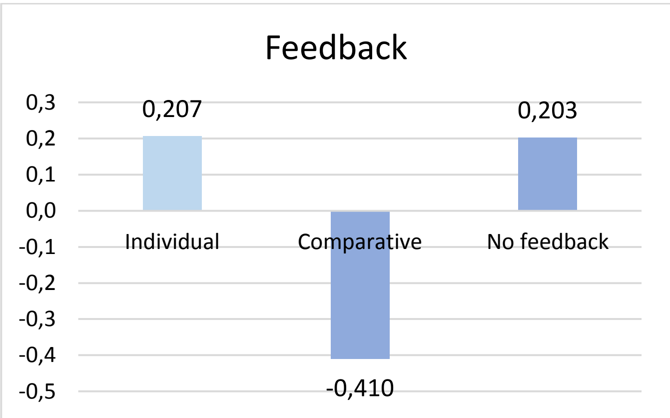

Figure 7.9: Preferences of each level of the attribute feedback

Tailored instructions

Respondents prefer simple and tailored instructions about their dwelling in a brochure. Compared this, a visit from an energy specialist is really disliked by the tenants. They prefer no instructions over instructions from an energy specialist.

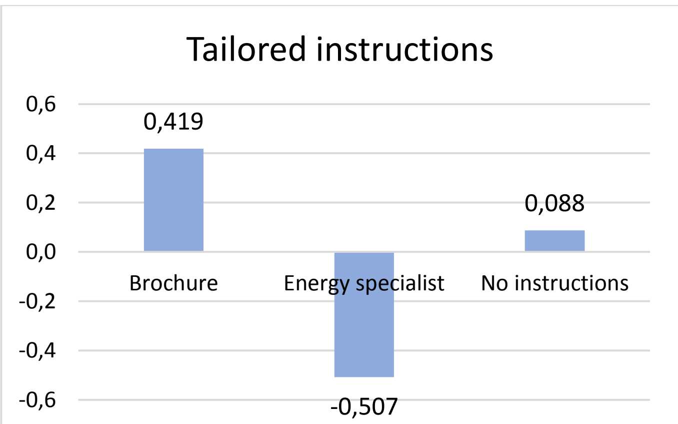

Figure 7.10: Preferences of each level of the attribute instructions on energy systems

Energy saving box
The energy saving box has a positive value of 0,115 for the β. This means that they prefer receiving such a box over not receiving it. However, the value is close to zero and significant on the 90% level. It seems therefore not really preferred as intervention strategy after a retrofit.

Reward
The value of reward as an intervention strategy is 0,285. This value is positive and therefore the respondents rather receive a reward then not receive it.

Base
The base values are indicating which of the options (a,b,c) are most preferred by respondents despite the answer. The respondents have a slightly preference for option b (0,574). This probably has no large effect on the outcomes, because there were 4 random choice sets distributed among the respondents and the answers were divided among option a and b.

Relative importance between the attributes
In order to say something about the preferences of the different attributes by the respondents, the relative importance of the attributes can be calculated.
The absolute difference between the highest and the lowers part worth value need to be calculated. The relative importance in percentages can be calculated. The values are illustrated in figure 7.11.

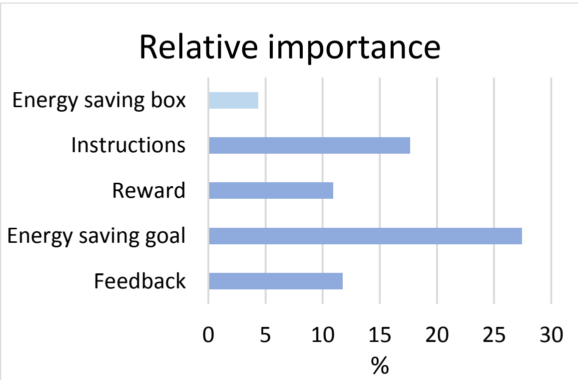

Figure 7.11: Relative importance of each attribute

The percentages mean that for choosing a combination of energy saving interventions, the presence or absence of an energy saving goal is the most important criteria. Instructions is the second important attribute compared with the others. As expected, the absence or presence of the energy saving box is least important when it comes to choosing based on these respondents. The importance of the variables does not say anything about the positive or negative effect the attribute has on the choice, but the figures 7.8, 7.9 and 7.10 do.

7.4.7 Adjusted energy behavior model

Based on the results of the tenant questionnaire, the theoretical energy saving behavior model for the thermal retrofit context is adjusted in figure 7.12. The results of the tested variables in figure 6.1 are explained.

The brochure with tailored and simple instructions on the energy systems is most preferred as intervention strategy. Individual goal setting and individual feedback and rewards are also useful strategies for this context.

The main motivation for participating in the retrofit according to the respondent group is cost saving. A large group of the respondents does not have knowledge about their energy saving. Presentation of the reached energy saving percentage is added to the model, because tenants indicated that they liked to know how much energy saving was reached after the retrofit. The housing association can choose whether they present the average saving percentage or at a more detailed level. This will influence tenants' attitude towards the housing associations and their attitude towards energy saving. It might also increase their knowledge about energy saving and the influence of their behavior.
The lifestyles and socio-demographic characteristics of a neighborhood can be consulted by the housing association to indicate which strategies would be more suited for the tenants of the retrofit. The results from this questionnaire are based on a predominantly elderly age group. It is possible that a younger age group is more willing to participate in other intervention strategies, such as collective strategies.

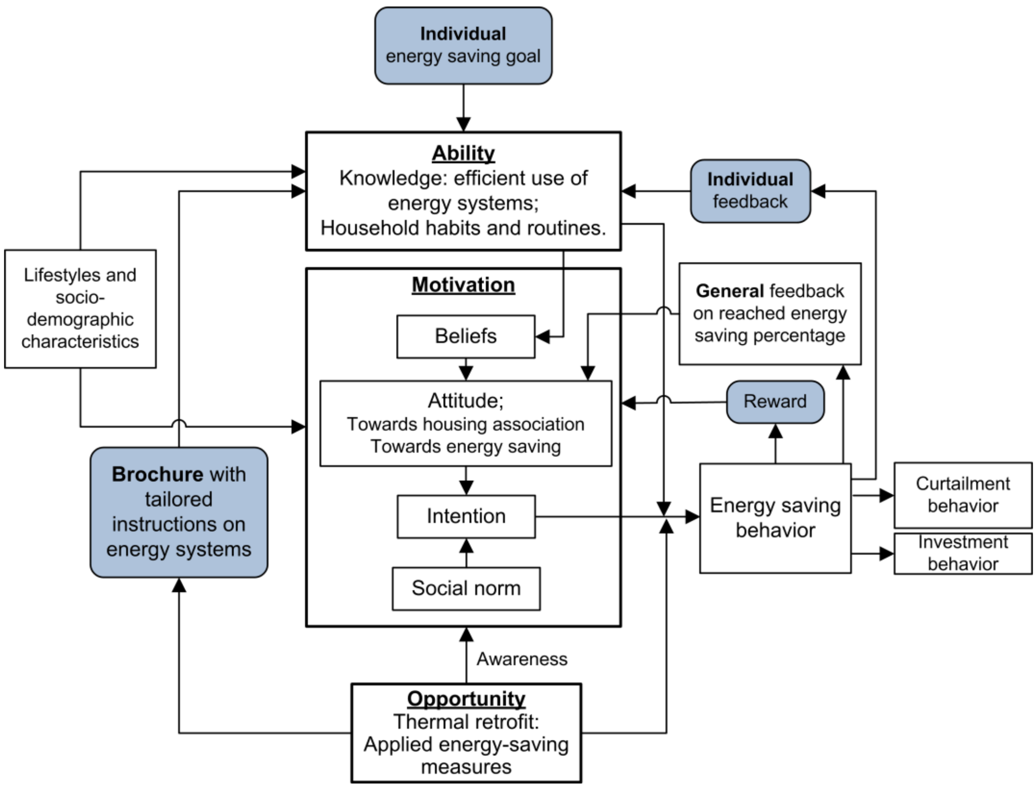

Figure 7.12: Energy behavior model for a social housing retrofit

7.5 Conclusion

The tenant questionnaire resulted in 147 respondents (response rate of 15,7%). Only 55 of these respondents could be included in the discrete choice experiment. The respondent characteristics of the total respondents show that the respondents do not represent the target group (tenants in the Dutch social housing sector). The elderly tenants are overrepresented and the young adults and middle aged tenants are underrepresented. The respondents of the discrete choice experiment represent the target group better than the total respondents. This shows that a lot of elderly have not completed this part of the questionnaire. This might be caused by the mentioned characteristic of elderly that they are already aware of their consumption and they do not need additional strategies to be stimulated to save energy.

The tenant questionnaire was conducted in order to answer the research question: *Can a thermal retrofit serve as a trigger for energy saving behavior for tenants and which intervention strategies are preferred according to tenants?* Based on the questionnaire results, it seems that a thermal retrofit has a potential to trigger behavioral change on certain behaviors when it is combined with the right intervention strategies. For two behaviors, a significant positive behavioral change was found by the respondents. The respondents changed the moment of turning the thermostat down before sleeping to an earlier moment. Also, after the retrofit more respondents considered a green label when buying appliances more often than before the retrofit. It should be taken into account that these are self-reported behaviors.

Cost saving was the most important motivation for participating in the retrofit, compared to comfort and the environment. This is useful for starting intervention strategies aimed at energy saving, as the motivation to save more money can triggered. Despite the saving motivation, there is a large group of tenants that are not aware of how much energy they saved due to the retrofit. Not all respondents are satisfied with the information they received before and after the retrofit. If the communication improves, the retrofit will be an opportunity to increase the energy knowledge of tenants and therefore make it easier for them to save energy after the retrofit.

The discrete choice experiment was designed to find tenants' preferences towards the intervention strategies derived from the literature and project leader interviews. Results show that the respondents prefer individual actions above collective strategies. The absence or presence of an energy saving goal was found to be the most important when choosing an alternative. The "no energy saving goal" is preferred over setting an individual or collective energy saving goal. This indicates that the respondents have a strong dislike for setting up an energy saving goal to save energy. The attribute 'instructions' was found second most important relatively to the other attributes in the experiment. A brochure with instructions was preferred over an energy specialist and no instructions. This implies that for this group of respondents a brochure with instructions for the energy systems is most preferred as intervention strategy in the context of a social housing retrofit. The respondents are positive towards receiving a reward when saving energy. This was expected, because people are sensitive towards free products. It is difficult to maintain the saving effect after a reward is given. It is therefore better to combine this strategy instead of using it on its own. However, the results of the experiment showed no significant effect on the tested interaction effects.
The respondents seem to prefer individual intervention strategies over collective strategies. The individual energy saving goal and receiving individual feedback have a positive outcome as intervention strategies.

Based on the questionnaire outcome, the energy behavior model is adjusted. The preferred intervention strategies are added. It is a theoretical model that can be used in further research to examine the relations and effects of these different variables at thermal retrofits in the social housing sector.

8. Discussion

This chapter will discuss some of the results of this research that need to be put into perspective.

Calculated versus actual energy saving

The energy analysis showed that there is a gap between the calculated and actual energy saving after a retrofit. The gap between calculated and actual energy consumptions *before* the retrofit (the prebound effect) is often larger than the gap *after* the retrofit. The gap before the retrofit between actual and theoretical energy consumption can be corrected by the calculation. When this is corrected, a part of this gap will move to the after-retrofit situation. Because the energy saving calculations did not use the actual energy consumptions before the retrofit as a starting point, it is not certain what the size of this remaining gap is. It is assumed by Atriensis that the saving percentage will stay the same, but this assumption is not needed when the actual energy consumption will be used as starting point of the energy saving calculation. The gap between theoretical and actual energy consumptions after the retrofit has the potential to be reduced by several factors besides the rebound effect: the energy saving measures that were applied and the amount of tailored communication of the housing association to increase the energy-saving knowledge of the tenants.

Questionnaire respondent characteristics

The questionnaire was send to 934 tenants and completed by 147 respondents. This is a response rate of 15,7% and is lower than expected. The results of the discrete choice experiment, as part of the questionnaire, are based on 55 respondents. The chi square goodness of fit shows that the respondents do not represent the target group very well. The elderly are slightly overrepresented and the age group between 25 and 45 year is underrepresented. Research found that elderly mention more often that they save enough energy and therefore do not need help through intervention strategies for household energy saving (Vine et al., 1989). The questionnaire results show a similar effect, as this reasoning has been mentioned by some of the elderly respondents. Also, the respondent characteristics of the discrete choice experiment show that many elderly have not completed this part: the average age of the discrete choice respondents is 57 against the average age of 63 of the total respondents. The fact that a younger group of respondents completed the discrete choice experiment can suggest that this group is more willing to be involved in energy saving actions after a retrofit. However, another plausible reason is that the questions of the discrete choice experiment were too complex to understand for the elderly respondents, as the options were quite long and similar to each other.

Interpretations of household behavior changes

The paired t-test results showed two significant changes in household behavior after the retrofit compared with the before-situation. It should be noticed that these answers are based on self-reported behaviors. This reduces the reliability of these results.

The found behavioral changes were explained by the change in context and the received intervention strategies at the retrofit. However, these behavioral changes do not have to imply a “conscious” positive change: the reason for the changes is not researched. In this research it is assumed that the positive change in choosing a green energy label when buying household appliances is caused by the retrofit and by the received intervention strategies. However, this behavior might have changed because more advertising is aimed at the energy labels of appliances in the past years.

Energy consumption knowledge

Results of the questionnaire show that 36% of the tenants do not know whether they saved energy after the retrofit. The last part of the retrofit at Omnia Wonen was completed early 2015, thus these respondents could not have any energy saving results yet. Excluding these tenants, the respondents that have no knowledge about the amount of energy they saved is still the largest group with 28,6%. It can be argued that due to temperature differences each year the energy bill changes. However, the saving effect of all retrofits seems large enough to be noticeable despite the changes in temperature during the year. The lack of knowledge is remarkable. It might have been expected that more tenants have paid attention to the decrease of their energy consumption, because 'savings' was the most important reason for these respondents to participate in the retrofit.

An explanation of this lack of knowledge can be that most tenants assumed that their energy consumption would decrease according to the presented percentage by the retrofit without doing anything about it. This is plausible when the housing association has not mentioned the possible influence of behavior on the energy saving when presenting the rent increase and energy saving percentage. However, the differences in these results between the respondents could not be explained by the differences in mentioning the influence of behavior.

Preferred intervention strategies

The preferences towards the presented intervention strategies are derived from the discrete choice experiment. It is striking that the proposed strategies that include interaction with other people are least preferred by the respondents: The collective energy saving goal, comparing feedback and the visit of an energy specialist for instructions all have an average negative preference. This indicates that there might be an aversion for collective actions and visits from energy specialists. A possible reason for this aversion is that tenants want to preserve their privacy and are therefore not eager to share their energy saving amount with the neighbors or invite people to their home. Another plausible reason is anxiety for opening the door for strangers. Before a retrofit, tenants need to let several people into their dwelling, for example an inspector to measure the energy index of the dwelling. An energy specialist might be seen as another one of those strangers they have to let into their home. A brochure with instructions is most preferred according to this research; this might be seen as the safer option. However, the fact that a brochure with instructions is most *preferred* does not mean that this is the most *effective* strategy for these tenants to use their energy systems correctly and therefore save energy.

9. Conclusion

9.1 Answering the research questions

The main research question to be answered by this research is:

How can the energy-saving potential of social housing tenants in the context of a thermal retrofit be improved?

To answer this question, four sub questions needed to be answered. A literature review was conducted and a field research on seven retrofit projects of seven different housing associations was set up to answer these sub questions. The answers are shortly explained before answering the main research question.

9.1.1 Influencing household energy behavior

The first question to be answered was "*What does energy-related household behavior consist of and which methods are known to influence this behavior for the purpose of energy saving?"* A literature study was conducted on household energy behavior and how to influence this behavior by intervention strategies in order to increase energy saving. The MOA-model of Ölander & Thogersen (1995) was used and adapted to illustrate the motivation, opportunity and ability factors that can lead to energy saving behavior in the household. The motivational and ability factor can be influenced by different intervention strategies, divided in antecedent and consequence strategies. They can also be influenced by increasing the knowledge about the energy systems that are installed at the retrofit. A thermal retrofit can be seen as an opportunity to start energy saving behavior (Walker et al., 2014).

9.1.2 The energy saving gap

The second question to be answered was *"How much on average do tenants miss out on energy savings after a thermal retrofit, according to the literature and according to the field research?"* The existing literature was examined to find information about the gap between theoretical and actual household energy consumption. There is a difference between the gap before the retrofit and the gap after the retrofit. When there is a gap between theoretical and actual energy consumption before the retrofit, this is referred to as the prebound effect (Sunikka-blank & Galvin, 2012). This can be corrected in the calculation by using the actual instead of the theoretical energy consumption as starting point of the calculation. The gap between the theoretical and actual energy consumption after the retrofit can be reduced by improving the behavioral parameters in the calculation, the communication about the applied energy saving measures, and intervention strategies aimed at behavioral change. Based on different studies, it is probable that residents miss out on energy savings on a range between 10 and 30 percent.

Ten zip code analyses were made of the energy consumptions before and after the retrofit projects in order to see how much the tenants have missed out on energy savings. The prebound effect, as found in the literature, was occurring at the majority of these projects. Therefore figure 3.1 and 3.2 in chapter 3 are found to be occurring in these recent retrofits in the Dutch social housing sector. Comparing the calculated and actual energy savings, it shows that the tenants have missed out on average 10,7% of energy savings.

9.1.3 Thermal retrofit process in the social housing sector

The third question to be answered was *"What is the current process for thermal retrofits in the social housing sector and is there space for intervention strategies after these projects, aimed at behavioral change?"* This question was answered by interviews with the project leaders of the retrofits. A lot of effort is put in convincing tenants to participate in the retrofit. The calculated energy savings and the rent increase are presented to the tenants. There is barely communication after the retrofit. Most project leaders indicated that this should be changed. All interviewees felt that guidance aimed at the knowledge of the use of the energy system was needed. Not all interviewees were convinced that intervention strategies aimed at behavioral change were part of the responsibility of the housing association. Some referred to the new "Woningwet", that expects housing associations to focus on their core business (Aedes, 2015). They claimed that this makes it difficult to pay attention to behavioral changes. However, affordable housing is also part of their core business and providing information and intervention strategies for energy saving behavior contributes to this. Moreover, tenants should always receive proper information as part of a thermal retrofit.

9.1.4 Energy saving perspective of tenants

The fourth and last research question to be answered was *"Can a thermal retrofit serve as a trigger for energy saving behavior for tenants and which intervention strategies are preferred according to tenants?"* A questionnaire, send to tenants of retrofit projects, was used to answer this question. The respondent group does not represent the target group, the conclusions based on the questionnaire should be interpreted by keeping the representation of the target group in mind. A large group of tenants lacks knowledge about their energy saving. It is hard to stimulate energy saving behavior if this awareness is not present. The motivation for participating in the retrofit for the respondents is mainly cost saving. When increasing tenants' knowledge and using cost saving for intervention strategies, a retrofit can serve as a trigger for energy saving behavior.

The most preferred intervention strategy that was presented to the tenants was clear instructions about their energy systems. This was expected from the literature on these subjects (Breukers et al., 2014; Groot et al., 2008). They prefer instructions in a brochure above instructions by an energy specialist. The most complex system that the tenants of the studied projects needed to adopt was a sun boiler. The need for tailored instructions will become even bigger, as in the future more complex systems will probably be applied at thermal retrofits.

9.1.5 Answering the main research question

This research studied different aspects of a thermal retrofit in the social housing sector: the energy-saving potential, the retrofit process according to project leaders and the current process and preferences towards intervention strategies according to tenants. The main research question can be answered by identifying possible improvements in the context of a thermal retrofit in order to increase the energy-saving potential of social housing tenants.

A thermal retrofit would reach its highest energy-saving potential when the energy saving calculation would be accurate, and therefore the rent increase calculation would be in balance with the energy saving of the tenant and the payback period for the housing association. In the ideal case, the housing association would give its tenants the right information and stimulation in order to use their energy systems in their retrofitted dwelling optimally. The tenants would be aware of their energy consumption and know how to save energy.

This research made clear that there are some mismatches between these different aspects of the thermal retrofit. This is illustrated in figure 9.1. The mismatches in this figure are explained. Next, the research question can be answered by explaining how these mismatches can be solved, which leads to an improvement of the energy-saving potential of tenants in the context of a thermal retrofit.

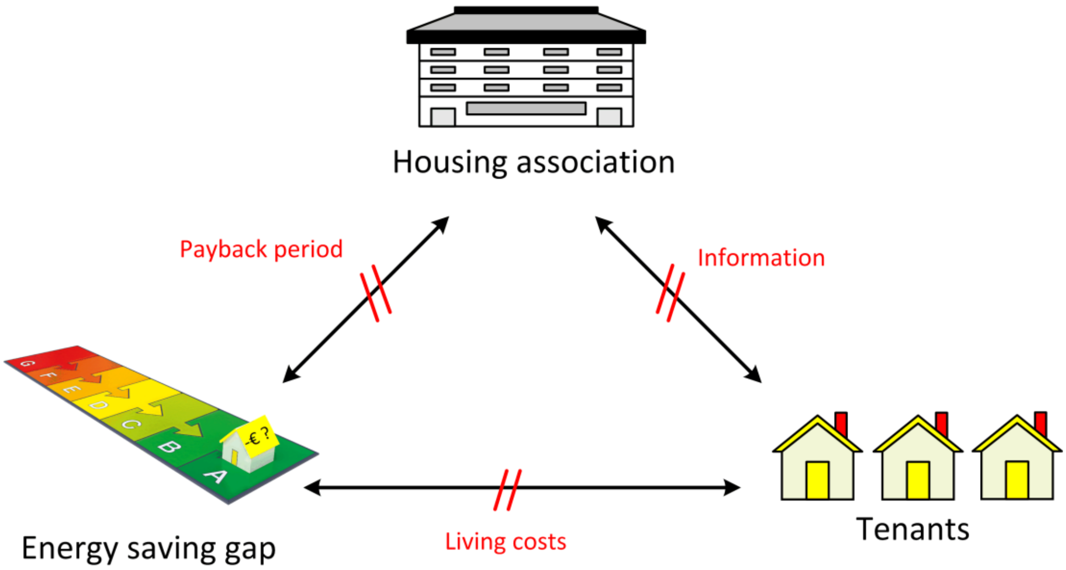

Figure 9.1: Mismatches at thermal retrofits in the social housing sector

First, the calculated energy saving is often different from the actual energy saving of tenants after a thermal retrofit. This has effect on both the tenants and the housing association that invested in the retrofit.

The effect on the tenants is that they save less energy than expected, and therefore the rent increase has a higher impact on their total living costs than expected. In figure 9.1, this is called the "living costs" mismatch. The income of the average social housing tenant is quite low compared to other Dutch households (Aedes, 2012). It is important for this group to keep their living costs low. A high percentage of these tenants are unaware of the energy saving they reached. It is hard to save energy when the energy-saving potential is unknown.

The effect on the housing association is that the investment in the retrofit is less effective than expected. This is indicated in figure 9.1 as "payback period" mismatch. The theoretical payback period is longer than initially calculated. The housing association receives the rent increase from the tenants, but when the 'living costs guarantee' is applied, they might have to lower this rent increase when the savings are lower than initially calculated.

These mismatches can be reduced by calculating a more realistic energy saving. This can be realized when housing associations start monitoring the energy consumptions of their housing stock. Using the actual energy consumption as starting point for the calculation instead of the theoretical consumption will improve the calculation of the energy saving. This leads to a fairer rent increase for the tenants. It also gives the housing association more insight in the effectiveness of its retrofit investment.

Secondly, there is also a mismatch between the housing association and the tenants. There is a lot of communication, but this is mainly aimed at convincing tenants to participate in the retrofit. After the retrofit is completed, there is no or little communication aimed at helping these tenants. The completion of the retrofit is now the ‘end goal’ of the housing association, while it seems a promising opportunity for the tenants to start energy saving behavior. Tenants need tailored information about the correct use of the energy systems. Housing associations seem to be aware of this need, but barely act on it. This is the “information” mismatch in figure 9.1. The differences in the questionnaire results between the tenants of the different housing associations cannot be explained by the differences in the communication. Both parties seem to have a different perception of the information that is needed at a social housing retrofit in order to reach the highest energy-saving potential.

This mismatch can be reduced by tailored and clear communication between a housing association and its tenants. The completion of the retrofit should not be the end of the project for the housing association, but the tenants need to be guided afterwards. Attention should be paid to the energy saving measures that are applied at the retrofit, and how dependent these measures are on household behavior. When there are active measures applied (often dependent on household behavior), tailored instructions about the efficient use of the system will increase the energy-saving potential of the tenants. A clear explanation about the calculated energy saving and the influence that household behavior can have, will increase tenants’ knowledge on their energy consumption. The housing association can consider using intervention strategies aimed at energy saving behavior, when the target group is expected to participate in this.

9.2 Recommendations

9.2.1 Recommendations for housing associations

It is recommended for housing associations to start monitoring the energy consumption of their housing stock. Requesting the data of the dwellings by the grid operators instead of using the free open data on the zip code level is recommended, because this provides more detailed information adapted to the housing stock. At the start of a retrofit, the actual energy consumptions can be consulted to see how much energy a neighborhood consumes on average compared with the theoretical energy consumption based on the energy index. This can help improving the retrofit strategy and considering the possibilities of using intervention strategies for more energy saving. The calculation of the energy savings will become more accurate when using the actual energy consumptions in the calculation.

The second recommendation is to be careful with statements about the rent increase based on the calculated energy savings to the tenants. This is a recommendation that Atriensis already gives to its clients. It is recommended based on this research to always mention the influence that household behavior can have on the calculated energy saving. The importance of mentioning this depends on the applied energy saving measures: passive measures such as insulation and PV panels are not dependent on household behavior, but an active measure such as ventilation is. When a high percentage is used as rent increase it also recommended to mention household behavior, especially when the “living costs guarantee” is applied (Woonbond, 2014).

The next recommendation is to present the reached savings of the neighborhood after the retrofit to the tenants. The questionnaire showed that cost saving was the most important reason for participating in the retrofit. Some respondents indicated in the questionnaire that they liked to know how much their neighborhood have saved since the retrofit. Some project leaders indicated that some kind of closure was desired by some projects. This would increase the transparency of the project and it can lead to more awareness among the tenants.

Looking at the future of thermal retrofits in the social housing sector, it is likely that more advanced energy systems will be applied to reach lower energy indexes. This will increase the importance of tailored information about the correct use of the energy systems. From both the interviews as well as from the questionnaire the importance but absence of tailored information has become clear. To save time, a standard brochure could be designed, and be tailored to every retrofit project. Monitoring the effectiveness of this information is also recommended: Asking the tenants after a while whether the use of the systems is clear could improve future projects. This can be combined with presenting the reached savings.

The last recommendation is to get to know your neighborhood and decide which strategies could be useful to increase the energy saving of these tenants. This research suggests that for a neighborhood with predominantly 45+ tenants, living alone or with 2 adults, collective initiatives are not preferred and thus will not result in energy saving results. The characteristics of the target group can also decide whether passive or active measures will be most effective.

9.2.2 Recommendations for further research

This research suggests several intervention strategies aimed at energy saving behavior that seem preferred and fitting to be applied after a social housing retrofit. A recommendation for further research is to test the effectiveness of these strategies in a study on applied energy saving measures and measuring behavioral changes and the effects on the energy consumption.

There could be more research on intervention strategies after a thermal retrofit aimed at the younger age group in the social housing sector. The age group of this research has probably affected the outcomes: it is plausible that the younger age group would be more willing to participate in other intervention strategies.

It is not certain whether the recommendations of this research will be applied by the housing associations, because they are more and more restricted to their core business. A recommendation for further research is to explore the possibilities of implementing tasks such as helping tenants to save energy into the current retrofit process without interfering with the core business of housing associations.

The last recommendation for further research is to study thermal retrofits specifically among home owners. Home owners invest in their own retrofit; thus it is expected that the awareness of the energy-saving potential is higher. Do they know how to use their energy systems as efficient as possible and if they do not, who can guide them?

9.2.3 Evaluation

A limitation of this research that has been mentioned several times is that the respondents of the tenant questionnaire do not represent the target group properly (as shown in table 7.8). If the respondents' characteristics were more evenly distributed, the research could have been extended with a Latent Class Analysis in order to present a more tailored advice on different segments.

The second limitation is about the conducted energy analyses. Two datasets with energy consumptions of the same dwellings are compared with each other to examine the differences in calculated and actual energy savings. Several criteria were set up to preserve the reliability of the comparison. However, these analyses are not completely reliable, because the corrections for the standard year consumption differ from each other. The explanation of the calculation used by the grid operators is not clear and unverifiable. According to Atriensis, the comparison of these datasets are as reliable as possible. The energy analyses would be more reliable and more extensive when the data from the grid operators were exactly the dwellings of the retrofit projects. Due to time and budget constrains this could not be achieved and the free zip code data were used.

Also, the calculations are based on the gas price of the year the theoretical energy consumptions were calculated. The gas price has decreased instead of the expected rise. The average gas price of 2015 was 0,65 cent/m^3. Therefore the actual energy savings are smaller than shown in the calculation. This is not taken into account in the conclusion because it is not something that could be predicted at the time of the retrofit.

The energy analyses are based on the gas consumptions only. The data for the calculation for the energy saving and the payback period also included the change in the amount of help energy. This effect was analyzed for each project, and it turned out that this has minimal influence on the outcomes. Only at Standvast Wonen this help energy changed significantly, however the applied rent increase is derived from the brochure and therefore this comparison is still valid.

Appendix F shows the number of tenants of each housing association that received and returned the questionnaire. In order to reach a higher response rate, the associations were asked for a similar retrofit (similar retrofit size and communication method) project to send the questionnaire to. Not all associations had such a project. This results in differences in the amount of tenants for each housing association. Besides that, there is also a great difference in the response rate. This varies from 8,8% to 34,5%. This can be explained by the involvement of the housing association with its tenants. Large housing associations in cities are often more distanced from their tenants than small housing associations in a small village. These tenants know the employees of the housing association and this probably leads to more willingness to involve in activities and filling in questionnaires. A higher response rate could be achieved when considering the relation of the tenants with their housing association. The questionnaire response of the online version is very low. This can be explained by the many elderly respondents. Another barrier might be that the link to the website must be typed into the browser instead of clicking the link in an e-mail.

The next limitation is about the design of the discrete choice experiment. Three mistakes have been made when coding from the profiles to the questionnaire answers. The option ‘brochure’ was left out twice (one was changed into energy specialist and one was left out). This means that the variable options are slightly ‘out of balance’ and it is possible that this has effected the outcomes. Nevertheless, the option ‘brochure’ is the most preferred option without these two options left out. The results still seem plausible. The interaction effects that were included in the design were all insignificant. The experiment would have been smaller (less questions) when there was only tested for the main effects. This probably led to more respondents for the experiment and that made the results more reliable. It should be considered whether the impact that including interaction effects has on the size of the design is worth it.

The criteria of the retrofit projects did not include criteria about the “size” of the retrofit: the decrease of the energy index and the amount of energy saving measures to be applied. It could have been more interesting to include larger retrofits in the research, applying more active measures instead of passive measures. This would probably have led to more deviations in calculated and actual consumption, because the effect of wrong use of energy systems would have been larger.

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Appendices

Appendix A: Project information

Housing association	Rhiant, Hendrik Ido Ambacht
Function of interviewee	Project leader
Interview date	24-09-2015
Energy Index	2,27 (E) → 1,29 (B)
Applied retrofit measures	Roof insulation HR++ windows with ventilation grates Mechanical ventilation Cavity wall/façade insulation
Rent increase (% over calculated saving)	50

Housing association	Standvast Wonen, Nijmegen
Energy Index	1,50 (C) → 1,19 (B)
Function of interviewee	Communication employee
Interview date	28-09-2015
Applied retrofit measures	Floor insulation HR++ windows Mechanical ventilation HR107 boiler (combi) Sun boiler
Rent increase (% over calculated saving)	50

Housing association	Urbanus, Belfeld
Function of interviewee	Director
Interview date	07-10-2015
Energy Index	2,61 (F) → B (1,29)
Applied retrofit measures	Roof insulation Cavity wall insulation Floor insulation HR++ windows with ventilation grates Improvement natural ventilation
Rent increase (% over calculated saving)	50

Housing association	GroenWest, Woerden
Function of interviewee	Project leader
Interview date	14-10-2015
Energy Index	1,80 (D) → 1,14 (B)
Applied retrofit measures	Roof insulation Cavity wall/façade insulation Floor insulation HR++ windows with ventilation grates Seal air leaks Mechanical ventilation
Rent increase (% over calculated saving)	50

Housing association	Omnia Wonen, Harderwijk
Function of interviewee	Project leader
Interview date	29-10-2015
Energy Index	1,94 (D) → 1,23 (B)
Applied retrofit measures	Roof insulation Cavity wall/façade insulation Floor insulation HR++ windows Seal air leaks DC ventilation HR107 boiler
Rent increase (% over calculated saving)	75

Housing association	`thuis, Eindhoven
Energy Index	1,63 (D) → 1,16 (B)
Function of interviewee	Project leader
Interview date	06-11-2015
Applied retrofit measures	HR++ windows with ventilation grates Mechanical ventilation HR107 boiler
Rent increase (% over calculated saving)	75

Housing association	Qua Wonen, Bergambacht
Function of interviewees	Project leader and employee quality care
Interview date	19-11-2015
Energy Index	1,85 (D) → 1,17 (B)
Applied retrofit measures	Roof insulation Adding facade insulation Seal air leaks
Rent increase (% over calculated saving)	16,7

Appendix B: Interview questions

1. When was the project executed?

2. What was the main motivation of the housing association to renovate this complex?

3. Which of the retrofit options suggested by Atriensis was applied to the complex?

4. Were there other renovation options combined with the thermal retrofit?

5. Were all dwellings of the complex part of the retrofit?

6. Did you apply the "70% rule" for participation?

7. When was the first communication with the tenants?

8. Did the tenants have sayings in the process of the thermal retrofit? How?

8. Did you apply a rent increase? Was this individually applied or an average rent increase for the whole complex?

9. How did you communicate this to the tenants?

10. How was the entire communication process from beginning to execution?

11. Did the tenants ask many questions about the rent increase?

13. Did you spent a lot of attention to the calculation of the rent increase, and to energy savings?

14. Did the tenants had many nuisance of the retrofit?

15. Did the tenants receive any information about their dwelling *after* the completion?

16. In what way, and by who did they receive information?

17. Is this the usual way your association treads these retrofits, or was this an exception? If it is, what is the usual, or current way?

18. Were the tenants approached in some way, for example a questionnaire, a while after completion about their opinion?

19. Do you feel that helping your tenants with energy savings at the time of the thermal retrofit belongs to the tasks of a housing association? Why?

20. Are there any other interesting projects aimed at communication and guidance of the tenants?

Appendix C: Operationalization scheme

Variables	Sub-variables	Indicator	Level of measurement	Question	Options
Socio-demographic factors	Age	Age	Ratio	What is your age?	
	Income	Net monthly household income	Ordinal	What is the net monthly income of your household?	Less than €1.500 Between €1.500 and €2.500 Between €2.500 and €3.500 More than €3.500 No answer
	Household composition	Household composition	Nominal	What is your household composition?	One person One adult with child(ren) Two adults with child(ren) Two adults no children Other, namely..
	Education level	Highest education completed	Nominal	What is your highest education?	None Low school Middle school Higher ? LBO MBO HBO/WO
	Working situation	Working situation	Nominal	Wat is your current situation? There are multiple answers possible	Job <12 hours Job ≥12 hours Entrepeneur House wife/man Student Unemployed Retired Other, namely..
	Years in current dwelling	Years in current dwelling	Ratio	How many years do you live in this dwelling?	
Ability	Change in habits/behavior	See: curtailment behavior			
	Knowledge	Energy consumption	Nominal	Which statement is most suitable to your situation, when it comes to the calculated energy savings compared to your actual energy savings after the renovation?	My savings are bigger than calculated. My savings are equal to the calculated savings. My savings are smaller than calculated. My energy consumption has stayed the same, so I did not save. My energy consumption has increased, so I did not save. I do not know (anymore/yet).
Motivation	Intention	Agreed with project	Nominal	Did you agree with the sustainable renovation?	Yes Yes, after doubting No
	Attitude	Motivation for project	Nominal?	What was the main reason for participating with the project?	a. Money or Environment (5 steps) b. Money or Comfort (5 steps) c. Environment or Comfort (5 steps)

Variables	Sub-variables	Indicator	Level of measurement	Question	Options
Energy saving behavior	Curtailment behavior	Shower time	Ordinal	How long do you shower on average? (Before and after the sustainable renovation)	≤ 4 minutes 5-8 minutes 9-12 minutes 13-16 minutes ≥ 17 minutes
		Shower frequency	Ordinal	How often do you shower on average per week? (Before and after the sustainable renovation)	≤ 1 2-4 5-6 7 > 7
		Ventilation window	Ordinal	How often do you use your windows for ventilation in the living room? (+ main bedroom) (Before and after the sustainable renovation)	Always Almost always Sometimes Seldom Never Not applicable
		Ventilation (grills?)	Ordinal	How often are your ventilation grills open? (Before and after the sustainable renovation)	Always Almost always Sometimes Seldom Never Not applicable
		Heating temperature	Ordinal	How long before bedtime do you turn the thermostat lower? (Before and after the sustainable renovation)	≥ 2 hours 1 – 2 hours 1 hour - 30 minutes Just before bedtime Not
		Heating empty rooms	Ordinal	How often are your radiators off in unused rooms? (Before and after the sustainable renovation)	Always Almost always Sometimes Seldom Never
	Investment behavior	Energy label of new household appliances	Ordinal	How often do you choose for an energy efficient label when buying household appliances? (Before and after the sustainable renovation)	Always Almost always Sometimes Seldom Never Not applicable
		Extra investment in appliances	Nominal	Did you buy new energy consuming appliances after the renovation, for example dryer, freezer or water bed?	Yes, namely…. No
		Extra investment in dwelling	Nominal	Did you made changes to the dwelling after the renovation, that leads to more energy consumption (extra room), or less energy consumption (insulation)?	Yes, namely.. No
Preferences of guidance	Satisfaction experienced renovation	Satisfaction of received guidance	Ordinal	How (dis)satisfied are you with the quality of the received information about the healthy and efficient use of the energy improved dwelling?	Very satisfied Satisfied Neutral Dissatisfied Very dissatisfied
		Satisfaction of received information about rent increase and calculated energy savings	Ordinal	How (dis)satisfied are you with the received information about the rent increase, as percentage of the calculated energy savings?	Very satisfied Satisfied Neutral Dissatisfied Very dissatisfied
		Wish for extra information	Nominal	Would you have liked to receive more information after the completion of the project about the efficient use of the energy improved dwelling?	Yes, namely…. No
	Preference for guidance after a sustainable renovation	Conjoint choice experiment			

Appendix D: 27 profiles for discrete choice experiment

Profile	Feedb 1	Feedb 2	Comm 1	Comm 2	Rew	Instr1	Instr2	Box	Feed_ Comm	Feedb _Rew	Comm _Rew
1	-1	-1	-1	-1	1	-1	-1	1	-1	-1	-1
2	-1	-1	-1	-1	-1	1	0	1	-1	-1	-1
3	-1	-1	-1	-1	1	0	1	-1	-1	-1	-1
4	-1	-1	1	0	1	1	0	1	-1	-1	1
5	-1	-1	1	0	-1	0	1	-1	-1	-1	-1
6	-1	-1	1	0	1	-1	-1	1	-1	-1	1
7	-1	-1	0	1	1	0	1	-1	-1	-1	1
8	-1	-1	0	1	-1	-1	-1	1	-1	-1	-1
9	-1	-1	0	1	1	1	0	1	-1	-1	1
10	1	0	-1	-1	1	1	0	-1	-1	1	-1
11	1	0	-1	-1	-1	0	1	1	-1	-1	-1
12	1	0	-1	-1	1	-1	-1	1	-1	1	-1
13	1	0	1	0	1	0	1	1	1	1	1
14	1	0	1	0	-1	-1	-1	1	1	-1	-1
15	1	0	1	0	1	1	0	-1	1	1	1
16	1	0	0	1	1	-1	-1	1	1	1	1
17	1	0	0	1	-1	1	0	-1	1	-1	-1
18	1	0	0	1	1	0	1	1	1	1	1
19	0	1	-1	-1	1	0	1	1	-1	1	-1
20	0	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
21	0	1	-1	-1	1	1	0	1	-1	1	-1
22	0	1	1	0	1	-1	-1	-1	1	1	1
23	0	1	1	0	-1	1	0	1	1	-1	-1
24	0	1	1	0	1	0	1	1	1	1	1
25	0	1	0	1	1	1	0	1	1	1	1
26	0	1	0	1	-1	0	1	1	1	-1	-1
27	0	1	0	1	1	-1	-1	1	1	1	1
Base	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Appendix E: Tenant questionnaire

Technische Universiteit
Eindhoven
University of Technology

Enquête energiebesparing na energiebesparende maatregelen

Deze enquête bestaat uit drie delen. De antwoorden worden voor niets anders dan dit onderzoek gebruikt, en volledig anoniem behandeld. De enquête is bedoeld voor de hoofdbewoner van uw woning.

Heeft u de uitvoering van de energiebesparende maatregelen (ingreep) meegemaakt in uw woning?

Met de energiebesparende maatregelen wordt bedoeld: Het onderhoudsproject dat door uw woningcorporatie destijds voor uw complex is aangekondigd en uitgevoerd.

O Ja: U start bij Deel 1.
O Nee: U start bij Deel 2 op pagina 4.

Deel 1

Beantwoord de eerste 8 vragen voor twee situaties: voor en na de het uitvoeren van de energiebesparende maatregelen (de ingreep) van uw woning. Is de situatie niet veranderd, dan vult u tweemaal hetzelfde in.

1. Hoe lang van te voren zet u uw thermostaat lager voor het slapen gaan?

Voor de ingreep	*Na de ingreep*
O 2 uur of langer	O 2 uur of langer
O 1 tot 2 uur	O 1 tot 2 uur
O Half uur tot 1 uur	O Half uur tot 1 uur
O Net voor het slapen	O Net voor het slapen
O Niet	O Niet

2. Hoe vaak staan de meeste van uw radiatoren uit in ongebruikte ruimtes?

Voor de ingreep	*Na de ingreep*
O Altijd	O Altijd
O Bijna altijd	O Bijna altijd
O Soms	O Soms
O Zelden	O Zelden
O Nooit	O Nooit

3. Hoe vaak staan de meeste van uw ventilatieroosters open?

Voor de ingreep	*Na de ingreep*
O Altijd	O Altijd
O Bijna altijd	O Bijna altijd
O Soms	O Soms
O Zelden	O Zelden
O Nooit	O Nooit
O Ik heb geen roosters	O Ik heb geen roosters

4. Hoe vaak gebruikt u uw ramen om te ventileren in de woonkamer?

Voor de ingreep	*Na de ingreep*
O Altijd	O Altijd
O Bijna altijd	O Bijna altijd
O Soms	O Soms
O Zelden	O Zelden
O Nooit	O Nooit
O Kan niet open	O Kan niet open

5. Hoe vaak gebruikt u uw ramen om te ventileren in de hoofdslaapkamer?

Voor de ingreep	*Na de ingreep*
O Altijd	O Altijd
O Bijna altijd	O Bijna altijd
O Soms	O Soms
O Zelden	O Zelden
O Nooit	O Nooit
O Kan niet open	O Kan niet open

6. Hoeveel minuten staat u gemiddeld onder de douche?

Voor de ingreep	*Na de ingreep*
O 4 minuten of minder	O 4 minuten of minder
O 5-8 minuten	O 5-8 minuten
O 9-12 minuten	O 9-12 minuten
O 13-16 minuten	O 13-16 minuten
O 17 minuten of meer	O 17 minuten of meer

7. Hoe vaak doucht u gemiddeld per week?

Voor de ingreep	*Na de ingreep*
O 1 keer of minder	O 1 keer of minder
O 2-4	O 2-4
O 5-6	O 5-6
O 7 (dagelijks)	O 7 (dagelijks)
O meer dan 7	O meer dan 7

8. Hoe vaak kiest u voor een energiezuinig label wanneer u nieuw witgoed aanschaft?
Witgoed is een verzamelnaam voor grote elektrische huishoudelijke apparatuur, waaronder wasmachine, koelkast, vriezer.

Voor de ingreep	*Na de ingreep*
O Altijd	O Altijd
O Bijna altijd	O Bijna altijd
O Soms	O Soms
O Zelden	O Zelden
O Nooit	O Nooit
O Niet van toepassing	O Niet van toepassing

9. Heeft u na de ingreep nieuwe elektrische apparaten gekocht die veel energie verbruiken, zoals een wasdroger, vriezer of waterbed?

O Ja, namelijk ____

O Nee

10. Hebben er grote veranderingen plaatsgevonden in uw huishoudensamenstelling sinds de ingreep? (bijv. gezinsuitbreiding)

O Ja, namelijk ____________________________

O Nee

11. Hebt u ingestemd met de energiebesparende maatregelen?

- O Ja
- O Ja, na twijfel
- O Nee (u kunt vraag 12 overslaan)

12. Wat is de voornaamste reden dat u hebt ingestemd met de energiebesparende maatregelen? *Geef dit op de onderstaande schaal aan, waarbij het middelste bolletje aangeeft dat u beide redenen even belangrijk vindt.*

a. Voornamelijk om de besparing	O	O	O	O	O	Voornamelijk om het milieu
b. Voornamelijk om de besparing	O	O	O	O	O	Voornamelijk om het comfort
c. Voornamelijk om het milieu	O	O	O	O	O	Voornamelijk om het comfort

13. Er is u vooraf een berekende energiebesparing gepresenteerd. Welke uitspraak over deze besparing denkt u dat het meest op uw situatie van toepassing is?

O Mijn besparing is groter dan de berekende besparing.
O Mijn besparing is even groot als de berekende besparing.
O Mijn besparing is kleiner dan de berekende besparing.
O Ik heb niet bespaard, want mijn energieverbruik is gelijk gebleven.
O Ik heb niet bespaard, want mijn energieverbruik is gestegen.
O Ik weet het niet (meer).

14. Hoe (on)tevreden bent u over de duidelijkheid van de gekregen informatie over de huurverhoging na de ingreep, berekend als een percentage van de energiebesparing?

O Erg tevreden
O Tevreden
O Neutraal
O Ontevreden
O Erg ontevreden

15. Hoe (on)tevreden ben u over de duidelijkheid van de gekregen informatie over het gezond en efficiënt omgaan met de veranderingen in uw woning?

O Erg tevreden
O Tevreden
O Neutraal
O Ontevreden
O Erg ontevreden

16. Had u na de voltooiing van de ingreep meer informatie willen ontvangen over hoe u zo goed mogelijk kan besparen op uw energieverbruik door de veranderingen in uw woning?

O Ja, namelijk ____
O Nee, ik ben tevreden met de ontvangen informatie

Deel 2

Het doel van dit deel van de vragenlijst is om te achterhalen hoe u als bewoner begeleid wil worden na het aanbrengen van energiebesparende maatregelen. Er zijn verschillende manieren om u te helpen bij het efficiënt omgaan met uw woning en installaties, en (daardoor) bij het besparen op uw energierekening. De volgende vragen gaan volgens een bepaalde methode, waarbij u elke keer twee keuzes worden voorgelegd. Deze keuzes bevatten verschillende combinaties van begeleidingsmethodes. Een voorbeeld:

Voorbeeldvraag: Welke aanpak spreekt u het meest aan om meer energie te besparen?

a) U ontvangt een energiebespaarbox en u kunt uw energieverbruik vergelijken met dat van de buurt.

b) U stelt met uw gezin een besparingsdoel vast en er komt een energiespecialist langs om u uitleg te geven over het gebruik van uw woning..

c) Geen van beide

De mogelijke begeleidingsmethodes worden hieronder toegelicht. Er volgen 14 vragen.

***1*. Feedback op energieverbruik:** Inzicht in uw energieverbruik via een display in de woonkamer of applicatie op uw tablet/smartphone. *Dat kan op twee manieren*:
1a. Vergelijkend met de buurt: U kunt uw energieverbruik anoniem vergelijken met het energieverbruik van de buurt.
1b. **Individueel**: U krijgt inzicht in uw eigen energieverbruik, waarbij u bijv. het verbruik per apparaat en het verloop van uw verbruik kunt zien.

2. Besparingsdoel vaststellen: U spreekt een bepaalde energiebesparing af dat u wilt gaan halen voor een bepaalde datum. Dit kan een percentage zijn (bijv. 10%), of een getal (bijv. de berekende besparing vanuit de woningcorporatie). *Dat kan op twee manieren:*
2a. Met de buurt: U stelt een besparingsdoel vast met de buurt, waardoor u elkaar kunt ondersteunen en motiveren.
2b. Individueel: U stelt een besparingsdoel vast met uw gezinsleden, die haalbaar is binnen uw huishouden.

3. Uitleg over woning: U ontvangt uitleg over de energie-gerelateerde kenmerken van uw woning. Hierdoor leert u hoe u de installaties en de woning zelf zo energie-efficiënt mogelijk kunt gebruiken. *Dat kan op twee manieren:*
3a. Brochure: U krijgt deze informatie schriftelijk toegestuurd.
3b. Energiespecialist: Er komt een energie expert langs, die u deze informatie zal geven en uw vragen kan beantwoorden.

4. Energiebespaarbox: U krijgt een pakketje thuisgestuurd met energiebesparende zaken. In dit pakket zitten bijv. energiezuinige LED-lampen, een douche-timer om bewust korter te douchen of een "standby-killer", een stekkerdoos met een knop om alle standby-apparaten uit te schakelen.

5. Beloning: Bij het behalen van een afgesproken besparingspercentage of –getal ontvangt u een beloning. Dit kan bijv. een cadeaubon zijn.

Omcirkel uw keuze.

1. **Welke aanpak spreekt u het meest aan om meer energie te besparen?**
a. U stelt een besparingsdoel vast met de buurt en u kan uw energieverbruik vergelijken met dat van de buurt via een display of app. U krijgt een energiebespaarbox en er komt een energiespecialist bij u thuis om u uitleg te geven over het gebruik van uw woning.
b. U stelt een besparingsdoel vast met de buurt. Er komt een energiespecialist bij u thuis om u uitleg te geven over het gebruik van uw woning. Haalt u het besparingsdoel, dan krijgt u een beloning.
c. Geen van beide

2. **Welke aanpak spreekt u het meest aan om meer energie te besparen?**
a. U stelt een besparingsdoel vast met uw gezinsleden. U krijgt een energiebespaarbox en een brochure met uitleg over het gebruik van uw woning. Haalt u het besparingsdoel, dan krijgt u een beloning.
b. U kunt uw energieverbruik vergelijken met dat van de buurt via een display of app. U krijgt een energiebespaarbox en als u veel bespaart krijgt u een beloning.
c. Geen van beide

3. **Welke aanpak spreekt u het meest aan om meer energie te besparen?**
a. U kunt uw energieverbruik vergelijken met dat van de buurt via een display of app.
b. U krijgt een brochure met uitleg over het gebruik van uw woning, en u krijgt een energiebespaarbox.
c. Geen van beide

4. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U stelt een besparingsdoel vast met uw gezinsleden en u kunt uw energieverbruik vergelijken met dat van de buurt via een display of app. U krijgt een energiebespaarbox en een brochure met uitleg over het gebruik van uw woning.

b. U stelt een besparingsdoel vast met de buurt. U kunt uw eigen energieverbruik inzien via een display of app en u krijgt een energiebespaarbox. Haalt u het besparingsdoel, dan krijgt u een beloning.

c. Geen van beide

5. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U kunt uw eigen energieverbruik inzien via een display of app en u krijgt een energiebespaarbox. Als u veel bespaart krijgt u een beloning.

b. U stelt een besparingsdoel vast met uw gezinsleden en u uw eigen energieverbruik inzien via een display of app. U krijgt een energiebespaarbox.

c. Geen van beide

6. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U stelt een besparingsdoel vast met uw gezinsleden en u kunt uw energieverbruik vergelijken met dat van de buurt via een display of app. Haalt u het besparingsdoel, dan krijgt u een beloning.

b. U stelt een besparingsdoel vast met de buurt. U krijgt een energiebespaarbox en een brochure met uitleg over het gebruik van uw woning. Haalt u het besparingsdoel, dan krijgt u een beloning.

c. Geen van beide

7. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U stelt een besparingsdoel vast met de buurt en u kunt uw energieverbruik vergelijken met dat van de buurt via een display of app. U krijgt een energiebespaarbox en een brochure met uitleg over het gebruik van uw woning. Haalt u het besparingsdoel, dan krijgt u een beloning.

b. U stelt een besparingsdoel vast met uw gezinsleden en u kunt uw energieverbruik inzien via een display of app. Er komt een energiespecialist langs om u uitleg te geven over het gebruik van uw woning. Haalt u het besparingsdoel, dan krijgt u een beloning.

c. Geen van beide

8. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U kunt uw eigen energieverbruik inzien via een display of app. Er komt een energiespecialist langs om u uitleg te geven over het gebruik van uw woning en u krijgt een energiebespaarbox.

b. U stelt een besparingsdoel vast met uw gezinsleden en u kunt uw energieverbruik vergelijken met dat van de buurt via een display of app. Er komt een energiespecialist langs om u uitleg te geven over het gebruik van uw woning en u krijgt een energiebespaarbox. Haalt u het besparingsdoel, dan krijgt u een beloning.

c. Geen van beide

9. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U stelt een besparingsdoel vast met uw gezinsleden en u krijgt een energiebespaarbox. Haalt u dit besparingsdoel, dan krijgt u een beloning.

b. U kunt uw energieverbruik vergelijken met dat van de buurt via een display of app. U krijgt een energiebespaarbox en er komt een energiespecialist langs om uitleg te geven over het gebruik van uw woning. Als u veel bespaart krijgt u een beloning.

c. Geen van beide

10. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U kunt uw eigen energieverbruik inzien via een display of app. U krijgt een brochure met uitleg over uw woning en als u veel bespaart krijgt u een beloning.

b. U stelt een besparingsdoel vast met uw gezinsleden en u kunt uw eigen energieverbruik inzien via een display of app. U krijgt een energiebespaarbox en er komt een energiespecialist langs om uitleg te geven over het gebruik van uw woning. Haalt u het besparingsdoel, dan krijgt u een beloning.

c. Geen van beide

11. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U krijgt een <u>brochure met uitleg</u> over het gebruik van uw woning, en u krijgt een <u>energiebespaarbox</u>.
b. U stelt een <u>besparingsdoel</u> vast met de buurt en u kunt uw <u>energieverbruik vergelijken</u> met dat van de buurt via een display of app. Haalt u het besparingsdoel, dan krijgt u een <u>beloning</u>.
c. Geen van beide

12. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U krijgt een <u>energiebespaarbox</u> en als u veel bespaart krijgt u een <u>beloning</u>.
b. U stelt een <u>besparingsdoel</u> vast met de buurt en u krijgt een <u>energiebespaarbox</u>.
c. Geen van beide

13. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. Er komt een <u>energiespecialist</u> langs om u uitleg te geven over het gebruik van uw woning. Als u veel bespaart krijgt u een <u>beloning</u>.
b. U stelt een <u>besparingsdoel</u> vast met uw gezinsleden. Er komt een <u>energiespecialist</u> langs om u uitleg te geven over het gebruik van uw woning.
c. Geen van beide

14. Welke aanpak spreekt u het meest aan om meer energie te besparen?

a. U stelt een <u>besparingsdoel</u> vast met de buurt en u kunt uw <u>eigen energieverbruik inzien</u> via een display of app. U krijgt een <u>brochure met uitleg</u> over het gebruik van uw woning.
b. U stelt een <u>besparingsdoel</u> vast met de buurt en u kunt uw <u>eigen energieverbruik inzien</u> via een display of app. Er komt een <u>energiespecialist</u> langs om u uitleg te geven over het gebruik van uw woning en u krijgt een <u>energiebespaarbox</u>. Haalt u het besparingsdoel, dan krijgt u een <u>beloning</u>.
c. Geen van beide

<u>Deel drie</u>

1. Wat is uw netto maandinkomen?

○ Minder dan €1000
○ Tussen de €1000 en €1500
○ Tussen de €1500 en €2000
○ Tussen de €2000 en €2500
○ Meer dan €2500
○ Geen antwoord

2. Wat is het netto maandinkomen van uw totale huishouden?

○ Minder dan €1.500,-
○ Tussen €1.500,- en €2.500,-
○ Tussen €2.500,- en €3.500,-
○ Meer dan €3.500,-
○ Geen antwoord

3. Wat is de huidige samenstelling van uw huishouden?

○ Eenpersoonshuishouden
○ Eén volwassene met kind(eren)
○ Twee volwassenen met kind(eren)
○ Twee volwassenen zonder kinderen
○ Anders, namelijk ___________________________

4. Wat is uw hoogst voltooide opleiding?

○ Geen
○ Basisonderwijs / lagere school
○ Lager/middelbaar voortgezet onderwijs
○ Hoger alg. voortgezet onderwijs
○ Lager beroepsonderwijs LBO
○ Middelbaar beroepsonderwijs MBO
○ HBO / WO

5. Wat is uw huidige situatie? Er zijn <u>meerdere</u> antwoorden mogelijk.
○ Betaalde baan minder dan 12 uur
○ Betaalde baan 12 uur of meer
○ Eigen bedrijf
○ Huisman/huisvrouw
○ Student/scholier
○ Werkloos/werkzoekend
○ (Deels) arbeidsongeschikt
○ Gepensioneerd
○ Anders, namelijk ___________________________

6. Wat is uw leeftijd?

______ jaar

7. Hoeveel jaar woont u in dit huis?

______ jaar

Dit is het einde van de vragenlijst, ik dank u hartelijk voor uw deelname! Bent u benieuwd naar de resultaten van het onderzoek en/of wilt u kans maken op de cadeaubon? Laat dan hier uw (e-mail)adres achter: ____

○ Ik wil de resultaten ontvangen
○ Ik wil mee-loten voor de cadeaubon

Heeft u nog opmerkingen? Die kan u hieronder kwijt:

De gegevens worden alleen voor dit onderzoek gebruikt, en anoniem behandeld.
U kunt nu de ingevulde enquête in de bijgevoegde kleine envelop doen, en kosteloos terugsturen. Er hoeft dus geen postzegel meer bij!

Appendix F: Project details of tenant questionnaire

Housing association *(city)*	City of complex	No. of complex	Year of retrofit	No. of tenants	No. of respondents	Response rate (%)
Rhiant *(Hendrik Ido Ambacht)*	Hendrik Ido Ambacht	112	2012	71	13	18,3
Urbanus *(Belfeld)*	Belfeld	15	2013/ 2014	58	20	34,5
GroenWest *(Woerden)*	Montfoort	1407	2013	52	11	21,2
Standvast Wonen *(Nijmegen)*	Nijmegen	508	2010	148	28	14,0
	Beuningen	608	2011	52		
Omnia Wonen *(Harderwijk)*	Nunspeet	18a	2013	65	30	14,1
		18b,c	2014	148		
Qua Wonen *(Bergambacht)*	Krimpen a/d Ijssel	75	2012/ 2013	117	35	15,6
	Schoonhoven	659	2012	108		
'thuis *(Eindhoven)*	Eindhoven	45	2012	64	10	8,8
	Best	114	2012	51		

Appendix G: Paired t-test

Groenwest: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Thermostat settings b – a	,300	1,059	,335	-,458	1,058	,896	9	,394
Pair 2	Radiator unused rooms b - a	,091	,302	,091	-,112	,293	1,000	10	,341
Pair 4	Window living room b - a	,000	,500	,167	-,384	,384	,000	8	1,000
Pair 6	Shower time b - a	-,300	,949	,300	-,979	,379	-1,000	9	,343

`thuis: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Thermostat settings b – a	,286	,756	,286	-,413	,985	1,000	6	,356
Pair 2	Radiator unused rooms b - a	,111	,333	,111	-,145	,367	1,000	8	,347
Pair 4	Window living room b - a	-,111	,333	,111	-,367	,145	-1,000	8	,347
Pair 8	Green label appliances b - a	,222	,667	,222	-,290	,735	1,000	8	,347

Urbanus: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Thermostat settings b – a	,294	,588	,143	-,008	,596	2,063	16	,056
Pair 2	Radiator unused rooms b - a	,368	1,012	,232	-,119	,856	1,587	18	,130
Pair 3	Ventilation grids b - a	,000	,365	,091	-,195	,195	,000	15	1,000
Pair 4	Window living room b - a	-,111	,758	,179	-,488	,266	-,622	17	,542
Pair 5	Window bed room b - a	-,105	,459	,105	-,326	,116	-1,000	18	,331

Qua Wonen: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Thermostat settings b – a	,000	,577	,115	-,238	,238	,000	24	1,000
Pair 2	Radiator unused rooms b - a	-,034	,680	,126	-,293	,224	-,273	28	,787
Pair 3	Ventilation grids b - a	,000	1,202	,276	-,579	,579	,000	18	1,000
Pair 4	Window living room b - a	-,393	,875	,165	-,732	-,054	-2,375	27	,025
Pair 5	Window bed room b - a	-,037	,587	,113	-,269	,195	-,328	26	,746
Pair 6	Shower time b - a	,179	,476	,090	-,006	,363	1,987	27	,057
Pair 7	Shower frequency b - a	,036	,189	,036	-,038	,109	1,000	27	,326
Pair 8	Green label appliances b - a	,292	,908	,185	-,092	,675	1,574	23	,129

Omnia Wonen: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Thermostat settings b – a	,303	,637	,111	,077	,529	2,734	32	,010
Pair 2	Radiator unused rooms b - a	-,114	,530	,090	-,296	,068	-1,276	34	,211
Pair 3	Ventilation grids b - a	,172	,711	,132	-,098	,443	1,307	28	,202
Pair 4	Window living room b - a	,167	1,090	,223	-,294	,627	,749	23	,461
Pair 5	Window bed room b - a	-,057	,236	,040	-,138	,024	-1,435	34	,160
Pair 6	Shower time b - a	,057	,338	,057	-,059	,173	1,000	34	,324
Pair 8	Green label appliances b - a	,156	,448	,079	-,005	,318	1,973	31	,057

Standvast Wonen: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Thermostat settings b – a	,050	,394	,088	-,134	,234	,567	19	,577
Pair 2	Radiator unused rooms b - a	,273	,883	,188	-,119	,664	1,449	21	,162
Pair 3	Ventilation grids b - a	,250	1,251	,280	-,336	,836	,893	19	,383
Pair 4	Window living room b - a	-,056	,639	,151	-,373	,262	-,369	17	,717
Pair 5	Window bed room b - a	,091	,426	,091	-,098	,280	1,000	21	,329
Pair 6	Shower time b - a	,091	,426	,091	-,098	,280	1,000	21	,329
Pair 7	Shower frequency b - a	-,048	,218	,048	-,147	,052	-1,000	20	,329
Pair 8	Green label appliances b - a	,100	,308	,069	-,044	,244	1,453	19	,163

Rhiant: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Thermostat settings b – a	,,444	,527	,176	,039	0,850	2,530	8	,0035
Pair 2	Radiator unused rooms b - a	,364	1,206	,364	-,447	1,174	1,000	10	,341
Pair 3	Ventilation grids b - a	,222	1,202	,401	-,702	1,146	,555	8	,594
Pair 4	Window living room b - a	,400	,966	,306	-,291	1,091	1,309	9	,223
Pair 5	Window bed room b - a	,100	,316	,100	-,126	,326	1,000	9	,343
Pair 6	Shower time b - a	,091	,302	,091	-,112	,293	1,000	10	,341
Pair 7	Shower frequency b - a	-,182	,603	,182	-,587	,223	-1,000	10	,341
Pair 8	Green label appliances b - a	,273	,647	,195	-,162	,707	1,399	10	,192

Appendix H: Multinomial Logit Model output

```
|-> DISCRETECHOICE;Lhs=CHOICE;Choices=1,2,base;Rhs=FEEDB1,FEEDB2,COMM1,COMM2
    ,REWARD,INSTR1,INSTR2,ENERGYSA,FEEDB_CO,FEEDB_RE,COMM_REW;Rh2=ONE$

+-------------------------------------------------------+
|WARNING:   Bad observations were found in the sample. |
|Found  13 bad observations among      770 individuals. |
|You can use ;CheckData to get a list of these points. |
+-------------------------------------------------------+

Normal exit:   5 iterations. Status=0, F=    756.6168

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable              Choice
Log likelihood function      -756.61682
Estimation based on N =    757, K =  13
Inf.Cr.AIC  =   1539.2 AIC/N =    2.033
Model estimated: Feb 24, 2016, 11:55:17
R2=1-LogL/LogL* Log-L fncn R-sqrd R2Adj
Constants only   -831.4176  .0900 .0821
Chi-squared[11]          =    149.60149
Prob [ chi squared > value ] =   .00000
Response data are given as ind. choices
Number of obs.=   770, skipped   13 obs
--------+--------------------------------------------------------------------
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
  FEEDB1|     .20665*       .11321     1.83  .0679     -.01523    .42853
  FEEDB2|    -.40954***     .11893    -3.44  .0006     -.64264   -.17645
   COMM1|     .23565**      .11517     2.05  .0407      .00992    .46138
   COMM2|    -.83677***     .12293    -6.81  .0000    -1.07772   -.59583
  REWARD|     .28516**      .12741     2.24  .0252      .03545    .53487
  INSTR1|     .41929***     .08897     4.71  .0000      .24491    .59367
  INSTR2|    -.50722***     .08602    -5.90  .0000     -.67582   -.33862
ENERGYSA|     .11464*       .06785     1.69  .0911     -.01835    .24763
FEEDB_CO|     .17251        .12455     1.39  .1660     -.07160    .41662
FEEDB_RE|    -.12440        .12938     -.96  .3363     -.37798    .12918
COMM_REW|    -.15962        .12899    -1.24  .2159     -.41244    .09320
     A_1|     .31615        .30822     1.03  .3050     -.28796    .92026
     A_2|     .57401*       .32813     1.75  .0802     -.06912   1.21714
--------+--------------------------------------------------------------------
Note: ***, **, * ==>  Significance at 1%, 5%, 10% level.
-----------------------------------------------------------------------------
```