LESSONS ON THE INTERACTION BETWEEN USERS AND TECHNOLOGIES IN ENERGY RENOVATIONS

JULY 2022

IEBB THEMA 2

DATAGEDREVEN OPTIMALISATIE VAN RENOVATIECONCEPTEN

TABLE OF CONTENTS

PART 1: INTRODUCTION

Renovations of existing residential building stock which aim to improve both energy efficiency and living conditions have a long history in the Netherlands. Parallel to this, the Dutch heating, cooling and ventilation sector has a long track record of innovation and evolution. In recent years, following the introduction of the Dutch Klimaatakkoord, many efforts have gone towards improving the collaboration between the housing and technology sectors to achieve new levels of efficiency and thermal comfort in the residential sector.

While the number of planned low and zero-energy renovations in the Netherlands is on the rise, achieving efficiency, cost savings and resident satisfaction once a building is operational continues to be challenging to achieve. This is partly due to mismatches between calculated and actual performance. Furthermore, the interaction between building occupants and heating, cooling and ventilation technologies, significantly influences the outcomes of energy renovations.

Goal of this Report

This report shares replicable lessons for technology providers, real estate developers, installers, building owners and managers interested in designing, implementing and monitoring more effective energy efficiency renovation technologies and concepts.

The report includes:

- Lessons for the design of more user-centered and effective energy renovation technologies and concepts. This includes recommendations for on the process of designing energy renovation technologies in such a way that takes into account future real people-technology interactions. Lessons are based on experience from real, executed projects.
- Lessons for monitoring the impacts of more user-centered energy renovation technologies and concepts. This includes insights into real people-technology interactions from executed projects in the field and recommendations on which parameters to measure and monitor to assess how a user-centered renovation concept performs in practice.

Workshop Approach

This report is based on input gathered in workshops conducted as part of the *Integrale Energietransitie in Bestaande Bouw Theme 2 - Data-driven Optimization of Renovation Concepts* project within *Activity 1 – Mobiliseren en activeren van informatie uit bestaande data en kennis* and *Activity 2 - Interactie gedrag en renovatieconcepten*.

The lessons contained in this report are derived from the practical experience of professionals shared in three workshops. The workshops were held with members of the IEBB Theme 2 consortium and other professionals working on user-centered design in energy renovation technologies. In total, 15 speakers presented on real implemented projects. All attendees were invited to discuss the lessons shared in the presentations and add to the points made by the speakers. Speakers and participants were asked to share knowledge on residents' interaction with the systems in their home, as well as monitoring methods and design methods.

The goals of the workshops were to:

- Gather insights on what is observed in executed projects, and hence what deserves attention in terms of the interaction of users with their homes.
- To inform the stakeholder field concerned the development of sustainable technologies for the home and with sustainable renovation projects by giving recommendations for planning.

This report contains a compilation of the lessons shared in the workshops – it offers a compilation of existing knowledge on residents' interaction with energy renovation systems in their home, as well as methods for monitoring behaviour. The lessons contained in this report are based on the real-life, practical experience of the workshop attendees and do not necessarily reflect the advice of the project consortium.

The energy renovation projects explored in the workshops are listed in Table 1 – these are the projects upon which the lessons in this report are based. See *Appendix I – Workshop Overview* for a full description of the workshops, attendees and for links to the presentations and recordings.

Table 1: Residential Projects Discussed in This Report

Name: 2nd Skin Project Location: South Holland Housing Type: 12 apartments, 3 stories Date of Renovation Completion: 2018 Energetic Aim: Energy-neutral and energy-neutral ready (Nul-op-de-meter/NOM and NOM-ready) Energy Technologies Used: Insulation, solar panels, ground-source heat pump, electric boiler, balanced ventilation convectors Actual Energy Performance: Energetic aim was achieved	Name: Nearly Energy Neutral Houses / Bijna Energieneutrale Gebouwen (BENG) Houses Location: Almere Housing Type: Row houses Date of Renovation Completion: n/a Energetic Aim: BENG Energy Technologies Used: Underfloor heating, heat-recovery ventilation
Name: Kolenkit buurt Location: Kolenkit District, Amsterdam Housing Type: Date of Renovation Completion: Energetic Aim: Energy technologies used: low-temperature floor heating with thermostats in each room, ventilation grates in the windows	Name: NOM New-build Location: Reigersbos, Amsterdam Housing Type: Apartment building Date of Renovation Completion: n/a Energetic Aim: NOM Energy Technologies Used: 45cm insulated walls with triple-pane glass, infrared heaters
Name: Inside Out, De Henriëttedreef Location: Overvecht, Utrecht Housing Type: High-rise apartment building, 10 storeys and 58 units Date of Renovation Completion: 2020 Energetic Aim: Energy Positive Energy Technologies Used: Rooftop and face PV, heat pumps, hot water boosters in apartments, pre-fab façade, smart grid with battery storage, deep insulation	Name: VACpunt Wonen Study Location: Across the Netherlands Housing Type: Many (including new-build, renovated houses, rental and owned homes) - 17 projects in total Date of Contruction/Renovation Completion: 2019-2012 Energetic Aim: Many (focused on buildings with high energy efficiency standards and new technologies Energy Technologies Used: Energy road system, heat pumps, low-temperature heating (LTV)
Name: IRIS Location: Kanaleneiland-Zuid District, Utrecht Housing Type: Apartments (12 blocks, 644 dwellings) Date of Renovation Completion: Ongoing Energetic Aim: NZEB Energy Technologies Used: Heating radiators, insulated glazing and windows with ventilation grills, improved front door, façade insulation, mechanical ventilation system, rooftop PV, insulation on the ground floor and roof.	Name: 3 NOM New-Builds and Renovations (42 houses) Locations: Roden & Holtenweg Date of Contruction/Renovation Completion: 2014, 2016 and 2017 Energetic Aim: NOM Energy Technologies Used: Energy road system, heat pumps, low-temperature heating (LTV)

PART 2: LESSONS ON DESIGN IN THE IMPLEMENTATION STAGE

As part of the workshops, speakers and participants discussed current approaches for designing energy renovation technologies, shortcomings with current approaches, and ideas and examples for designing technologies in a more user-centered way.

This section contains lessons for building owners, technology providers, construction companies and installers wishing to take the needs of building occupants into account in the implementation stage.[1]

The lessons learned shared here are categorised according to three basic needs of residents:

- The need for thermal comfort
- The need for fresh air
- The need for a manageable and comfortable living environment

The Need for Thermal Comfort

Thermal comfort is influenced and achieved by changing indoor temperatures and humidity levels, as well as the number of occupants and the amount of physical activity of residents at a given time, as well as what residents are wearing. The primary energy systems impacting thermal comfort include the heating system, ventilation system and windows.

Observations & What We See in Practice

- From an installation perspective, there are typically many components involved in the regulation, control and distribution of heat.
- Low-temperature heating systems introduce new ways of heating (e. g. convective heating instead of radiant heating) .
- It can take longer to heat (or cool) with efficient low temperature heating. Because the temperature is also more stable in well-insulated housing, heating effects can become so subtle they become difficult for residents to perceive. Residents may come to believe that their heating is not working.
- In some observed projects, residents were asked or advised to keep their thermostat at a fixed setpoint (e.g. 20 degrees) or not to use it at all. From an energy efficiency point of view, low-temperature heating should be kept as stable as possible. However, it was found that the residents attempt to adjust the heating for comfort. Thermostats tend to be prominently present in the living room, which makes it counterintuitive not to use them.
- Optimal interfaces for human interaction with the systems may not exist yet. They might not be intuitive or easy to understand.
- In observed projects, some residents did not have a smart meter in their homes, which made it more difficult for them and external parties to monitor energy consumption.
- In observed projects, interfaces were not always congruent with the capabilities of the system. (For example, in one case, a thermostat showed a range from 18-24 degrees, but the system's settings only provided 22 degrees). Such occurrences maybe due to design, a maladjusted system or incompatible resident practices such as window opening or blocking of heat distribution sources with furniture. It may be difficult to pinpoint which (combination of) these reasons lead to the observed result. See Image 1.

[1] The lessons contained in this report are based on the real-life, practical experience of the workshop attendees and do not necessarily reflect the advice of the project consortium.

- Current regulations specify that zero energy needs to be proven per dwelling unit. It should be questioned whether this is an effective strategy going forward, since consumption varies a lot per dwelling unit for a wide range of reasons (including system robustness).
- In novel systems or novel combinations of systems, mismatches may occur. These can result in interfaces that are unreachable, difficult to operate or contradictory.
- Heat loss calculations NZEB are now designed for 22 degree set point (not 20). This is because of "koude val" (or the feeling of cold air drafts especially near windows), assuming people will find 20 degrees too cold.

Image 1: Workshop slide illustrating the discrepancy between the expectations of installers and residents

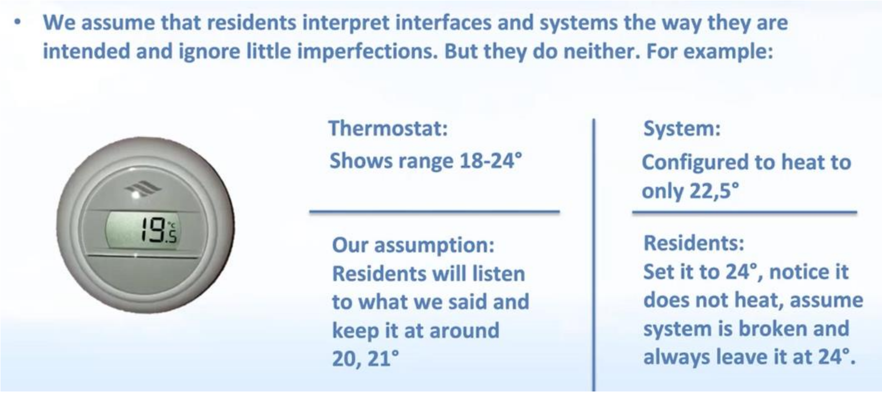


Image Source: Stella Boess

How Things Can go Wrong

- When a heating system does not reach the temperature set point shown on a thermostat, residents lose trust. They may leave the setpoint at the highest setting (leading to high costs) and turn to counter-productive practices like purchasing electric heaters.
- In the Netherlands, the Huurcommissie sees it as a fault if the temperature cannot reach 20 degrees C in living areas and 15C in the halls, corridors, etc. Yet due to issues with the (adjustment of) new technology, this sometimes occurs. In some cases, it persisted for some time.
- In low-temperature heating systems, users do not get direct thermal feedback in the same way that they would with radiators. This might cause disquiet and uncertainty about the functioning of the system.
- In a well-insulated dwelling, the temperature will become more balanced, and with that, more pleasant and healthy, but also less noticeable for the residents. They may miss a recognisable heat source. In addition, if residents open windows or doors during an extreme outdoor temperature period, the indoor climate system struggles longer to recover, due to its lower power.
- With low-temperature heating, residents are no longer exposed to radiant heating. Residents may feel colder than with their previous heat sources. This means that the temperature set point alone may no longer be a good indicator of thermal comfort. This challenge relates to the residents' perception.
- it can be difficult for residents to achieve a specific desired temperature via the thermostat, because the actual indoor temperature depends on several other factors as well, such as irradiation and heat transmission between housing units (e.g. in apartments with shared walls). This combination of factors makes it difficult for residents to understand why the temperature in their dwelling can be quite different from the setting they selected on their thermostat.
- Mistakes during the installation of building services technology might inadvertently prevent the technology from working optimally (for example a door frame might block the underfloor heating pipe, which would prevent the heat from fully reaching the house). See Image 2 for example.

- If the operation and maintenance of ventilation systems is difficult to do, residents are not able to keep it up in the long run, even if it has been explained to them. This can result in increased energy consumption and a risk to residents' health in well-insulated buildings.

Image 2: Heating equipment being inadvertently prevented from working optimally

Image Source: Woon!

Dos & Don'ts for Improving the Interaction Between People and Technology

- Inform residents on how to adjust temperature settings
- Communicate successes and benefits to residents (lower energy bills, better air quality, greater levels of reliability, for example).
- Recognize that preferences will vary from person to person. Create greater variability in heating set point options (within the boundaries of what a heat pump can offer).
- Consider that some of the features of the home will have an impact on heating and cooling needs. A cold basement, for example, might cause heating needs to increase in winter, but might reduce cooling needs in summer.
- Consider that people are unique and have a wide range of preferences (some prefer cooler temperatures, others prefer warmer temperatures). If the systems you design cannot deliver high enough temperatures, the design needs to account for those higher heating needs without unfairly disadvantaging these residents.
- Consider that residents may need a reference point to interpret their own thermal comfort. For example, something to provide residents with an answer to the following: "Would I normally feel warm at this temperature? Then the heating must be set to the right level."
- Weigh the impacts of alternative heating methods in terms of thermal comfort and energy efficiency. The right mix of for example underfloor heating (convective heat) and infrared panels (radiative heat) may not be the most energy efficient on paper, but it may be so in practice because residents experience comfort and do not feel the need to introduce extra heat sources.
- In multi-unit buildings, consider how the homes will be sub-metered and billed for usage. In cases with high levels of heat transmission between units, and in cases where the overall influence by residents on the system is very low, it may be advisable not to settle heat bills on a unit-by-unit basis.

The Need for Fresh Air

Fresh air in the home is influenced by the ability to open windows and by the ventilation system.

Observations & What We See in Practice

- Ventilation systems are now designed to ensure an optimal exchange of air in a home. In principle, windows do not need to be opened ventilation purposes. However, residents will likely still want to open windows for fresh air and to engage with the outdoors. One participant stated that when averaged over a whole year, windows in one project were open five percent of the time.
- Windows, though efficient (insulated, triple pane) may be not be designed to open in a way that still saves energy. Likewise, they may not be easy to operate, for example due to being too heavy.
- How the ventilation system responds to the control panel in the home is often not well-understood or apparent for residents.

How Things Can go Wrong

- We sometimes see the combination of low temperature floor heating (30C) and trickle vents in the windows. This creates cold draft from the vent to the floor due to cold air going down and warm air going up. Besides an energy efficiency risk, this combination is also a risk for accidents, since residents climb on chairs to close the vents. When they have closed them, they often stay closed, jeopardizing residents' health due to bad indoor air quality. The combination should either be avoided or a supplementary heat source by the window added.
- Residents are often not familiar with the ventilation systems, or ventilation principles in a net-zero energy home. Residents might therefore disengage with the system and not be willing to use it or maintain it.
- Residents might have the perception that it is unnecessary to have the ventilation constantly running and see it as a waste of energy.
- CO2 levels might reach uncomfortable and unhealthy levels in rooms which are poorly ventilated.
- Residents might find the system slow, irritating, and may have issues with control, they might also have the feeling that the system is not transparent.
- While the ventilation serves to clean the air, residents could feel a loss of control over their situation if they cannot open windows for fresh air or to connect with the outdoors.
- Residents might block or disable ventilation systems (e.g. closing valves) and regular maintenance may not be performed.
- When there is a lack of feedback from the ventilation system (for example if nothing immediately happens when a button is pressed), residents might feel insecure and lose trust in the system.

Dos & Don'ts for Improving the Interaction Between People and Technology

- Windows are an underestimated design element, since their operation is apparent, and the feedback is clear and immediate. With that, windows are one of the most trustworthy interfaces in the house for residents. If residents feel a need for something, such as fresh air, they will try to realize it! This is likely why people turn to windows quickly instead of other alternatives that are less clear, trustworthy and have less direct feedback.
- Consider CO2-controlled mechanical ventilation boxes to help with the turnover of air in the home. Sleeping rooms deserve extra attention to CO2 levels, for example by monitoring CO2 and/or providing double inflow valves for extra air flow without extra noise.
- Improve user interfaces of ventilation systems to provide users with feedback. Make them smarter and more transparent. The Toon thermostat and Factory Zero technologies offer a good example of how feedback can be provided directly to users in the moment. However, the positioning of the feedback could be reconsidered as it could be connected to other household practices than heating and the living room thermostat.

- Design for variability, accounting for diversity in preferences and use (for example noise tolerance when the ventilation system is at a higher setting, differences in levels of interaction with the system, etc.).
- Assume residents will wish to open windows. The observed renovation projects revealed that 'fresh' air also means cooler air for residents, otherwise it does not feel fresh for their lungs. Besides fresh air, windows also have a function of connecting people with the outdoors which is a need for many.

The Need for a Manageable and Comfortable Living Environment

Observations & What We See in Practice

- We focus on advising residents to change or adopt behaviours, but forget that our renovation concepts often expect too much from residents.
- When technologies and features do not work the same way after a renovation as they did before (for example if windows do not need to be opened, or the heating can be adjusted via a central thermostat), residents may need to "unlearn and re-learn" habits. This unlearning and re-learning should be supported by renovation consortia, for example through service design concepts. If this is not done, residents are probably more likely to maintain pre-renovation habits like opening windows.
- The financial arrangements for tenants in (nearly) zero-energy buildings are still in flux (energy efficient home fee ("energieprestatievergoeding" (EPV)), introduced in 2016 , https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels/bestaande-bouw/energieprestatievergoeding. These arrangements importantly determine financial manageability for housing corporations and tenants alike and play a crucial role in adoption and upscaling.
- Technologies and renovation concepts are currently often designed and implemented from a perspective of technical feasibility. Their integration in the home and their functioning in the context of residents' daily life practices are not yet sufficiently considered in the design phases.
- The new technologies bring with them a need for changes in lifestyles and daily life practices. This is currently often treated as an 'after renovation' issue, to be addressed in instruction materials for residents.

How Things Can go Wrong

- When the user's perspective is not sufficiently considered, there will likely be a discrepancy between expected user interaction with realized systems. For example, if there are very different levels of user action complexity within one system. Residents may be told to have *little interaction* with elements like thermostats which are visually the most accessible to them ("don't touch it and leave it on 20"), while they are told to *interact more intensely* with a ventilation system they cannot see or assess ("put it on the timer after showering and cooking"), and then told to enact *highly complex procedures* with something they rarely see and are not alerted to, like servicing the ventilation system filters. In all likelihood, in such a scenario, the residents will end up doing the opposite to the instruction: they will *interact a lot* with the thermostat due to its perceptual availability, and *omit* filter servicing due to its remoteness.
- Because energy is often low on the list of priorities for residents (especially when they are just moving homes), learning about new technologies, and adjusting temperature settings might not be top-of-mind for them. The system could remain untouched and ultimately remain in a sub-optimal setting for extended periods of time.[2]
- Residents may be afraid of trying to understand new technology and might not engage with it at all.
- User interfaces, depending on the design, may be intimidating. Especially in cases where someone is coming from a home without a thermostat or ventilation controls. See Image 3.

[2] Example: "We moved residents from a home without a thermostat to a home with a thermostat. It was never touched, and in the end the resident was left with a bill of 2.400. It turns out the thermostat had been set to 23 degrees and never changed."

  - In the experience of one housing corporation, it was essential that in-home display were reliable. Residents experience it as distressing when they break down.
- There might be confusion among residents about what costs the EPV does and does not cover.
- In cases where de-mountable, battery-operated thermostats are placed in each room, they may unknowingly be switched by residents. The same goes for ventilation valves when they are taken out for cleaning. These elements are currently often not been designed for consistent lay operation.
- In new-build homes, residents might have very little awareness about what they are buying into. The same goes for tenants moving into a NZEB renovated home.
- In new-build or renovation, the selling or renting agent may not know or may not feel confident about explaining the new technology, and may not inform residents properly or at all.

Image 3: Ventilation controls may not be intuitive for residents

Image Source: BikBouw

Dos & Don'ts for Improving the Interaction Between People and Technology

- There are risks for all parties throughout the renovation process, especially when new technologies are being used. As much as possible, try to identify and communicate about the risks in a planning process (for example, a building owner might be required to come up with innovative solutions for sub-metering and billing, a resident might have to cope with technologies not working perfectly, etc.). Anticipating such risks improves the chances of acting on them.
- It is important to understand how residents are using components of their home (from a non-technical point of view). By understanding what matters to them, it becomes easier to communicate about the installations in a meaningful way and to potentially provide feedback to manufacturers on design improvements
- When making assumptions about what might be 'better' for residents, involve residents in evaluating and adapting these assumptions.
- Set up coherent instructions on how residents should interact with, and service, the system. Make these instructions accessible for people of all abilities.
- Design the technologies like heating and ventilation units to be user-friendly for maintenance and make them part of the home experience (i. e. no servicing of filters on an attic or in a shed).
- For multi-unit rental buildings, form a technical team made up of tenants on-site. This can serve to provide a first point of contact when residents have questions, and can also help build trust among residents in the new technologies
- Manuals for residents should be designed from the perspective of the resident and their daily life practices, and not from the perspective of the technology. Currently the practice is often to make manuals for residents by simply combining the manuals of the various technologies that

are implemented. This does not work. For example, if all thermostats and ventilation valves look the same, make sure to explain to residents that the thermostats or ventilation valves should not be switched from room to room.
- Manuals for residents should not be used to compensate for deficient design. Better than explaining to residents how to compensate as in the previous point, design and commission interfaces and technologies where this cannot occur.
- Test and if needed redesign the heating and ventilation units to make it easier for residents to change filters and otherwise service the technologies.
- Have a plan in place to respond in case residents try to override the technology or when the system does not function correctly. This is essential to ensure the health of residents. Manufacturers should monitor the use of their products and adjust interfaces and technologies if needed. Building owners and manufacturers should have a system of remote notification to initiate repairs. An additional option is to invest in training/peer-training residents (e.g. one ambassador) to signal and adapt to overrides or system malfunctioning. In most housing blocks or housing projects, there are a few active residents who are interested in these topics. If so, this is a valuable resource since peers are often more trusted than outsiders.
- The relationship between building owners and residents might change. Where the relationship was once at a distance (providing only "products"), in cases with low energy renovations the engagement should be much higher and more proactive (moving to a "product and service" model).
- Moving towards "product and service" models (or Product Service Systems, PSS), also requires having policies in place for privacy protection of residents, since it likely involves collecting data from residents (GDPR protection of natural persons, EU Regulation 2016/679).
- If you are a building owner with the ambition to get started with a zero-energy renovation, keep it simple in the beginning. Consider starting out with an insulation project, or a boiler conversion for example.
- Builders and installers should adapt their process from project to project as they learn more about taking a resident-centric approach
- Recognize that there are many players involved in a successful NOM renovation. Even if all players are making decisions with the best of intentions, things can still go wrong and will go wrong. This should be assumed as the default, with responses in place, rather than assuming that everything will go right. Be patient and continue to innovate.

PART 3: LESSONS FOR THE PLANNING STAGE

Given the lessons above, there are steps technology providers, real estate developers, installers, building owners and managers can take in the planning stages to better take user preferences and behaviour into account.

Planning

- Make contact with different residents (differences in interaction with house)
- Develop usage scenarios and think them through during planning
- Bring different suppliers and planners together to make a robust system that is easy to use and can be used in different ways. Draw up requirements, test interim results against the requirements and with residents, adjust system
- Automate what can be done, and make control easy for the resident (action-reaction)
- Have a recovery ready in case the resident tries to override the system
- Information materials about how a house works - in the residents' language
- Plan for diversity! (different temperatures and local heating)

- Map residents' knowledge of the current state of the house and use it as a basis for information provision
- Create prototypes of the intended product and service and test them with residents
- Adapt product and service decisions accordingly

Designing the Actual Home Environment

- Combine product choices with service choices. It does not go well by itself
- During the initial use period especially, listen to residents and observe the issues they experience
- Maintain a trustful relationship so that residents want to collaborate in the necessary adjustments.
- Monitor analytically (is it right that thermometer is on a certain setting? How are the CO2 values? Is the heating working and is there enough hot water. Etc.)
- Guarantee the privacy of residents
- Provide feedback to residents on things that are difficult to determine, such as ventilation.

Evaluation

- Keep contact, really seeing what is happening. Listening to residents in what they say
- Do not expect residents to be able to report on the house 1:1. A translation is needed to the technical functioning of the house.
- Do not charge for heat on a one-to-one basis

Don'ts

- Reason from your own perspective and your image of the technology you offer.
- Give residents a lot of verbal information that is not based on their activities in the house.
- Neglect to compare the assumptions of different parts (active or inactive contribution of residents).
- Force residents to accept a temperature setpoint they cannot estimate in advance.
- Force residents to use complex reasoning to follow the technology.

PART 4: LESSONS ON MONITORING

Monitoring zero-energy renovations is essential for understanding if systems (e.g. heat pumps, ventilation, PV) working and performing as expected. Insights can be used to learn, reconfigure, adapt and improve design.

In this section lessons are shared about which aspects of a zero- energy renovation should be monitored, assessed and measured to achieve these goals. Some reflections are shared about how design processes can be improved by making use of these assessments.

- There are two types of energy-saving actions – this is important to consider when understanding the motivations of residents:
  - Investments (e.g. solar panels, heat pump, insulation)
  - Curtailment (conservation) (e.g. shorter showers)
- The outcome of an energy renovation is influenced by a large number of actors. This includes for example housing corporations, contractors who implements systems (and the laws and regulations governing technologies), technology providers who design the system (and the

guidelines which they use). When we approach renovations from a design perspective, it is essential to address the motivation and autonomy of residents in their homes (consider that they may be motivated, for example, to save money, to be comfortable, ease of use) and by social interactions (e.g. neighbor experience). Image 4 illustrates this point.

- Consider what motivates people:
  - Financial: Such as return on investment
  - Hedonic: Such as comfort and ease of use
  - Norms: Such as fitting in, wanting to do the right thing
- Consider that people are often motivated by a mix of the above points. They might not always be aware of what motivates them.
- Behaviour change requires a good understanding of habits. Changing habits is easiest in times of disruption (e.g. during a renovation, after moving homes). Repeated and frequent feedback is necessary for changing habits, and feedback has to be direct.
  - In the experience of one housing corporation, feedback is most effective for residents when it is real-time, easily accessible, permanently available, clearly structured and interactive. See Image X for example.
- Monitoring can have additional benefits such as nudging energy-saving behaviour. For example, by showing end-users how much energy is being consumed relative to what was expected they may adapt their behaviour.
  - In the experience of one housing corporation, making the real-time insights available for the residents in a format that does not require a password or app, could strengthened accessibility and the association with the building.
- Be willing to adapt technologies and configurations after the renovation. Be mindful that the feedback loop back to technology providers, installations and building owners needs to align with the design cycle for new technology.

Image X: Example of real-time energy feedback provided to residents via an in-home display

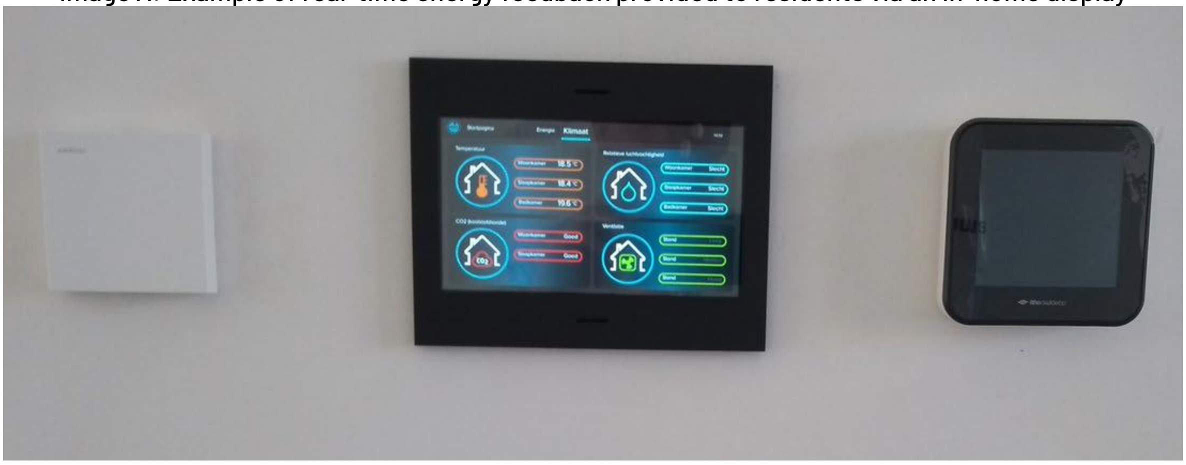


Image Source: Woonbond

What to measure:

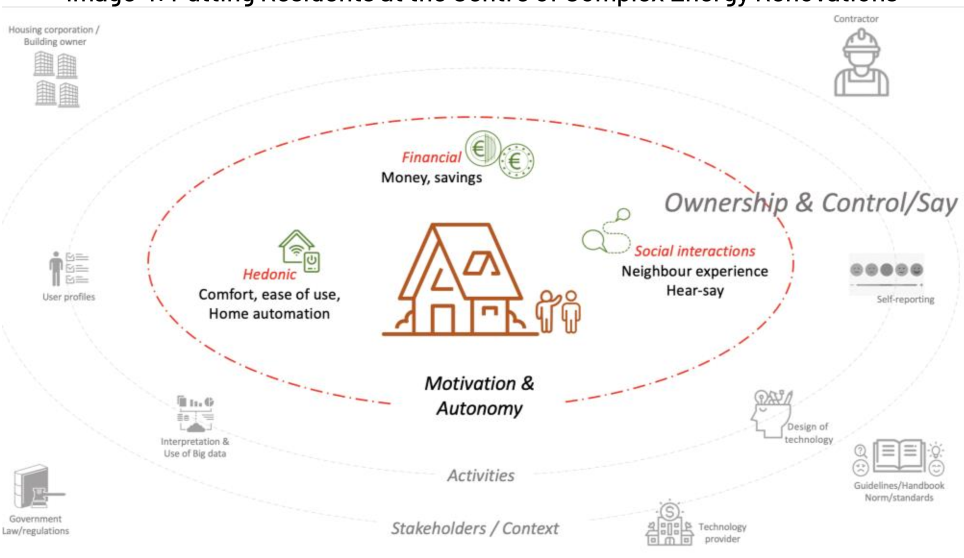
- Qualitative insights. Questionnaires can provide insights but are not enough. Walk-throughs consisting of 1.5 hour visits with residents can provide much greater insight and understanding into how people interact with their home.
- Sensor data: [3]
  - Air quality data (CO2 levels in ppm)
  - Energy consumption data

Lessons for housing corporations:

[3] See Appendix II for an overview of potential measurement points.

- Net-zero energy renovation projects are not just technology projects. This means all stakeholders within the corporation need to be involved, not just the technology division. All systems need adjusting, the contracts, processes, admin, social support.
- Projects should be treated as a project: they require dedicated resources beyond business-as-usual.
- Monitoring is a new task for a housing corporation. It is not something that can be done on the side. Data analysis requires expertise and needs to be part of a job description or outsourced.
    - Housing corporations should ensure that they have direct access to monitoring data.
- Data is not scary. (Big) data can help organizations improve their services. Monitoring systems can do more than record – they can support decision making.
- It takes time for residents to get used to the new energy structure of the home (in one housing corporation’s experience, two to three years).

Image 4: Putting Residents at the Centre of Complex Energy Renovations



Source: Monitoring Workshop

CONCLUSIONS

In summary, the practitioners’ review on outcomes after renovations leads to a number of recommendations for project implementation, user behaviour and the design of technologies. They pertain to key technologies involved in NZEB renovations from a resident perspective, which are thermal comfort, fresh air and a manageable and comfortable living environment that supports daily life practices.

As the number of zero-energy renovations accelerates across the Netherlands, and globally, it will become increasingly important to re-think how energy efficiency renovation technologies for homes are designed to optimize the interaction between people and technologies.

Achieving this will require action from a wide range of market parties such as:

- Building owners
- Real estate developers
- Property managers
- Contractors

- Architects
- Installers
- Technology companies
- Designers
- Residents
- And more

A one-size-fits-all approach or pathway does not exist for ensuring that people have a good experience and use technologies optimally in energy efficient housing.

As technology, and the experience of residents, continues to evolve, what will the next era of interaction look like between people and energy technologies? Perhaps technology can be created in an adaptable way, such that it can take different types of behaviour into account. Perhaps technology can be developed with upgradability/flexibility so that it can remain robust into the future (for example following the model of mobile phones or electric cars which can be updated through software updates).

While this form of technology has not yet reached the housing renovation sector, there is broad consensus among practitioners working in this realm that such an approach is essential for achieving future energy goals.

APPENDIX I – WORKSHOP OVERVIEW

On 11 February, 2021 and 15 March, 2021, the *Integrale Energietransitie in Bestaande Bouw Theme 2 - Data-driven Optimization of Renovation Concepts* project consortium organized two workshops focused on sharing and documenting the collective knowledge of workshop participants on optimizing the interaction between people and technology in energy efficiency housing. The focus was on net-zero energy[4] and low-energy renovations, as well as new-build projects constructed to high energy efficiency standards. Participants included researchers, building owners (housing corporations), contractors, technology providers and associations.

The workshop and webinar focused on highlighting lessons and specific examples of what works and what doesn't work for optimizing the interaction between people and technology in the low and zero-energy renovation projects. The workshop focused on heating and ventilation technologies, in low-, zero- and positive-energy renovation projects in the Netherlands. The workshop and webinar agendas can be found in Appendix I. It set out to answer the questions '*what do we know about how behaviour influences the effectiveness of deep energy renovations? And what do we know about how deep energy renovations influence behaviour? How do we know this?*'

On 17 June, 2021, a follow-up workshop was organized entitled *Monitoring Behaviour in Energy Renovations: What and How?*. The objective of the workshop was to share and document the group's collective knowledge on do's and don'ts related to monitoring the interaction between people and technology. Discussions took place on the following topics:

- what worked and hasn't worked in monitoring interaction between people and technology.
- how human behaviour influences low energy systems, and vice versa.
- how to use the results to coach the occupant and create a better performing building.
- how to incorporate insights, lessons learned in profiling, redesign of technologies and regulations/standards.

Speakers in the workshops included:

- Aardgasvrij Stichting !WOON
- BeNext
- BIK Bouw
- Haagse Hoogeschool
- Making Space
- TU Delft Faculty of Architecture and the Built Environment
- TU Delft Faculty of Industrial Design Engineering
- TU Eindhoven Department of the Built Environment
- TNO
- Utrecht Sustainability Institute
- W/E Adviseurs
- Waterweg Wonen
- Wageningen University / AMS Institute
- Woonborg
- Zehnder Group

Links to the workshop recordings and presentations can be found here:

- February 11: Interaction Between People and Technology in Energy Renovations (Part 1)
    - Insights into the Interaction Between People and Technology in Deep Energy Renovations - Stella Boess, TU Delft
    - Meet 2nd SKIN - Jan Floor, BikBouw
    - Case Study - Wilfred Gerritse, Waterweg Wonen
    - BENG and the User - Baudouin Knaapen, Team Aardgasvrij Stichting !WOON
- March 15: Interaction Between People and Technology in Energy Renovations (Part 2)
- June 17: Monitoring Behaviour: What and How?
    - A link to the Miro board used in this workshop can be found here

[4] In this summary, the following terms are used interchangeably: net-zero energy, nul-op-de-meter (NOM), energy-neutral, zero-energy and net zero energy. NOM is the Dutch abbreviation for a house that produces as much renewable energy as it uses yearly on site. As an example, a house consuming 5000 kWh per year for heating and electricity is said to be NOM if 5000 kWh electricity is produced yearly by solar PV-cells.

APPENDIX II – POTENTIAL MEASUREMENT POINTS

The following provides an example of the kind of measurement points that can be take before during and after an energy renovation.

Occupant Opinions and Perceptions
Interviews
Group discussion
Questionnaire/ survey
Diary

Total energy use
Meter data (via BMS) - electricity
Meter data (via BMS) - gas
Energy bills

Temperatures
Temp sensor - air
Temp sensor - wall
Temp sensor - ceiling
Temp sensor - floor
Temp sensor - window
Outdoor air temp
Solar radiation
Wind velocity
Radiant temp
Operative temp

Space heating
Thermostat reading
Temp sensor - water pipe
Temp sensor - radiator
Flow meter - hot water
Heat to radiators meter

Domestic Hot Water
Hot Tap water (flow)
Hot Tap water (temperatures)

Heat pump
Heatpump mode
Heatpump power meter

Ventilation/infiltration
Fan power meter
Ventilation flow rate
Window sensors (open/ close)
Air tightness / permeability

Sound
dB sensor

Indoor Air Quality
CO2 sensor
RH sensors (humidity)
Other

Occupant (presence, behaviour)
Motion sensor
Number of persons
Perceived thermal comfort
Activity
Clothes
General health
General happiness

Appliances (kWh meter)

ACKNOWLEDGEMENTS

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

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

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