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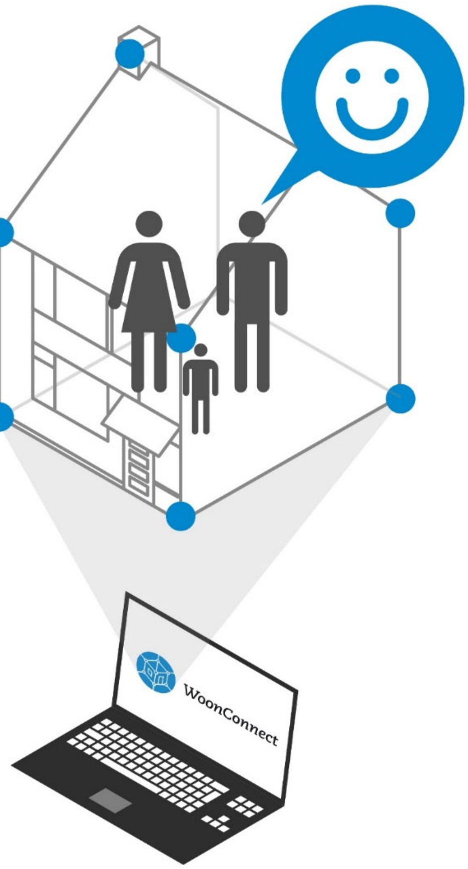

Design of a 'fit for person' comfort assessment tool within a BIM-environment

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EINDHOVEN UNIVERSITY OF TECHNOLOGY

Stan Ackermans Institute

SMART BUILDINGS & CITIES

Design of a 'fit for person' comfort assessment tool within a BIM-environment

By

Ir. Randy van Eck

A dissertation submitted in partial fulfillment of the requirements for the degree of Professional Doctorate of Engineering

The design described in this thesis has been carried out in accordance with the TU/e Code of Scientific Conduct

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Executive summary

The following report provides a summary of the two year cooperation between *Eindhoven University of Technology* (TU/e) and *De Twee Snoeken.* The goal of the cooperation between both parties was to develop new software modules for *WoonConnect*, a product that is developed by *De Twee Snoeken*. *WoonConnect* is an integral platform used for managing, planning and performing calculations for large scale housing renovation projects within the Netherlands. It also acts as a communication platform between different parties, including real-estate managers, engineers, contractors and occupants. To provide these functions, *WoonConnect* makes use of a building information modeling environment (BIM-environment) combined with automated calculations from the Dutch building decree. The platform also makes use of automated questionnaires to collect data on the occupant.

De Twee Snoeken wished to expand the current functionality of the software to better fit the requirements of the rapidly changing Dutch housing market. The Dutch market is undergoing a (sustainable) transition due to both market demand and ambitions set by the government. To analyze the transition, a market study was performed to determine how different parties are involved in the transition and were they put the focus to successfully achieve the set ambitions. As part of the market analysis, different sustainability criteria and international assessment tools were analyzed. Also interviews were held with real-estate agents, occupants, contractors and engineers on how they perceived the ongoing transition of the market.

The study revealed several niches. One of the niches showed that (improving) comfort provides a strong motivation factor for occupants to consider renovating their dwelling. Real-estate agents also stated that, when renovating dwellings, improved comfort was often used as persuasion factor to better involve occupants. However, because the criteria for a comfortable home can vary from person to person, it is difficult to provide one-size-fits-all guidelines. As a result, custom-tailored advice is necessary.

Within the project, the focus of the project therefore shifted to the development of a module that can provide more customized advice on improving comfort. The intended purpose of the comfort module is to generate personalized renovation advice based on the input provided by the occupant (problem based approach). The data that is generated by these occupants also proves useful for *WoonConnect*, real-estate users and engineers as said data can help to understand the needs of the occupants. Said knowledge can be used to improve the overall quality and satisfaction rates of the renovation project.

The project has led to the development of a prototype of the comfort module that was integrated within the existing structure of *WoonConnect's* BIM-environment and tested in a case study. The software uses several calculation methods that are in line with both the building decree and (inter) national assessment tools. The software is therefore capable of providing personal renovation advice for heating, cooling, draft, moisture problems, sound problems, lighting and the indoor air quality. These criteria are also connected to the energy calculation (NEN 7120) and cost model of *WoonConnect.* The user therefore received integral feedback on comfort, costs and energy (consumption) within one integral package. To further develop and validate the module, *WoonConnect* also aims to use data mining techniques to collect feedback from the occupants.

As part of the validation study, a usability test was performed with occupants to test how the module affected the choice of the occupants. Overall, the result showed positive responses. Most respondents stated that they liked the problem-based approach as it provides a 'social' factor to the given advice. Furthermore, the users also appreciated the integral package as a whole. The collective feedback on the investment costs, the energy bill and comfort combined with the visual approach of displaying the possible options was deemed as a playful and engaging method to gain renovation advice.

The respondents liked that they could weight different renovation options based on their impact and costs. Some respondents also stated that the package should also display additional information on the duration of the renovation and maintenance costs. Although the small-scale usability test cannot prove if people will actually invest more in the renovation of the dwelling themselves, the respondents did show a higher willingness to do so. A comparative study showed that respondents using *WoonConnect* spent an additional 15% on possible renovation options compared to those using traditional paper checklists.

Colophon

Project information

Project title: Design of a 'fit for person' comfort assessment tool within a BIM-environment
PDEng program: Smart (energy) Buildings & Cities
University chair: Information Systems in the Built Environment/Design of Decision Support Systems
Development period: 01 March 2017 until 01 March 2019

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Smart (energy) buildings and cities program
https://www.tue.nl/studeren/graduate-school/pdeng-smart-buildings-cities/

De Twee Snoeken
(https://www.tweesnoeken.nl/)

WoonConnect BV
(http://*WoonConnect*.nl/)

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Contents

1 Introduction

The first chapter addresses the purpose of the document and provides an introduction to the project, project-objectives and the company.

1.1 Document introduction

The following document describes the cooperation between *De Twee Snoeken* (*DTS)* and *Eindhoven university of Technology (TU/e)*. The cooperation was part of a two year joined PDEng-project within the Smart Cities and Buildings program (*SB&C*). The goal of this cooperation was to develop new modules for the digital platform *WoonConnect* [1], which is maintained and employed by *De Twee Snoeken*. *De Twee Snoeken* aims to develop these new modules to further strengthen the functions, application, business model and usability of *WoonConnect* within the Dutch built environment. To strengthen its position, *De Twee Snoeken* wishes to mostly focus on the rapidly changing building market and the existing transitions towards a sustainable built environment. Before developing the new module(s), a market study will have to be performed to identify which niches prove useful.

As part of the joined PDEng-cooperation, it is required to report the results of the development and the background studies. The following document, therefore, provides an overview of the following parts.

- The document will provide a market study that indicates what developments proved interesting for the further development of *WoonConnect.*
- The document describes the results and end-product developed during the last two-year cooperation between *DTS* and the *TU/e.* The document also provides advice on further developments or studies.
- The document supports the design decisions of the end-product with regards to the fundamental theory, discussion, risk management and background which were needed.
- The document addresses how the end-product fits within the existing business plan and market that *DTS* uses. Besides the business implementation, the social impact must also be considered.

A summary of the project structure is displayed in Figure 1. To develop the new module(s), the report first describes the ongoing market transition, how *WoonConnect* fits in the transition and a market analysis about market and user interests. The output of these studies are used to define several niches for further developing *WoonConnect*. After the study, the concept and design of the new module is described. The document finishes with an evaluation of the existing business canvas. The document also provides additional recommendations on how to proceed after the project has been finished. Additional documents or data that supported the development of the new modules are added in annex.

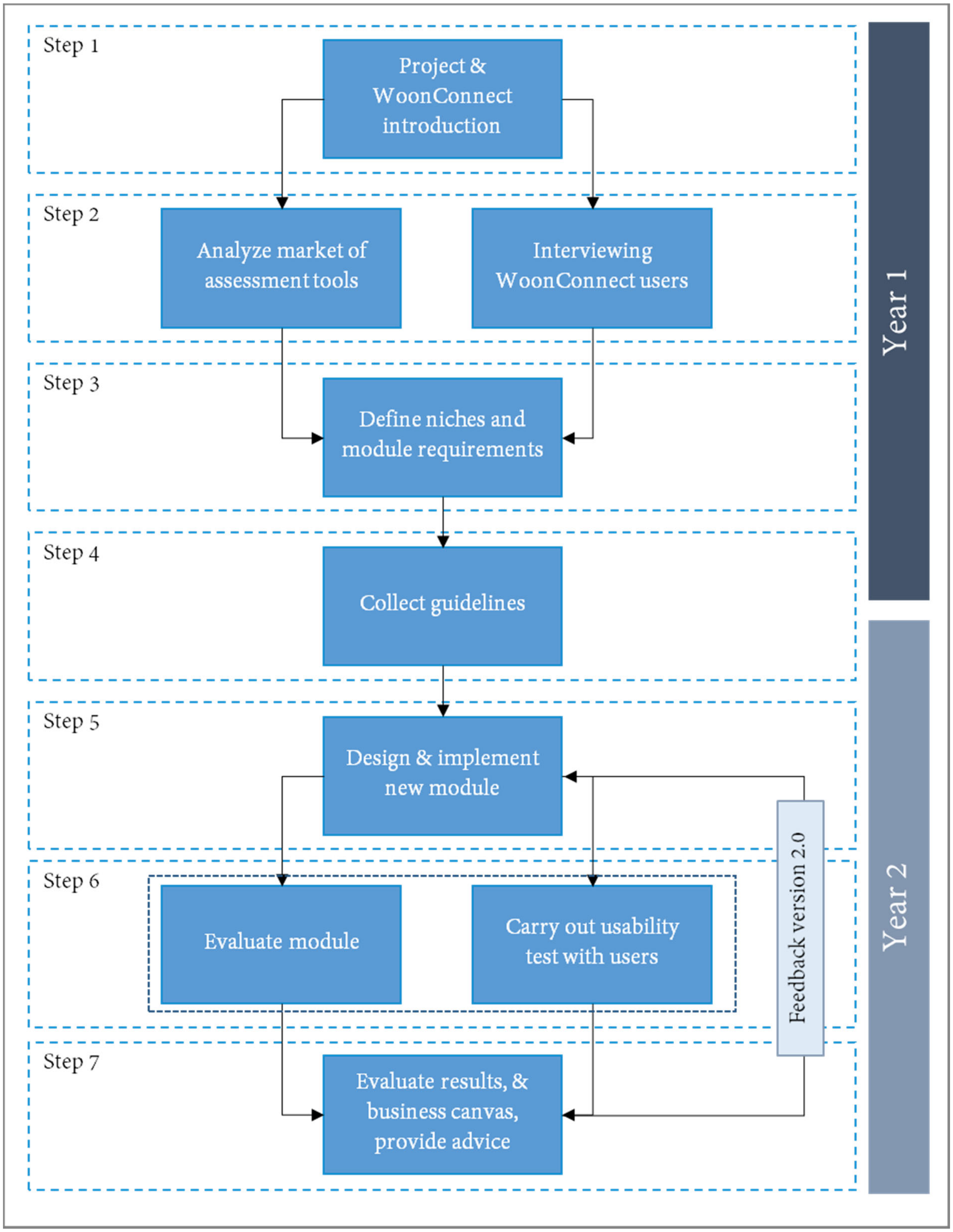


Figure 1: Project sequence overview (step by step) and time frame for the PDEng-project. The structure is also used for the report.

1.2 Market background - the transition of the (existing) Dutch built environment

To better understand the purpose of *WoonConnect*, it is required to understand the Dutch built environment and the ongoing trends. Figure 2 shows a brief summary of the Dutch transitions including set ambitions and plans to create a sustainable built environment. For explaining the Dutch market, a fore- and backcasting approach was used to show how the built environment will likely change in the upcoming years.

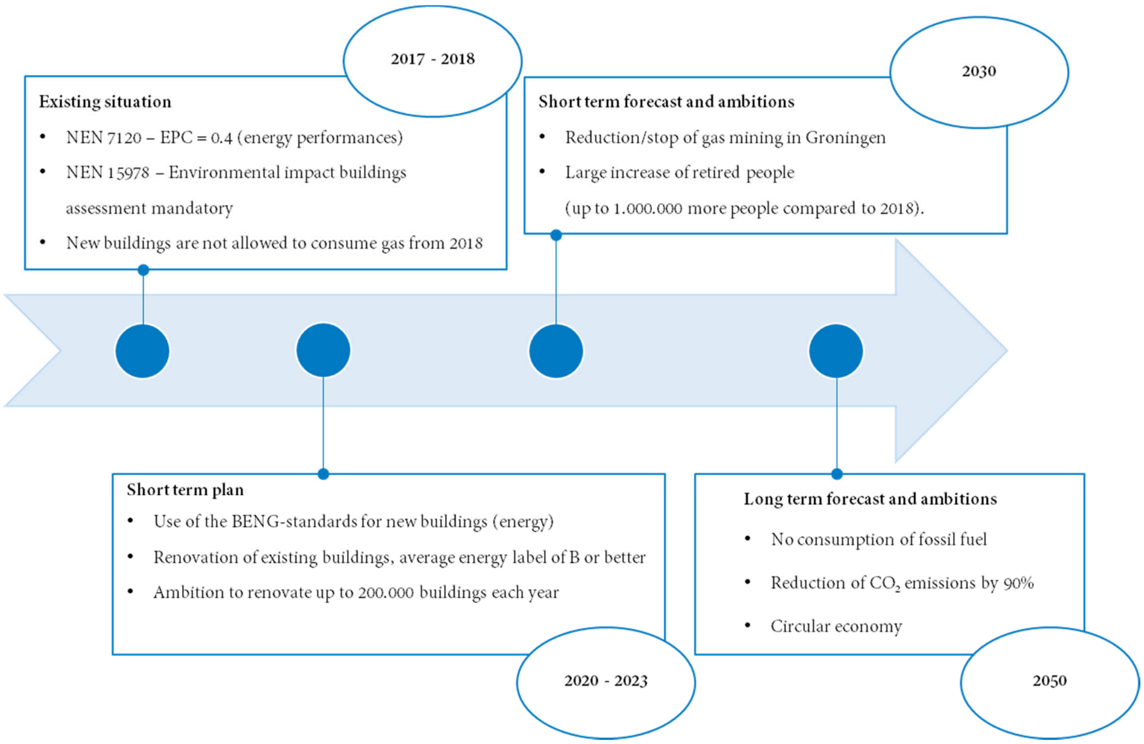


Figure 2 Graphical summary of the Dutch energy transition and set ambitions for the built environment.

The long term ambition of the Dutch government is to create a sustainable built environment and economy by the year 2050. These ambitions are part of the climate agreements signed by the Dutch government to help counter climate change [2]. One of these ambitions is to reduce the carbon emissions in 2050 by 90% compared to 1990. Another ambition is that the Dutch economy, including the building market, becomes circular in its waste management and resource consumption [3]. Because of these ambitions, The Dutch building market is undergoing 'a sustainable transition'.

The transition did not start all at once and it will likely continue to change as the regulations are becoming stricter. For example, before 2017-2018 new buildings already had to meet several standards with regards to the energy and material consumption. These standards are described for the energy consumption through the NEN 7120 – '*Energieprestatie Gebouw*' (energy performance buildings) [4], which later on will replaced by the BENG standards in 2020 [5], [6]. As part of the energy consumption, new buildings built after July 2018 are also not allowed to consume gas or other fossil fuels for cooking and space heating [7].

For the material consumption within dwelling, the regulations have been described through NEN 15978 – *Milieuprestatie Gebouw* (environmental impact of the building) [8]. Based on said material assessment, from 2018 onwards all new buildings are required to have an environmental impact of 1.0 euro/m2 or less. Reducing and indexing the material consumption through a calculation method is estimated to be a first step to become circular [9].

However, most of these regulations are focusing on new buildings alone. With a total building stock of about 7,7 million houses and a replenishment rate of only about 60.000 new dwellings each year [10], a lot of attention is also being paid to the existing housing market. For example, the government and housing corporations have the ambition that by 2020 corporate-owned houses have an energy label of at least B or higher [11]. Other ambitions are also to make the Dutch existing housing market independent from gas and other fossil fuels on the long run. Disconnecting from natural gas is needed to reduce the burden of gas mining in Groningen (Northern province of the Netherlands), as the environmental and social impact are very high [12].

To enforce the renovation, municipalities have to prepare plans on how to renovate the existing housing market to become gasless by 2021 [13]. When these plans are ready, the government hopes that the Dutch housing market can renovate between 200.000 and 300.000 dwellings each year. The government estimated that such a rate is needed if they wish to achieve the ambition to renovate all existing dwellings into gasless, CO_2-neutral buildings by 2050 [13].

As all these ambitions seem to indicate, the transition is a complex process and will provide an enormous challenge. These challenges are not only related to technology. They are also related to the logistics, (data) management and planning, regulations, financing and social factors. For example, one financial challenge regarding the current ambitions is already mentioned by [14], [15]. Based on their estimations, the cost to renovate an average existing gas consuming house up to the point that they consume no gas can cost each household around 18.500,- euro. Considering that most households cannot provide said budget themselves [14], [15] finding a party that can provide the budget or finding other ways to have the occupants contribute will be definitely be a challenge.

One example of a social challenge is the rapidly aging Dutch population as displayed in Figure 3. It is estimated that by 2030 that the amount of Dutch people in retirement will increase by over one million people compared to 2015 [16]. The increasing elderly population will have a large impact on the building types needed, as not all buildings are suitable to house senior people without support [17]. As a result, either many new retirement homes need to be built or the existing houses must be converted to self-reliant care homes to support these people (Dutch: "*levensloopbestendige woningen*"). To identify which buildings can easily be converted into self-reliant houses requires a lot of data on the quality of the existing buildings. Another challenge is collecting information on the occupant's health, as the required living conditions can differ for people suffering from blindness, dementia, or loss of mobility.

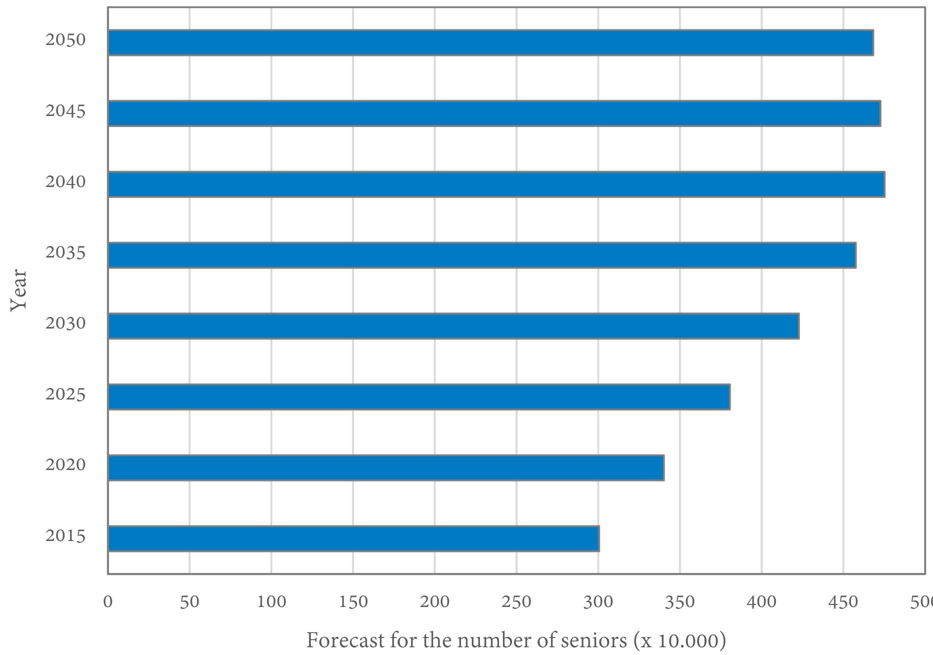


Figure 3: Estimation of the amount of senior people (people with an age of 65 or older) within the Netherlands from 2015 until 2050. Data retrieved from [16].

Another example, in terms of management and logistics, lies within the ambition to become circular by 2050 [3]. The commonly used theoretical definition of becoming circular means that raw materials will be used and reused efficiently without any harmful emissions into the environment [3]. Therefore all material debris created during the demolition/renovation phase needs to be recycled, reused or processed into new materials without emitting any emissions. Said ambition will require the adoption of new business and financial models [18]. However, to keep track of which materials are used where, the quantities, and how they can be reused will require 'smart' management and logistics systems. Otherwise the vast amount of materials and waste cannot be properly processed. The management system should also be long term planned, especially since the average lifespan of a building is long compared to other products.

As these examples, ambitions and regulations imply, the sustainable transition of the Dutch housing market is a complex process. The transitions has a large impact on many disciplines: technology, the social aspects, logistics, management, planning and the business structure. Because of the all these disciplines, the government advocates that a more custom approach is needed for each neighborhood [13]. To deal with all these challenges and different disciplines in a custom, multidisciplinary environment, a "smart" integral system or tool is required.

1.3 The digital platform of *WoonConnect* and *BouwConnect*

As described in the previous chapter, the transition at the Dutch housing market has to deal with many challenges covering different disciplines. These challenges are not only limited to technology but are also related to management, financial, (data) management, social issues and logistics. As a result, smart multi-disciplinary tools could be useful to manage said challenges. Such a niche was one of the main reasons why *WoonConnect* was developed.

WoonConnect is a digital system that acts a support tool that addresses and manages some of these disciplines, both on a building and urban scale. *WoonConnect* manages these disciplines by providing an integral digital building platform. The digital platform consists of several parts, including a digital material/system database (*BouwConnect* [19]) that keeps track of which materials are used based on a building information model (BIM-model). The platform also uses questionnaires to collect on site data and an assessment module for calculating energy consumption. Using direct input from different households allows for a more custom approach, as the input of the occupants is used for the development. To further explain the platform, the following paragraph will further explain what *BouwConnect* is and the functions for which *WoonConnect* can be used.

1.3.1 BouwConnect

One of the corner stones of the digital building platform is the material & system database *BouwConnect* [19]. A screenshot of the interface is shown in Figure 4 below. *BouwConnect* is a digital database in which BIM-supported copies are stored for different systems (e.g. HVAC-systems, kitchen and bathrooms appliances) and materials (e.g. bricks, walls, insulation, steel beams). All these aspects are modeled and stored as 'objects'[1]. *BouwConnect* stores different types of information in these objects, such as physical properties, dimensions and costs.

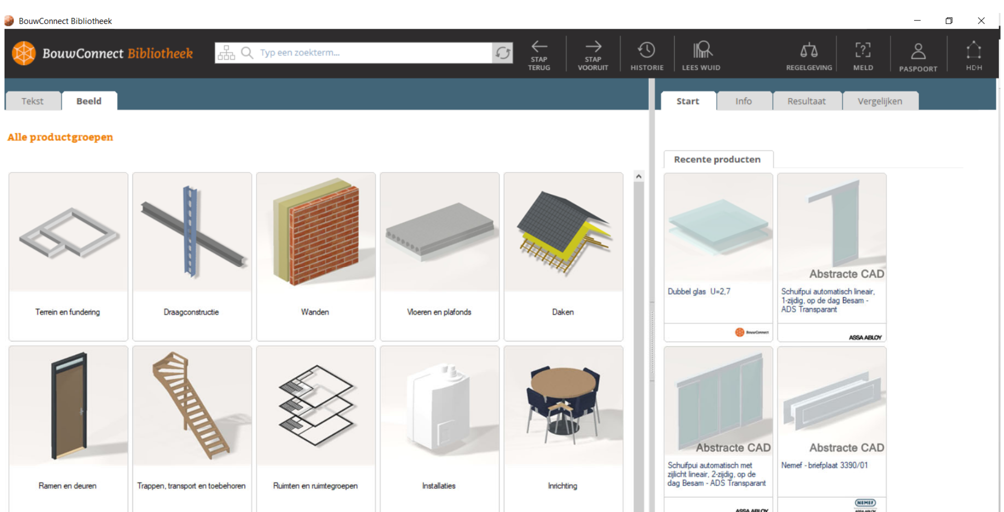


Figure 4: Overview of the BouwConnect library [19]. *All object can be copied into a bim-environment. The allocated properties are saved alongside the models, and are based on factory default standards.*

[1] *BouwConnect* and *WoonConnect* are object based in terms of programming.

For example, the material insulation has properties such as isolation values, density, heat capacity and color. The values of these properties affect the costs per square meter of the material being used. An example for systems is a boiler. A boiler system has properties such as the heating capacity, size, efficiency and costs per unit. These properties can be altered and saved into templates for standard factory products.

All these systems and materials can be copied into a BIM-environment as 'visual' objects by the user. Through the *BouwConnect* plug-in, the allocated properties are saved alongside the BIM-documents. The plug-in keeps track of the properties that the user has allocated to the material or system. If required, the user can print these properties into a paper report or help the user to carry out assessments for the energy consumption, costs or fire safety. These assessments help the users to share required system and material properties more easily between the different parties (e.g. an engineer and a contractor). Since the data is also stored separately for the BIM-model, information on the material properties can be stored and managed more easily alongside the digital models.

1.3.2 *WoonConnect*

For *WoonConnect*, the digital passport of the building is constructed through the different objects from *BouwConnect* within one BIM-model (called the base model). A screenshot of the interface is shown in Figure 5. The base BIM-model is often called the digital house ("*Het digitale huis"*). The digital house model allows for a visual overview model in which the properties of the materials and systems are stored. The information can also be used for the calculations and assessments carried out by *WoonConnect*. Besides the base information stored in the *BouwConnect Bibliotheek*, additional information for the assessment is collected through two additional methods. The first one is an on-site observations by the user (*warme opname)* and the second one is an online questionnaire that can be filled in by the occupants (*Energie-buddy* or *E-buddy)*.

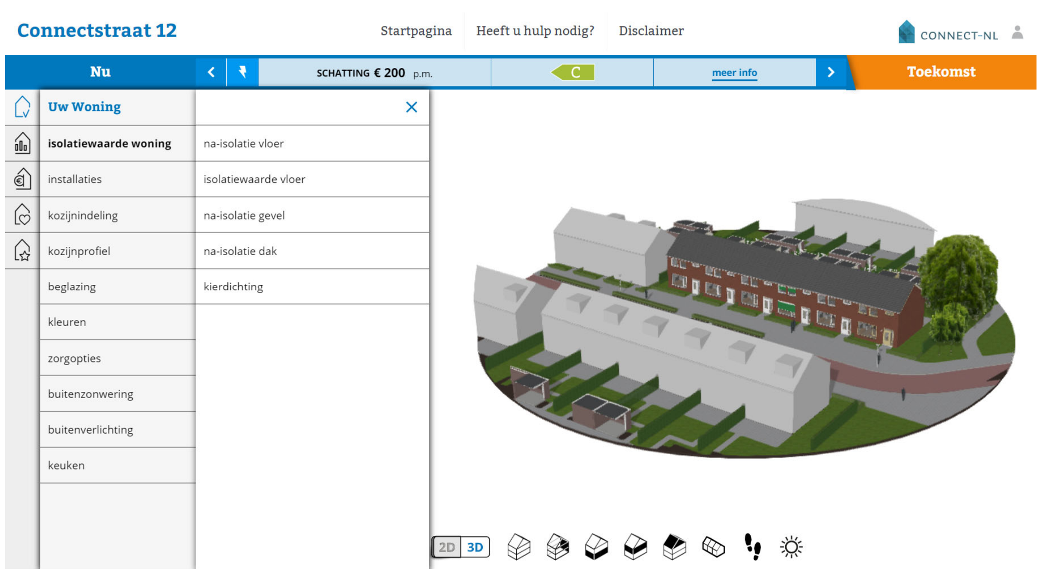


Figure 5: Graphical interface of WoonConnect for occupants (occupant's account). The interface provides, based on the BIM-model, direct feedback on the energy consumption (200 euro per month). Occupants can make different adjustments as well, for example for the insulation value (isolatiewaarde woning).

For the on-site observation, *DTS* or the users of *WoonConnect*'s software collect information on the dwellings through technical drawings and on-site observations. The observation mostly focuses on technical properties and dimensions that are representative for the dwellings. The main goal of the on-site observation is to create several base designs that act as templates for connecting the input of the occupants. The base BIM-model is also used to give a first assessment of the situation.

Figure 6 below explains in a graphic how the questionnaires relate to the base model. The online questionnaire focuses on collecting more specific information about each household. These questions focus on information such as what heating set points the people use, whether they make use of a gas or an electrical heating system and so on. Said data is used to further define the BIM-model for each individual household. To this extent, *WoonConnect* is unique compared to other NEN 7120 tools, as these tools often make use of average values rather than direct on-site information from the occupants.

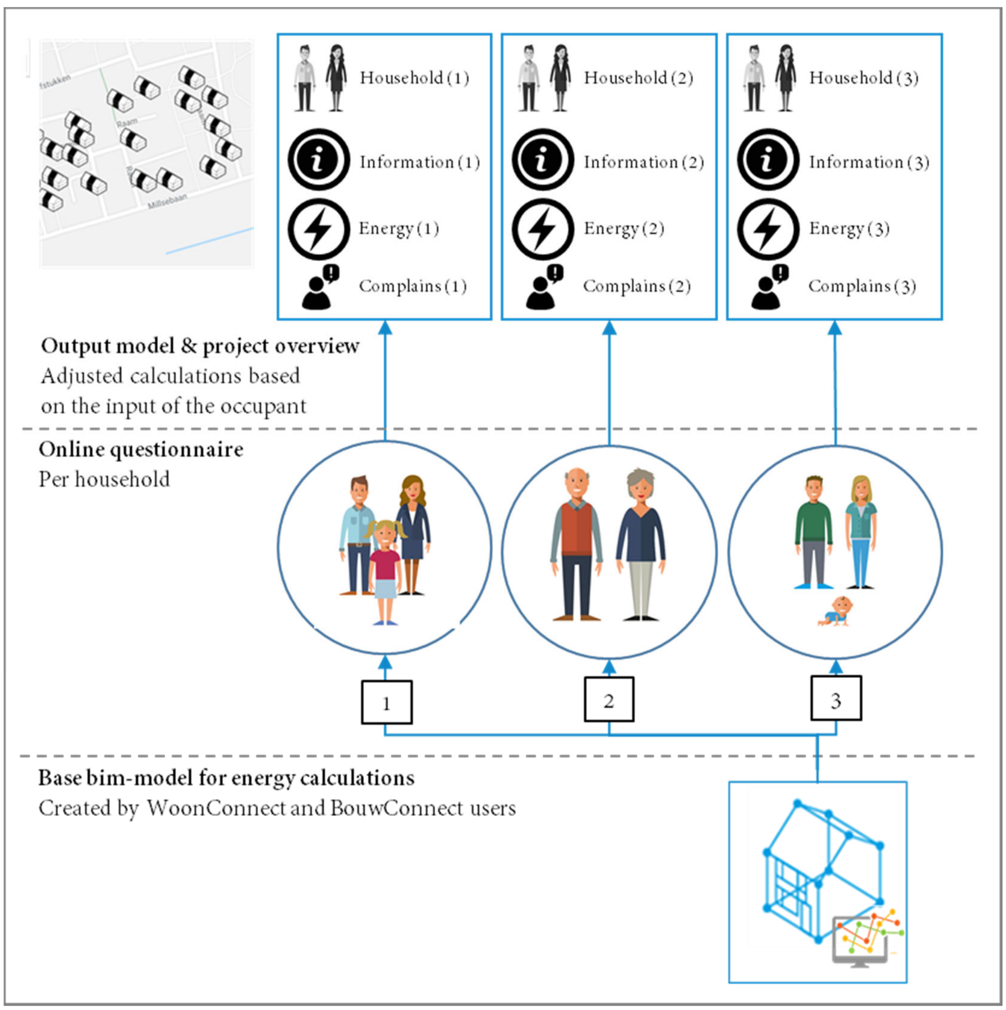


Figure 6: Graphical overview a WoonConnect project, .from the base model (lower part) until the overview of the neighborhood (upper part). In this case, the base model/ questionnaire can be used for any number of households the user sees fit.

For the municipalities and real-estate, *WoonConnect* summarizes all collected information into a graphical project and data overview of the neighborhood. Whereas the occupants only have access to their own profile, the municipalities and real-estate can still retrieve individual information per household. The collected information of these different households can be processed within an overview platform of the project site. Within the platform, *WoonConnect* can perform several additional functions based on the digital model, the questionnaires and the input of the occupants.

- *WoonConnect* acts as a communication platform between occupants, real-estate agents and the engineers. Data added by one party is also shared with the others, and adjustments made to the design are visible to all parties. In terms of the occupants, complains, remarks or preferences are also made visible for the other parties. The other users can use this information to better manage or maintain the project.
- *WoonConnect* automatically performs assessments for energy, costs and building regulations based on the digital house model and repeats said calculations for all households. The input provided by the occupants is translated to the assessment tools to provide personal calculations for the energy consumption and costs. The users receive direct feedback on these criteria when adjusting the BIM-model with new building input.
- *WoonConnect* provides a digital renovation platform for the occupants. Occupants will be able to renovate and adjust their house within *WoonConnect*. The influence of options such as insulation, new glass or a new heating system is directly calculated within the energy consumption of the building. *WoonConnect* also gives an estimation on the (renovation) costs and the energy bill.
- *WoonConnect* also provides an overview of the materials needed for these renovation. Based on the *BouwConnect* database, the model provides a list of the required materials. The engineers and housing corporations can use these list to order and buy the needed materials.
- *WoonConnect* can act as a long term planning and maintenance support tool. *WoonConnect* can generate multiple renovation scenarios, which can represent different stages of the renovation process. These different scenarios allow the user to create a long term renovation and maintenance plans (*Dutch: meerjarig onderhoudsplan or MJOP).* Furthermore, the planning can also be shared with the occupants in a printed or digital version. Said reports help to make the renovation project transparent for the occupants.
- *WoonConnect* can print the information into paper documents. These documents can be used to advise the occupant. The assessments are carried out in accordance with Dutch building regulations. Therefore the printed output can be used to apply for a building permit.

1.4 *WoonConnect* evaluation and market study (2017)

As part of the PDEng-project, *WoonConnect* as an assessment tool has been further developed. *DTS* asked beforehand to evaluate which assessment modules would be worthwhile to develop based on costumer and market demand. To satisfy their request, several design questions had to be answered first.

- Which (sustainable) assessment criteria are available when comparing different tools?
- Which assessment criteria are interesting to develop, based on user interests, regulations and ambitions of the (transition) market?
- What do the users find important when operating a (sustainable) assessment tool?

To answer these questions, a market study was carried out around existing assessment tools. In a second stage, interviews were held with different users of *WoonConnect*, including occupants.

1.4.1 The market of (sustainable) assessment tools

To identify which assessment criteria *WoonConnect* can adopts in its system, an analysis was carried out. The main purpose of the analysis was to identity which assessment schemes and criteria are available for the Dutch and international market. A second purpose was also to understand the strengths, limitations and potential shortcomings of these systems. A third purpose was to identify which assessment schemes will likely provide the most value for *WoonConnect*. For these evaluations, a comparison was made between tools available on the Dutch market (BREEAM [20], Leed [21] and GPR [22]. An overview of the comparison is added in Annex I – Market analysis.

Comparison of tools from the assessment criteria point of view

For the analysis, a comparison was made between *WoonConnect* (2017) and several tools that are known on the Dutch market: *BREEAM-nl, LEED* and *GPR* [20]–[22] and the Dutch building code. Additional literature was also used for comparing international tools [23]–[26]

Figure 7 displays the comparison of these tools for different criteria assessment categories based on the categorization of [25]. [25] Compared different tools for their ability to assess "*energy*", "*indoor climate*", "*materials*", "*water (management)*", "*economical value*", "*urban planning and transport*", "*usability and safety*" and "*management*" by identifying the number of assessment criteria used by each tool. For the comparison of *WoonConnect* with the other Dutch tools, one additional category is added on request of the company: "*life cycle resistance for seniors*". Due to the predicted problems regarding senior housing the criteria "*life cycle resistance for seniors*" is expected to become a more important criteria in the nearby future.

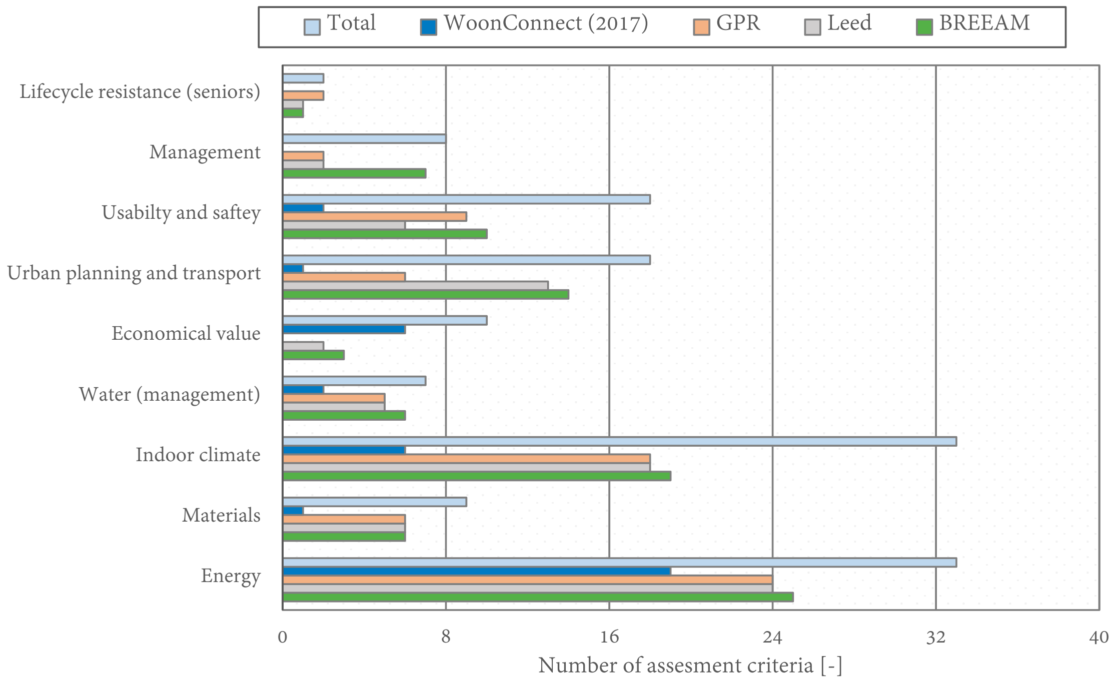


Figure 7: Number of assessment criteria per tool and category, derived from [25]. *The category 'lifecycle resistance buildings for seniors' is added as well.*

From the first analysis, several conclusions were drawn. First of all there is no tool that addresses all assessment criteria at once, with BREEAM considering the largest amount of criteria. Besides the amount of criteria, each tool has some scope of which criteria should be used. For example, only BREEAM provides credits for how the management of the projects is addressed. Meanwhile, LEED is considered to have a more throughout comfort assessment scheme [24].

Even though no tools addressed all criteria, multiple assessment methods were based on the same documents, which was also concluded by [24]. *WoonConnect* already uses some of these documents as well, although it is mostly limited to what is required for the Dutch regulations. As a result, *WoonConnect* lagged behind for the different categories; exception are the categories "*energy*" and "*economical value*".

Another factor noticeable is that no tool had an extensive assessment regarding *life cycle resistance* for seniors yet. Most tools only assessed the accessibility for people with wheelchairs. For example, "*Does the building have a ramp or a wide enough door*"? Evaluation of other relevant factors for common scenarios such as dementia, blindness and reduced mobility were not mentioned within the reference documents of each tool. Pragmatically speaking these factors can be considered through addressing questions such as "*Can a staircase elevator be installed*?" or "*Are there anti-fall measurements installed*?".

Comparison of (environmental) tools from a functionality point of view

Besides the comparison of the assessment criteria, a study was also conducted to analyze the usability of *WoonConnect*. The comparison focused on similar tools (BREEAM, LEED and GPR) in terms of functionality, the calculation methodology and how the certification method is carried out. For the analysis, several studies were used which focused on the comparison and development of these tools [23]–[25], [27], [28], the role of these assessment tools in the built environment [28]–[32] and the evaluations of their usability, strengths and weaknesses [24], [26], [27], [30], [33]–[35]. An overview, derived from the work of [28], is shown in Appendix 1. Based on said analyses, several noticeable differences were analyzed and several criteria to improve the design were found.

The first noticeable difference is that most assessment tools do support some form of a digital platform. Only BREEAM displays no link to one package, but does refer to which documents are needed. Of the other tools, GPR uses an online interface, which allows the user to adjust and rapidly create scenarios. Even so, GPR has limited calculation capacities itself and does not support a visual BIM-model. Besides GPR, LEED also has support in the form of a software package called IES [36]. The package, similar to *WoonConnect*, does support the integration of BIM-models. *WoonConnect* also uses its BIM-core and the *BouwConnect* library to carry out the assessments itself. Nonetheless, all approaches allow for a quick generation of different scenarios within one integral package for the design itself. The BIM-model core therefore assists designs teams into making more efficient decisions, improves analyses and provides easier access to information [37].

Another noticeable difference was how most tools approach the certification method. With the exception of BREAAM, the other tools only delivered a single issued label at the end of the design. Research considers the single issued label a potential threat, as this could lead to users only optimizing the design for the short term-evaluation, which can lead to selective disclosure of only short term effects [30]. For *WoonConnect* said problem is likely not an issue, the main reason being that *WoonConnect* provides an assessment as direct feedback from the model.

Besides differences in the certification method and the software approach, these sources also provided advice on how to verify and potentially validate the software. First of all, assessment schemes should be transparent in the sources they use [24], [30], [35]. Although BREEAM has a scientific foundation, LEED was considered to be more transparent, with the IES-software package being a major advantage [24]. There were several factors to consider to make the tool transparent. First of all, the sources used for the calculation and evaluation of the output should be cited clearly in the tools. These sources should be recognized and developed based on proof, for example university studies or regulations [30], [35].

Another factor to consider within each tool is that they require regular updates [23], [28]. These updates have several purposes, first of all to keep the software package up to date with the latest regulations. A second purpose is to ensure that new systems, relevant for the criteria assessment, can be taken into consideration. Lastly, regular updates give the possibility to consider customer feedback within the improvement of the software product.

Given feedback is important, as the input from independent third parties is important for successfully developing a (sustainable) assessment tool. As stated by [35], many consumers and experts have pointed out the important role that independent third parties can play in green marketing and eco assessments. Successfully considering the input of feedback will therefore help to improve the acceptance, which will help to build recognition. Third party recognition is important, as due to market demands green advertising claims and labels almost grew 300% between 2006 and 2009 [30], [35]. Due to the sharp increase of green lables, [30] stated that the consumer has become more skeptical about the authenticity of such assessment labels.

To summarize the market study, if *WoonConnect* aims to develop a new assessment module, the BIM-approach provides a solid base. The BIM-core can help to carry out assessments as an integral package, while making it easier to provide a transparent overview. Also, the maintenance function of *WoonConnect* helps to avoid a single issued label approach, as the software can be used throughout the life-cycle of the building. The market study yielded several recommendations for the design. To verify the new module, it should be transparent in its usage and assessment. Lastly, *WoonConnect* should consider to be open to feedback from third parties to improve the overall acceptance of the new modules.

1.4.2 Interviews with *WoonConnect* users

Based on the market analysis in the previous paragraph, interviews were held with the different users of the *WoonConnect* software. For these interviews, three main user groups were addressed: occupants, real-estate agents/ government employees and technical specialists. In total, 42 people were personally interviewed through a beforehand prepared open questionnaire. These questions had several purposes. First of all it was used to identify which (sustainable) assessment criteria had the most value for these users. The second goal was to understand what people expect from a software tool such as *WoonConnect*. The information can be used to design the interface later on. A more in depth overview of the interviews and the output is added in *Annex II – Interviews with the WoonConnect users*.

The output from the interviews can be divided into two parts: what the people found important with regards to the assessment criteria and what they expected from assessment tools such as BREEAM, LEED and *WoonConnect*. With regards to the assessment schemes, both real-estate employees and engineers stated that these tools should provide an integral overview of the project and should not only address one criteria alone. The assessment should not only focus on, for example, energy but also on aspects such as costs, materials and comfort. More importantly, from a program point of view, most of the real-estate agents and technical specialist agreed that they often look at the trade-off between the different assessment criteria and the costs. For analyzing this trade-off, the ability to rapidly compare cost-performance scenarios is crucial when designing a building.

Both parties agreed that integral assessment schemes are needed to assess sustainability as a whole. Furthermore they did agreed that the energy and material consumption play the largest role in evaluating sustainably on the Dutch market. These criteria and allocated factors where called out most often during the interviews. A given reason was the hard set regulations set by the government. Aspects such as water consumption and pollution/waste management were considered less important. However, real-estate agents also expressed the need to assess comfort and usability. The need for these criteria is needed to increase interest and participation with the occupants which didn't have much affinity with the material and energy consumption.

This need was also confirmed when interviewing the occupants themselves, as most occupants stated they found usability, size and comfort the most important aspects of their building. Some occupants even rated these criteria higher than the monthly upkeep costs and the sale price of the building. When asked about how they would assess sustainability within a building, most occupants could only answer with pragmatic examples such as "use of solar cells", "add insulation" or "don't use plastics". The relation with the set regulations was not often mentioned, and often the occupants were not even aware of these ambitions from the government and what they exactly meant.

When discussing about the usability of such tools, most of the building engineers and real-estate employees stated the need for an integral assessment package. Aspects such as energy, material consumption, comfort and costs should preferably be assessed within one package. This integral approach allows the user to make a trade-off between their most relevant criteria without having to deal with hidden trade-offs.

Another mentioned advantage of this integral approach is that it provides a better communication platform, as the use of several tools often leads to miscommunication and data loss according to the engineers. To this extent, the BIM-approach of *WoonConnect* and *BouwConnect* has potential, as the software already provides an integral model to rapidly compare scenarios for costs and energy, whereas other tools are often paper-based tools which are especially limited when the user wish to rapidly compare different scenarios and design options.

Several pieces of advice were given regarding *WoonConnect*'s aim to further develop their capabilities for performance evaluations. First of all, the experienced users stated that *WoonConnect* should be transparent in what assessment schemes they use. This requirement fits with the market study. To satisfy this requirement, the respondents stated that the source material should be cited and accessible for the users.

Another piece of advice was that the tool should make a clear separation between what is required (regulation wise) and what are additional suggestions. It was especially important that *WoonConnect* should provide advice based on their preferences. Lastly, attention should be plaid in developing a visual and user friendly interface. The less experienced users stated that this is important to more easily learn, understand and use the module.

1.4.3 Niches for the further development of *WoonConnect*'s new assessment module(s)

Based on the market evaluation and the interviews, several opportunities were deemed interesting for the further development of *WoonConnect*. First of all, the integral BIM-modeling approach of *WoonConnect* provides a good starting point to further develop additional assessment modules. The capability of *WoonConnect* to rapidly generate scenarios including costs and energy consumption seems to fit with the need of the experienced users: the need to assess different criteria in one integral transparent package without hidden trade-offs. In terms of what criteria to implement, three categories were deemed most feasible based on set ambitions of the Dutch government and the interests of the market.

First of all there seems to be a need to assess life cycle resistance for seniors. Most existing tools seemed to have only a limited capability to assess this criterion. What they do assess focuses mostly on wheelchair users. Criteria such as dementia or blindness are not mentioned in the reference materials, while such criteria can have a large impact on the occupants and their living conditions. A need for such a module seems high, as there is a rapidly aging population. This is estimated to cause a lot of stress for the Dutch built environment [16], [17].

The second need seems to focus on material consumption. Multiple people during the interviews stated that they find it important to assess the quantities and quality of the materials in one overview together with the energy consumption. It is also already part of the regulations to compute the material consumption in a (new) building [8], [9]. Since the government has set the ambition to become circular, the need to develop material assessment tools becomes more important [3]. One part *DTS* could focus on is using the BIM-approach of *WoonConnect* and *BouwConnect* to calculate the material consumption based on the 3d model. The BouwConnect database could be used to store the data required from the emission tables for the 3d object in the BIM. Additional '*material passports'* can also be developed do indicate which material can be recycled, reused (and where) or are 100% waste.

The last development that seems to have value is the development of a comfort assessment module. Both municipalities and real-estate stated that comfort is an important motivation factor for occupants, as it provides added value and a 'common language' for this group. As a result, these parties often use comfort as a selling point when dealing with the renovation of a neighborhood. The occupants also confirmed that comfort is an important factor for them, with some rating comfort higher than (low) costs. Since the occupant is an important user within the principles of *WoonConnect*, comfort can be used to improve the communication between the stakeholders as a common language. Besides communication, comfort could also be used as a pull factor to motivate occupants into agreeing and investing into the renovation of their dwelling.

1.5 Project goal – the design of a 'fit for person' comfort module within the BIM-environment of *WoonConnect*

The main goal of the cooperation between *Eindhoven University of Technology* and *De Twee Snoeken* is to further develop *WoonConnect* with new assessment modules based on market interests. The outcome of the market study and the interviews with occupants, real-estate agents and engineers showed several potential options for further developing the software. For the PDEng cooperation, the choice was made to focus on first developing a module to assess comfort based on the input provided by occupants (problem based approach).

A comfort assessment module was deemed the best choice since the module already fits with several existing functions of *WoonConnect* and its BIM-environment. Moreover, a large part of the calculations was already integrated as part of the building decree. The second reason was that the module could improve the user experience of *WoonConnect* for the occupants, which forms an important part of the user segment and business plan of *WoonConnect*. The improved usability should lie in using comfort as a pull factor to motivate people into choosing to renovate their houses. The increased participation of the occupants should also increase the usability for the engineers and the real-estate agents that use *WoonConnect*.

2 Design, validation and verification requirements for the comfort module

The goal of this PDEng-project is to develop a software-module that can calculate and evaluate comfort based on the BIM-core of *WoonConnect*. For developing the tool, *DTS* and *TU/e* have set several design, verification and validation requirements which have to be met for developing the comfort module.

2.1 Design requirements comfort calculation and evaluation module

For the development of the new comfort calculation and evaluation module several design requirements were set up.

2.1.1 The module should be able to work with the existing functions of *WoonConnect*

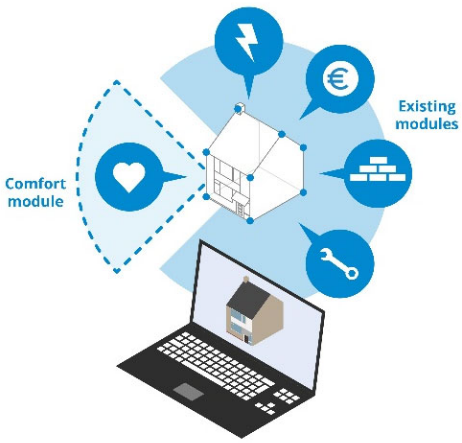


Figure 8: The module should work with existing functions of WoonConnect

The comfort module should at the very least be able to interact with the functions that *WoonConnect* already provides (Figure 8). These functions were described in paragraph 1.3.2. It is especially important that *WoonConnect* shows the trade-off between comfort, energy and costs by generating several scenarios.

2.1.2 The module should automatically calculate the assessment based on the BIM-structure

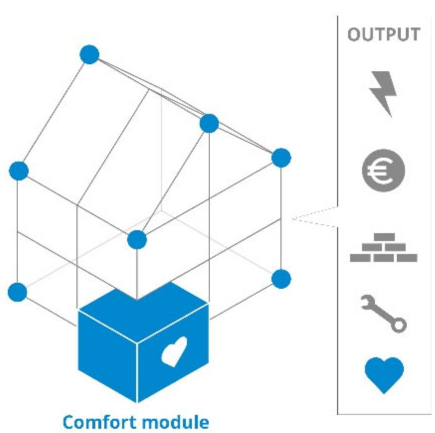


Figure 9: the module should automatically calculate the assessment based on the BIM-model.

The module should fit within *WoonConnect*'s current structure (Figure 9). *WoonConnect* has an object oriented program system combined with a building information modelling environment. The module should assess these calculations automatically from the model where possible. The information required for the calculations should come from the BIM-model and objects where possible to limit the (direct) information required from the occupants.

2.1.3 The module should be able to use the input from the occupants to generate output

The module should be able to consider the preferences and complains of the occupants to generate 'fit for person' advice (Figure 10). The information should be used in the evaluation and should be used to provide advice on the possible renovation options. The advice should consist of suggestions for what the user can do to improve comfort in certain areas. Furthermore, *WoonConnect* wishes to use the data provided by the occupants to improve their calculation models and advice.

Figure 10: The modules should be able to use the input form the occupants for providing personal advice

2.1.4 The module should be able to display potential renovation options based on given input

The module should display the (maximum) potential of the buildings (Figure 11). *WoonConnect* will provide suggestions for possible renovation options when the user states that he wants to improve certain aspects of the building (problem based advice). The suggestions also give feedback on the energy consumption, costs, comfort improvement and other information the user requires to make a choice.

Figure 11: The module should be able to display the potential renovation options

2.1.5 The module should be based on (intern) national assessment schemes

The module must be based on existing assessment schemes available for calculating comfort (Figure 12). To strengthen the validation of the comfort assessment module, the used literature should come from (inter)national recognized sources and the building regulations were possible.

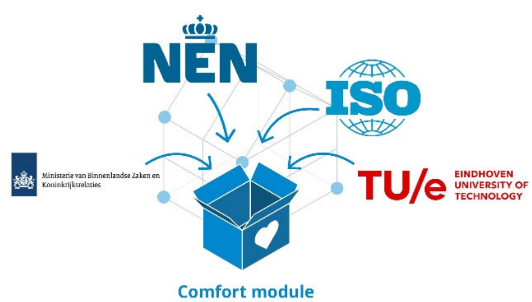


Figure 12: The module should be based on (intern) national assessment schemes.

2.2 Validation and verification requirements

The new module needs to meet several validation and verification requirements. These requirements are derived from the interviews, literature and requirements stated by the company. These sources have led to the following five verification and validation criteria.

2.2.1 Use of (inter)nationally recognized methods to calculate comfort

The first verification requirement is that the module uses (inter)nationally recognized calculation and evaluation methods for building the software. Recognized means that the method has been developed by an official party or is supported by the regulations of the Netherlands.

2.2.2 The information and methods should be 'transparent' and accessible for the users

The second verification requirements is that the literature used for the calculation and evaluation should be accessible to the users (transparent). The document therefore provides a paper summary including the discussion and sources that led to the development of the software. The document also describes how *WoonConnect* carries out the calculations. Besides a paper report, multiple respondents within the interviews also stated that they wished to have access to the information within the platform itself.

2.2.3 The comfort assessment module should be tested in a case study

The first validation requirement is that the tool should be tested in a 'case study'. The goal of the case study is to test the interface, the generated output and the outline of the process.

2.2.4 The comfort assessment method is tested in a usability test

The second validation requirement is that the tool should be tested in a 'usability test'. The goal of the test is to validate whether the software design succeeds in its intended purposes and to collect feedback from the (potential) users.

2.2.5 The comfort module requires regular updates for further validating the schemes

The last verification/validation requirement is that *De Twee Snoeken* needs to maintain the module, especially if they intend to use it for third parties. Updates are needed for new (physical) systems, regulations and to reevaluate the assessments provided by the software. To satisfy this need, *De Twee Snoeken* wishes to use the feedback and data from the users (occupants) to further validate and fine-tune the modules. For the design, the system should be built in such a way that data collection is possible for improving the pieces of advice given by *WoonConnect*

3 Comfort module design and description

The following chapter describes the (conceptual) design of the comfort module, including the background information and relevant discussions.

3.1 Description of the comfort module

Figure 13 shows the conceptual design of the new comfort module. The principle of the comfort module consists of three parts:

- The personal assessment that helps to translate the input of the occupants to advice and model input.
- the structural assessment based on the BIM-environment that acts as a framework for what can be improved and forms the connection between the different calculations
- The summary of said data within the existing output project overview interfaces of *WoonConnect*.

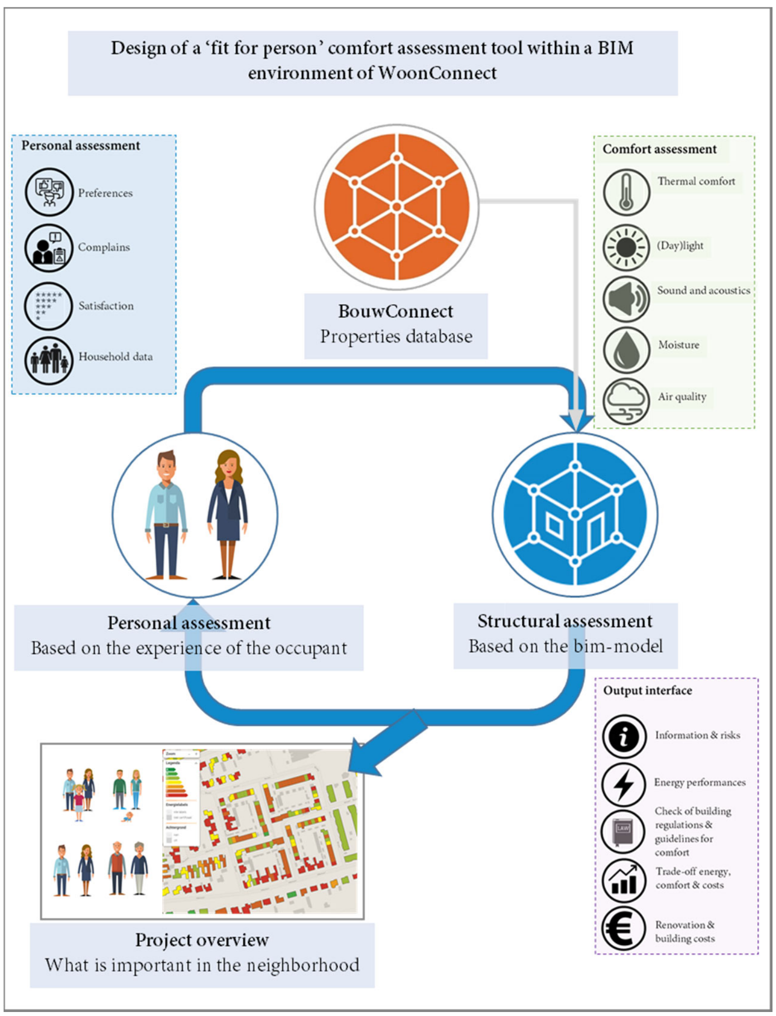


Figure 13: Conceptual design of the comfort module.

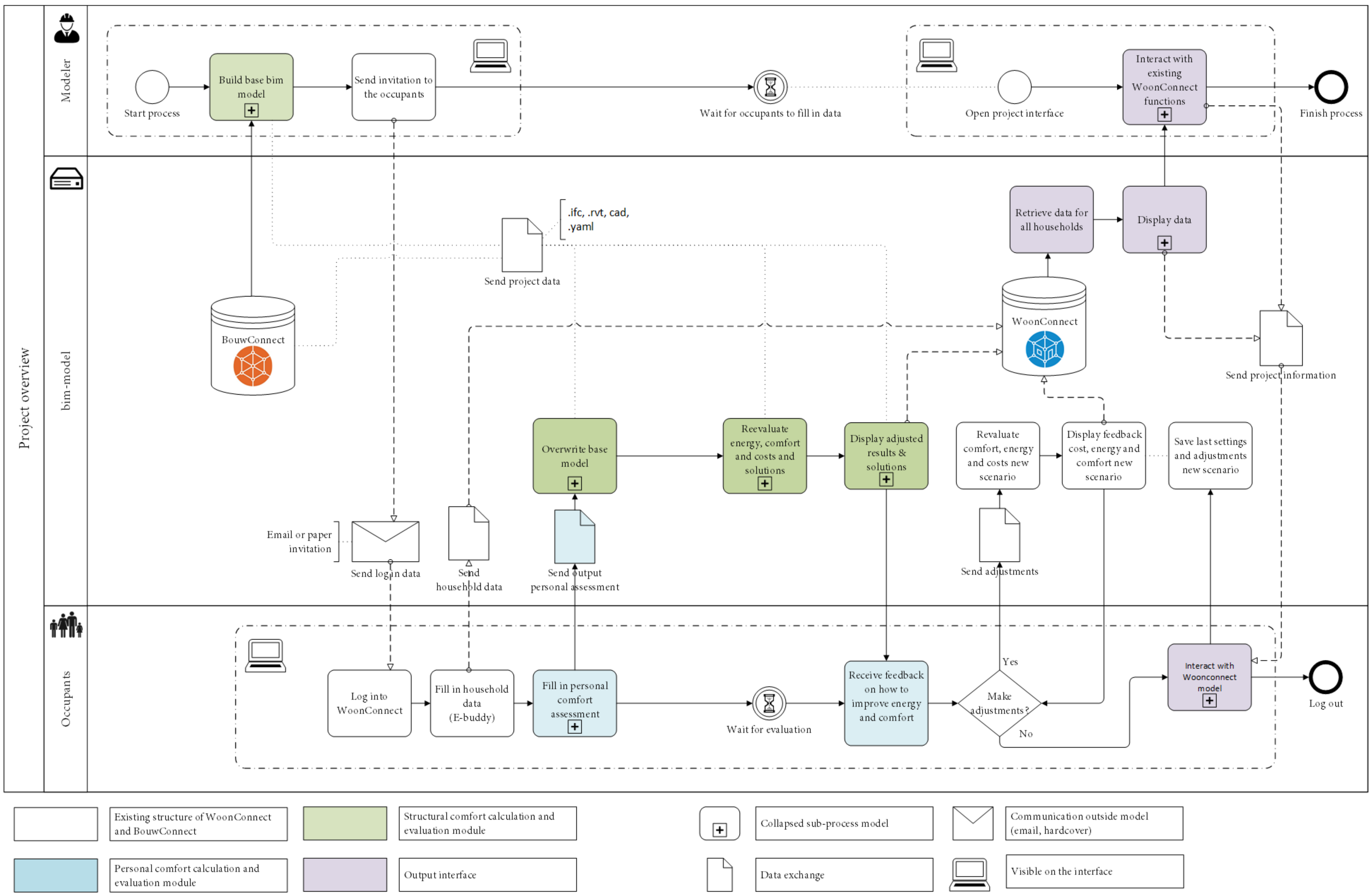


Figure 14: Information process model for a WoonConnect project. For the development of the new comfort module, the colored areas are adjusted for the model. The green actions are addressed in chapter 3.4, the blue actions are addressed in chapter 3.5 and the purple actions are addressed in chapter 3.6.

For explaining the design, an information process model was built (Figure 14 previous page). The process model shows the relation between the modeler, the BIM-model and the occupant within a *WoonConnect* project. The process model displays the relation between these groups by showing the information flow and actions of each group. These actions and information flows are required to successfully set up a *WoonConnect* project.

The purpose of the first part, the personal assessment module, is to act as a personal guideline for what the occupant wants to improve and to better understand the occupant's needs. Hence the part of the title *"Fit for person" comfort assessment module*. The needs and preferences of the occupant are derived from the household data, satisfaction ratings and complaints. In turn, the output of the model aims to use the input from the occupant to provide problem-based solutions and advice.

The second part of the module consists of a structural assessment based on the building information model. The structural model provides a framework for what the occupant can improve. It also acts as a platform for combining different criteria, including energy, costs and comfort into one multidisciplinary model to generate feedback. Based on the international guidelines, *De Twee Snoeken* wishes to use the existing BIM-structure of *BouwConnect* and *WoonConnect* to provide this multidisciplinary approach. Hence the part of the title *"Within a BIM-environment of WoonConnect"*.

The output of these parts should be connected to the existing functions of *WoonConnect* interface (see "*paragraph 1.3.2 WoonConnect*"). The resulting output and data should help the modeler to better understand the needs, preferences and problems of the occupants within the project area. Sequentially the modeler can use this information to better persuade and motivate the occupants into renovating their dwelling.

Within Figure 14, the green, blue and purple colored actions within the process information model display which parts of the process are adjusted for implementing the comfort module. The collapsed sub-process models are shown in corresponding chapters and provide a detailed description of the software. However, before explaining these sub models, section 3.2 and 3.3 will first address how *WoonConnect* will define comfort and what guidelines *WoonConnect* will use to assess comfort. After these chapters, the process model is explained step by step.

Chapter 3.4 will describe the first step; mainly how *WoonConnect* integrates the comfort within its existing BIM-structure. These new actions are represented by the green actions in the process model. Next, chapter 3.5 addresses the personal assessment from the occupants. These actions are represented by the blue actions within the process model. Lastly, chapter 3.6 will explain what adjustments are made to the main interface. These are represented by the purple actions of the process model.

3.2 Definitions for comfort

There is no single definition of comfort. Therefore the following chapter summarizes several international recognized sources, including the definitions upheld by BREEAM, LEED, GPR, the Dutch building code and the Perfection-framework. '*Annex III – Comparison of comfort categories for the different tools'* gives an overview of which criteria these tools use to define comfort.

3.2.1 Different categories for assessing comfort

Breeam-nl

Breeam-(nl) is an (inter)national assessment standard developed by the Dutch green building Council [20]. BREEAM defines comfort under the term '*Health and Wellbeing*' and has divided the assessment for comfort into 14 main chapters and several sub chapters. For each chapter they specify what documents to use. For gaining credits, the user has to provide proof that they comply with the requirements.

LEED

LEED is an international green building framework and rating system [21]**.** LEED addresses comfort under the section 'Health and human experience'. From their website, LEED states that: "*buildings and spaces with good indoor environmental quality protect the health and comfort of building occupants. A high-quality indoor environment also works to improve the building's value, enhance productivity, decrease absenteeism and reduce liability for building designers and owners*" [25].

GPR

GPR is a Dutch communication tool used for carrying out sustainable assessments [22]. GPR addresses comfort under the section health and divides it into four main categories, sound, air quality, thermal comfort and light and visual comfort.

PERFECTION

PERFECTION is a coordinated collaboration between academic institutes and the industry, including the TU/e [38]. The objective of this cooperation is the development of a framework and a set of indicators concerning the overall quality of the indoor environment of buildings for both comfort and health related metrics. The desired purpose of PERFECTION is to help enable the application of new building design and technologies that improve the impact of the indoor built environment on the human wellbeing.

Dutch building code

The Dutch building code of 2012 describes all aspects related to comfort and health under the section "*Hoofdstuk 3. Technische bouwvoorschriften uit het oogpunt van gezondheid*". The Dutch building decree also describes which methods have to be used to assess certain comfort criteria.

3.2.2 The experience of comfort and freedom in control of the indoor environment

One additional factor that the Dutch building code does not address, but the other tools do, is the ability of the occupant to control and influence their indoor surroundings. The narrative is that the psychological effect of feeling in control over one's environment plays an important role for experiencing satisfaction about one's comfort [39]. Additional factors for personal control include the level in which people can control their surroundings, the frequency to do so and the ability to quickly reach the desired conditions. [40, pp. 125–162]. For example, [41] shows that there is a relation in experiencing comfort and the ability of occupants to self-operate windows. As a result [41] concluded that personal control is a key factor to reach a good satisfaction rate for occupants.

Although these sources are discussing situations in an office setting, there is no indication that personal control does not play a role in the comfort experience of a dwelling. Therefore *WoonConnect* will also consider options within the assessment that improve the ability for self-control in a dwelling. Within *WoonConnect*, the ability for self-control is also considered in the assessment of a criteria. The comfort module will also provide advice on how to give more self-control to the occupants.

3.2.3 Comfort assessment criteria for *WoonConnect*

The previous sections gave an overview of how other tools define comfort. These definitions also provide the basic for defining comfort in *WoonConnect*. When determining how to define comfort within *WoonConnect*, several factors had to be considered. These factors include the regulations and none-regulated methods, the ability to determine the criteria within the BIM-model of *WoonConnect* and the expertise required to perform the assessment. First of all, the building regulations are a key-factor to consider as these regulations often provide binding rules on how to define and calculate comfort for the Dutch built environment. The list provided the first criteria to calculate and assess comfort in *WoonConnect*.

However, the Dutch regulations do not consider all possible criteria. For example, there are no regulations for evaluating visual comfort, self-control and thermal comfort. Other tools do assess these criteria. For thermal comfort, regulations have stated demands considering infiltration and draft; however, there are no direct demands for thermal comfort except to scale the HVAC-system for a fixed temperature (NEN 7120) [4]. All other tools consider thermal comfort. Therefore *WoonConnect* aims to assess thermal comfort as well under the criteria heating and cooling.

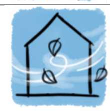
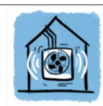
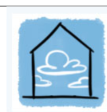
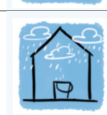
Although other tools consider thermal comfort in one calculation, *WoonConnect* will keep heating, cooling and draft separated. The reason is that the terms are easier to understand for the non-expert users (occupants). Another factor to consider is that *WoonConnect* aims to provide feedback based on the input of the occupants. Having a separation between both parts will help to better personalize the advice given to the user. For example, possible actions to take when the occupant has problems with heating are different than when the indoor climate is too hot.

Based on this principle, air humidity is also evaluated separately. Although there are regulations concerning the restriction of moisture in the structure, the focus does not lay on the air humidity in general. As a result, moisture problems are defined according the regulations of the Dutch building code, but air humidity is evaluated separated.

Besides the mandatory and additional demands, the ability to implement the software for the BIM-environment also plays a role in selecting which criteria to implement. For the regulations, criteria such as "*pest and vermin control*" and "r*estriction of damaging and toxic materials*" were considered too difficult to address in the BIM-model for now, as the required information to assess these criteria within the BIM-environment would be hard to obtain. For both criteria, the required information is often not available within many (internal) projects. These criteria can therefore not be addressed in the BIM-environment with the given methods that are available.

In summary, the above discussion has led to the following comfort criteria being assessed in the first version of *WoonConnect's* comfort module (Table 1 next page). The exact documents used to calculate these criteria are further explained in the next chapter.

Table 1: Overview of the comfort criteria considered for the development of WoonConnect comfort module.

Temperature related comfort criteria			
1		Heating	The ability for the dwelling to heat and regulate the building sufficient to prevent a cold indoor environment based on the heating set point specified by the occupants.
2		Cooling	The ability for the dwelling to cool and regulate the building to prevent overheating.
3		Draft	The ability of the building to prevent draft and unintended infiltration.
Sound related comfort criteria			
4		Sound reduction outdoor environment	Reduction of sound from the outdoor environment, for example, from traffic and air planes, based on local sound maps.
5		Sound reduction installations	Reduction of sound from HVAC-installations and common household equipment.
6		Sound restriction between rooms	Restriction of sound in the room and between rooms, including the sound propagation of adjacent buildings.
Sight and light related comfort criteria			
7		(Day) lighting	Openings in the façade to increase daylighting and the quality of the visual comfort.
Air quality and moisture related comfort criteria			
8		Indoor air quality & air change rate	Ability to ventilate the building to prevent a bad indoor climate and other pollutions.
9		Restriction of moisture (structural)	Ability of the dwellings to reduce problems with moisture in the structure, including long term problems and maintenance.
10		Air humidity	Ability of the dwellings to regulate the indoor air humidity.
Additional criteria			
11		Usability	Size of the building and the quality of the interior

3.3 Guidelines for calculating and evaluating comfort

For calculating comfort, there are several guidelines that have a ranging level of complexity. The first section discusses how complex these calculations should be for the design of the software. The second section describes the decisions made by the company for implementing the software. The last section provides a summary of which calculations methods are being used.

3.3.1 Determining the modeling complexity for calculating and evaluating comfort

For designing a calculation tool there are often several methods available. The method that the user should use can depend on several factors and often a trade-off between these factors has to be considered:

- Minimum required accuracy in accordance with the regulations and the model complexity needed to sufficiently assess a design.
- The amount of data needed and available to build the model.
- The accuracy and quality of the available data.
- Ad- and disadvantages for using simulation or traditional design tools.
- Available calculation time and the required computational requirements.
- Experience of the (intended) user regarding the assessment itself.

Modeling complexity, required input data and the skill of the intended user

In terms of accuracy, complexity, amount of (quality) data required, [42]–[45] provide an overview to determine a trade-off. These sources state that, when modeling, there is often a trade-off needed between the required complexity, accuracy and the required amount of data to build a fit for solution model. In these sources the general assumption is that complex models are more accurate, as they are a better representation of reality and consider more variables within their calculations (abstraction error) [45]. Figure 15 provides a visual overview of how [45] describes the relation between the resolution, the scope and size of the model. To describe the accuracy of a calculation model, [45] often describes complexity as the relation between the resolution of the model, the scope and the size (number of components or variables).

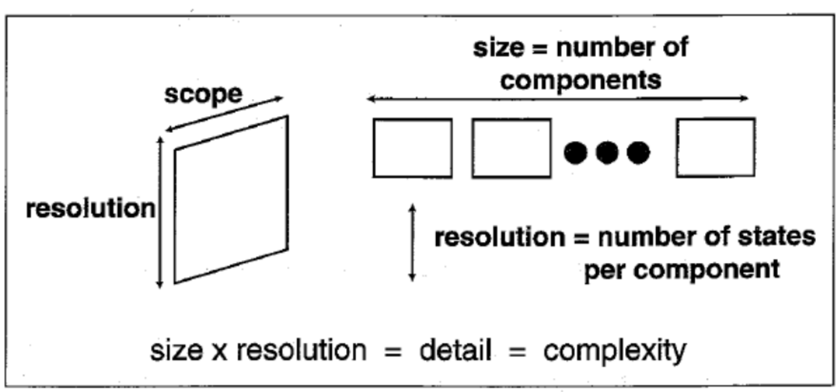


Figure 15: Model complexity visualized according to [45] , which shows the relation between the resolution, the scope and the number of components.

Overall, any combination can be made with these variables. For example, traditional tools often are solution-oriented and have therefore a narrower scope and resolution. They often focus on one discipline within (static) extreme conditions (worst case scenario) or average situations [46]. Advanced tools often consider a higher complexity and often integrate several disciplines together whilst focusing more on understanding the problems and process [46].

However, to build these advanced models and fill in these extra variables, more data is needed for the input. The increased amount of required data can adversely effect on the quality of the model, as low-quality or over-simplified data can cause errors as well. Therefore, when building models, a trade-off between the quality of the data and the modeling complexity should be considered. A visual overview of the relation is shown in Figure 16, which shows the relationship between the model complexity and the uncertainty caused by the low skill user and uncertainty in the data.

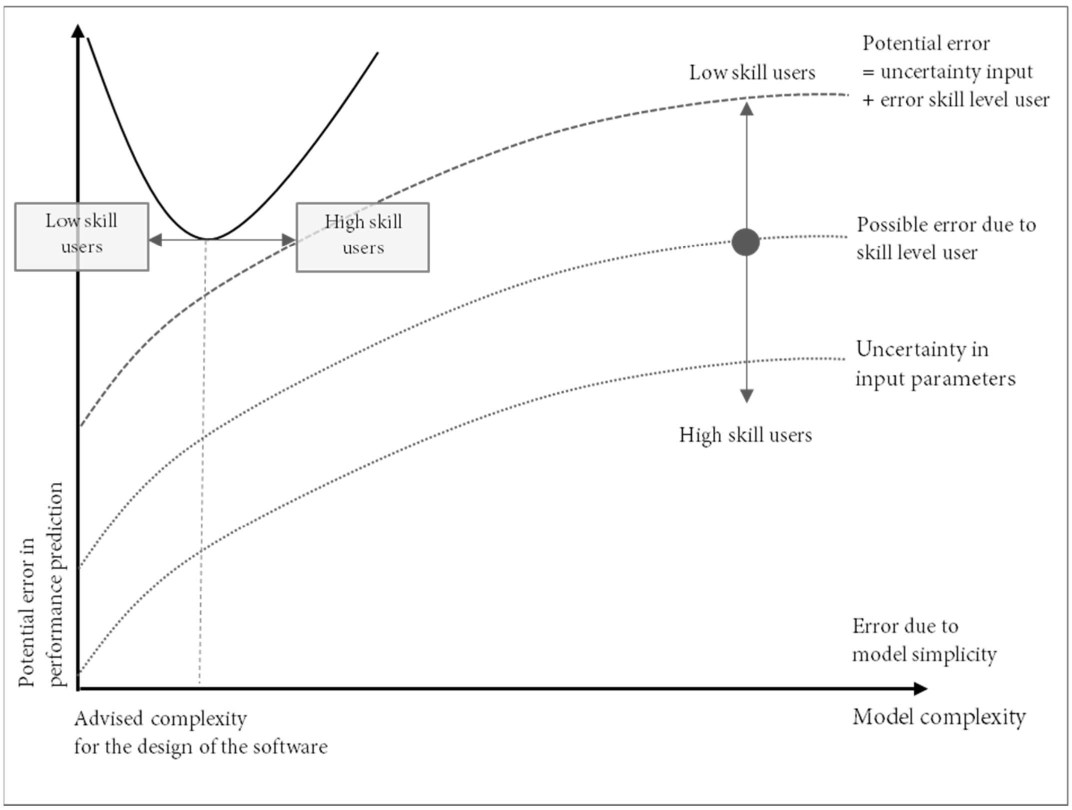


Figure 16: Trade-off between the model complexity and uncertainty of the input data adopted from [43]. *For this project we considered an additional factor, the skill level of the (intended) user. The intended user can influence the advised trade-off. A low skill user will likely make more errors in choosing the right data and operating the model. Within a complex model, this possibility is likely to increase as more data is required to build the model. The total potential error can therefore increase.*

The potential error related to the data lays in using incorrect or not representative data, which will affect the performance predictions. The possibility of using wrong data is also known as the potential error due to the uncertainty of the data or the potential error due to data abstraction [42], [43]. When building an assessment module for external usage, it needs to be considered whether the data can already be provided through the software or whether it must be entered by the users. A large part of the required data to build this model can be stored in the *BouwConnect* library. Nonetheless, it is unavoidable that the model requires additional data from the users.

The previous sources have one shortcoming regarding the modeling complexity and collecting data from the users. They evaluate the required model complexity from one viewpoint: that of an advanced user and his ability to choose a computational method himself for a given situation. When designing an assessment tool for different users, the skill of the (intended) users should also be considered.

For the design of the software, it was assumed that the skill factor of the intended user plays a large role in the correct use of the software. A trained user should be able to identify whether the (input) data is of sufficient quality and should know and understand the limits of a computational model. A trained user also knows what input data he needs to provide and what to fill in for a given assessment. Based on this knowledge, an experienced user can compensate for shortcomings of a simpler model when evaluating the output.

A low skill user is unlikely to be able to assess the quality of the data and therefore has a larger possibility to provide incorrect input data. This likelihood will increase when dealing with more advanced models as the amount of required data also increases. A low skill user is therefore more likely to misinterpret the results and their meaning as he does not understand the physical meaning and limits of a computational model. For *WoonConnect*, the intended users are often municipalities, housing corporations and occupants. Based on the interviews, it was clear that these groups had less experience with these tools than engineers.

A practical example of a situation where the skill level of the user often caused problems in the past is with Computer Fluid Dynamics calculations (*CFD-calculations*) [47]. This software is often regarded as easy to use and was very appealing to engineers, but it requires nearly academicals levels of teachings to understand the background of the model. The danger in this lies in the fact that due to the availability of this user-friendly CFD software, non-skilled users could produce credible-looking and impressive results. But chances are very likely that these results were unrealistic, inaccurate or completely incorrect. Because of the problem, the software is sometimes called 'Colors For Directors' by experts [47].

Computational time and required resources

Another factor to consider when designing a module is the (allowed) calculation time and computational power. Both factors are also dependent on the complexity on one side. It is also dependent on the intended communication mediums for the software. For *WoonConnect*, the intendent medium is a website. The web tool can be accessed through different mobile platforms and aims to provide direct feedback to the user for costs and energy. Due to the direct feedback approach, the expected computational power and time should be low.

A high computational time is also a limit of the more advanced tools, especially in cases where there is limited computational power available. For example, for the project advanced computational models for comfort such as radiance and HAMbase were tested, [47], [48]. W*oonConnect* should be able to run these calculations in an integral package, as most data could be added within the *BouwConnect* library or was already present. The possibility was already tested in a project which aimed to couple radiance to a BIM-model based on .IFC-files (*Industry Foundation Classes*) [48].

From these tests it was clear that that the required simulation time and power would be very high. For example, based on the tests by [48], the combined processing and conversion time could easily extend several minutes for a simple single dwelling daylight calculation. For HAMbase, simple tests with a terraced dwelling were also longer than half a minute.

For a web based approach, these times were considered too long for the company and customers. The user could think that the website freezes, thus closing and therefore terminating the process before it can finish. Nonetheless, the tests did show that a tools like *WoonConnect* can support more advanced computational methods.

3.3.2 Design considerations for *WoonConnect*'s new comfort module

Based on the previous tests and discussions, the following design requirements were made for the development of the new tool.

- A low complexity is required to limit the computational times and to accommodate the skill level of the occupants and government employees. Although *WoonConnect* considers that advanced calculation methods are more accurate, the simulation time and the skill level of the user proved decisive for the design of the module.
- The minimum level of complexity should be based on the regulations. These documents were verified in the past and should at the very least provide credible results. For criteria not specified in the regulations, international sources should be used.
- Because these tools are less complex, and therefore less accurate, attentions should be paid to limit the shortcomings of these documents. Known weaknesses of these documents were addressed through additional model check-ups of the situation.

- Although these tools are less accurate, they were considered suitable for the purpose of *WoonConnect*. *WoonConnect* aims to provide advice on how to renovate an average building based on an average setting. *DTS* does consider that these less complex tools might struggle in certain specific situations in which the calculation methods are limited themselves. If these situation occur, *DTS* may consider doing a more in depth study.
- Data wise the required input must be stored in the *BouwConnect* library and the BIM-model. The library ensures that (average) data is available to automatically perform the calculations. Since the physical properties are bound to these objects, changes made to the model will be reflected in each assessment. For example, insulation affects both the sound insulation and heating capacities. Choosing a different type of insulation effects both assessments.
- Additional data can also be retrieved from the occupants through the digital questionnaire if the assessment requires a more specific evaluation. It is however preferred to keep the questionnaire short to limit the amount of date required from the occupants.
- *WoonConnect* aims to use the input from the questionnaire to provide more personal assessments. Since data is collected from the occupants for the assessments, the calculations are better fitted for the situation.
- *DTS* considers that, due to the low skill users, attention should be paid to the design of the interface. A well designed interface should help reduce the chance of errors made by the low-skill users.

3.3.3 Overview of the documents for calculating and evaluating comfort

Based on the previous chapter, sources were collected to calculate and evaluate comfort within the BIM-environment of *WoonConnect*. A summary of the documents is shown in Table 2 on the next page(s) and an in depth-description of the criteria is shown in "*Annex IV – Overview of the sources used for the calculation and assessment of the criteria"*. The annex also displays which assessment methods are mandatory for the Dutch building decree. Additional limits of these sources are also addressed and described within the annex. Since *De Twee Snoeken* might consider to implement more advanced comfort calculations in the future, the required sources to build the complex models were also added. *De Twee Snoeken* can use these documents as a starting point for these developments.

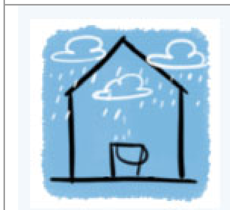
For most criteria, literature was used to define how well the building performs in relation to different calculations. An exception are the criteria *heating* and *cooling*. For heating and cooling, NEN 7120 [4] was used as a starting point to calculate the heating and cooling demand. Although NEN 7120 has limited options to assess thermal comfort directly, the method itself proved fast to use and was already fully automated in the BIM-environment of *WoonConnect*. Advanced methods such as described in Isso 74 or HAMbase [49], [50] are considered for future versions of the software.

For evaluating heating and cooling, the heating and cooling demand as determined by NEN 7120 were used as a reference scale. The principle is that when the cooling and heating demand for space heating/ cooling is low, it will be easier for the building to maintain a certain (indoor) temperature. For the temperature, a variable heating and cooling set point can be specified by the occupants themselves within the software. The main limitation of the method however is that the calculations focus on maintaining a given temperature rather than simulating the indoor temperature. The second limit is that the method cannot address local thermal discomfort within the same room.

Since the methodology is limited, additional calculations were performed with simulation software. The purpose of these calculations was to test how different renovation options contribute to thermal comfort in relation to the heating and cooling demand of a test building. For the test building, several simulations were run for a terraced dwelling in *Uden*, The Netherlands. Based on the resulting output, the threshold references *WoonConnect* uses to provide renovation advice were determined. An overview of these calculations are shown in '*Annex V* - Case study Uden and heating/cooling scenarios'.

Table 2: Summary of the different sources used to calculate comfort for each comfort criterion n.

Criteria	Summary of each criteria and used sources
 **Heating**	*WoonConnect* provides an assessment for how well the building can be heated based on the heating demand calculated by NEN 7120 [4], [51]. For the thresholds, *WoonConnect* looks to reduce the heating demand for space heating step by step. The thresholds were tested through additional calculations (*Annex V - Case study Uden and heating/cooling* scenarios*)*. To compute the heating demand for space heating, a variable thermostat set point given by the occupant acts as input.
 **Cooling**	*WoonConnect* provides an assessment for cooling based on the cooling load calculated by NEN 7120 [4], [51]. For the evaluation, *WoonConnect* looks to reduce the cooling load, both by providing passive options (solar screens) and active methods (cooling units, bypass systems). The thresholds were also tested through additional calculations (*Annex V - Case study Uden and heating/cooling* scenarios*)*. To compute the cooling demand, occupants can fill in a variable cooling set point.
 **Draft**	*WoonConnect* assesses draft based on design tips to increase the air tightness of the building and to prevent large thermal differences between rooms [52], [53]. The assessment *WoonConnect* provides consist of different steps which are increasingly more expensive or are more difficult to implement.
 **Sound – outdoor environment**	For the sound insulation from the outdoor environment, *WoonConnect* calculates with sound production levels provided by sound maps [54]. Based on the present sound production, *WoonConnect* calculates the sound reduction values of the facades towards the indoor environment and the indoor sound levels in accordance with [55]–[57].
 **Sound – installation**	For the criteria "*sound from installations*", *WoonConnect* assesses two major parts. The first part addresses the quality of the installation system with regards to the sound production. The second part addresses where the installation systems are located within the dwelling [52], [55], [58].
 **Sound – indoor (rooms acoustics)**	For assessing the sound reduction between different rooms or floors, *WoonConnect* provides an assessment of the sound insulating quality of the walls or floors that separate the rooms (and buildings) in accordance with [57], [59]–[62].

Criteria	**Summary of each criteria and used sources**
 **Ventilation and air quality**	For the indoor air quality, *WoonConnect* addresses the amount of ventilation (both for windows and the ventilation system) that is available at the building [53], [63]–[65]. The quality of the ventilation system will be higher when the system is capable of delivering more fresh air to the building then is required for the regulations [63] or by providing more flexibility for the occupants to ventilate (e.g. adjustable ventilation for the kitchen or bathroom).
 **(Day)lighting**	*WoonConnect* addresses the quality of lighting based on the size of the windows in relation to the surface area [66]–[68]. A limit of the method is that it only addresses the size of the windows as indicator for the quality of daylighting but cannot say anything about problems, for example, blinding. Based on [67], [68], extra demands were added for when blinds have to be applied.
 **Structural moisture problems**	The occupant can specify if he has problems with leakages, mold growth or flooded basements. *WoonConnect* will give information on the costs to repair such problems. Additionally, *WoonConnect* will provide advice on how to reduce maintenance related to structural moisture problems. For the given advice, *WoonConnect* uses input from technical handbooks and calculations for thermal bridges [69], [70].
 **Air humidity**	For assessing air humidity, *WoonConnect* combines both aspects of ventilation and structural moisture problems [63]–[65], [69]. For assessing the air humidity, *WoonConnect* looks first of all whether there are structural problems present (leakages), which have to be resolved first. Additional options to improve or better regulate the air humidity are based on the ability to add vapor (in case of a dry indoor environment) or to remove moisture more rapidly for rooms that have a high moisture product (ventilation).
 **Usability**	*WoonConnect* will assess usability based on the value for the appreciation of immovable properties (*Dutch: "Waardering onroerende zaken")* [71]. For the assessment *WoonConnect* will look at the size of the building, size of the garden and the size of the residential and residual areas. The assessment also looks at the quality of fixed furniture (bathroom, kitchen and toilet).

3.4 Calculating and assessing comfort within the existing BIM-structure of *WoonConnect*

For assessing comfort, the documents referred to in *"Annex IV – Overview of the sources used for the calculation and assessment of the criteria"* are implemented within the BIM-structure of *WoonConnect* and *BouwConnect*. To implement these assessment, the existing object based structure of *WoonConnect* was adjusted.

3.4.1 Existing structure of *WoonConnect* and implementing the comfort module

For implementing the new comfort module, first the existing structure of a *WoonConnect*-project is explained. Figure 17 (next page) displays the sub process model of how a *WoonConnect* project is built and how the comfort calculation affect the existing structure (green). A *WoonConnect*-project starts by building a BIM-model, which consists of different layers, objects and properties. The information to build these layers comes from the *BouwConnect* library.

In the BIM-model, the modeler has to build the design with layers and objects. When the modeler has completed the model, he can use to model to carry out assessments. These are successful when there are no errors or when the design meets the requirements set by the designer. If the model is completed, the modeler can add renovation options to the design. The renovation options can be altered by the occupant later on (see *"chapter 3.5 The personal comfort calculation and assessment module").* When the options and the BIM-model are set, the modeler can save the project as a base model and send the invitations to the occupants.

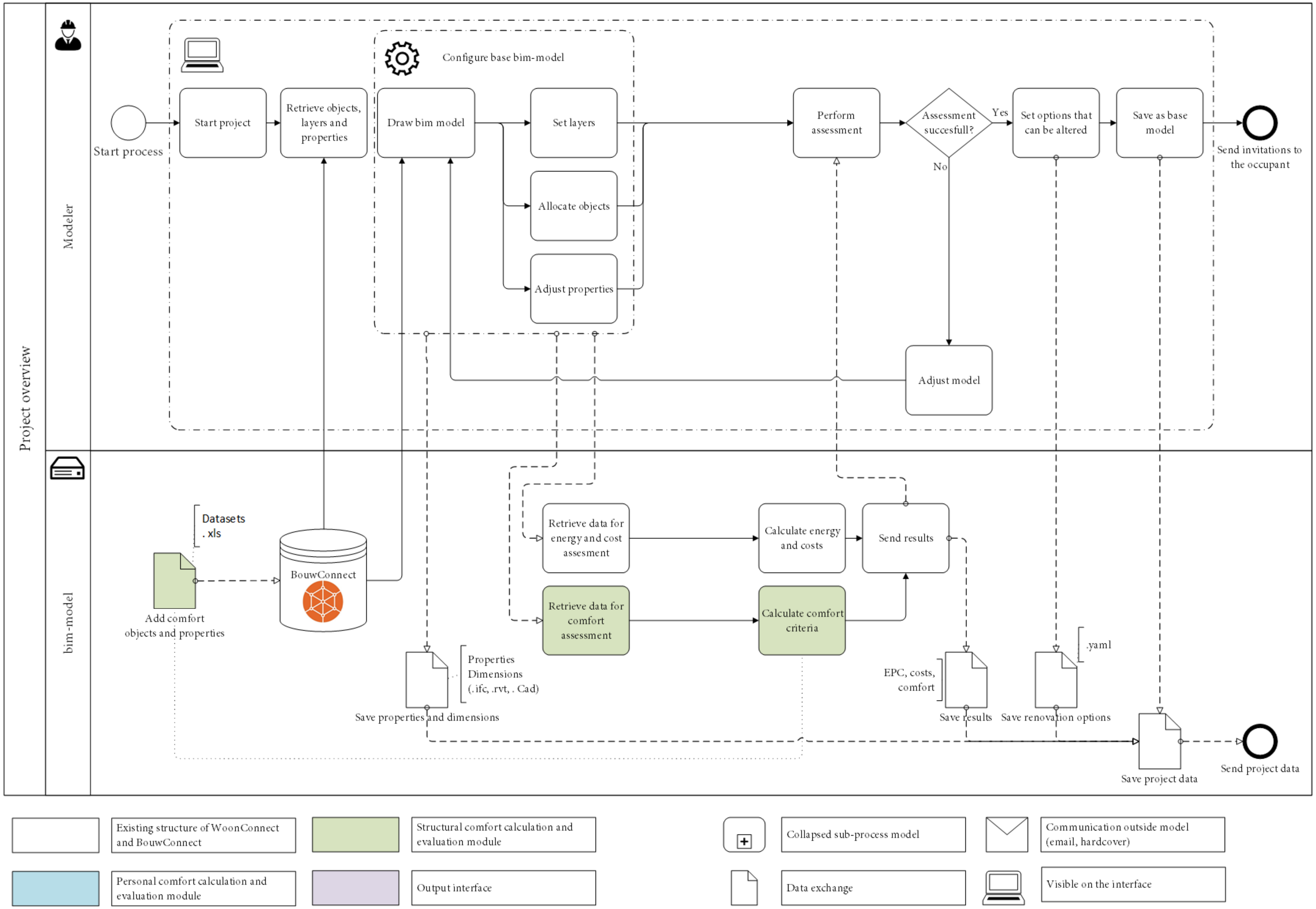


Figure 17: Overview of how a WoonConnect base model project is built by the modeler (collapsed sub process model for "build base model). The green parts show what has been altered for assessing comfort within the existing structure

Explanation of the existing structure behind WoonConnect

Figure 18 shows the structure behind the *BouwConnect* model. The existing structure consists of layers. These layers are named according to the Dutch building code and represent the different rooms or areas within the design. The left side displays the structure for the different scales ranging from the direct surroundings (*omgeving* (*eigen perceel*)), the dwelling itself (*energiegebouw*), the residential areas (*verblijfsgebieden*) (bedroom, living room, kitchen) and the residual areas (*restgebieden*) (bathroom, toilet, hallways). The right side shows the structure allocated to the layers, including the facades and the windows- and door frames. The user must provide some information on these layers, such as the dimensions, the structure, and the type of the layer.

Figure 18: The structure and layers behind BouwConnect's BIM-model. The left side displays the different layers of the model, the right side displays the structure.

After the layer is specified, the user can allocate "objects" to the layer. Figure 19 shows an example of such an object: a boiler. The boiler can be allocated as an object to a layer. By placing these objects in the BIM-environment, they also get a physical positions compared to a 3-d axis. Additional properties are also stored according to a standard template. For the different products variants, *BouwConnect* uses information from the factory, licenses, dimensions and nen-document. A modeler can overwrite these properties with own values, however, he cannot alter the template behind each object.

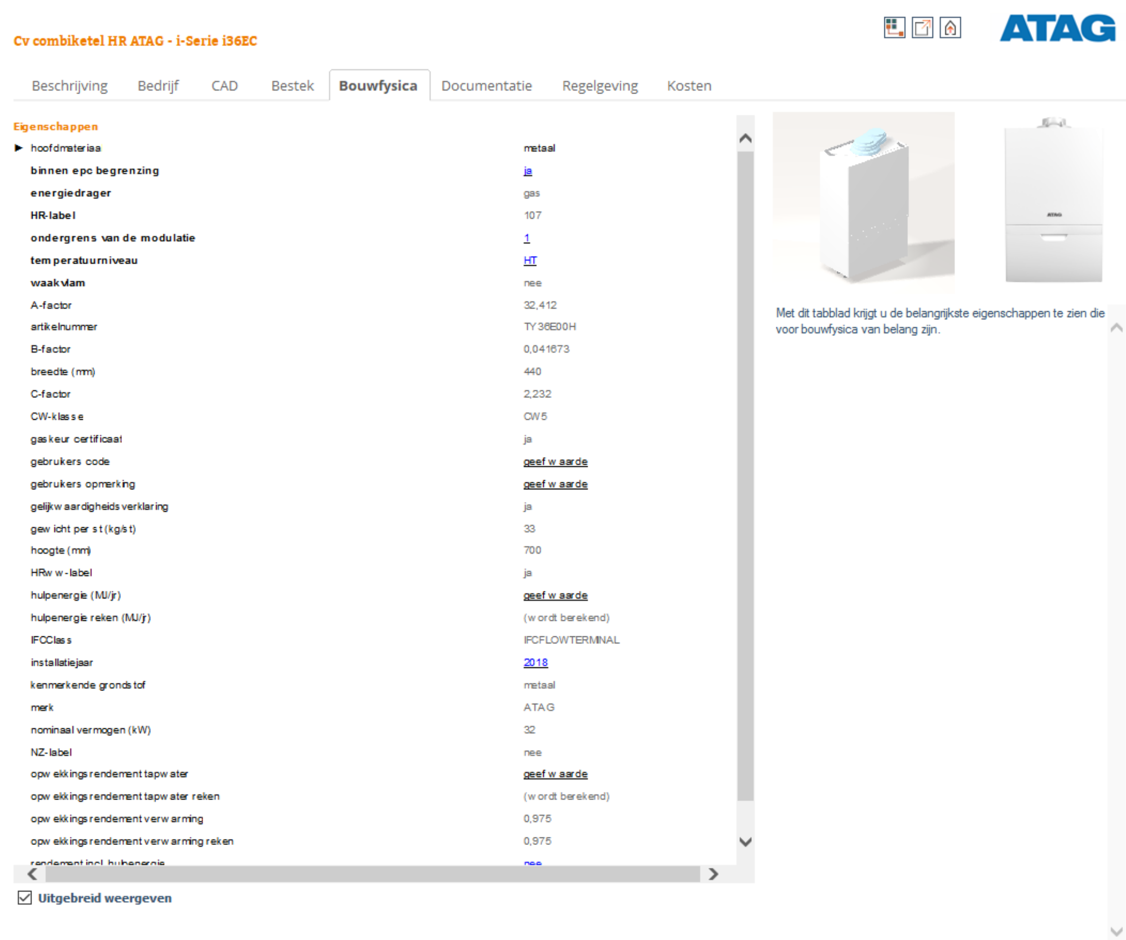


Figure 19: Example of a heating boiler as an object and the template containing all properties.

An overview of the resulting BIM-model is shown in Figure 20. For the calculations and assessments, the (default) values needed for the formulas are retrieved from the combination of objects, layers, properties and physical location(s) within the BIM-model. The resulting output of the calculations is portrayed back to the modeler. If a needed object is missing, an error is portrayed, and the user needs to add additional information or objects. The user can repeat the previous process and expand the BIM-model until he is satisfied with the results.

Figure 20: Overview of the BIM-model made in WoonConnect. The upper figure shows the 3d model created in WoonConnect BIM-environment. The lower figures shows the resulting floor plans for the first and second floor.

How the engineer can determine which objects can be altered by the occupant

When the base model has been finished, the modeler can determine which options can be renovated. Figure 21 displays a graphical overview of how the renovation options are chosen by the modeler. For the BIM-model, the modeler can specify which objects can be altered. These options are saved alongside the model including their properties.

Within *WoonConnect*, the occupant can alter these objects to build a new renovated scenario, however, the options the occupant can choose from are not infinite. These options are limited to what the modeler activates as possible renovation options during the setup of the model. The exact amount of renovation options can be determined by the modeler himself. For example, in Figure 21 the occupant cannot influence his surroundings or the size of the building. These layers or objects are fixed.

However, the occupant can alter the type of glazing or the heating system. In case of the windows, the modeler can also determine what options are not eligible. For example, single sheeted glass is likely a bad solution to improve comfort or the energy consumption. Therefore the modeler can turn the option “off”. As a result, the occupant will not see the options ‘single sheeted glass’ as options later on.

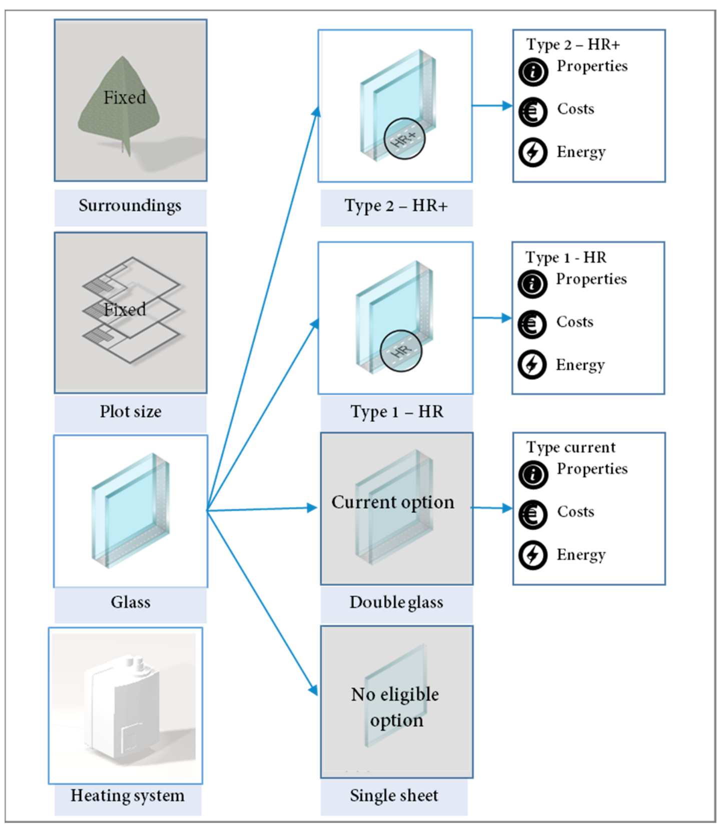


Figure 21: Example of a choice process displaying the different objects that the occupant later on can alter.

Adding new objects and properties in BouwConnect for calculating the comfort criteria
The previous sections described the existing structure of *WoonConnect* and how a model is built. The first design requirement was that the new comfort module fits within the existing structure and corresponds with the existing functions described in the previous paragraph.

To meet these requirements, *BouwConnect* [19] was expanded with new objects (and properties) required for the calculations. The new objects should be usable by the modeler in the same way as the existing objects and must be added to the BIM-environment as part of the assessment.

3.4.2 Assessment for comfort based on the BIM-model of *WoonConnect*
The previous section explained how *WoonConnect* calculates comfort based on the existing structure. For assessing comfort within the structure of *WoonConnect*, the design decision made was to evaluate comfort based on the output of the calculations. The output of the models is compared to a score and threshold based system similar to that of the other tools discussed in chapter 1.4. For the structure of the score system, a similar structure was used as the home health care module that was developed for *WoonConnect* in the period of 2017-2018 [72], [73].

The home health care module was designed to assess the ability of a dwelling to support self-reliant living based on the amount of points the dwelling could score [72]. The resulting score was divided into a total 'home health care label' ranging from F (very bad, cannot support elderly people) to A (very good, can support elderly and disabled people). Each label could be reached when a minimum score and several thresholds were reached. The goal of the thresholds is to prevent scenarios that are certain to cause problems. For example, a dwelling can have a very high score with regards to the home health care; however, if the entrance is not accessible for a wheelchair, the building should not be called a self-reliant dwelling.

Score and threshold based assessment scheme for the comfort module
For the development of the structural comfort module a similar structure was chosen as the home health care unit. The main reasons were that the system fits in line with the existing modules for the energy label and the home health care module, thus providing a coherent program for the end-user. Secondly, the score and threshold approach proved easier to understand for a part of the costumer segment as they require limited knowledge of the physical properties.

Similar as with the home health care assessment module, the assessment is carried out on a scale ranging from F to A. Label F indicates that the building is not very well equipped to guarantee a good comfort. On the other hand, A indicates the building is better equipped to provide, on average, good comfort and that the building has more system flexibility in countering discomfort. For setting up the assessment, the following requirements for the score based and the thresholds based assessment for comfort were set.

Score based assessment system

For the score based assessment system datasets were built for *WoonConnect*. The dataset is added in *Annex 4*. An example from the data set is shown in Table 3. The scores are based on several 'questions' that are asked from the model. The answers to these questions are predetermined scales derived from the guidelines collected in chapter 3.3 and are related to the output of the calculations methods, objects and their properties. To each of these parts, a score is attached to identify what can be improved with regards to the renovation options. A penalty score is given for situations or objects that are certain to cause problems with regards to comfort.

Table 3: Example of a data set built for the object 'windows'. The object affects heating, cooling, sound insulation and draft. Since this question is room based, point are allocated for the outcome of each individual room. Therefore a room with double glass will not gain the same amount of points as a room with HR +++ glass.

Id number	91.91									
Question asked from the model	What type of glazing is used within each room?									
Layer within *WoonConnect*?	Room layer (points awarded per room)									
Possible states	**Heating**	**Cooling**	**Sound reduction from installations**	**Sound reduction outdoor environment**	**Sound restriction between rooms**	**(day)lighting**	**Indoor air quality & air change rate**	**Restriction of moisture (structure)**	**Air humidity**	**Draft and infiltration**
HR +++ glass or triple glass	50	10	-	50	-	-	-	-	-	50
HR++ glass	20	10	-	20	-	-	-	-	-	20
HR+ glass	10	10	-	10	-	-	-	-	-	10
HR glass	10	10	-	10	-	-	-	-	-	10
Double glass	0	0	-	0	-	-	-	-	-	0
Glass front	-10	0	-	-10	-	-	-	-	-	-10
Single sheeted glass	-20	-10	-	-20	-	-	-	-	-	-20

To fit the scores to the existing structure, each question is allocated to one of the different layers described in Figure 22 (next page). Based on the type of layer, the score is determined slightly different in the total assessment. Objects that are attached to the building layer are only counted once in the assessment, since they effect the building as a whole. On the other hand, objects such as the type of glazing can differ per room, residential or residual area. The score gained for an object marked with 'room, residential area or residual area can differ per individual room or area and allows the model to deal with differences between each room (e.g. three rooms have single sheeted glass, the other rooms have double glazing).

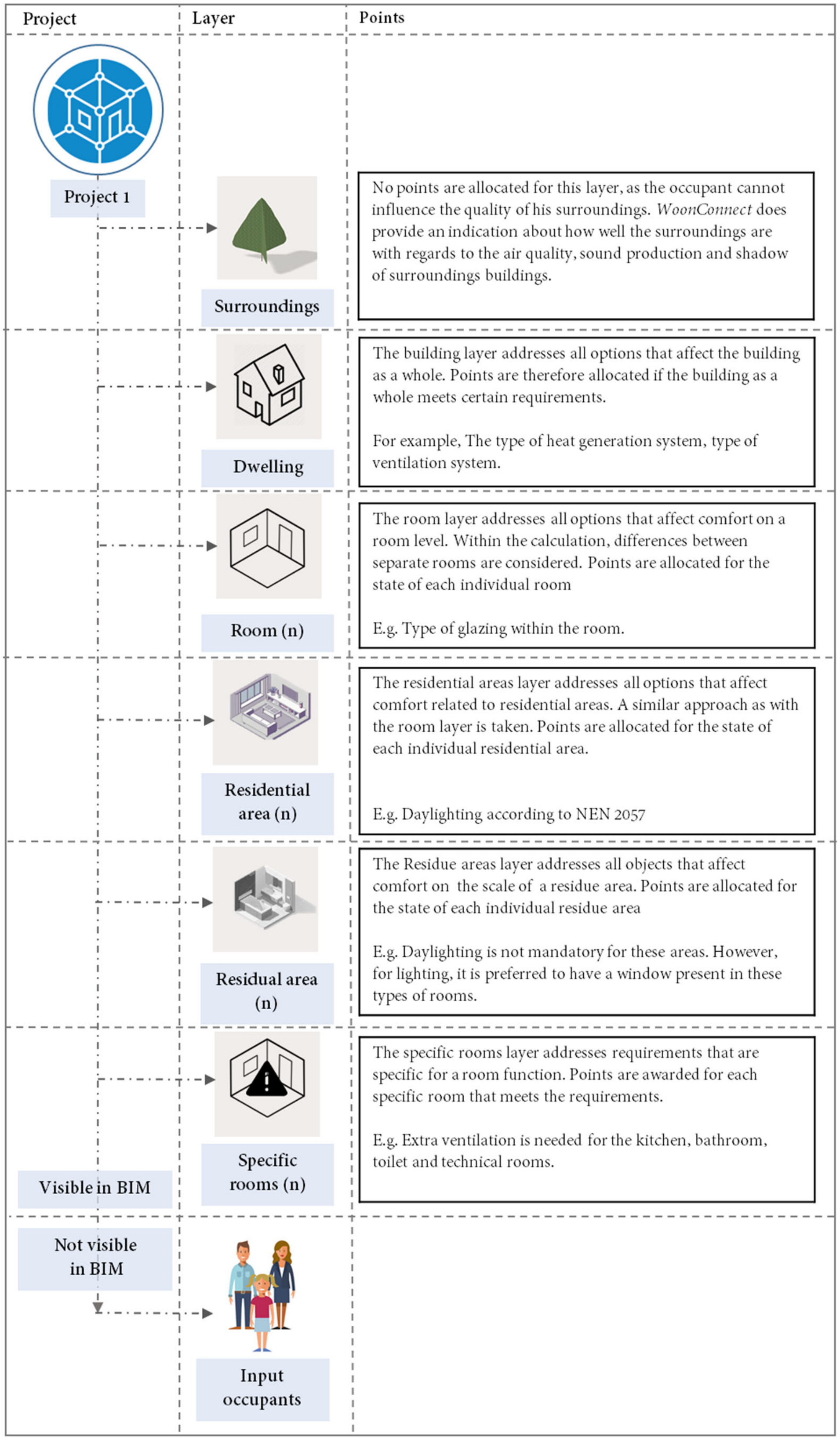


Figure 22: Graphic explaining how the scores are related to each layer, including examples. All questions/ scenarios are allocated to one of these layers and points are awarded accordingly.

Threshold based assessment system

Besides the score based assessment system, *WoonConnect* also makes use of thresholds. An overview of these thresholds for each criteria is shown in "*Annex IV – Overview of the sources used for the calculation and assessment of the criteria"*. For setting up these thresholds the following design requirements were considered.

The first requirement for the thresholds is that they point out combinations that are certain to cause problems related to comfort or health. If possible, the thresholds are based on the output of the different NEN-calculation methods (e.g. ventilation rate of the building, expressed in m3/h, sound insulation of the walls expressed in decibel).

The second requirement is that the threshold system acts as a guideline reference scale for improving comfort step by step. These reference scales for the thresholds are based on the different documents used for calculating comfort and internal discussions between the PDEng and DTS. The thresholds are based on the following structure

- Whether the situation is certain to cause a lot of discomfort or health issues (label F thresholds).
- The regulations for existing, renovation or new buildings. (label E, D and C)
- Descriptions from literature about how to improve comfort above the standards of new buildings by providing a more flexible system (label B and A thresholds).

Calculation of the structural assessment of the BIM-model

To provide an indication about how well building is equipped to provide good comfort, *WoonConnect* aims to give an individual assessment for each comfort criteria defined in section 3.2. The reason why *De Twee Snoeken* wanted to express the assessment of a criteria in one label is to make it easier to understand for their costumer segment. The abstraction of each assessment was deemed required, as from the interviews it was clear that many of the users could not understand all physical details behind the model. The total assessment for each criteria will also be expressed through a label, ranging from F (very bad, a lot can be improved) to A (very good, little can still be improved). To reach a certain label, the model has to meet both the threshold requirements and have a minimum number of points. To calculate the score system, *WoonConnect* first calculates a minimum *($S_{min\_criteria}$)* and maximum ($S_{max\_criteria}$) number of points that the model can achieve for each comfort criteria through the following equations.

Equation (1): Calculation of the minimum achievable score in WoonConnect for one comfort criteria (n)

$$S_{min\_n} = \sum_{Q_{dwelling}}^{n} (S_{Qmin\_dweling}) + \sum_{Q_{room}}^{n} (m_{room} \times S_{\mathrm{Qmin}\_rooms}) + \sum_{Q_{residential}}^{n} (m_{residential} \times S_{Qmin\_residential}) + \sum_{Q_{Residue}}^{n} (m_{residue} \times S_{\mathrm{Qmin}\_residue}) + \sum_{Q_{Specific\_room}}^{n} (m_{Specific\_room} \times S_{Qmin\_Specific\_room})$$

Equation (2): Calculation of the maximum achievable score in WoonConnect for one comfort criterion (n).

$$S_{max\_n} = \sum_{Q_{dwelling}}^{n}(S_{\mathrm{Qmax}\_dweling}) + \sum_{Q_{room}}^{n}(m_{room} \times S_{\mathrm{Qmax}\_rooms}) + \sum_{Q_{residential}}^{n}(m_{residential} \times S_{Qmax\_residential}) + \sum_{Q_{Residue}}^{n}(m_{residue} \times S_{\mathrm{Qmax}\_residue}) + \sum_{Q_{Specific\_room}}^{n}(m_{Specific\_room} \times S_{Qmax\_Specific\_room})$$

In which:

S_{min_n}	= Minimum achievable score for comfort criterion n.
S_{max_n}	= Maximum achievable score for comfort criterion n.
m_{layer}	= Multiplier for the minimum or maximum score based on the layer type, number of rooms, residential areas, residue areas or specific rooms within the model.
Q_{layer}	= Number of questions related to the comfort criterion n at a given layer.
S_{Qmin_layer}	= Minimum score achievable for every question at given a layer (dwelling, residential, residual or specific room).
S_{Qmax_layer}	= Maximum score achievable for every question at given a layer (dwelling, residential, residual or specific room).

The resulting range, defined by S_{min_n} and S_{max_n}, represents the potential score to be gained for the model for one comfort criterion. For the assessment of the comfort criteria, *WoonConnect* divides the range into six equal parts. To improve the assessment, the score has to be increased sufficiently. The occupant or the modeler can increase the score by choosing options that improve comfort. For example, double glazing improves the given score for the comfort criteria heating, draft and sound insulation. Choosing or altering such options will affect the score given for the model. The resulting score for a given scenario is computed through the following equation and can be repeated for different scenarios.

Equation (3): Calculation of the score for a scenario (m) related to a comfort criteria n.

$$S_{scenario(m),n} = \sum_{Q_{dwelling}}^{n}(S_{\mathrm{Q\_dwelling}}) + \sum_{Q_{room}}^{n}(S_{\mathrm{Q}\_rooms}) + \sum_{Q_{residential}}^{n}(S_{Q\_residential}) + \sum_{Q_{Residue}}^{n}(S_{\mathrm{Q}\_residue}) + \sum_{Q_{Specific\_room}}^{n}(S_{Q\_Specific\_room})$$

In which:

$S_{scenario(m),n}$	= Total score for comfort criterion n for given model scenario (m)
S_{Q_layer}	= Score given for all question within the different layers: '*dwelling*', '*room*', '*residential area*', '*residue area*' and the '*specific rooms*'
Q_{layer}	= Number of questions related to the comfort criteria n at a given layer

Within equation 3, the difference between the questions allocated to the layer 'dwelling' and the questions allocated to the layer 'room', 'residential area', 'residue area' and the 'specific rooms' comes into play. Table 4 displays an example for how the score is determined at the dwelling layer. The total score given for the question addressing the layer '*dwelling*' has only one answer or 'model state'. For example, a roof as a whole is insulated, not just parts of it. The score given to the question: "What type of insulation is being used in the dwelling" can therefore only have one answer and therefore gains one score.

Table 4: Example for how the score is determined for a question at the layer 'dwelling'.

Question asked from the model	**How is the roof insulated?**	
Layer within *WoonConnect*?	Dwelling layer	
$Q_{dwelling\_1}$	**Possible state of the model**	$S_{Q\_dwelling\_1}$
When is the roof insulated?	Roof is insulated according to regulations for new buildings as of 2015 (Rc > 6,0 m².K/W)	100
	Roof is insulated according to regulations from after 2010 (Rc > 3,5 m².K/W)	50
	Roof is insulated according to regulations between 2000 and 2010 (Rc > 3,0 m².K/W)	20
	Roof is insulated according to regulations between 1990 and 2000 (Rc > 2,5 m².K/W)	10
	Roof is insulated according to regulations between 1980 and 1990 (Rc > 2,0 m².K/W)	0
	Roof is not insulated (before) 1980 (Rc > 1,3 m².K/W)	-50

For the other layers, a different approach is used. The main reason is that the state of each room or area can differ compared to the dwelling layer. For example, a dwelling can have HR++ glazing at one room and single sheeted glass at another room. Therefore, the total score calculated for a question at a room or area layer is determined through the following equation:

Equation (4): Calculation of the score for a question in the room, residential, residue or specific room criteria.

$$S_{Q\_room} = \sum_{n=1}^{p_{room}} S_{room\_n}$$

In which:

S_{Q_room} = Total score given for the question based on the state of each individual room or area.

S_{Room_n} = Score given for the state of said room or area. The score can differ per room or area. If there is a combination of options possible, the lowest score is decisive for the displayed score at given room or area.

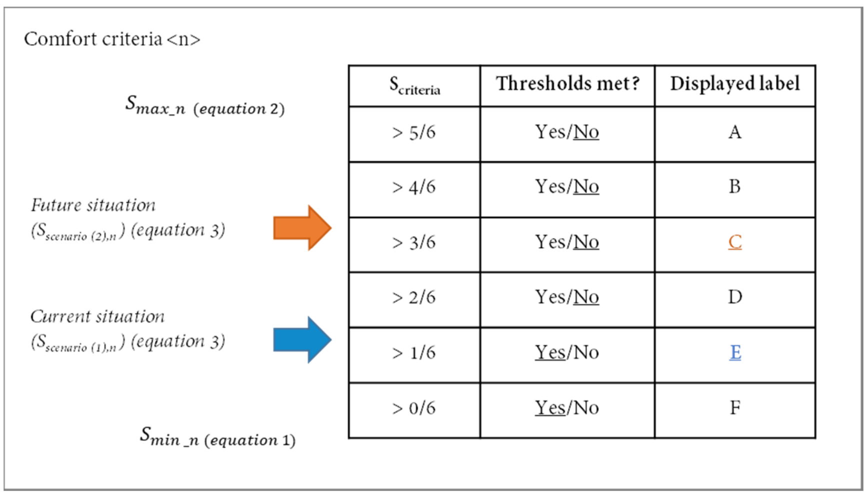
p_{room} = Number rooms or areas for which the question is repeated in the model. A score is given for each individual room or area

When all question related to the model have been solved, the thresholds are checked. The thresholds are met when the BIM-model has the correct state for certain questions. For example, if the threshold describes that the building must have an insulated roof, then the state of the question from Table 4 must be that it is insulated. If the question retrieves the correct answer, then the threshold is met.

Displayed structural assessment label within WoonConnect

The previous section described how the score and thresholds behind the comfort assessment are determined for the BIM-model. When the model has solved all questions and has checked the thresholds related to the comfort criteria, *WoonConnect* will provide a total label for said criteria.

The graphic shown in Figure 23 explains the total assessment. *WoonConnect* displays a certain label when a minimum score has been reached and corresponding thresholds are met. The final label can range from 'F' (very bad) to 'A' (very good). Figure 24 shows how the resulting labels are printed on the interface for each individual comfort criterion. As part of the verification criteria, the assessment can be printed as a hard copy document ("*comfortrapport downloaden*"). The document contains a more detailed description behind the model, including the provided scores, corresponding physical model properties and thresholds behind the model.



$S_{criteria}$	Thresholds met?	Displayed label
> 5/6	Yes/No	A
> 4/6	Yes/No	B
> 3/6	Yes/No	C
> 2/6	Yes/No	D
> 1/6	Yes/No	E
> 0/6	Yes/No	F

Figure 23: Graphic explaining how the displayed label is determined within WoonConnect's interface.

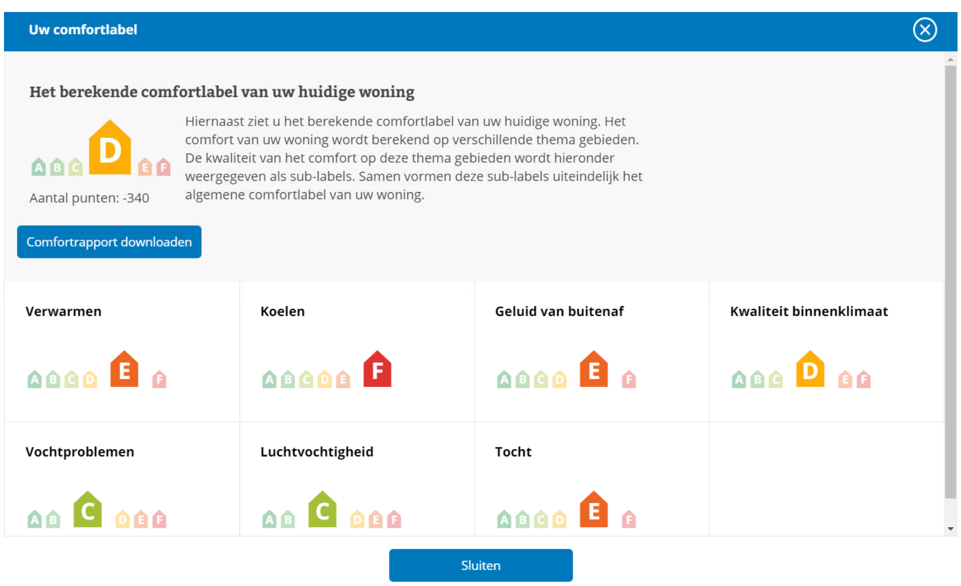


Figure 24: Screenshot of the interface displaying the individual structural assessments for each comfort criterion.

3.4.3 Using personal data to build a 'fit for person' model for the occupant

The previous section went into detail on the existing structure of *WoonConnect*, how new objects and properties are added in *BouwConnect* and how *WoonConnect* calculates and assesses comfort based on the BIM-model. This section will go in to detail on how the input of the occupant is used as data to provide '*fit for person*' advice on the renovation.

Figure 26 on the following page shows the collapsed sub-process for how *WoonConnect* uses the input from the occupant to provide better fitted calculations. Within the sub-process, the first step that the occupant has to fill in the personal comfort assessment. The resulting output is saved for each individual household that fills in the questionnaire. The output of this questionnaire is translated to abstract data which is used to overwrite default values of the base model built earlier by the modeler. For example, in Figure 25, the modeler assumed that the building has double glazing for the base model scenario. However, the occupant can specify that his building still uses single sheeted glass. For the structural assessment, the default double glazing 'state' is replaced with the worse single sheeted glass for the calculation of the relevant criteria. The resulting model is saved as a new scenario.

After the adjusted properties have overwritten the default values, *WoonConnect* will reevaluate the assessment for energy, the comfort criteria and costs. After the reevaluation is completed, *WoonConnect* displays the updated results to the user. Based on the evaluation, *WoonConnect* determines the remaining solutions to improve comfort and energy. *WoonConnect* determines the possible solutions by evaluating the list of renovation options set up by the modeler to the current settings. Based on the remaining options, *WoonConnect* will display the results to the user. In the example of Figure 25, the advice will be to install HR glass or better.

Base model (assumption modeler)	**Answer occupant (overwrites default setting)**	**Advice shown to the user**
• Triple glass • HR ++ glass • HR + glass • HR glass ✓ Double glazing • Additional glass front • Single sheeted glass	• Triple glass • HR ++ glass • HR + glass • HR glass • Double glazing • Additional glass front ✓ Single sheeted glass	• Triple glass • HR ++ glass • HR + glass • HR glass • Double glazing • Additional glass front • Single sheeted glass

Figure 25: Example of a process from the base model scenario (left), to the adjusted scenario based on the occupant input (center) and the printed advice shown to the user (right). The light grey options cannot be chosen, as they are turned off by the modeler.

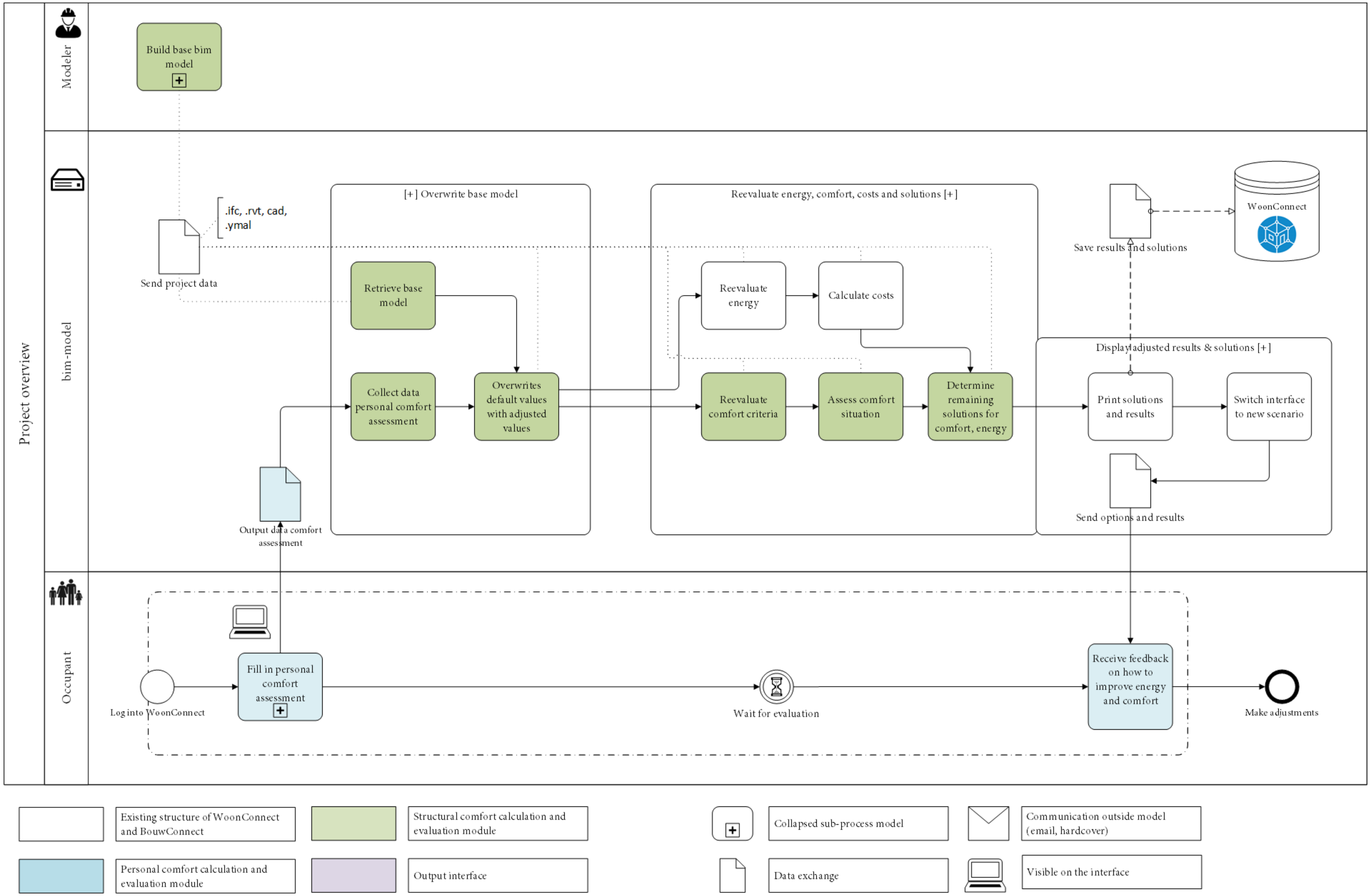


Figure 26: Process model for how the personal comfort assessment (blue) is being used to overwrite base model values in WoonConnect (green). The resulting output is printed and visible to the occupant.

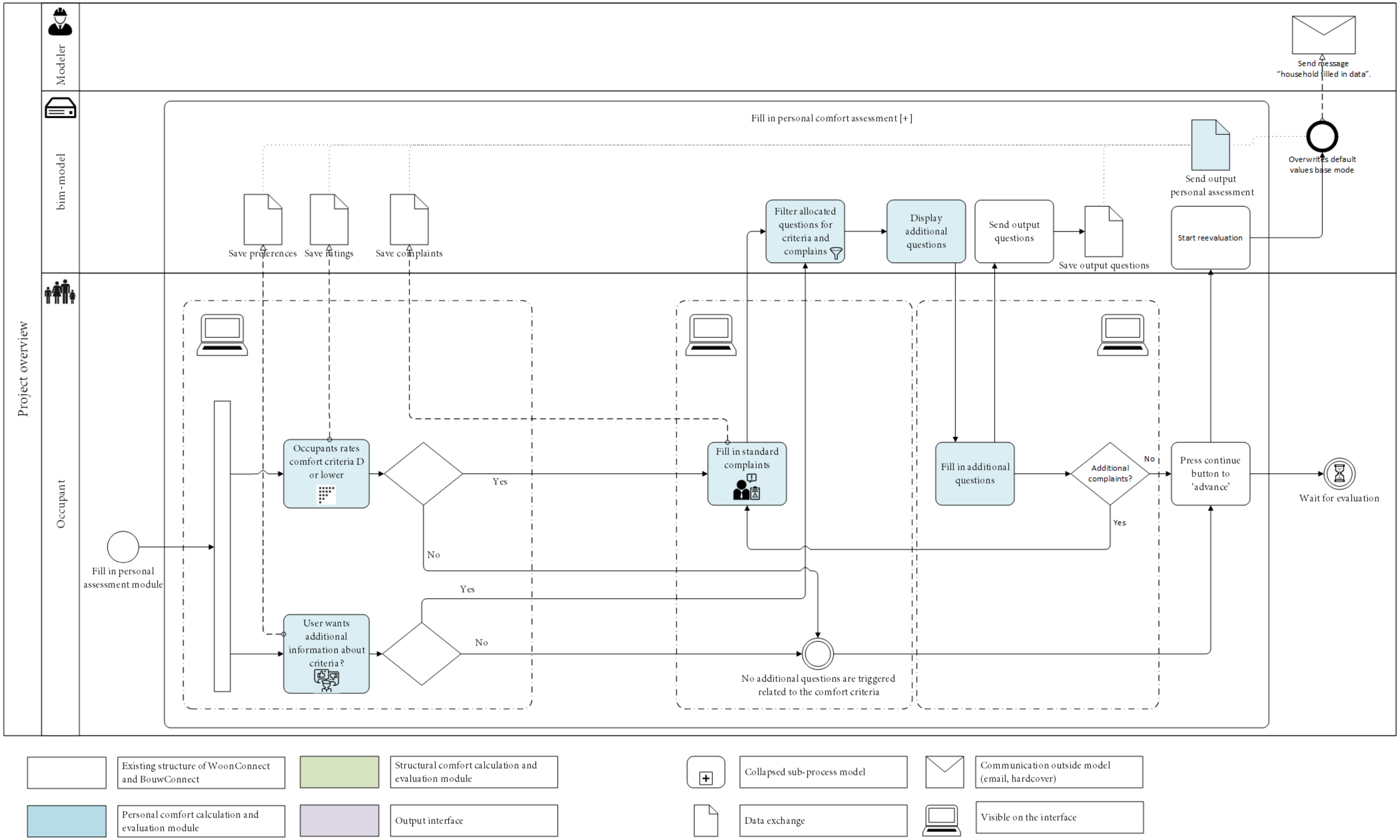


Figure 27: Process model used for the personal assessment. This personal assessment is based on the ratings, preferences, complaints and additional questions filled in by the occupant. The exact information shown at each blue step is shown in Figure 28

3.5 The personal comfort calculation and assessment module

Whereas the structural assessment addresses comfort based on the BIM-model, *WoonConnect* also aims to consider the opinion, complaints and input of the occupants for the assessment and given advice. The personal assessment of the module has several purposes. The first purpose is collect feedback on the dwelling in terms of how satisfied the occupants are with their comfort. The modeler can use the feedback to provide better fitted advice. The second purpose is to collect information on the occupants that can be used to fine-tune the energy and comfort assessments. The last purpose is to provide (personal) advice based on this feedback and input.

3.5.1 Complaint, rating and preferences approach

Figure 27 on the previous page show the process model for how *WoonConnect* will ask people to evaluate their comfort experience within their dwelling. The occupant can start this process when pressing the button of the comfort module. To evaluate comfort, the occupant is asked three pieces of information (see Figure 28). The first and second pieces focus on rating the building with regards to comfort and by determining if the occupant wants to improve said criteria. For the rating, a similar A to F scale is used as in the structural assessment ("S*ection: 3.4.2 Assessment for comfort based on the BIM-model* of *WoonConnect").*

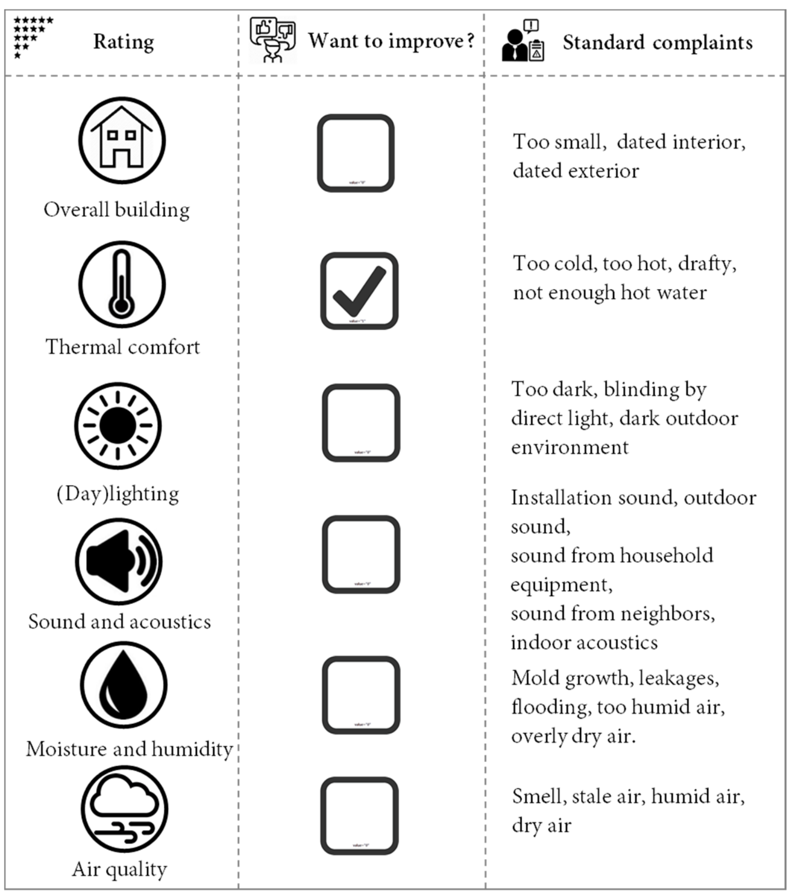


Figure 28: Overview of how the people can make their preferences known in the software. The list of standard complains can still be extended.

An explanation of what each scale means is displayed in Table 5 below. The proposed explanation of the rating system is based on two parts. These parts are the severity and regularity of the complaint and whether the occupant has options to counter discomfort.

Table 5: Overview of the rating system for assessing (dis) comfort.

Rating	Explanation rating system of the occupants for each label
A	The user actively experiences the dwelling as very comfortable. For example, the dwelling is very spacious, quiet or light. If the user experiences discomfort, the dwelling provides multiple options to act against the problem quickly.
B	The user experiences the dwelling as comfortable. If the user experiences discomfort, the dwelling provides sufficient options to act against the problem.
C	The user sometimes experiences discomfort, but it only happens infrequently. If the user experiences discomfort, the dwelling provides sufficient options to act against the problem.
D	The user experiences discomfort regularly during certain periods or under certain conditions, but not during fixed intervals. For example, when opening windows or when opening a door. The user is unable to act against the problem.
E	The user experiences discomfort during certain periods or during fixed intervals. For example, cold during winter, leakages during long rain periods. The user is unable to act against the problem.
F	The user experiences discomfort on a daily or weekly basis. The user is unable to act against the problems.

After the occupant has rated the different comfort criteria and whether he wants to improve a criteria or not, the complaint interface shows up. The complaint interface shows several standardized complaints related to the different comfort criteria. Initially, only complaints relating to criteria that have been rated D or lower are shown. Through filtering the rating and complaints in advance, *WoonConnect* aims to limit the information required from the occupant and therefore to provide better fitted advice. When the occupant has filled in his complaints, the interface will switch to a third interface.

3.5.2 Limiting the amount of input needed from the occupants

Figure 29 shows an example of how the questions are filtered based on the rating and complaints. Based on the rating, preferences and the complaints, the third interface will show additional questions about the dwelling that are related to the complaints. However, the interface will not show all questions at once. If the occupant has to fill in too many questions, he might be dissuaded into filling in the information at all. Therefore the questions are filtered based on the rating system displayed in Figure 27 to reduce the information burden of the occupant.

However, the questions can also be triggered based on the preferences of the occupant. If the rating is very high (C or higher), the occupant can still ask for additional options. The occupant can trigger the additional questions by checking the box ‘want to improve’ on. However, unlike the complaints filter, all questions related to the criteria as a whole will be shown.

The occupant is free to fill in the shown questions. The output of these questions are used to overwrite the default values used within the model and to evaluate which options can still be altered. If the occupant does not fill in the questions, the default values are retained.

Comfort criteria	Thermal comfort	
Rating	E	
 	**Standard complaint**	
	Drafty, too cold	
	Triggered question	
	What type of glazing do you have?	
Base model (assumption modeler)	**Answer occupant (overwrites default setting)**	**Shown advice to the user**
• Triple glass • HR ++ glass • HR + glass ✓ HR glass • Double glazing • Additional glass front • Single sheeted glass	• Triple glass • HR ++ glass • HR + glass • HR glass • Double glazing • Additional glass front ✓ Single sheeted glass	• Triple glass • HR ++ glass • HR + glass ✓ HR glass • Double glazing • Additional glass front • Single sheeted glass

Figure 29. Example of a whole process based on the example of Section 3.3.2. The occupant has rated thermal comfort low (E). As a result, the standard complaints "too cold", "drafty", "too hot" and "not enough warm water" are shown on the second interface. In this example, the occupant filled in the standard complaints "drafty" and "too cold". One of the questions that is triggered is what type of glazing the occupant uses. For the shown advice, the remaining options are shown that can be improved.

3.5.3 Closing the personal assessment interface

After the occupant has filled in the rating, preferences, complaints and questions, he can select a button to show the results. Selecting this button will trigger the evaluation scheme described in Section 3.3.2. The reevaluation will start and the advice is determined. The input filled in by the occupant is saved. The modeler can retrieve the information later on for each household that fills in this information.

After the model is done with the reevaluation, the interface will switch to a digital model of the building where the occupant can interact with it and can make adjustments to the dwelling (Figure 30). The shown adjustments are limited to the options set and determined by the modeler in the previous step. In the existing structure, *WoonConnect* can already show these options for reducing the energy consumption and costs. For the comfort assessment module, a new tab will display the renovation options related to comfort. Selecting any of these renovation options will display the feedback directly in the comfort assessment and the energy assessment by altering the energy consumption and costs. Also the visual model shown in the interface will change, depending on the situation.

In case of doubt, the occupant can select an advice button. Pressing the button will trigger *WoonConnect* to show some advice based on the reference tables (*see Session "3.4.2 Assessment for comfort based on the BIM-model* of WoonConnect*").* When the occupant is done making adjustments, he can close the interface. The personal in charge of the project will receive a notification that this household has filled in the information and the latest settings are saved.

Figure 30: Example where the visual model changes. In this case study, the occupant stated in the question that he already has implemented PV and does have a sun screen on the front side. If the occupant chooses a new renovation option, it will be portrayed in the BIM-environment.

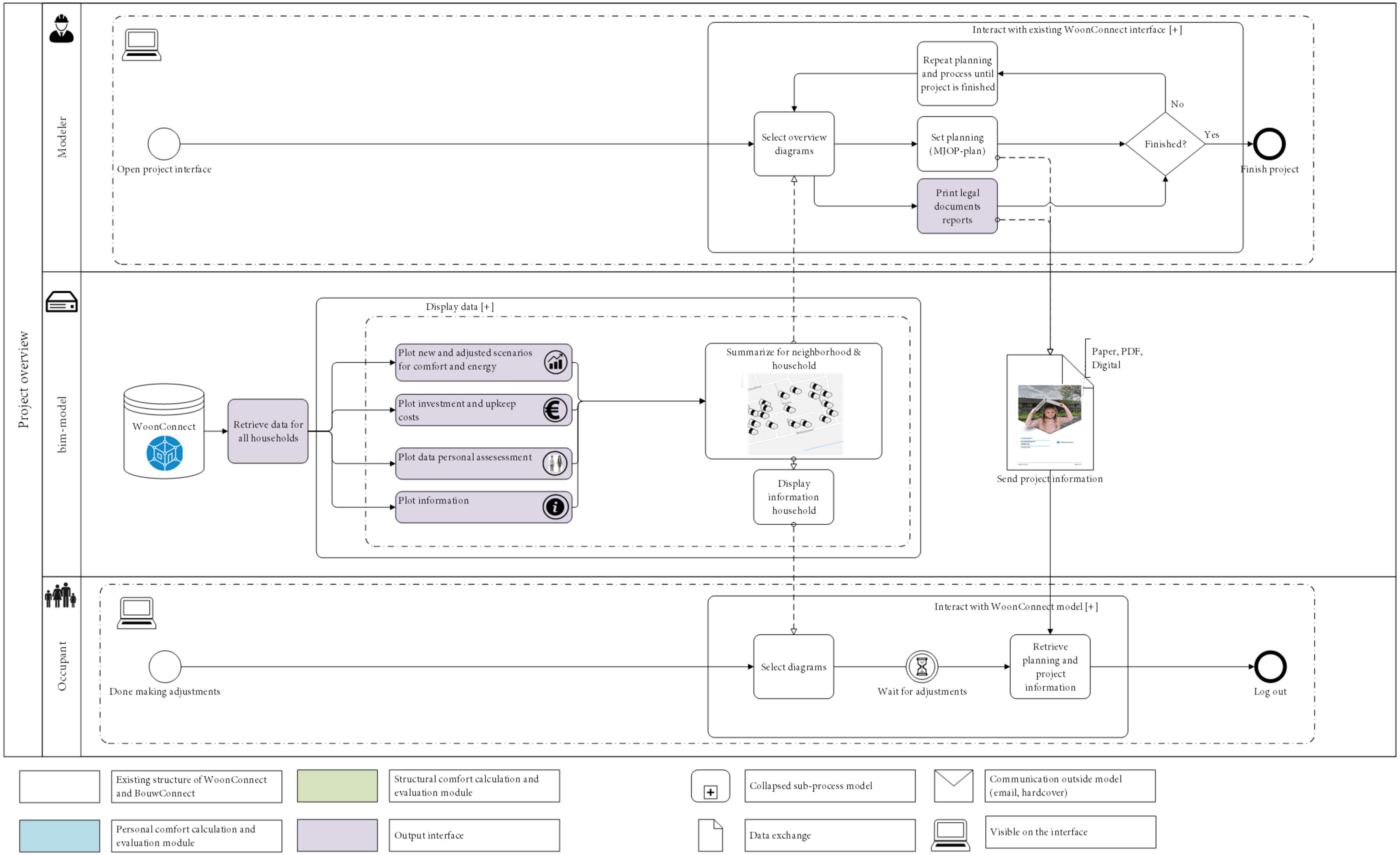


Figure 31: Process model for how the information of WoonConnect is translated to the output interface for both the occupants and the person in charge of the model. The information of each household is combined into a site plan of the neighborhood.

3.6 Combining the structural and the personal comfort calculation in one interface

The previous chapter describes both the structural assessment model and the personal assessment model for comfort. The output of these assessments are connected to the existing output functions of *WoonConnect (* Figure 31 previous page*)*. As with the costs, home health care and energy consumption, a total comfort label will be displayed to evaluate the building for comfort. Also the existing functions are updated to implement the new comfort assessments.

3.6.1 Calculation of a personal comfort assessment label of a building

The preference for *WoonConnect* is to express the comfort assessment in one comfort assessment label, ranging from A till F. The personal comfort assessment label of a building ("*persoonlijke comfortlabel gebouw*") displays in the interface combines the structural assessment described in chapter 3.4 and the personal assessment described at chapter 3.5. The purpose of the total comfort assessment label is to display how well the structural state of the building fits with the personal preferences of the occupant.

To combine both the structural and personal assessment, a weighted average is proposed. The weighted value of a comfort criterion is derived from the personal rating given by the occupants given in *section 3.5.1 Complaint, rating and preferences approach.* If an occupant assesses a certain comfort criteria as bad (label D, E or F), the weighted value of said criteria increases in the total assessment. Therefore, if project manager wishes to increase the personal assessment label of the building, he has to address these points first.

To calculate the personal comfort assessment label the following equation is used:

Equation (5): Calculation of the personal assessment label of a building,

$$\text{Personal comfort assessment label building}_{(m)} = \sum_{k=1}^{n} \frac{X_k \times P_{scenario(m),k}}{k}$$

Personal comfort assessment label building	= Total score of the building considering the personal and structural assessment of the building for scenario m
X_k	= Weight factor derived from the personal comfort assessment for each comfort criterion k
$P_{Scenario(m),k}$	= Structural assessment for criterion k within a scenario m
n	= Total number of comfort criteria displayed in chapter 3.2.

3.6.2 Connecting the comfort module to the output interface of the project manager and occupant

The same system as used for the energy and cost calculations is reused for the comfort module. The project manager will be able to see the comfort assessment for each individual dwelling in the project plan together with the adjustments the occupant chose. The interface also displays additional information about complaints, ratings and preferences per household. The project manager can then use the data to analyze the neighborhood, to summarize and to identify common complaints within the neighborhood. Additionally, the model assures that user can estimate the costs for the renovation. The calculation output can also be printed into a personal report. The report (Dutch*:* "*persoonlijk maatwerkadviesrapport*") provides advice on what renovation options are best suited to decrease costs and to counter discomfort.

4 Comfort module implementation

The previous chapter describes the design of the comfort module and how the different parts work together. The following chapter gives a summary about the implementation phase. In order to add the structural and personal comfort assessment module within the existing structure, several tasks had to be completed. The first task was to add new objects and properties to the *BouwConnect* library. Secondly, the calculations for the structural and personal comfort assessment had to be programmed and connected to the existing structure. Lastly, the existing interface and paper reports had to be adjusted or expanded.

De Twee Snoeken planned a testing period to perform these tasks from August 2018 to December 2018 for the case study dwelling in *Uden*. The testing period has led to the construction of a prototype of the software. The prototype is called version 1.0 hereafter. Screenshots of the resulting interface are added in Annex VII – Interface design.

4.1 Adjustments to the *BouwConnect* library

De Twee Snoeken added additional properties and objects to the *BouwConnect* library for assessing and calculating the comfort criteria in version 1.0. These new objects are added in *BouwConnect* Version 8.0.

4.2 Programming of the comfort module calculation and assessments module

De Twee Snoeken programmed the new calculation methods within their structure. During the testing period, the goal was to implement several criteria first based on the available data for the case study of *Uden*. *WoonConnect* already supported several calculations from the list including lighting, heating, cooling, sound insulation between the outdoor environment and the indoor environment, draft and the indoor air quality, which were implemented in line with the building regulations. For the implementation these methods were used for providing feedback and the setting up the score tables. *De Twee Snoeken* aims to implement the other criteria at a later time step.

As a PDEng, I assisted in providing the data for the assessments and helped to translate the guidelines into an objective set of analysis criteria. The end result is the dataset added in "*Annex IV – Overview of the sources used for the calculation and assessment of the criteria*".

4.3 Design of the interface and paper reports

De Twee Snoeken adjusted several interfaces and (paper) reports to connect the new modules with version 1.0 of the software. Both the structural and personal comfort calculations are visualized in *WoonConnect*'s interfaces and reports.

As a PDEng, I assisted in the design by providing mockups for the paper reports and by providing feedback during the development.

5 Comfort module verification, validation and customer feedback

Several validation and verification criteria were specified in chapter 2.2. The following chapter will address these validation and verification criteria based on version 1.0 of the software.

5.1 Verification and transparency of the sources used for calculating and evaluating comfort

The first verification criterion stated that the sources used for calculating and evaluating comfort should be based on (inter)nationally recognized sources. The second verification criterion stated that the software should be transparent about what sources it uses to calculate and assess comfort. Users prefer to have access to the information sources to better understand the calculations.

To meet these two verification criteria, the method, background and standards were summarized and cited for third parties in this report. A summary of the used sources is provided in the report. Chapter 3 provides a description of how *WoonConnect* performs its assessments. The used methods to calculate the different criteria are added in "*Annex IV – Overview of the sources used for the calculation and assessment of the criteria*". Additional calculations used for determining the thresholds for heating and cooling were also summarized in "*Annex V - Case study Uden and heating/cooling scenarios*".

The interface also provides a summary of the information for its users. An example is shown in Figure 32. In the interface, the information from the previous chapter is made accessible to the users through "info icons". The exact information displayed in the descriptions has been summarized based on the input from the interviews with the users. To make the software transparent for its users, occupants and real estate agents suggested that the following information should be present within the interface upon direct request (e.g. for heating, see Figure 32):

- What aspects of the building are affected by said criteria?
  (E.g. domestic hot water, gas consumption for heating).
- What key parts of the building have (the most) effect on the criteria and should be addressed to improve comfort?
  (E.g. type of heating system, insulation thickness, type of glass, type ventilation system).
- What sources are used for the calculation and evaluation of the results?
  (For heating *WoonConnect* uses NEN 7120 and the resulting heating demand as main indicator).
- Which personal information is required to provide a better estimation?
  (E.g. number of people in the household or the preferred thermostat heating set points)

For people that want an extensive overview of the calculations, the "*comfortrapport*" can be downloaded. The "*comfortrapport*" document provides the in-depth description of the calculation performed for the model, including properties and appointed scores described in chapter 3.

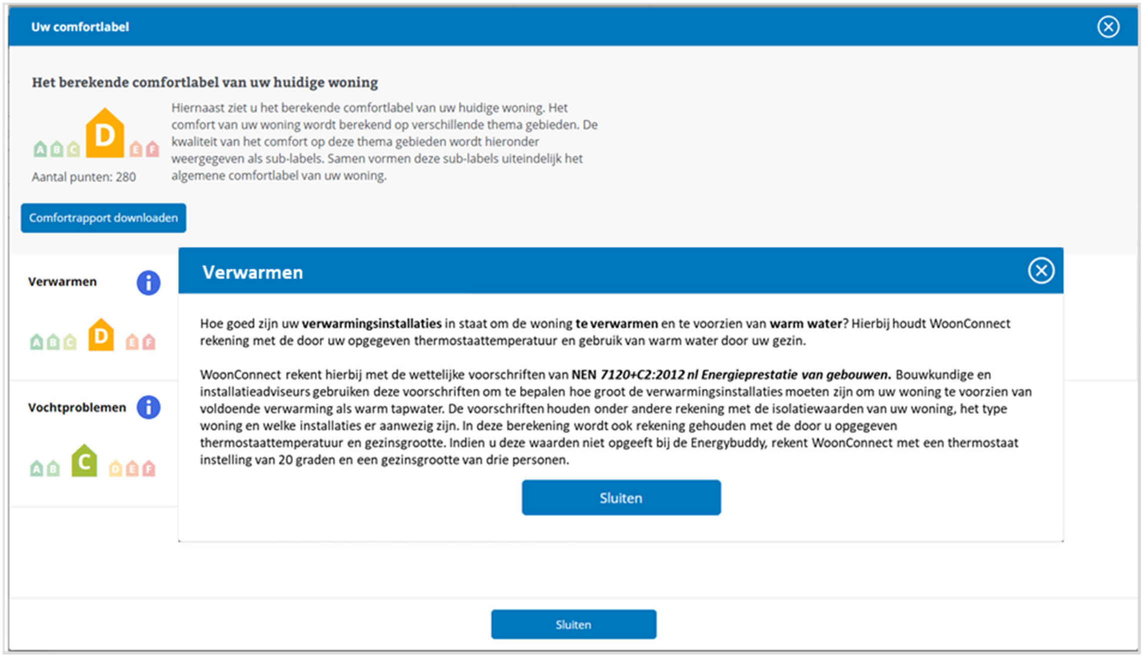


Figure 32: Example of how WoonConnect displays the (Dutch) information to the user in version 1.0.

5.2 Testing the comfort assessment module in a case study

The first validation requirement is that the tool should be tested in a 'case study'. The goal of the test was to evaluate how the new module would fit within the existing BIM-structure, to evaluate the output generated by the calculations and to test the interface in practice. The calculations for lighting, heating, cooling, ventilation, usability and sound insulation were already present in the current modules and had been tested according to the building regulations. The output of these calculations were used as input for the assessments and costs. The extra calculations for moisture, air humidity, installation sound and draft will be implemented at a later time step. To test the module, the case study of *Uden* was used (from the heating and cooling scenarios). Based on the case study the following parts were tested during the implementation phase.

- The case study was used to evaluate how the comfort assessments would perform when using actual data and how renovation options would influence the printed labels for each comfort criterion, the costs and the energy demand.
- The case study was used to test if the system could provide advice based on the possible options associated with the assessment schemes.
- The case study was used to test how users would be able to interact with the software and gain access to the comfort ratings, complaints, information and advice interface(s).
- The resulting output of the calculations were printed in 'paper reports' to help design the print reports.

An example for how module works, based on version 1.0 of the prototype, is displayed in Table 6 and Figure 33 below. In the existing situation *Woonconnect* gives the structure a score of E for heating, indicating that there are still options that can be chosen to improve thermal comfort with respect to heating. Based on the study performed for heating and cooling (Annex V), it was known that in the existing situation the dwelling already has double glazing, implemented draft prevention and has a HR 107-boiler. However, the dwelling was not insulated and had a natural ventilation system.

Based on these settings, the software retrieves additional advice from the structural assessment framework. For the case study, possible options to decrease the heating demand are to insulate the roof, walls and floors, to install HR++ glass, to install a more efficient heating system (heat pump), or to change from natural ventilation to mechanical ventilation (including CO_2 or heat recovery systems). The user is free to choose which options to implement; however, *WoonConnect* will display which options must be combined. For example, a heat pump will require the dwelling to be insulated and to have floor heating to work effectively. Within the given advice, the structural assessment provides a reference point for what options are best to implement first or which options to combine with the other options (threshold requirements). Meeting these requirements will improve the label, indicating that the structure is better equipped to prevent discomfort related to (insufficient) heating. Selecting the options will provide direct feedback on the costs, energy labels and the visual model.

Table 6: Example of the output generated for the case study of Uden for different scenarios to increase thermal comfort.

	Existing scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Printed label for the heating	E	D	C	B	A
Investment costs*	€ -	€ 5.380	€ 7.487	€ 15.477	€ 48.056
Options	- HR 107 boiler - Draft prevention - Double glazing	- Insulate roofing (Rc = 3,5 m2.k/w) - Insulate walls (cavity) (Rc = 1,69 m2.k/w)	- Insulate roofing (Rc = 6,0 m2.k/w) - Insulate walls (cavity) (Rc = 1,69 m2.k/w) - Insulate floors (Rc = 3,5 m2.k/w)	- Install mechanical ventilation - Installment of HR ++ glass - Insulation (previous step)	- Insulate roofing (Rc = 6,0 m2.k/w) - Insulate walls (outdoor) (Rc = 4,5 m2.k/w) - Insulate floors (Rc = 3,5 m2.k/w) - Mechanical Heat recovery - Heat pump & floor heating
Gas consumption (m3/year)*	2342	1343	1336	1101	0
Electrical consumption (kWh/year)*	3475	2385	2384	2446	4544
Estimation energy bill (euro/year)*	2274,71	1394,64	1390	1256,21	1045,12

**The values are calculated based on the BIM-model and NEN 7120. The estimated energy bill is derived from the consumption (0.23 €/kWh and 0.63 €/m^3-gas).*

Figure 33: Example of how the visual BIM-model is adjusted after the renovation options have been selected (new insulation for the outer wall was added). The model also provides direct feedback on the costs per month and the energy label.

5.3 Usability testing and feedback

The second validation criterion stated that feedback from the users should be collected. To collect feedback from the users, a usability test was carried out using version 1.0 of the software and the case study of *Uden,* the Netherlands. A usability test is the process of learning about users from the users by observing them using a product to accomplish specifics goals of interest to them [74]. Within this definition, the intended user is the occupant that uses the software to renovate the building and to gain information about the renovation itself. By carrying out a usability test with several occupants, two goals were set to be accomplished.

- To collect feedback on the design of the interface for improving the software in version 2.0.
- To collect feedback on how the people are influenced in their (renovation) choices and how they acted based on the output provided by the *WoonConnect*.

5.3.1 Method for the usability test

To collect feedback, a usability test was carried out with several users. Since the software was still a prototype, the users were given a guide for how to use version 1.0 of the software. The guide described different objectives and questions that the users had to solve. An overview of the test is added in "*Annex VI – Usability test*". The output of these questions were used to collect feedback on the design and to analyze how the software influenced their (renovation) choices.

For testing how the software influenced the decision of the users, several questions were asked before and after the usability test. These questions addressed why people wanted to renovate their building, and what parts of the software influenced their choices. Additionally, users were asked to select renovation options they would find interesting in two different settings. In the first setting, users were asked what renovations they found interesting on paper, including costs. In the second setting, the same renovations options were shown using the interface, including information about how the options contribute to comfort. After the test, people were also free to interact with the software and to provide feedback.

The results of each test were processed through a paper report and a digital recording of the screen. To analyze how the software influences the choices, the output of the questions in the both settings were compared. Additional questions also addressed if people actively made different choices within the second setting and why. Feedback on the design was registered through the recording. The digital recording kept track of remarks on the design and questions not related to the test. The digital recording also kept track where people made mistakes (screen recording of the desktop).

5.3.2 Summary of the results usability test

The following chapter provides a summary of the output from the usability test. In total, 15 users participated in the usability test. Figure 34 displays the output from the first questions: "What would be the main reason why you would renovate your building"? Improving living comfort (47%) and reducing the energy bill (33%) were mentioned to be the main reasons for renovating their dwelling. For "other", some people stated that making the dwelling life-cycle resistance would be the main reason for renovating their dwelling. Increasing the house value was also mentioned, but several respondents answered that the value of the dwelling would be more important if they did not want to settle. If settling was their priority, then reducing the energy bill and improving living comfort were deemed more important.

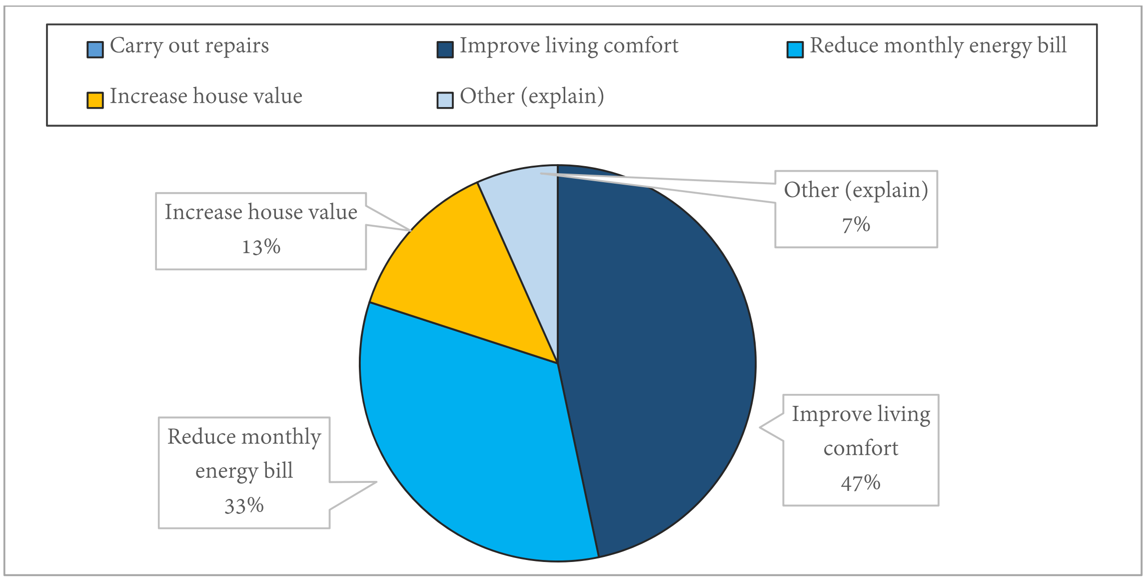
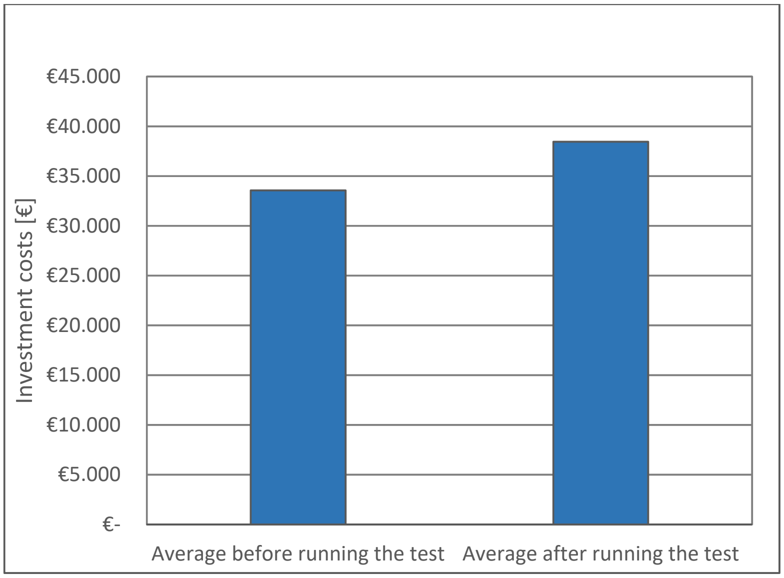


Figure 34: Output of the question: "What would be the main reason why you would renovate your building"?

In Figure 35, the average investment from the two different scenarios were compared. The left bar displays the average value of the renovation options people were interested in before running through the software. The right bar shows the average value after the respondents used the software. On average, the results showed a higher interest after running the software. After running the test, the average willingness to invest was 15% higher than before running the test. When asked if people actively chose differently (Figure 36), most people answered with "yes" (73%).

When asked why the chose differently and what the main influencing factors were, several reasons were mentioned. First of all, the direct feedback on the energy bill was deemed important. Also the visual representation of showing the information was appreciated, as it helped to understand what the renovation. Several people also stated that it was the "total package" that played an important role. Displaying the options in relation to the investment costs, feedback on the energy bill, comfort and the visual representation were all mentioned factors that the users considered in their choices.



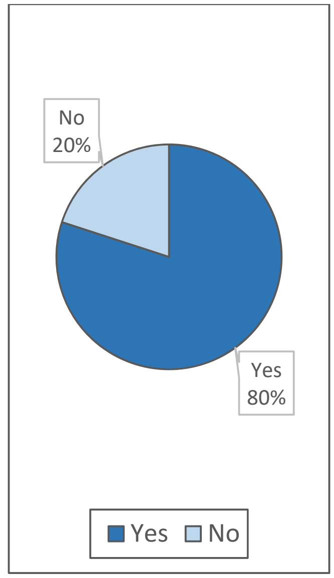


Figure 35: (Left) Comparison of the value for the renovations options chosen by the occupant within the two different scenarios.

Figure 36: (Right) Output to the question: Did you actively choose different compared to the first setting?

Besides comparing the output from both scenarios, users were also asked to provide feedback on the concept. A summary of both positive and negative feedback is shown in Table 7. In terms of positive feedback, all users stated that the visual representation of the system(s) and the graphical design ware of high quality. A second remark was that they liked the integral information that was provided for energy, investments costs and comfort for different options. The occupants also liked the problem based approach as it provided a social factor to the software.

Although the integral package was liked, some people did remark that showing all these factors is merely a minimum requirement when looking for renovation options. They were of the opinion that the information should be delivered by default when a party consults them on renovating their dwelling. The last remark was that most users found the system accessible and 'playful' as a method to gain personal renovation advice.

Table 7: Summary of the feedback provided by the users.

+ **Positive feedback**	**Negative feedback** –
Integral package (feedback energy consumption, investment costs, contribution to comfort).	Difference in the renovation options could be clearer
Problem focused approach rather than option based approach	Clearer difference required between the style of the personal and structural assessment scores.
Visually clear and appealing software.	(Bugs)
Accessible system, the system provides an easy 'playful' method to gain personal renovation advice.	
Problem based approach provided a social factor	

However, there was also some negative feedback. Although the visual representation of the renovations was liked, some renovation options looked too much alike in terms of their contribution to comfort and the energy bill. The only difference was the costs. Not showing the difference between the options might still be a limit of the prototype; however, for future updates the differences should be made clearer. Some suggestions were to textually explain the difference or add symbols for what options could contribute to what forms of comfort. If the difference is very small however, additional indicators about ‘quality’, ‘construction time’ or ‘sustainability’ should be added as well.

A second remark was about the personal and structural comfort assessment. Multiple people did not understand the difference on sight. The main reason was that the personal rating looked similar to the structural rating. Although they understood the style for the structural assessment (coherent style with the energy label), the suggestion was to change the style of the personal rating from an A to F system; for example, to a smiley based system. The same advice was also given for the structural assessment to better display the difference between the labels.

The final negative remark was that there were still some “minor bugs” present. Although people understood that the software was still a prototype, they stated that minor bugs should be removed as soon as possible. The main stated reason was that bugs could ‘discourage’ people from using the software. An overview of these bugs was summarized for *De Twee Snoeken* to be resolved in version 2.0.

In summary, all users were positive about the approach to provide personalized renovation advice. The users appreciated the integral and visual approach for providing (personal) renovation advice and information. Most users also stated that the software would help them to make choices more consciously as they are able to weight different reasons. Remarks that were deemed negative seemed to be mostly style based and can therefore be adjusted in a future version.

However, whether the feedback provided by the software will result in people investing more into their building cannot be stated with certainty. While the average value of the selected options was higher after using the software, the number of participants is not large enough to make a definitive statement.

Furthermore, it should also be considered that the test was carried out in a controlled environment. If people have to actually pay for the investments they selected, the results may be different. If the *De Twee Snoeken* wishes to validate whether the software helps, they could consider comparing the invested costs, number of logins and number of people that participate in the software between a project that uses the new module and a project that does not use the new module.

In relation to the question whether people would invest more by using the software, several users stated that the impact of the software will likely be higher when it is given to people that are already actively looking to renovate. The main reason would be that people, through the software, could make choices more consciously and better weight the different factors. Nevertheless, if the willingness to renovate is not present, users might be less inclined to spend time on the software. Some users therefore suggested that the software could be part of active promotions carried out by the municipality or housing corporations or might be provided to them as an independent application.

5.4 Future updates and further validation using occupant data

The final validation criterion *De Twee Snoeken* stated was that they want to use input from the occupants to test whether the structural and personal assessments are good matches in future updates. The last validation criteria could not be carried out during the PDEng project. Main reasons were the time limit and the time it would require to collect the data. As a result, *De Twee Snoeken* asked for suggestions(s) on how they can use occupant data to validate the assessments they provide. A suggestion for how *De Twee Snoeken* can use occupant data to validate their software for future updates is further discussed in Chapter 7.

6 Fitting the comfort assessment module within the business plan of *WoonConnect*

As part of the PDEng program, the business plan for the product and the social impact should be considered. The following chapter goes into detail on how the module can be used within the existing business plan. The first paragraph will address the existing business plan. The second paragraph will go into detail on how the comfort module fits within the existing structure.

6.1 Existing business plan of *WoonConnect*

The following section explains the business model for *WoonConnect*, according to the principles of a business lean canvas. More information can also be found on the website of the company [1], [19].

6.1.1 Problems and existing alternatives

The main niches that *WoonConnect* addresses is the rapidly changing built environment and the complexity of the transition process. As shown in Figure 37, the transition proves to be a challenge, not just in terms of technology, but also in terms of logistics, social aspects, financing, (data) management and planning. In the current situation, these factors are often addressed separately. This is disadvantageous, as acting insufficiently on one of these matters could lead to unsuccessful projects [75], [76].

Figure 37: Problem & existing alternatives.

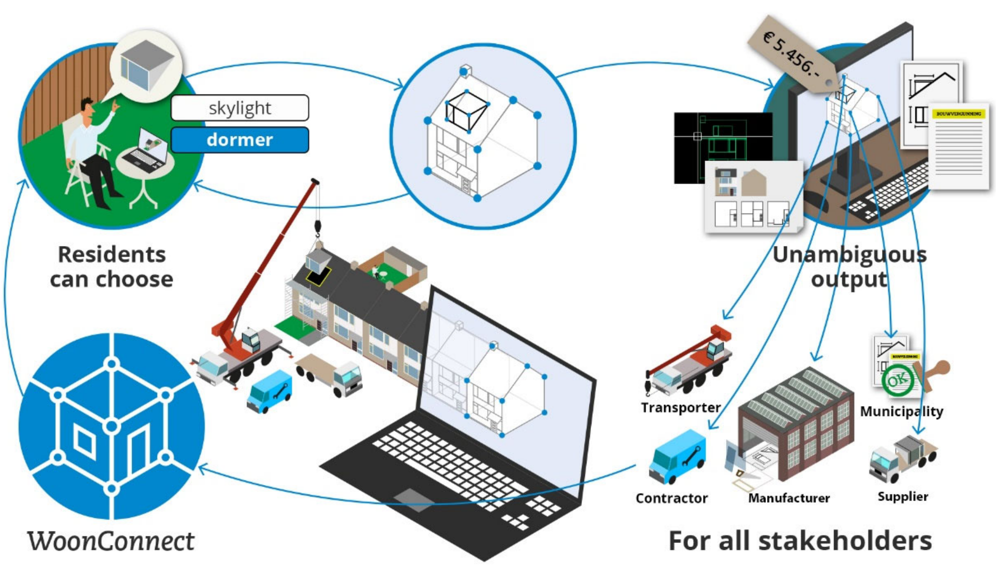


Figure 38: Solution & unique value proposition of the software within the existing business canvas.

6.1.2 Solution and unique value proposition

The unique value of *WoonConnect* to help resolve the problems is it that it acts as an integral management and information system. The integral system shows all relevant information for assessments, planning, costs and regulations within one digital platform (Figure 38 & Figure 39). Through the use of the software as an integral communication platform, it is estimated that the usage of *WoonConnect* can lead to numerous savings throughout the Netherlands built environment [75]. One of the unique properties of *WoonConnect* is that it also acts as a communication platform between the different users. These users consist of real-estate agents and engineers but also occupants. Involving occupants within the software is unique, as their feedback, problems and preferences can be made known easily to all parties. Including the occupant within the platform therefore allows the system also to better deal with the social challenges of a renovation project.

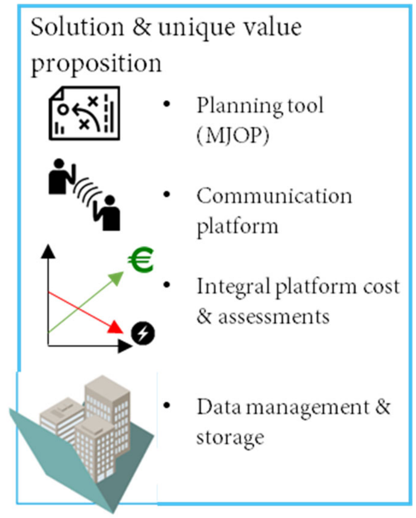


Figure 39: Textual summary of the solution & unique value proposition.

6.1.3 High level concept(s) and mediums

WoonConnect is accessible as an online platform. *BouwConnect* can be installed as a plug-in for existing building information model (BIM) software packages or as a standalone license. Both tools makes use of two high level concepts. The first concept is the integration of a BIM-model to manage data and to provide a visual overview. The existing information database behind BIM is also extended with the *BouwConnect* database, which helps to manage the data on an object level. The second concept is the usage of assessment schemes to assess building performances. Based on the BIM-model and the *BouwConnect* database, assessments of the energy consumption, lighting, fire-safety and room sizes are automatically calculated alongside the costs. This information is given as direct feedback to the users within one integral package. Through the BIM-module, the occupant can alter the model, through which they get direct visual feedback on the costs and other criteria.

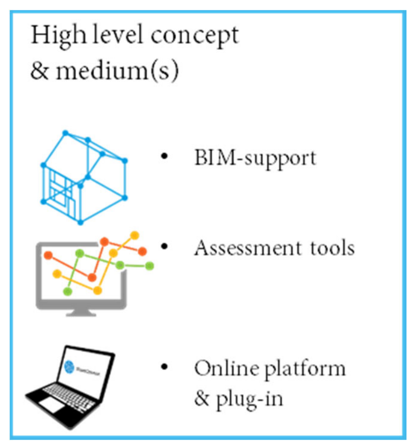


Figure 40: High level concept & medium(s)

6.1.4 Advantages and disadvantages

From a market point of view there are several disadvantages and advantages to identify. One disadvantage is that assessment tools and software packages require a lot of recognition by the market before they are generally accepted [27], [30]. A second disadvantage is that policy makers have a lot of influence on which tools are used [31]. If the trend is to use a certain software, it will also effect which tools the other parties involved will use.

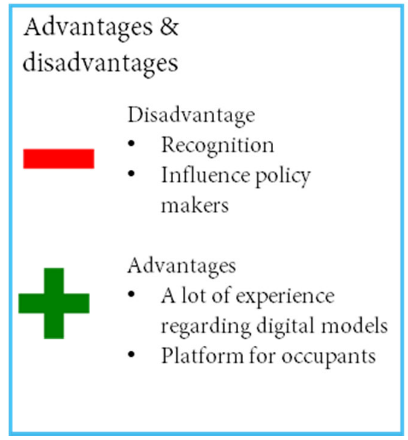


Figure 41: Ad- and disadvantages of the concept.

However, *WoonConnect* has also some advantages. First of all, DTS has a lot of experience regarding the development of digital models and the use of the BIM-environment. A lot of companies and housing corporation do not have this experience, or this is only limited to the usage of software, not the development. Another advantage is that *WoonConnect* makes use of the input of occupants for its assessments and communication. Using occupant data as input allows for more personal and accurate representations of the situation.

6.1.5 *User segments and early adopters*

WoonConnect is being used by several types of customers, including municipalities, real-estate and housing corporations, home owners and engineers. Occupants are not necessarily customers, but they are an important users within *WoonConnect*. Some of the early adopters consist of the province of Brabant and several major Dutch municipalities. These early adopters also participate in the several collaborations [77],[78]. In these collaborations, multiple parties have pledged themselves to use the digital system as way to improve the current method of managing projects within the Dutch built environment.

Figure 42: User segment & early adopters

6.1.5 Cost and revenues regarding the use of *WoonConnect*

The cost for digitalizing the *WoonConnect* models consist of collecting on-site data (*warme opname)* and building the model within BIM-software. Depending on the situation, the models have to be stored on a server. The costs for the upkeep mostly consist of power and maintenance. In terms of upkeep for the software, costs are made for resolving bugs and customer support. Development costs are optional but are necessary to increase/ improve the functionality of *WoonConnect*.

In terms of revenue, profit is generated through the sale of licenses for *WoonConnect*. These are sold per building/ household. In case of *BouwConnect*, the licenses are sold per 'plug-in' license. Depending the situation, the price per license might differ when the costumer wishes to have additional functionality. These licenses are initial costs, meaning that after the first subscription the user has to pay a yearly fee for the licenses he wishes to use. Additionally, *WoonConnect* is often used in subsidy-funded research projects. Although the profit of these projects are low, they do help to further improve the software and provide input for further developments.

Figure 43: Cost and revenue stream for the software.

6.2 Added value of the comfort module within the business plan

The previous chapter provided an overview of the existing business plan employed by De Twee Snoeken. The following chapter will go into detail of how the comfort module will fit within the existing business plan of *De Twee Snoeken*.

6.2.1 Problems, existing alternatives and the new added value proposition of the comfort module

As already summarized in Chapter 1, the Dutch built environment is undergoing a transition. The transition is a complex challenge which is not only limited to technology. The transitions provides social, financial and logistic challenges as well. To manage these challenges, a multidisciplinary approach is required.

Comfort is also one part of the multidisciplinary approach. As show in Figure 44, the system will provide feedback based on the complaints and ratings that the occupant fill in within the model. Using such factors to provide a problem based approach to renovate the building will help to soften the communication between the occupants and real-estate users. Furthermore, the problem based approach also helps as an additional persuasion and motivation factor for the occupants to invest and participate in the renovation of their dwelling. As the output is generated based on the input provided by the occupants, the software will also provide a more personalized advice on how to renovate the building.

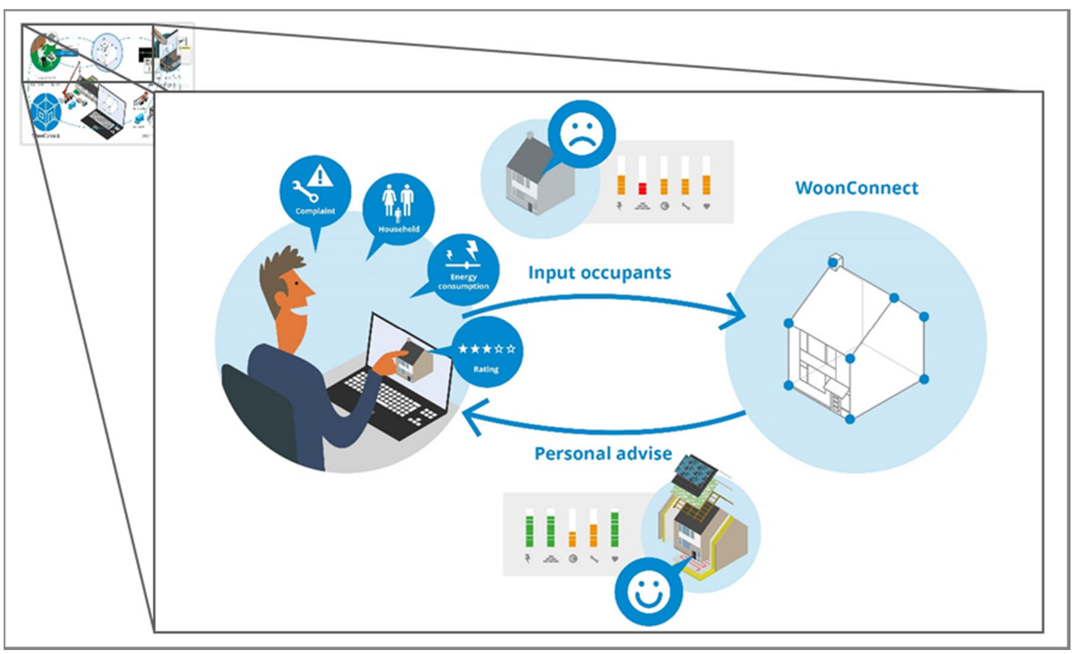


Figure 44: Added value of the comfort module in relation to the existing structure from Figure 38.

That comfort can play an important role in motivating occupants is also addressed by [76], which provided several guidelines for successfully renovating a social housing project. These guidelines were produced through multiple interviews with real-estate corporations considering different renovation projects. The proposed guidelines consist of both success and lag factors regarding the management, communication, financing and technology within a renovation project. The document also proposed several solutions for the lag factors.

For example, one lag factor in terms of financing was that there are few feasible measures for renovating housing due to the fixed structures and systems of most dwellings. Estimations from [15] state that these costs could be as high a € 18.500,- for renovating an average Dutch dwelling to consume no gas. As a proposed solution, [76] suggested that combining the energy efficient measures with maintenance and other upgrades for the house could prove an additional factor for making renovation more appealing. Such an approach also seemed feasible based on the output from usability test, as most respondents liked the concept of providing problem based advice within an integral package.

6.2.2 Costs and usage of the module within a project

Using the comfort module will affect the cost and usage structure behind *WoonConnect*.

- The use of the module will require a more complex BIM-model to be built. The modeler will therefore require additional time to build the BIM-model. The extra time is needed to add additional objects related to comfort. Using the module will therefore increase the cost required to build the models.

- The use of the comfort module over a longer period of time will require maintenance when finished. As with the energy modules, the comfort module will require updates for bugs and new systems. Additional costs should be considered for maintenance.

- To generate profit, additional costs could be charged when using the module. Furthermore, *WoonConnect* could consider selling the personal comfort assessment module (and home health care module) as a separate application. The separate application could be disconnected from the more cost intensive BIM-model, but still provide advice on which renovations options are best suited for given complaints and preferences. Even if the list is not fitted to the exact situation of the occupant, he can still retrieve advice and information based on their preferences. By combining the output of *WoonConnect* with possible contractors that can perform the job, *WoonConnect* could charge money for advertisements. The contractor could use the tools as an advertisement platform to regain his costs. Lastly, such an application approach could also make the occupant more independent from the municipality when collecting information to renovate their building.

7 Advice for the further development of the software

The previous chapters went into detail on the development, evaluation and use of the comfort module. The following chapter gives advice on (possible) future steps.

7.1 Using occupant data to further validate the method

One of the validation requirements for the comfort module is that *De Twee Snoeken* wishes to use the data collected from the occupants to improve the given advice. The following paragraph displays how *De Twee Snoeken* can use occupant data for further validating their methods.

7.1.1 Collecting data

One of the system requirements for developing the comfort module is that *De Twee Snoeken* wishes to use the occupant input for validating the calculations carried out for the comfort module. To collect data from the occupants, *WoonConnect* uses ratings, preferences, household data and complaints.

There are two reasons why *De Twee Snoeken* wishes to collect data.

- The first reason is to further develop the structural assessment given by the model to the occupant.
- The second reason is to determine weight factors for different types of household profiles.

In the first version of the comfort module, the structural assessment is set up based on both literature and expert opinions. The main purpose of the structural assessment is to act as a framework for what (still) can be improved for a building. The structural assessment therefore provides an estimation for how well the building is equipped to provide good comfort for an average household. The expectation therefore is that, on average, occupants will be more satisfied with the comfort of their building when it has a high structural assessment and that the occupant will be less satisfied when the structural assessment is low.

However, it might be the case that the structural assessment is either too negative or too positive in the assessment (discrepancy). The structural assessment might state the building is ill equipped for providing good comfort (e.g. a structural score of D), yet the average occupant might be very satisfied (personal score of B or A).

Since *De Twee Snoeken* wishes to have a small discrepancy between the structural assessment and the opinion of different occupants, analyzing the relation between the structural assessment and the ratings provided by the occupants can help to improve the assessment given by the model. The second reason *De Twee Snoeken* wishes to collect data is to derive weight factors. The structural assessment is built surrounding 'an average' occupant. Then again, the level of satisfaction with comfort could be dependent on variables such as the household composition.

Although there is no literature that shows a direct relation between household composition and the experience of comfort, there are multiple sources that dictate that the experience of comfort can differentiate based on gender or age. Both variables are present when defining a household.

For example, there is sufficient proof that variables such as gender have an effect on the experience of thermal comfort, as shown by a literature review by [79]. A household with more female members might therefore experience more discomfort than a predominantly male household. As another example shows, noise pollution (as a result of bad insulation) can have more negative effects on children [80]. Households with young children might therefore value sound insulation higher. Also the preference for (natural) lighting is unalike for different age groups, especially elderly people are stated to benefit more from better access to proper lighting [81], [82]. As the previous examples implied, age and gender all have effect on the experience and satisfaction of comfort. Both variables are crucial for defining a household.

As a result of these differences, a young family might already be satisfied (personal score of B) with a structural assessment score C for lighting. On the other side, a household that consists of elderly persons might give a personal score of E (not satisfied) for the same dwelling. The difference could lie in fact that the elderly people tend to be more sensitive for lighting than the younger people.

To address these differences, *De Twee Snoeken* wishes to use weight factors to better represent different types of households within the structural assessment. For example, if elderly people live in the dwelling, the structural assessment given for thermal comfort should be weighted heavier in the total score given to the building. To derive these weight factors, *De Twee Snoeken* wishes to use data that they collect within each project.

7.1.2 Suggestion of the variables that should be collected

Before *De Twee* Snoeken can derive these factors they will have to collect data from several projects. Suggestions for the variables that should be collected are shown Table 8 below.

Table 8: Suggestions of the variables that should be collected by WoonConnect.

		Variable name	Type of data	Potential outcome	Description
ID	1	NumberID	Continuous	1….n	ID number of the household
	2	Filled_in	Categorical	1 = yes 0 = no	Check whether the occupant used the rating screen.
Dwelling related variables	3	Dwelling_type	Categorical	0 = apartment 1 = studio 2 = terraced 3 = end-dwelling 4 = semidetached dwelling 5 = detached dwelling 6 = other	Type of dwelling
	4	Dwelling_age	Continuous	1….n	Age of the dwelling
	5	Structural assessment criteria n	Categorical	0 = A 1 = B 2 = C 3 = D 4 = E 5 = F	The assessment given to the structure for comfort criteria n.
	6	Personal rating for criteria n	Categorical	0 = A 1 = B 2 = C 3 = D 4 = E 5 = F	The personal assessment given by the occupant for comfort criteria n.
	7	Rating total dwelling	Categorical	0 = A 1 = B 2 = C 3 = D 4 = E 5 = F	Rating given for the dwelling as a whole.
	8	Already invested in the dwelling? (investment)	Categorical	0 =No 1 =Yes	Did the occupant already do anything to improve the dwelling?
Household variables	9	Household_size	Continuous	1….n	Size of the household
	10	Household_age	Continuous	1….n	Average age of the household
	11	Children?	Categorical	1 = yes 0 = no	Are children living in the dwelling?

7.1.3 Processing data

After the data has been collected, *De Twee Snoeken* can consider processing the data by using software such as *Statistical Package for the Social Sciences (*SPSS). For the first set of data, the results are expected to be similar to Figure 48 below. The average personal assessment (p_average) is expected to be dependent on the structural state of the building (s); if the structural state is bad (F), then it is expected that the personal assessment will also be bad (score =1). If the structural assessment is deemed good (A), it is expected that the average personal will rate his personal rating high as well. An explanation of what each (personal) score consists of is explained in table 2 (next page). However, each household can give a different individual personal score (p_m). Due to differences in the age, gender or family composition, each individual score might differ.

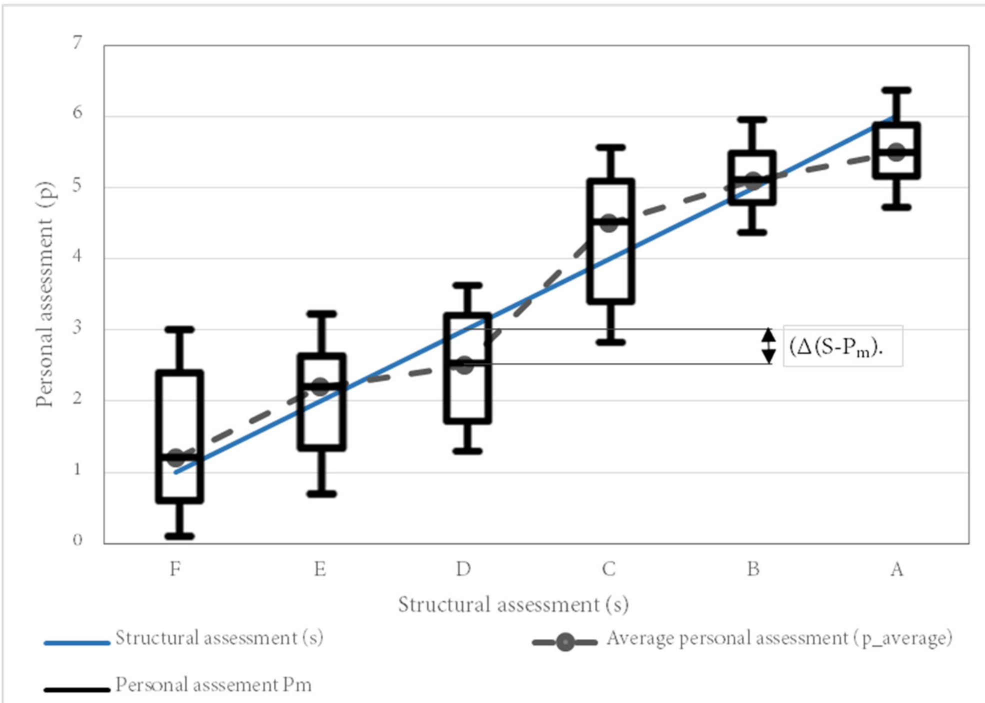


Figure 45: Example of how the data can be plotted for a comfort criteria n

To accomplish the first goal, whether the structural assessment is in line with the personal assessment, *De Twee Snoeken* can consider calculating the difference between (the average) personal assessment (P_average) and the structural assessment (s). The difference between both variables can be calculated using the ordinary linear regression method (OLS) (Δ(S-P_average). In case *De Twee Snoeken* wishes to not average out the given scores but instead prefers to evaluate each individual personal assessment (Pm) the Weighted least Square (WLS) might be used ($\Delta(S-P_m)$). Both calculations can be performed using SPSS software.

In both cases the differences between the variables could be analyzed to determine if the score is too high or too low. If the difference between both variables is too large; for example, Δ(S-p) > 1 or -1, then the difference between the structural assessment and the personal assessment are insufficiently aligned. In case of Δ(S-p) < -1, the structural assessment is too low. On the other hand, if Δ(S-p) > 1, then the structural assessment is too high and people on average experience more discomfort than expected. In both cases the structural assessment can be increased or decreased based on the given situation. Based on the outcome, *De Twee Snoeken* can adjust the evaluation scheme.

7.1.4 Derive weight factors for different types of households

The second goal for *De Twee Snoeken* was to derive weight factors for each comfort criteria (X_k) in relation to different households. The purpose of the weight factors is to influence the assessment based on the type of household. To determine these weight factors, a similar method as in the previous paragraph can be used. The input from the occupants should first be filtered to form different types of households or building types. To define each household or building type, the data from Table 8 can be used to form different groups

To form these groups, a cluster analysis carried out in *SPSS* could provide an option. The output of a cluster analysis divides a data set into different groups or 'clusters' based on the similarities between the different data sets and the characteristics. In the case of *WoonConnect*, these characteristics could be the different factors related to household or building type. Based on the resulting clusters the relation between the structural assessment and the input of the occupants can be analyzed. An example is shown in Figure 46 below.

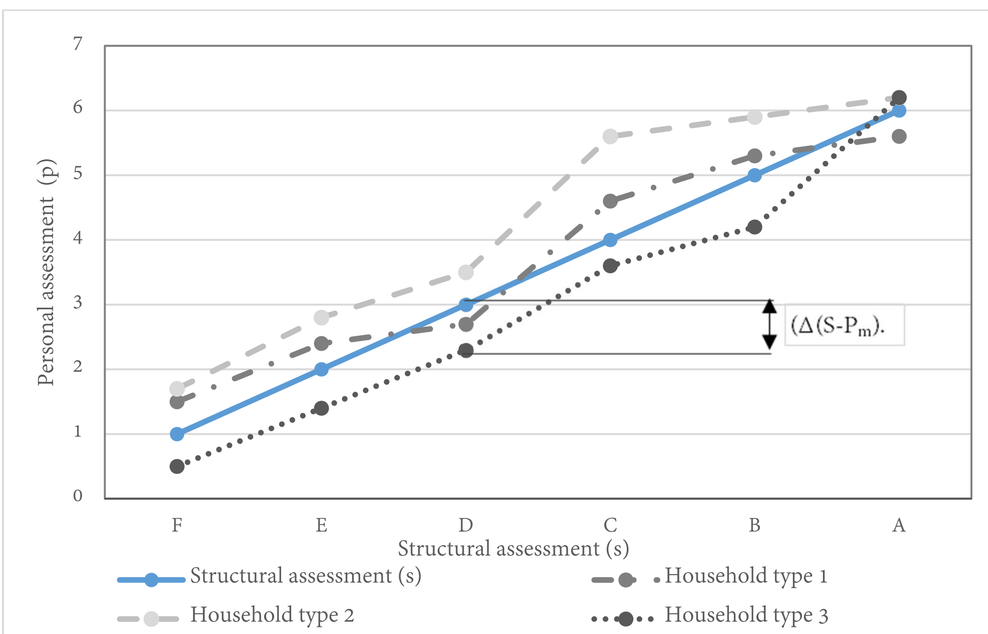


Figure 46: Example where the data is filtered into different clusters.

The resulting data can be processed through a similar method as in step one: either through the OLS or WLS-method. The weighted value (X_k) can then be defined as the difference between the structural assessment and the personal assessment ($X_k = \Delta(S\text{-}p)$). If the resulting output is negative, the comfort criteria should be weighted more heavily in the total assessment, when the resulting output is positive, the criteria should be weighted less heavily in the total assessment. The resulting weight factor can be used for calculating the total assessment displayed in "*paragraph 3.6.1 Calculation of a personal comfort assessment label of a building*".

7.2 Use of complex and simpler calculation methods within *WoonConnect* projects

As discussed in Chapter 3.2, there is a wide selection of tools available for the calculation of different criteria which can be used to assess a situation for comfort. Within the comfort module, the preference was to implement and use simpler methods for providing renovation advice.

The main reason for using these methods was because the required calculation time, amount of data and computational requirements are low, thus making them more suitable for the web based approach that *WoonConnect* uses. Especially a low computational time was required to provide fast feedback to the occupant. The second reasons was that the advanced methods will require more expertise to operate, which occupants and real-estate managers don't always have. Furthermore, the abstract approach of a label system makes it easier to communicate which scenarios are likely good and which scenarios are not.

As a result, *WoonConnect* used multiple automated NEN-calculations that are in line with the Dutch building decree. Although NEN-documents are accepted by the Dutch building decree as a valid method, the methods do have some limitations. These methods don't always perfectly predict real world results because they have a limited resolution, or due using abstractions for certain veriables or processes [44], [45]. Therefore simpler methods are more suitable for representing average scenarios, however, they might be less suitable for analyzing specific cases. Complex methods can, due to the higher resolution and number of variables, better simulate specific scenarios if suitable data is present. As a result, complex tools can be used to provide better tailored advice at the cost of increased simulation time, computational requirements and required data [42]–[45].

De Twee Snoeken is aware of the shortcomings of the simpler methods and are therefore considering implementing advanced calculation methods as well. The calculation methods that can be used for performing these advanced calculations are summarized in appendix IV.

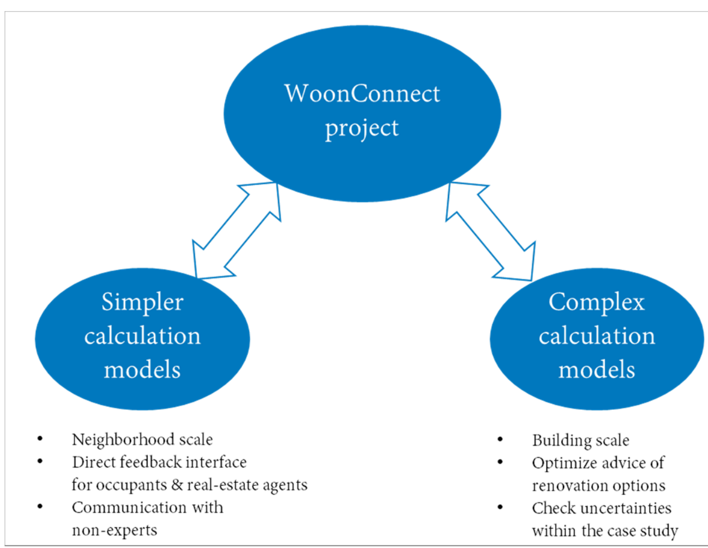


Figure 47: Overview of how De Twee Snoeken can consider implementing more complex calculation methods within a WoonConnect project.

However, due to the differences in usability and simulation time, *De Twee Snoeken* might consider using the advanced calculations methods differently in a *WoonConnect* project than the simpler methods. Figure 47 shows an overview of how both types of models could be used for a *WoonConnect* project. The simpler methods could be used for providing direct feedback within the interface on a large scale and to communicate with the non-expert users. The advanced methods could be used to analyze the projects on an individual building scale; for example, only the base model, to reduce the required computation time. In case there are uncertainties or if *De Twee Snoeken* wishes to perform more accurate calculations, the advanced models can be used for the base model. The resulting output of the advanced models could help to understand uncertainties, discrepancies or potential risks in the simpler methods which can be used to form better advice within the simpler methods.

For example, a discrepancy in actual energy performances and simulated energy performances is an uncertainty found within some *WoonConnect* projects. The main reason are limits of the NEN 7120 method, which can be attributed to several factors [83]–[86]. In such scenarios, *De Twee Snoeken* can use the advanced computational methods to determine what factors have the most influence on the discrepancy and use said knowledge to fine tune the advice.

8 Conclusion and evaluation

The goal of the PDEng cooperation was to design additional modules for *WoonConnect* centered on market, user and company interests. Based on a market study, the choice was made to design a comfort module that can use the input from occupants as a mean to generate personalized renovation advice. Prior to building the comfort module, several design, verification and validation requirements were stated. Table 9 below shows an overview of these requirements.

The project has led to the development and testing of a first prototype of the comfort module. The resulting comfort module has two parts: The structural and the personal module. The structural module uses the BIM-model behind *WoonConnect* to provide an assessment for comfort and acts as a framework for what can be improved. The personal comfort module uses the rating, complaints and preferences filled in by the occupant to determine which renovation options are most suitable. The combination of both modules allows the software to provide personal advice on how to renovate the building while providing direct feedback on costs, energy and the regulations.

In line with PDEng guidelines, advice on how to use the module within the business plan is added as well. Furthermore, the document also includes advice on how to continue with further developing and validating the module in future updates.

Table 9: Overview of the different requirements.

Design criteria	**Type of criteria**	**Check?**
A market study was performed to identify possible options for the further development of *WoonConnect*?	Design question	Yes
The module works with the existing functions of *WoonConnect*?	Design requirement	Yes
The module automatically performs calculations based on the BIM-structure?	Design requirement	Yes
The module uses occupant input, preferences and complaints to generate output?	Design requirement	Yes
The module displays the potential renovation options based on given input?	Design requirement	Yes
The module uses (inter) national sources for calculating and evaluating comfort?	Design requirement/ Verification requirement	Yes
The calculations and evaluation methods are made accessible and transparent for third parties?	Verification requirement	Yes
The module(s) were tested using a case study?	Validation requirement	Yes
Feedback was collected through a usability test?	Validation requirement	Yes
Occupant data and feedback was used to validate if the personal assessments are in line with the structural assessment?	Validation requirement	No*

*The document provides advice on how to proceed with the validation criteria.

9 Literature

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Annex I – Market analysis

For the comparison of the tools from a usability point of view, the table suggested by [28] was used as a starting point. Within this article, a comparison was made between BREEAM [20], LEED [87] and several other tools.

Table 10: Comparison of the tools according to the literature of [28].

	BREEAM	LEED	GPR	*WoonConnect* (2017)
History				
First version	1993	1998	2010	2013
Last version	2014	2009	2017	2017-2018
Structure				
Categories	69	7	6	-
Number of criteria	114	107	72	Potential if all criteria are implemented (114)*
Number of sub criteria	–	–	-	-
Type of project				
New	O	O	O	O**
Interior	–	O	–	O**
Façades	O	O	O	O**
Existing	O	O	O	O**
Renovation	O	O	O	O**
Combination of different structures possible?	O	O	O	O**
Rating and evaluation system				
Approach	Simple additive	Simple additive	Additive	-
Scoring system	Credits	Points	Points of model input	-
Rating level	Overall grade Pass Good Very good Excellent Outstanding	Points Overall grade Certified Silver Gold Platinum	Number of points for each category with 1 being very bad and 10 being very good	-

Certification Method				
Pre-design	O	O	O	O
Design	O	O	O	O
Construction Operations	O	O	O	O
Performance data	O	-	-	O
Operations	O	-	-	O
Occupation period (years)	Not specified	n/a	-	As long as digital licenses remain active
Validity (years)	n/a	5	-	As long as digital licenses remain active
Certification phases	1	2	1 (ability to validate the process through an expert)	Before renovation and after each renovation step***
Other criteria				
Software or paper based assessment scheme	Paper based, additional tools required	Both paper based on software package (IES software)	Software package, Limited additional tools required	Software package, carries out own assessments based on digital model
BIM-based model structure	no	Yes (import of models)	no	yes

* Total amount of criteria that the other tools evaluate.

** Can be developed depending on the requirements.

*** *WoonConnect* has a scenario editor that can represent different design or renovation stages. Therefore the certification consist of direct feedback after each (future) adjustment.

Annex II – Interviews with the *WoonConnect* users

To determining which aspects *WoonConnect* could focus on, interviews were held with different types of *WoonConnect* users and customers. These users consists of occupants (including home owner associations), real-estate employees and municipality employees and technical specialists (engineers, contractors and architects). In total, 42 people were interviewed. An overview of the ratio of different people and their output is shown below in Figure 48.

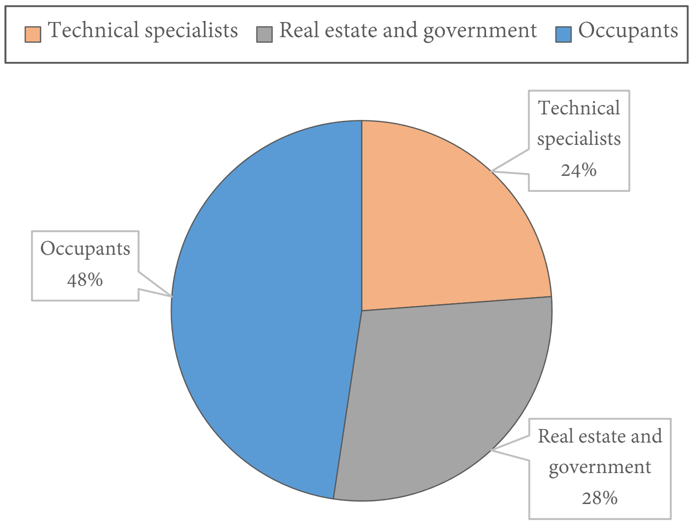


Figure 48: Ratio of the different participants within the interview. In total, 42 people were interviewed, divided into the categories technical specialists (engineers, architects, contractors), real-estate and government employees and occupants (includes home owner associations).

Figure 49 shows the output for both the first question and the second question for the different participants (in Dutch). In these graphs, a separation is made between the criteria relevant for their expertise (output question 1 – what do you consider the most important aspects of a building?) and what they consider the most important factor when addressing sustainability within a building (output question 2). Figure 50 displays the output from the third question. Here, the average score of the different participants displays how people would rank different criteria for what they found the most important within the sustainable transition. Lastly, Figure 51 shows if the participants have experience with (sustainable) assessment tools or not.

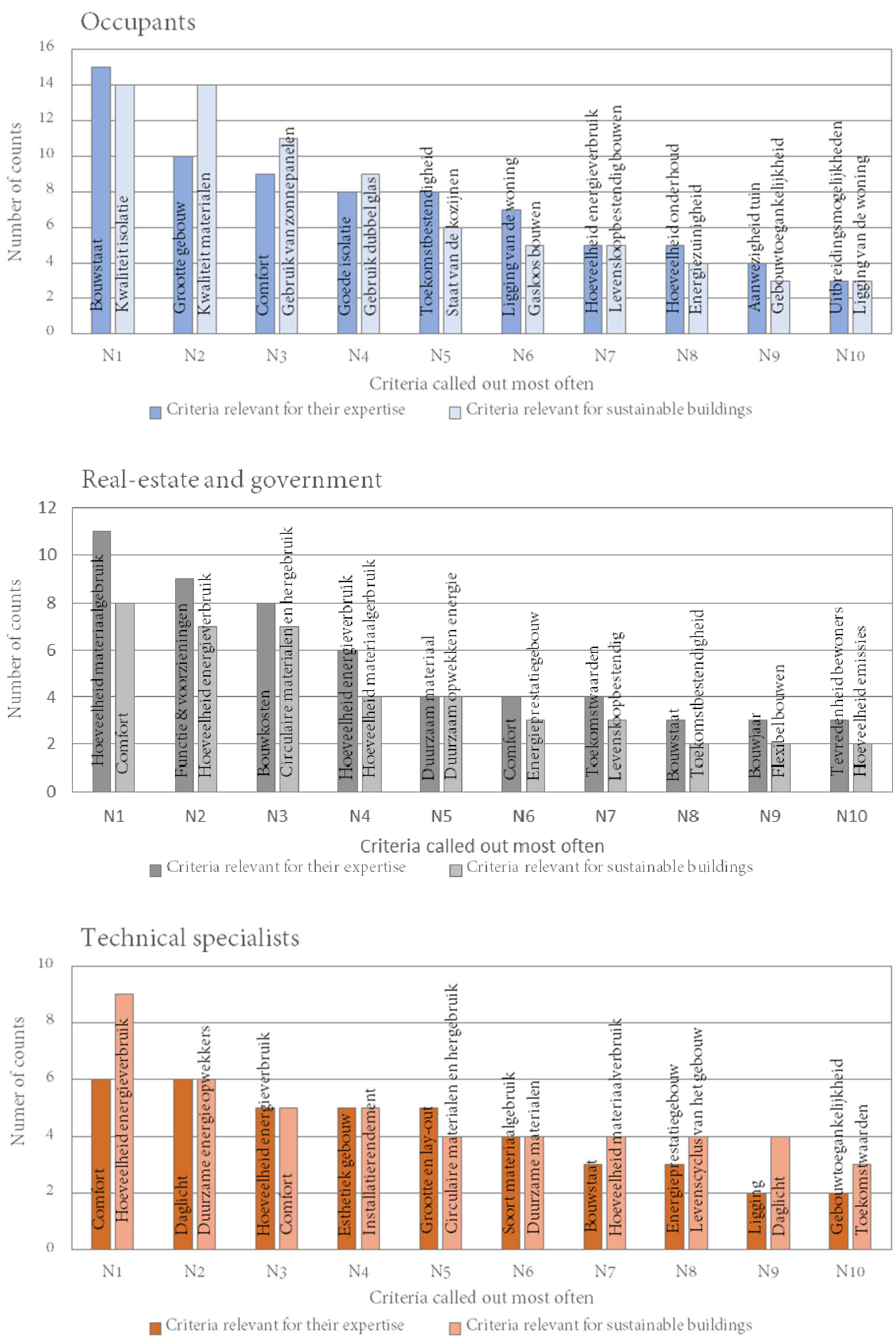


Figure 49: Overview of the criteria mentioned by the different users within the interviews and the number of counts for each time a criteria was mentioned per question.

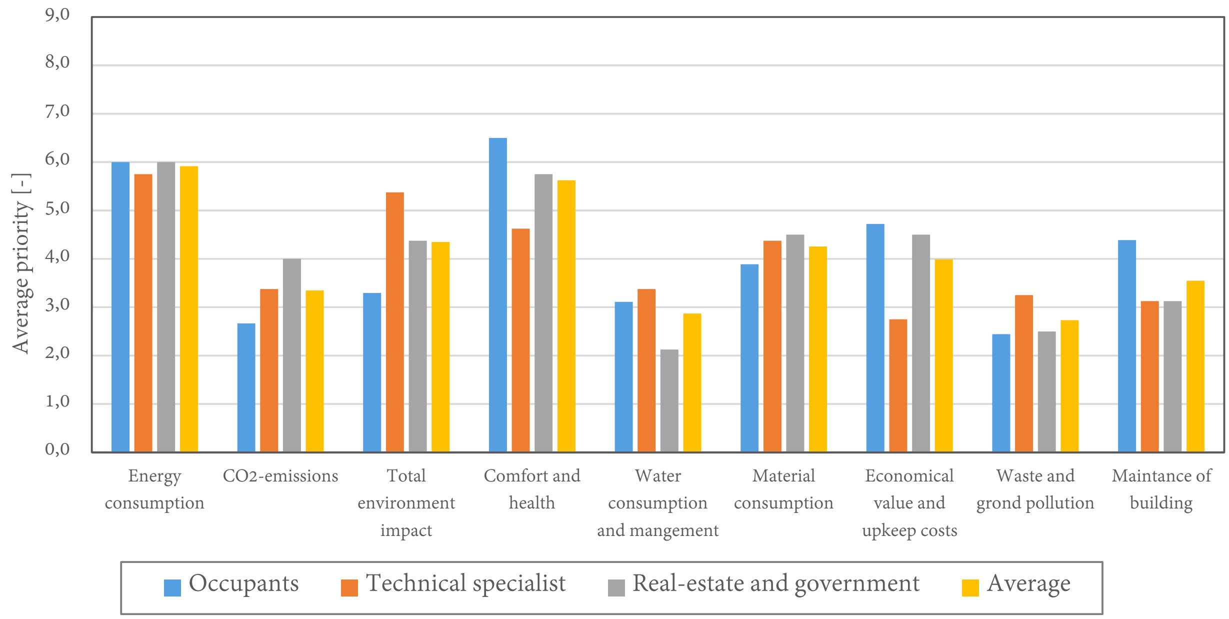


Figure 50: Average score of the output of the third question, divided over the different participants.

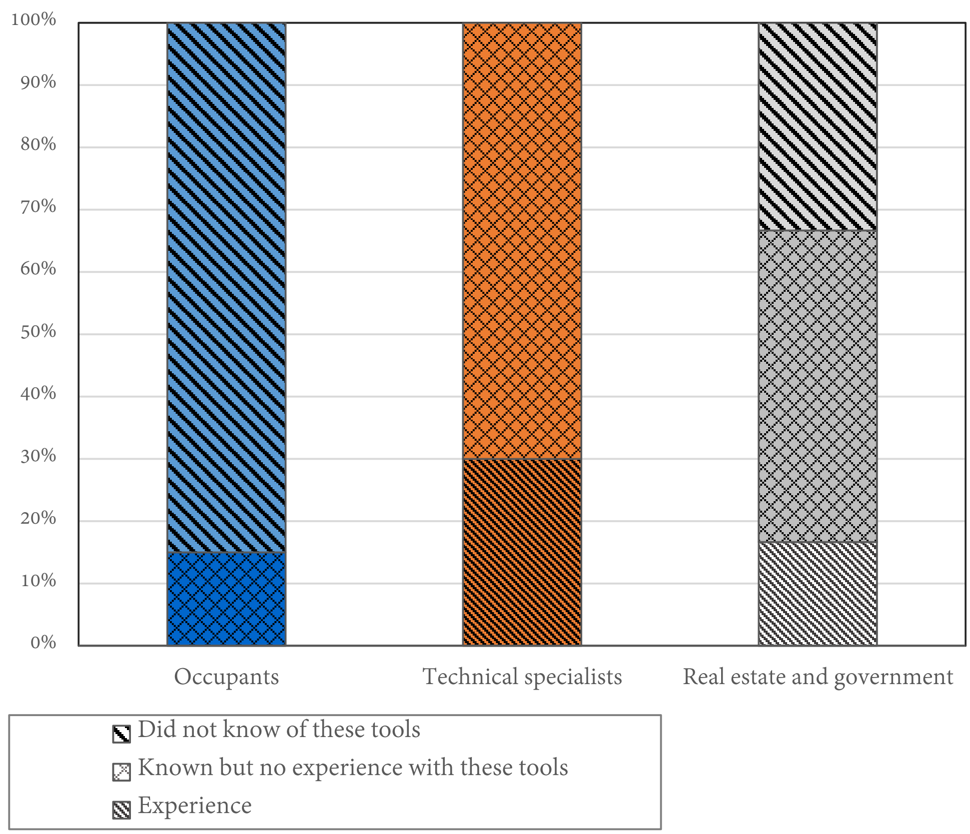


Figure 51: Output to the question: Are you familiar with assessment tools and do you have work experience with these assessment tools?

Annex III – Comparison of comfort categories for the different tools

Table 11 below gives an overview of the different comfort criteria that are being addressed in the different tools.

Table 11: Overview of the different categories for comfort and health within the different sources.

BREEAM-nl	LEED	GPR	PERFECTION	Dutch building code
"Health and wellbeing"	"Health and human experience"	"Health"	-	"Chapter 3"
Sight and light related comfort criteria				
• Daylight • Blinding • Use of high frequent lights • Use of artificial lighting • Lighting and control	• Lighting • Outside view • Glare measurement and control • Illumination factor • Daylight	• Daylight • Visual comfort (scenery)	• Daylight • Visual comfort • Electrical lighting	• Daylight
Sound related comfort criteria				
• Indoor acoustics • Sound insulation outdoor • Installation sound production	• Noise level (indoor)	• Sound insulation façade • Sound insulation between dwellings • Sound insulation between rooms • Installation sound production	• Airborne insulation between spaces • Impact sound of floors • Reverberation • Speech intelligibility • Background noise level	• Protection from outdoor sound production • Protection from installation sound • Restriction of sound and echo (indoor), restriction of sound between rooms

Temperature related comfort criteria				
• Thermal comfort • Temperature control • Infiltration and draft	• Thermal comfort • Temperature control (zoned control)	• Thermal comfort Thermal control	• Thermal comfort • Infiltration and draft	• Infiltration and draft
Air quality and moisture related comfort criteria				
• Indoor air quality • Organic bindings	• Ventilation • Natural ventilation • Ventilation system • Air purification, supply of fresh air • Air-quality sensors (Co_2-monitoring	• Ventilation • Ventilation control and additional requirements • Concentration of dust • Emissions from installation systems	• Indoor air quality & air refreshment rates • Indoor air quality – air change rate – air contaminations	• Restriction of moisture • Air refreshment rates • Supply and exhaust from fumes
Additional comfort criteria				
• Access to a private outdoor area	• Volatile organic compounds (VOC)		• Feeling of safety and positive stimulation	• Restriction of damaging and toxic materials
• Building accessibility	• Electromagnetic pollution		• Accessibility	• Protection against vermin and pests
	• Microbiological contamination level		• Functionality	

Annex IV – Overview of the sources used for the calculation and assessment of the criteria

For calculating and assessing comfort, one verification criterion was to provide an overview of the used sources. The following annex shows the following information per comfort criteria and explains what parts can be adjusted as renovation options within the model.

Main documents

- Which sources are mandatory or optional? Mandatory means that the calculation is in line with the requirements of the regulations. Optional means that the model is expanded with additional check-ups to provide more insight on the criteria or evaluation.
- What additional documents can be used to expand the model's resolution or scope, both for mandatory calculations and optional calculations?

Parts considered in *WoonConnect*'s assessment

- Which parts of the assessments are automated within *WoonConnect*'s BIM-structure? This list is also addressed as potential options that can be renovated within a project.
- What situations are preferable to improve comfort?

Reference thresholds for the assessment

- Reference table which *WoonConnect* uses to evaluate comfort and to provide renovation advice based on the output of the BIM-model, including the minimum required thresholds at each label.

Data and score table for each object, layer and situation

The data set used for version 1.0 is added in an Excel-file. The Excel file contains an overview of the model questions, the potential outcome(s), given scores and minimum required thresholds. The file also contains an overview of what model questions are allocated to which standardized complaints.

1 Thermal comfort - Heating

Summary
WoonConnect assesses heating by looking at the heating demand and the ability of the system to heat the building to a certain temperature set point. The given temperature set point can be set by the occupant themselves through the questionnaire and can therefore be variable based on the occupant's preferences. This temperature can be easier reached by either having a proficient heating-system or by reducing the heating demand. The heating demand can be reduced by added insulation, preventing leakage and draft or using mechanical ventilation with heat recovery.

Main documents	**Dutch building code**
NEN 7120 – Energie prestatie gebouw [4]	Mandatory
NEN 7120 – Achtergrond document ter ondersteuning van de norm NEN 7120 [51]	Mandatory
Building physics handbook – part 2 heating, ventilation and cooling [70]	Optional
Future documents for building simulation software	
nen-EN-ISO 52017-1 Energieprestatie van gebouwen - Voelbare en latente warmtebelasting en binnentemperaturen - Deel 1: Algemene berekeningsmethode [88]	Optional
ISSO-publicatie 32 - Uitgangspunten temperatuursimulatieberekeningen [89]	Optional
ISSO-publicatie 51 - Warmteverliesberekening voor woningen en woongebouwen Bepaling benodigd vermogen per vertrek en totaal [90]	Optional
HAMbase Part 1 and Part 2 [50]	Optional
Isso 7730, isso 74 [49], [91],	Optional

* Replaced NEN 7120 as of 01-09-2018

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Insulation value of the roof, floors and outer walls.	Higher insulation decreases the heating demand and keeps the building at a more stable temperature.
Are there thermal bridges?	Thermal bridges or missing patches of insulation can cause local heat loss in certain areas, which leads to a higher heating demand. These can cause local discomfort.
Type of glazing	Glass with a higher insulation value decreases the heating demand.
Insulation value of the window frames.	Window frames with a higher insulation value decrease the heating demand.
Type of heating system and the capacity of the heating system.	Newer heating systems have a higher efficiency and can generate and distribute heat faster. This heating system should have sufficient capacity to heat the building as determined by NEN 7120.
Type of heating delivering system	Usage of different types of heating delivering systems such as high and low temperature systems or floor heating. Floor heating in general has a more evenly distributed heating capacity.
Mass density of the building (kg/m2)	Heavier mass buildings tends to have a higher heat capacity compared to light weighted structures. Heavier weighted mass building are therefore less influences by sudden temperature changes.

Use of smart meters with wi-fi control	The ability to monitor the temperature and control the heating set point from different locations increases the flexibility of the heating system, thus reducing discomfort.
Use of separate thermostats for different floors	The ability to regulate the temperature and heat supply on different floors, increases the flexibility of the system by providing more options to regulate the heating set points at different locations.
Placement of radiators near windows	The placement of radiators near windows prevents draft and local discomfort for heating as a result of downdraught from the windows.
Use of mechanical ventilation including heat recovery	More ventilation means a higher heating demand. However, mechanical ventilation prevents the need for fresh air supply directly from the outdoor environment. Combined with heating recovery, a mechanical ventilation system allows for a more stable indoor temperature.
Usage of infiltration prevention around window frames	Adding additional infiltration prevention measurements near window frames prevents unwanted infiltration from the outside, which decreases draft and the heating demand.

Reference thresholds for the assessment	
Label	**Threshold requirements to improve the thermal comfort assessment (reference)**
F	• Use of single sheeted glass or less (U-value > 5.8 W/m2.K) • No usage of infiltration prevention around window frames
E	• Minimum usage of double sheeted glazing or better. (U-value < 3,3 W/m2.K) • Usage of infiltration prevention methods around window frames • Minimum usage of HR 100 boiler or better
D	• Insulation of the roof = (Rc > 2,0 m2.K/W) • Insulation of the facades = (Rc > 3,0 m2.K/W)
C	• Minimum usage of a HR 107 boiler system or better Minimum usage of HR glass or better (U-value < 2,0 W/m2.K)
B	• Use of mechanical ventilation to decrease dependency on windows (exhaust) and to increase air tightness • Insulation of the floors = (Rc > 3,5 m2.K/W)
A	• Use of mechanical ventilation (supply and exhaust), including heat recovery. • Insulation of floors, roofs and the facade according to standards of 2015. • Rc_roof = (Rc > 6,0 m2.K/W) • Rc_floor = (Rc > 3,5 m2.K/W) • Rc_walls = (Rc > 4,5 m2.K/W)

2 Thermal comfort - Cooling

Summary	
WoonConnect assesses cooling through looking at the ability of the building to reduce the high cooling demand and risk of overheating as calculated by NEN 7120. The preference is to first reduce the cooling demand and to prevent high indoor temperatures through other means then a cooling system (passive measurements). Using a cooling system will contribute to an increased electricity consumption, which is often not desired for renovation projects. Therefore WoonConnect looks at the amount of fresh air that is being supplied to the dwelling, the use of shading and the use of bypass systems to decrease the cooling demand.The occupant is able to fill in a variable cooling set point if a cooling system is present. The cooling demand and risk of overheating is also derived from NEN 7120. If the Twee Snoeken wishes to build a simulation tool, the same documents that are being used for heating can be used.	
Main documents	**Dutch building**
NEN 7120 – Energie prestatie gebouw [4]	Mandatory
NEN 7120 – Achtergrond document ter ondersteuning van de norm NEN 7120 [51]	Mandatory
Building physics handbook – part 2 heating, ventilation and cooling [70]	Optional
NTA 8778:2012 nl Harmonisatie Begrippenkader - Binnenmilieu in woningen [63]	Optional
Future documents	
nen-EN-ISO 52017-1 Energieprestatie van gebouwen - Voelbare en latente warmtebelasting en binnentemperaturen - Deel 1: Algemene berekeningsmethode [88]	Optional
ISSO-publicatie 32 - Uitgangspunten temperatuursimulatieberekeningen [89]	Optional
ISSO-publicatie 51 - Warmteverliesberekening voor woningen en woongebouwen Bepaling benodigd vermogen per vertrek en totaal [90]	Optional
Heat Air and Moisture model for Building And Systems Evaluation Part 1 and Part 2 [50]	Optional
Isso 7730, isso 74 [49], [91],	Optional

* Replaced NEN 7120 as of 01-09-2018

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Risk of overheating general building	WoonConnect looks at the risk for the building to overheat, based on calculation of NEN 7120 – Chapter 17.8. The lower the value, the lower the change is for overheating.
Ventilation system and air change rate	WoonConnect looks at the ability to supply fresh air more rapidly (1.3 and 1.5 times regulations in accordance with NTA). The increased supply of fresh air reduces the impact that internal heat gains have on the indoor temperature as warm air is being removed more often.
Ventilation system has access to a bypass system	A bypass regulates the air of the temperature that is being supplied to the building when heat recovery is present. A bypass system can switch the mechanical system off or on when the supply temperature is warmer then the indoor temperature.
Ventilation system has access to a CO2 regulator	The air change is regulated by a CO2-sensor. When CO2 values increase, the air change rate is increased as well.
Ventilation system inlet is located in a shaded place	If the supply inlet is placed in full sun light, the sun can preheat the air that enters the building. During summer, the placement can increase the temperature of the air supplied to the dwelling.
Presence of a cooling system	A cooling system is present to provide cooling when required.
Thick insulation of walls, roofs and floors and windows must be combined with a cooling system of an adjusted ventilation system.	High insulation of walls, roofs, windows and floors is positive for decreasing the heating demand, but can cause problems during summer. If thick insulation is present, proper ventilation or a cooling system should be present to minimize overheating during the summer.
Sufficient infiltration from windows	The building should have sufficient infiltration coming from (multiple) windows or doors so the occupant can cool the building easier during the evening/ night. Not having windows to cool will have a negative effect on the experience of thermal comfort.
Use of smart meters with wi-fi control for regulation the thermostat.	Ability to monitor the temperature and control the heating or cooling set point from different locations allows for a more flexible system.
Use of separate thermostats for different floors	The ability to regulate the temperature and heat supply on different floors, increases the flexibility of the system by providing more options to regulate the heating set points at different locations.
Access to (outdoor) sun screens	The presence of sun screens prevents solar radiation from entering the building. Large glass surface without sun screens increases the change of overheating, especially for surfaces oriented on the south.
Mass density of the building (kg/m2)	Heavier mass buildings tends to have a higher heat capacity compared to light weighted structures. Heavier weighted mass building are therefore less influences by sudden temperature changes.
Use of glass with a high ZTA value (> 40%)	Glass with a high ZTA value prevents solar radiation from entering the dwelling which decreases the cooling demand.
Usage of infiltration prevention around window frames	Prevents unwanted infiltration from the outside. During winter this prevents heating from leaving the dwelling but during summer it prevents heat from the outside to enter the dwelling.

Reference thresholds for the assessment	
Label	**Threshold requirements to reduce the cooling demand and risk of overheating.**
F	• Risk of overheating according to NEN 7120 section 17.8 is higher than 4 (> 4 [-]) • Use of single sheeted glass or less (U-value > 5.8 W/m2.K) • No usage of infiltration prevention around window frames • Insufficient ventilation through windows or the ventilation system (NTA class D or worse)
E	• Minimum usage of double sheeted glass or better. (U-value < 3,3 W/m2.K) • Sufficient ventilation through windows or the ventilation system in accordance with the building regulations (NTA class C or better). • Application of infiltration prevention around window frames
D	• Risk of overheating according to NEN 7120 section 17.8 is higher than 2 (> 2 [-]) • All residential rooms should have access to sunscreens.
C	• The ventilation system has an increased ventilation rate in accordance with NTA class B (1.3 times regulations indicated rates) • Residue areas, if possible, should have access to openable windows.
B	• Risk of overheating according to NEN 7120 section 17.8 is smaller than 1 (< 1 [-]) • If the building as mechanical ventilation for both the exhaust and inlet, it should have a bypass function for additional cooling (night cooling)
A	• A airco of central cooling system is present (negatively effects electricity consumption)

3 Thermal comfort - Draft

Summary	
WoonConnect assesses draft based on design tips of the buildings physics handbook. The overall set up is to prevent air displaced due to large temperature differences (e.g. cool surface) and to prevent unwanted air infiltration from the outside.	
Main documents	**Dutch building**
NEN 7120 – Energie prestatie gebouw [4]	Mandatory
NEN 7120 – Achtergrond document ter ondersteuning van de norm NEN 7120 [51]	Mandatory
BENG regulations NTA 8800. [6]*	Mandatory
Building physics handbook – part 2 heating, ventilation and cooling [70]	Optional
NEN 1087 [64]and NEN 8087 [65]	Mandatory
NEN 2778 [69]	Mandatory
Woning checklist [52]	Optional
Future documents	
No documents available	-

*Replaced NEN 7120 as of 01-09-2018

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Building/system part**
Placement of radiators near windows	Placing radiators near windows prevents draft and local discomfort for heating as a result of downdraught (*Dutch* = "*koudeval*")
Open connection between different floors (e.g. chair cases)	An open connection between floors can lead to air displacement as a result of temperature differences. Heat rises, which can cause draft over larger heights (e.g. between floors). Closing these openings will prevent this from happening.
Height of ventilation inlets	Adivce from NEN 1087 states that the height of the inlets should be 1800mm or higher above the floor to reduce draft & downdraught as a result of fresh (cold) air entering the building.
Draft prevention mailbox	Draft prevention for the mail box prevents unwanted infiltration through the opening.
Insulation value of the roof, floors and outer walls	Better insulation decreases the heating demand and keeps the building at a more stable temperature. This also prevents down draught from non-insulated building parts or from cracks in the wall.
Are thermal bridges present?	Thermal bridges or missing patches of insulation can cause local heat loss in certain areas. These can cause local discomfort or down draught when the temperature difference is too high.
Insulation value of the glass	Glass with a higher insulation value decreases the heating demand and will prevent downdraught near windows within a room.
Type of window frame	Window frames with a higher insulation value decreases the heating demand and will prevent down draught near windows
Usage of infiltration prevention around window frames	Infiltration measurements surrounding window or door frames help to prevent draft coming from cracks or gaps between the walls and the frames.

Reference thresholds for the assessment	
Label	**Threshold requirements to decrease draft**
F	• Use of single sheeted glass or less (U-value > 5.8 W/m2.K) • No usage of infiltration prevention around window frames
E	• Minimum usage of double glazing or better for all residential areas first. (U-value < 3,3 W/m2.K) • Application of infiltration prevention around window frames
D	• Minimum usage of double sheeted glass or better for all rooms, including residue areas. (U-value < 3,3 W/m2.K) • Application of infiltration prevention around window frames for residue areas aswell
C	• Insulation of the roof = (Rc > 2,0 m2.K/W) • Insulation of the facades = (Rc > 3,0 m2.K/W) • Insulation of the floors = (Rc > 1,3 m2.K/W) • Ventilation inlets (natural and mechanical) should be placed at a height greater than 1800 mm above the floor. • Natural ventilation inlets should be adjustable by the occupant
B	• The dwelling should have no open connection between the upper floors and the ground floor by placing the staircase in a separate room then the living area or the kitchen. • Minimum usage of HR glass, U-value < 2.0 W/m2.k)
A	• Insulation of floors, roofs and the facade according to standards of 2015. • Rc_roof = (Rc > 6,0 m2.K/W) • Rc_floor = (Rc > 3,5 m2.K/W) • Rc_walls = (Rc > 4,5 m2.K/W) • Minimum usage of HR+ glass, U-value < 1.6 W/m2.k)

4 Sound – sound reduction outdoor environment

Main documents	
WoonConnect assesses the sound insulation from the outdoor based on site sound maps and according the methodology described by GGG 97 and NEN 5077. The method makes an estimation about the indoor sound level through calculating the sound insulation value of the structure. The method makes an estimation of the indoor sound level based on the sound level derived from sound maps for the given situation.	
Main documents	**Dutch building**
NEN 5077 [55]	Mandatory
GGG 97	Optional
NEN 12354 part 3 [92]	Optional
Sound maps [54]	Optional
Bouwkunde tabellen boek [57]	Optional
Future documents	
Unknown	-

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Outdoor environment	WoonConnect makes uses of sound maps to determine the outdoor sound level in a neighborhood. For the calculation, the measured sound levels are used to determine the indoor sound level. These sound maps are available for rail roads, traffic and air traffic.
Sound insulation of the wall according to NEN 5077 and GGG 97	The NEN 5077 calculates the sound insulation value of the structure. The calculation considers windows (frames), wall compositions to determine the value. The higher the sound insulation value, the better the wall is capable the insulate sound on the inside.
Application of sound-proof natural ventilation shafts	Natural ventilation inlets above the window can be expanded with sound insulation shafts to reduce the sound insulation from the outside.
Mass density of the building (kg/m2)	Heavier mass buildings tend to have a higher insulation value for sound then lighter constructions.
Insulation of walls, roofs and floors and windows.	High insulation of walls, roofs and floors is positive for the sound insulation. Especially if the insulation material has higher sound absorption properties. When renovating a dwelling, insulation can be chosen with a higher sound insulation capacity.
Cracks around window and door frames	Large openings or cracks in the window and door frames contribute to a bad sound insulation level of the façade as well. When improving the sound insulation of the façade, these cracks or openings should be addressed first.
Type of glass or window	Thicker glass or double glazing has an overall higher sound insulation value then single sheeted glass. The best sound insulation can be achieved by using triple glazing.
Use of outdoor sun screens	Certain types of (heavier) outdoor sunscreens can contribute to the sound insulation when lowered.

Reference thresholds for the assessment	
Label	**Threshold requirements to improve sound insulation of the outer wall.**
F	• Use of single sheeted glass • No usage of infiltration prevention around window frames • Sound reduction value façade = G*A*,*k* < 15 dB (existing structure)
E	• Sound reduction value façade = G*A*,*k* < 20 dB (existing structure) • Use of double glass or better. • Usage of infiltration prevention around window frames
D	• Sound reduction value façade = G*A*,*k* >= 20 dB or better for rooms subjected to the sound. • Sound level in the interior L_{room} = 33 dB or below for rooms subjected to the sound.
C	• Sound reduction façade G*A*,*k* >= 20 or better for all residential rooms (requirement new buildings) • Sound level in the interior L_{room} = 33 dB or below for all residential rooms. (requirement new buildings) • Residue areas Hr + glass or better
B	• Sound reduction façade G*A*,*k* >= 25 dB or better for all residential rooms. • Sound level in the interior L_{room} = 33 dB or below for all residential rooms.
A	• Sound reduction façade G*A*,*k* >= 25 dB or better for all residential rooms. • Sound level in the interior L_{room} = 30 or below for all residential rooms.

5 Sound – sound reduction from installations and household equipment

Main documents
WoonConnect assesses the sound of installations for two parts: The HVAC-system and for the placement of common household equipment such as a washing machine and dryer. For each type of system, WoonConnect looks at two parts. The first parts assess the quality of the systems to reduce the sound production itself. The second part looks at where the installations are located in the dwelling and how that room is build. In a later stage, *WoonConnect* can expand the method with a similar calculation as for the outdoor environment by calculating the sound insulation value of the structure surrounding the installation system.

Main documents	**Dutch building code**
NTR 5076:2015 [58]	Optional
Woningchecklist [52]	Optional/ Mandatory
Nen 5077 [55]	Mandatory
Future documents	
Nen 5077 – expand for installation sound	Mandatory

* Building regulations use the same calculation for installation sound as described in NEN 5077.

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Build-up boiler system Build-up heat pump system Build-up ventilation system	A installation system has to meet several options to reduce its sound production: • Placed in a sound proof closet or housing. • Use of silencers for ventilation exhausts and inlets • Use of low power systems • Use of direct currency • The system is suspended from the floor and attached to the walls with springs to reduce sound production from vibrations.
Location of the installations	The preference is that the installations are placed in a separate room away from the bedrooms such as the attic, garage of basement. If possible, the best solution would be to place the systems in a room that is designated for installations. It is not preferable that the systems are placed in a residential area (bathroom, kitchen, living room or bedroom).
Location of the household equipment	Preference is that household equipment is placed in a separate room away from the bedrooms such as an attic, basement, garage or a scullery.
Sound insulation of the walls and floors of the room where these systems are located.	Similar as with the sound insulation of the façade, the quality of the walls and floors in which the installation system are located also play a role in the sound reduction. A heavier wall/ floor is preferred over a light weight wall and there should be no cracks or openings in the structure.

Reference thresholds for the assessment	
Label	**Threshold requirements to reduce sound production from installations or by placing them in a proper location**
F	• HVAC-installations are located in a residential area such as a bedroom, kitchen or living room. • Household equipment is located in a residential area such as a bedroom, kitchen or living room
E	• HVAC-installations are located in a residue area such as a bathroom, garage, attic or technical room • Household equipment is located in a residue area such as a bathroom, garage, attic or technical room
D	• HVAC-Installations are suspended from the floors and walls
C	• HVAC-installations are placed in a separate room that is closed off from the rest of the building through a door. • The installation room is not horizontal adjacent to a bedroom area.
B	• HVAC-Installations are equipped with sound reducing fixtures, piping or sound proof casings • Household equipment is located in a residential area such as a bathroom or kitchen and is placed on a sound absorbing underground.
A	• HVAC-Installations are placed in a designated installation room or sound proof closet within a residual area. • Household equipment is placed in a separate designated residual area

6 Sound – sound reduction between rooms

Summary	
For sound insulation between rooms *WoonConnect* looks at the quality and sound reduction values of the structure that separates rooms. The structure consist of both floors (sound reduction between different floors or apartments) and walls (sound reduction between two adjacent rooms or between two adjacent dwellings).	
Main documents	**Dutch building code**
Tabellenboek [57]	Optional
NPR 5086 Noise control in dwellings – noise control of lightweight partition walls between dwellings. [59]	Mandatory (input for 5077)
NPR 5071:1981 nl Geluidwering in woongebouwen - Voorbeelden van maatregelen tegen galm, lawaai door slaande deuren en dergelijke in gemeenschappelijke ruimten, afgestemd op NEN 1070 [60]	Optional
Nen 1070: Noise control in buildings – specifications and rating of quality [61]	Optional
Building physics handbook – part 3 Sound [62]	Optional
Future documents	
NEN 5077 - expand for indoor environment, de method can be repeated for interior rooms together with echo.	Mandatory
Nen-en-iso 12354-1 Building acoustics – estimation of acoustic performances of buildings from the performance of the elements – part 1: airborne insulation between room	Optional
Nen 12354-2 12354-1 Building acoustics – estimation of acoustic performances of buildings from the performance of the elements – part 2: Impact sound insulation between rooms	Optional

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Location staircases	For sound reduction between different floors it's preferred to have the staircase in a separated room. Having the staircase in a separated room helps to reduce the air sound propagation that will travel between the different floors.
Location of bedrooms	It is preferred to have the bedrooms not connected directly to the kitchen or living room but separated by a hall to reduce sound from common household equipment such as a TV.
Quality indoor walls	There should be no gaps or holes should be present in the wall. It is preferred to have a heavier constructions which often have higher sound insulation properties compared to light weighted structures. Light weight constructions (example wood with plaster board) require different solutions to reduce sound problems between the rooms such as added insulation.
Quality indoor floors	There should be no gaps or holes should be present in the floor. It is preferred to have heavier construction (concrete) which has a higher insulation value for contact sound. In case of a lightweight wooden floor, a floating screed or floor can be used to increase the sound insulation of a floor.
Quality dwelling separation wall	The wall separating two dwellings should have no holes or gaps. It is preferred to have heavier construction (concrete) which have a higher sound insulation value. Furthermore, it is preferred if a cavity is present between both dwellings.
Quality dwelling separation floors	There should be no gaps or holes should be present in the floor that separates the dwelling. It is preferred to have heavier construction (concrete) which has a higher insulation value for contact sound. In case of a lightweight wooden floor, a floating screed or floor can be used to increase the sound insulation of a floor.
Use of a front wall or second wall for dwelling separation walls	If no cavity is present, a front wall can provide an alternative options to reduce sound between two adjacent dwellings.
Surface of (wooden) staircases	Wooden staircases can contribute to sound discomfort as a result of contact sound. Upholstery of the staircases can prevent can prevent contract sound by providing a softer surface material.
Use of acoustical plaster	Use of acoustical plaster or finishing can help to reduce the echo in the room if preferred.

Reference thresholds for the assessment	
Label	**Threshold requirements to reduce sound between two rooms or dwellings**

F	• For different rooms inside the same dwelling.
	  ○ There are cracks or holes present in the separating walls or floors.
	• For structures (floors and walls) that separate two dwellings
	  ○ There are cracks or holes present in the separating walls or floors.
	  ○ The structure of the wall separating the dwelling is a light weighted timber frame construction without any sound insulation

E	• For different rooms inside the same dwelling.
	  ○ There are no cracks or holes present in the separating walls or floors.
	• For structures (floors and walls) that separate two dwellings
	  ○ There are no cracks or holes present in the separating walls or floors.

	○ The structure of the wall separating the dwelling is made stone or concrete materials ○ The floor separating the structure is a light weighted timber frame OR from concrete, thickness < 200 mm
D	• For different rooms inside the same dwelling. ○ The floor separating the structure between to rooms is made from concrete, thickness < 200 mm OR The floor separating the structure between is a timber frame construction • For structures (floors and walls) that separate two dwellings ○ The floor separating the structure is made from concrete, thickness > 200 mm
C	• For different rooms inside the same dwelling. ○ Bedrooms do not share a door with the living room ○ Internal floors are from concrete, > 200 mm • For structures (floors and walls) that separate two dwellings ○ The floor separating the structure is made from concrete, thickness > 300 mm ○ The floor, if it is a timber frame construction, contains some form of sound insulation or is disconnected from the surface ○ The wall separating the dwelling contains a cavity. ○ If the wall separating the dwellings is a single layer of bricks, it contains a “front wall” to reduce sound.
B	• For different rooms inside the same dwelling. ○ Stair case connecting the separate floors is located in a separate room or hallway ○ The chair case has a soft surface to reduce contact sound • For structures (floors and walls) that separate two dwellings ○ No demands
A	• For different rooms inside the same dwelling. ○ Internal walls are made from concrete or stone material ○ If the walls are a light weighted wooden structure, tit contains sound insulation. ○ Internal floors are from concrete, > 300 mm • For structures (floors and walls) that separate two dwellings ○ The floor separating the structure is made from concrete, thickness > 300 mm and is disconnected from the structure

7 (Day)light

Sumamary	
WoonConnect considers the amount of light entering the building through looking at the equivalent floor spacing (Aeq) as calculated by NEN 2057. This method however only focuses on the window area for sunlight to enter, but does not consider demands regarding sun screens or window dimensions. Additional checks are based on guidelines from building physics handbooks and lighting design handbooks and focus on the use of blinds or sunscreens and the dimensions of the windows. For the future, *WoonConnect* can still expand the model with simplified daylight simulations. In contrary with NEN 2057, said method calculates a lighting level within a room.	
Main documents	**Dutch building code**
NEN 2057 [66]	Mandatory
Building physics handbook – part 1 design with light [53]	Optional
IESNA lighting handbook [68]	Optional
Future documents	
Average daylight factor: a simple basis for daylight design, Information Paper 15/88, Building Research Establishment, Watford, UK. [93]	Optional
Development of advanced daylight calculations BIM-automated coupling with radiance, accordance to the ray-trace methodology [48].	Optional

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Aeq both in m2 and % per room	WoonConnect calculates how large windows are relative to the surface area of said room. A higher value indicates that the room has many openings for daylight to enter. According to the regulations, the value may not be lower than 10% for living rooms, bedrooms, kitchens or study rooms.
User of (solar) blinds or outdoor sunscreens per room	To prevent blinding from direct sunlight, the building should have access to indoor or outdoor sunscreens. According to physical handbooks, blinds are especially needed when Aeq/Asurface > 15 a 20%
Window dimensions per room	Good room dimensions ensure that the light enters the dwelling in an equal matter. The rule of thumb is that the height of the windows should at least half the depth of the room (window height > 2 x depth of the room back wall) to let daylight enter the building sufficient. Based on NEN 2057, the windows should have at the very least have a lower frame height of 800 mm or lower.
Use of window stickers and positions of windows for sensitive rooms	The use of windows stickers can prevent privacy problems. Otherwise, the window could be placed above a height of 1800mm to prevent privacy problems for sensitive rooms such as a bathroom or toilet.
Amount of windows within a room and the orientation	Having more windows in different orientations bring a more dynamic form of lighting in the building compared to a window limited to one wall.
Use of bright colors instead of dark colors	Usage of bright colors with higher reflective value improves the amount of light within a room.
Use of glass panel doors or skylights for internal rooms	Using glass panels or skylights can bring additional daylighting inside the dwelling for rooms that have no (direct) access to daylight.
Use of outdoor lighting near entrances for safety reasons	Use of outdoor lighting near the entrances of the building helps to increase the experience of safety.

Skyline factor	The skyline factor displays how much daylight is obscured by surrounding buildings. A low skyline factor indicates that the buildings is surrounded with a lot of high rise buildings, whilest a high skyline factor shows that the room has an open view.
Type of light switches	Besides standard light switches, light dimmers can be used to regulate electric lighting. Light dimmers allows the user to have more flexibility in regulating the lighting levels to their own preferences.
Use of windows for non-mandatory rooms	Non all rooms types are required to have access to direct daylight according to the Dutch regulations. For example, a bathroom, a toilet, a basement, the hallway or the attic are not required to have access to daylight. However, to increase the quality of the daylight, it is better if these rooms do have access to a window for daylighting.

Reference thresholds for the assessment	
Label	**Threshold values for daylighting**
F	• Aeq_area < 0,5 m2 for on residential area or more
E	• Aeq_area > 0,5 m2 for each residential area
D	• Aeq_area/A_surface > 10% for residential areas
C	• Aeq_room/A_surface > 10% for each residential area • Residential areas have access to sunscreens (indoor or outdoor) to prevent blinding
B	• Aeq_living room/ A_surface > 15% • Aeq_living room has several windows • Badroom and hallway/entrance have access to an outdoor window • Bathroom has direct access to daylight • Entrance area has direct access to daylight
A	• Aeq_ room/ A_surface > 15% • Aeq_living room/ A_surface > 20% • Residential areas have access to outdoor sun screens for east, south and west oriented facades.

8 Indoor air quality and air change rate

Summary	
To increase the air quality in the dwelling, *WoonConnect* considers the air change rate due to infiltration and from windows, the air change rates delivered to the building through ventilation and the methods the building uses to ventilate the dwelling. To improve the indoor quality, sufficient air change is crucial and, if possible, it is preferred to have a larger air change rate then is being advised in the regulations. Besides the air change rates, *WoonConnect* also looks at the option to temporary increase the ventilation rate for sensitive rooms such as the bathroom, the kitchen or the technical rooms. For future developments, there are no commercial tools available to calculate the air change rates in buildings. There are theoretic models available in the form of Computer fluid dynamics models (cfd). These kind of models are capable to analyses air streams within a building but require high levels of theoretical understanding, data and computational times to operate.	
Main documents	**Dutch building code**
NTA 8778: Harmonized Conceptual Framework – indoor environment in residential buildings. [63]	Optional
NEN 1087: Ventilation in buildings – Determination methods for new estate [64]	Mandatory
NEN 8087: Ventilation in buildings – Determination methods for existing buildings [65]	Mandatory
Air quality maps Netherlands [54]	Optional
Buildings physics handbook part 2 – heating, ventilation and cooling [70]	Optional
Future developments	
No document available	-

Table 12: NTA classes for the rate of air change from NTA 8778.

	Heel goed	**Goed**	**Matig**	**Onvoldoende**
Klasse NTA 8778	A	B	C	D
Woonkamer en slaapkamer(s)	4 m³/uur/m²	3.2 m³/uur/m²	2,5 m³/uur/m²	Minder dan 2,5 m³/uur/m²
Keuken	Hoogstand 400 m³/uur	Hoogstand 300 m³/uur	75 m³/uur	Minder dan 75 m³
Toilet	25 m³/uur	25 m³/uur	25 m³/uur	Minder dan 25 m³
Badkamer	70 m³/uur	70 m³/uur	50 m³/uur	Minder dan 50 m³

	Heel goed	**Goed**	**Matig (eis nieuwbouw)**	**Onvoldoende**
Klasse NTA 8778	A	B	C	D
Lucht toevoer	Traploos	Traploos	4 standen (incl. dicht)	Open/ dicht
Lucht afvoer	Traploos	Traploos	4 standen (incl. dicht)	Open/ dicht
Vraagsturing	CO2	Tijdklok	Geen	Geen
Bediening	Schakelaar in keuken en badkamer (met naloop	70 m3/uur	Schakelaar in keuken	-

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Location of the dwelling	Is the dwelling located in an area with a low air pollution level or a high air pollution level? WoonConnect makes use of a pollution map to indicate if the dwelling lays in an area with higher air pollution levels.
Ventilation rate of the system	WoonConnect calculates the amount of ventilation required in a dwelling. The advice, based on the NTA classes, is to have a higher ventilation rate then advised by the regulations.
CO2 controlled system	A Co_2 controlled system can detect the quality of the air and add or remove air if the CO_2-levels in the room if the levels are too high.
Type of heating distribution system (radiator, floor heating)	Traditional radiators can be more difficult to clean and due to the higher temperature radiators can easier burn dust. Low temperature systems and floor heating do not have these kind of problems.
Type and location of heating system	Use of non-gas based systems reduces the need for burning fossil fuels within the dwellings, thus reducing the chance of CO pollution. It is preferred that the heating system is situated in a technical room or residual area (attic, garage) and not in a residential area (kitchen) to prevent smell from such a system.
Use of a CO-sensor	For safety reasons, a CO sensor near the heating system can detect leakages or problems with the system.
Sufficient options to ventilate through windows (*Dutch = spui*)	The dwelling must have sufficient windows to ventilate the indoor environment in accordance with NEN 1087 and NEN 8087.
Height of ventilation inlets > 1800mm	The preferred height of the ventilation inlets is higher than 1800 mm to better mix the fresh air with the indoor environment.
Separation of kitchen and the living room	Separating the kitchen with the living room prevents smell from food or from the furnace to enter the living room if required.
Presence of additional ventilation for the kitchen	Additional ventilation is present or can be switched on to increase the ventilation rate in the kitchen when required. Having additional ventilation helps to reduce CO2-production or smell when the kitchen is being used.
Presence of additional ventilation for the bathroom	Additional ventilation is present or can be switched on to increase the ventilation rate in the bathroom when required. This helps to reduce moisture production and smell when the bathroom is in use.
Presence of additional ventilation or windows for the room with the installations	Additional ventilation is present or can be switched on to increase the ventilation rate in the technical rooms when required. This helps to reduce CO, moisture and smell production of HVAC-systems.
Presence of additional ventilation or windows for the room that contains large household equipment's such as the dryer and the washing machine	Additional ventilation is present or can be switched on to increase the ventilation rate in room with large household equipment when required. Household equipment such as dryers or washing machines can cause problems with smell or moisture when placed in a badly ventilated space.
Windows in different building orientations	To improve the ability to ventilate the building through windows, the preference is to have multiple windows in different orientations or locations for each residential area. Having multiple windows helps to increase the efficiency of ventilation through windows.

Presence of windows in residual area's (toilets, hallways)	It is not mandatory for residual areas to have openable windows. For the air quality it is preferred that these rooms also have access to windows that can be opened. These additional windows help to increase the ventilation rate of the overall building.
Insulation material should not be visible from the interior.	To prevent dust or irritations as a result from insulation materials, the insulation materials (e.g. glass wool) should be covered up inside the structure of the dwelling.

Reference thresholds for the assessment	
Label	**Threshold requirements to increase the air quality**
F	• Insufficient ventilation capacity from windows in accordance with NEN 1087 and NEN 8087. • Insufficient ventilation capacity from the ventilation system in accordance with NEN 1087 and NEN 8087 (NTA class D) • Heating system, gas burning unit is located in a residential area.
E	• Sufficient ventilation capacity from windows in accordance with NEN 1087 and NEN 8087. • Sufficient ventilation capacity from the ventilation system in accordance with NEN 1087 and NEN 8087 (NTA class C or better) • Heating system, gas burning unit is located in a residue area.
D	• The bathroom has access to a openable window OR The bathroom has access to an additional mechanical ventilation which can be turned on or off.
C	• The bathroom also has access to an additional mechanical ventilation which can be turned on or off. • The kitchen has access to additional mechanical ventilation which can be turned on or off when required. • Residential area including the living room has access to multiple widows or ventilation shafts that can provide additional air
B	• The ventilation capacity from the ventilation system is 1.3 times higher than recommended in accordance with NEN 1087 and NEN 8087 (NTA class B or better)
A	• The ventilation capacity from the ventilation system is 1.6 times higher than recommended in accordance with NEN 1087 and NEN 8087 (NTA class A or better) • The ventilation system is CO_2 regulated for each exhaust point

9 Moisture problems related to the structure.

Main documents	
Moisture and mold problems are, with the exception of thermal bridges, difficult to assess in a model but can have a severe influence on the health and comfort experience of an occupant. The assessment to restrict problems with moisture in the structure are therefore based on two parts. The first part is whether the occupant has complains or problems with structural damage as a result of moisture or flooding. The causes can range from structural damage, thermal bridges or ground water. Depending on what type of problems are present (and where), the solutions can be different as well. The assessment of *WoonConnect* therefore indicates where the problems are present. However, to resolve the problem, an onsite observation is still advised. *WoonConnect* therefore records the problems for the technical staff to address. The second part focuses on reducing the maintenance related to moisture problems. *WoonConnect* looks at certain options that can reduce the need for maintenance related to moisture.	
Main documents	**Dutch building**
Nen 2778: Moisture control in buildings [69]	Mandatory
Buildings physics handbook part 2 - heating, ventilation and cooling [70]	Optional
Future documents	
NEN 2778 – Thermal bridge calculation	Optional

* Advice in accordance with the regulations

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Are there thermal bridges present?	Thermal bridges increase the chance of mold growth in the indoor environment. The cold surface can cause water vapor to condensate on the interior walls. If present, thermal bridges can be resolved by improving the insulation of the wall, roof or floors depending on where the thermal bridge is located.
Does the occupant have problems with mold growth?	*WoonConnect* asks the occupants if they are having problems with mold growth and where this mold is located. If present, a contractor or consultant should make an observation on site to determine the exact cause.
Does the occupant have problems with leakages?	*WoonConnect* ask occupant if they are having problems with leakages and where these are located. If present, a contractor or consultant should make an observation on site to determine the exact cause.
Does the occupant have problems with moisture of flooding in the crawl space or cellar?	*WoonConnect* ask occupants if they are having problems with moisture or flooding's in the crawl space or cellar. If present, a contractor or consultant should make an observation on site to determine the exact cause.
Insulation	Insulation helps to prevent thermal bridges when applied correctly, which can cause problems with mold growth. New regulations also require that there are preemptive moisture prevention measurements in place. (Artikel 3.5 building regulations)
Warm structure roofing	Placing the insulation above the wooden structure instead of in between the structure prevents condensation at the structural beams. Over a longer period of time, said condensation can cause problems for wooden structures.
Type of window frames	In terms of maintenance, plastic of aluminum frames require less maintenance to prevent moisture problems. Wooden frames are allowed but require regular maintenance to prevent the degradation of the wood overtime.

Reference thresholds for the assessment	
Label	**Threshold requirements for structural moisture problems**
F	• The occupant states that he has problems with moisture, leakages or flooding as a standard complaint. A building engineer has to make an oberservation on site to determine which options could be taken.
E	• None
D	• None
C	• None
B	• The building makes use of wooden frames for windows or doors • The insulation of the roof is placed in between the structural beams (cold structure)
A	• The building makes use of plastic or aluminum frames for windows or doors • The insulation of the roof is placed above the structural beams (warm structure)

10 Air humidity

Summary	
Besides the structural damage related to moisture, *WoonConnect* also addressed air humidity. For assessing the air humidity, *WoonConnect* looks first of all whether there are structural problems present (leakages), which have to be resolved first. Additional options to improve or better regulate the air humidity are based on the ability to add vapor (in case of a dry indoor environment) or to remove moisture more rapidly for rooms that have a high moisture product (ventilation). Adding or removing moisture is partly depended on the ventilation rate, therefore several similar documents were used for the assessment.	
Main documents	**Dutch building code**
NTA 8778: Harmonized Conceptual Framework – indoor environment in residential buildings. [63]	Optional
NEN 1087: Ventilation in buildings – Determination methods for new estate [64]	Mandatory
NEN 8087: Ventilation in buildings – Determination methods for existing buildings [65]	Mandatory
Nen 2778: Moisture control in buildings [69]	Mandatory
Future documents	
Hambase model [50]	Optional

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Are there any moisture of leakage problems present?	Before being able to improve the indoor air humidity, moisture, flooding or leakage problems have to be resolved first as these provide an uncontrollable source of moisture production.
Ventilation system and air change rate	If the ventilation system is capable to add fresh air more rapidly (1.3 and 1.5 times regulations according to NTA 8778), moist air can be removed more rapidly.
Presence of additional ventilation for the kitchen	It is preferred to have additional ventilation that can be switched on or off to increase the ventilation rate in the bathroom, kitchen or technical rooms when required. Additional ventilation helps to reduce moisture production and smell when these rooms are being used.
Presence of additional ventilation for the bathroom	
Presence of additional ventilation or windows for the room with the installations	
Presence of additional ventilation or windows for the room that contains large household equipment's such as the dryer and the washing machine	Additional ventilation is present or can be switched on to increase the ventilation rate in room with large household equipment when required. Household equipment such as dryers or washing machines can cause problems with smell or moisture when placed in a badly ventilated space.
Sufficient options to ventilate through windows (*Dutch = spui*)	A dwelling must have sufficient access to ventilation through windows. Sufficient air change rates help to remove moisture from the indoor environment.
Height of ventilation inlets > 1800mm	The preferred height of the ventilation inlets is higher than 1800 mm to better mix the fresh air with the indoor environment.
Windows in different building orientations	To improve the ability to ventilate the building through windows, the preference is to have multiple windows in different orientations or locations for each residential area. Having multiple windows helps to increase the efficiency of ventilation through windows.

Reference thresholds for the assessment	
Label	**Threshold requirements to improve the air humidity**
F	• There should be no leakages, floods or thermal bridges present at the dwelling • Insufficient ventilation capacity from windows in accordance with NEN 1087 and NEN 8087. • Insufficient ventilation capacity from the ventilation system in accordance with NEN 1087 and NEN 8087 (NTA class D)
E	• Leakages, thermal bridges and flooding in the building have been resovled. • There is sufficient ventilation capacity from windows in accordance with NEN 1087 and NEN 8087. • There is sufficient ventilation capacity from the ventilation system in accordance with NEN 1087 and NEN 8087 (NTA class C)
D	• The residue area that contain common household equipment such as the washer and dryer have access to openable windows for additional ventilation.
C	• Bathrooms areas have access to additional mechanical ventilation that can be turned on/off. The additional ventilation helps to reduce moisture after the usage of the bathroom. • Kitchen areas have access to additional mechanical ventilation that can be turned on/off. The additional ventilation helps to reduce moisture after the usage of the kitchen.
B	• The ventilation capacity from the ventilation system is 1.3 times higher than recommended in accordance with NEN 1087 and NEN 8087 (NTA class B or better). • Residue areas also have access to ventilation through windows.
A	• The ventilation capacity from the ventilation system is 1.6 times higher than recommended in accordance with NEN 1087 and NEN 8087 (NTA class A or better).

11 Other criteria - Usability quality of interior and building size.

Summary	
The assessment of the usability and quality of the interior is based on the assessment scheme provided by the rent commission to determine the value of a dwelling (*Dutch WOZ-waarde).* For this assessment *WoonConnect* looks at the size of the building, size of the garden and the size of the residential and residual areas. The assessment also looks at the quality of fixed furniture (bathroom, kitchen and toilet)	
Main documents	**Dutch building code**
Woningwaarderingsstelsel [71]	Yes
Future documents	
Woonkeur [94]	Yes

Parts considered in *WoonConnect*'s BIM-model assessment	
Building/system part	**Description**
Size of the residential area, including the bathroom.	A larger size of the residential areas allow for more flexibility in the lay-out and for the placement of furniture.
Size of the residual areas	Larger residual areas allow for more storage and flexibility in the lay-out and placement of furniture.
Number of heated rooms	The number of rooms that have access to a radiator or floor heating.
Size and quality of the kitchen	Size means the dimensions of the kitchen counter. Quality means the use of higher quality materials such as hardwood or natural stone instead of chipboard materials. It also addressed whether the building provides built in equipment.
Size and quality of the bathroom	Size is translated into the presence of a bath (and shower) and number of toilets. Quality is translated into the use of better quality materials (e.g. natural stone).
Size of the outdoor area.	The size of the outdoor area. A larger outdoor area increase the WOZ-value and allows space for future expansions.
Carport presence	Presence of roofing for a car or bikes.

Reference thresholds for the assessment	
Label	**Threshold requirements to improve usability**
F	• Combined surfaces for residential area < 30m^2 • Bathroom area < 3 m^2 • Combined surfaces for residue area < 10 m^2 • Not all residential areas have access to a heating unit (radiator, floor heating) • Kitchen counter size is smaller than 1 m (or less then 4 woz-points)
E	• Combined surfaces for residential area >= 30 m^2 • Bathroom area >= 3 m^2 • Combined surfaces for residue area >= 10 m^2 • All residential areas have access to a heating unit (radiator, floor heating) • Kitchen counter size is larger than 1 m
D	• The dwelling has access to a private outdoor area.
C	• Combined surfaces for residential area >= 55 m^2 • Combined surfaces for residue area >=30 m^2
B	• The dwelling has access to a private outdoor area, size is 25 m^2 or larger.
A	• Combined surfaces for residential area >= 80 m^2 • Combined surfaces for residue area >=40 m^2

Annex V - Case study *Uden* and heating/cooling scenarios

For determining the thresholds for heating and cooling, additional simulation were run. To run these simulations, the software tool Vabi elements [95]was used to analyze how these thresholds affect a dwelling and its indoor temperature. For running these simulations, a test case study was chosen for *Uden*, The Netherlands. The main reason for why the case study was chosen was because *WoonConnect* was already being used for the renovation of the neighborhood. Therefore a lot of data was present for building the model.

The floor plans of the dwelling are shown in Figure 52 below. The case study consists of a typical Dutch terraced dwelling built in the 1970's. Within the current situation, no energy saving measurements were in place with the exception of double glazing and a modern gas boiler system (HR 107). Otherwise, only limited floor, roof and wall insulation was present. Also no ventilation adjustments were made, the existing ventilation system has both a natural supply and exhaust. For occupant behavior, a young family was assumed, including a child. Domestic hot water was therefore assumed to be 84 liter/day. Otherwise, the Vabi-model was set up in accordance with the Dutch regulations and uses the same data for the *WoonConnect* project.

Figure 52: Floorplan(s) for the case study dwelling of Uden. Left shows the first floor, right shows the second floor.

Validation of the models

For modelling the dwelling, the output of Vabi Elements simulation was compared to the energy calculations of *WoonConnect (Ebuddy)*. The results of both models are shown in Figure 53 and Figure 54 below. The first figure displays the gas consumption required for cooking, space heating and domestic hot water. The second figure compares the plug loads for devices, lighting, auxiliary installation systems (pumps) and electric cooking systems. In both cases, the plug loads were also used as input for the internal heat gain.

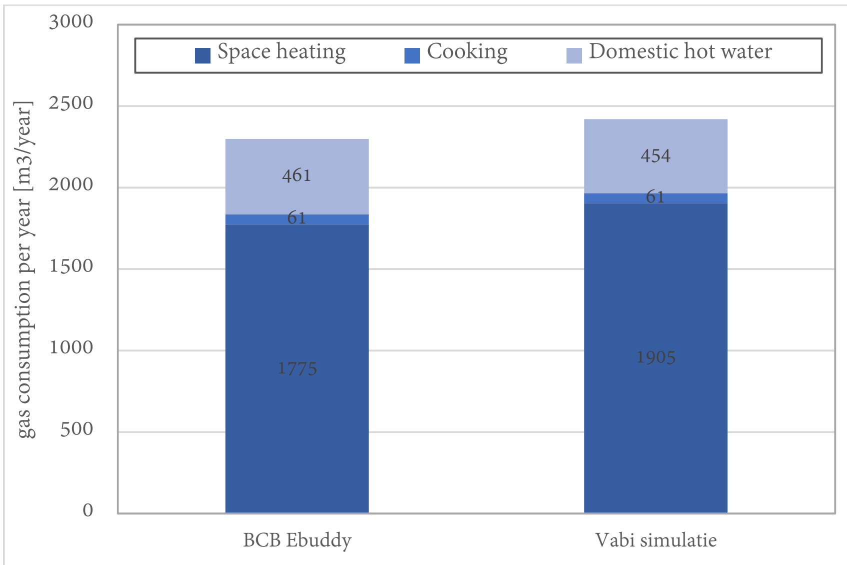


Figure 53: Comparison of the gas consumption (m3-gas/year) calculated by both the energy module of WoonConnect and Vabi elements

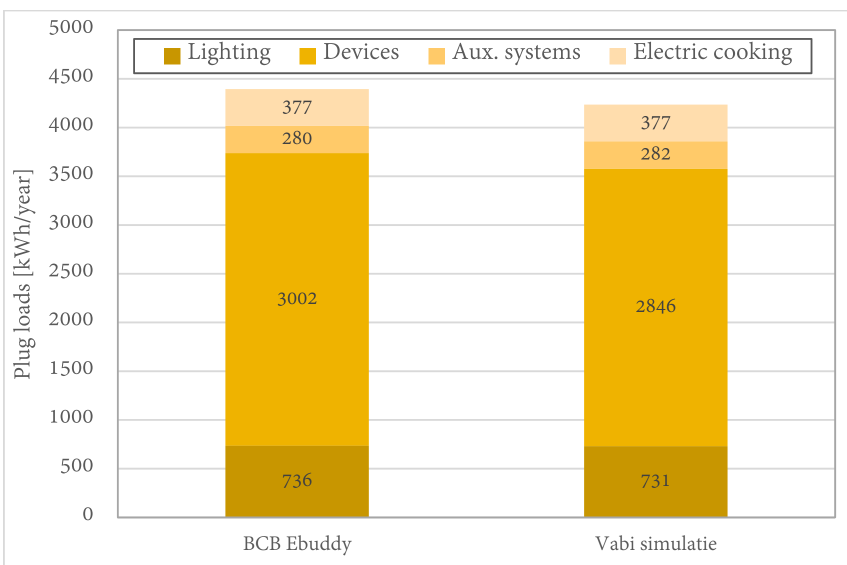


Figure 54: Comparison of the plug loads (kWh-electric/year) calculated by both the energy module of WoonConnect and Vabi elements

Overall, the differences between both models were deemed small. Found differences were likely caused by inherent differences of the software (e.g. round off error) or by the differences in simulation time step. Vabi uses a simulation time step of t = 1 hour, while *WoonConnect*'s Ebuddy calculates the systems on a monthly basis. The time step itself can have a significant influence on the simulation gas or energy consumption [86]. The influence of said models lies within the rounding off or averaging out hourly profiles (e.g. presence, internal heat gains and weather influence). Another influence factor that causes differences is the thermal mass of the building [86].

To test if the model was representative for the case study dwelling, the output of the models was benchmarked with measurement and reference data of the neighborhood. These results are shown in Figure 55 and Figure 56 below. As reference data for the gas and electric consumption of dwellings, data from Senternovem [96], data from CBS for *Uden* [97] and data from the net provider (Enexis) was compared to the output of the calculation models.

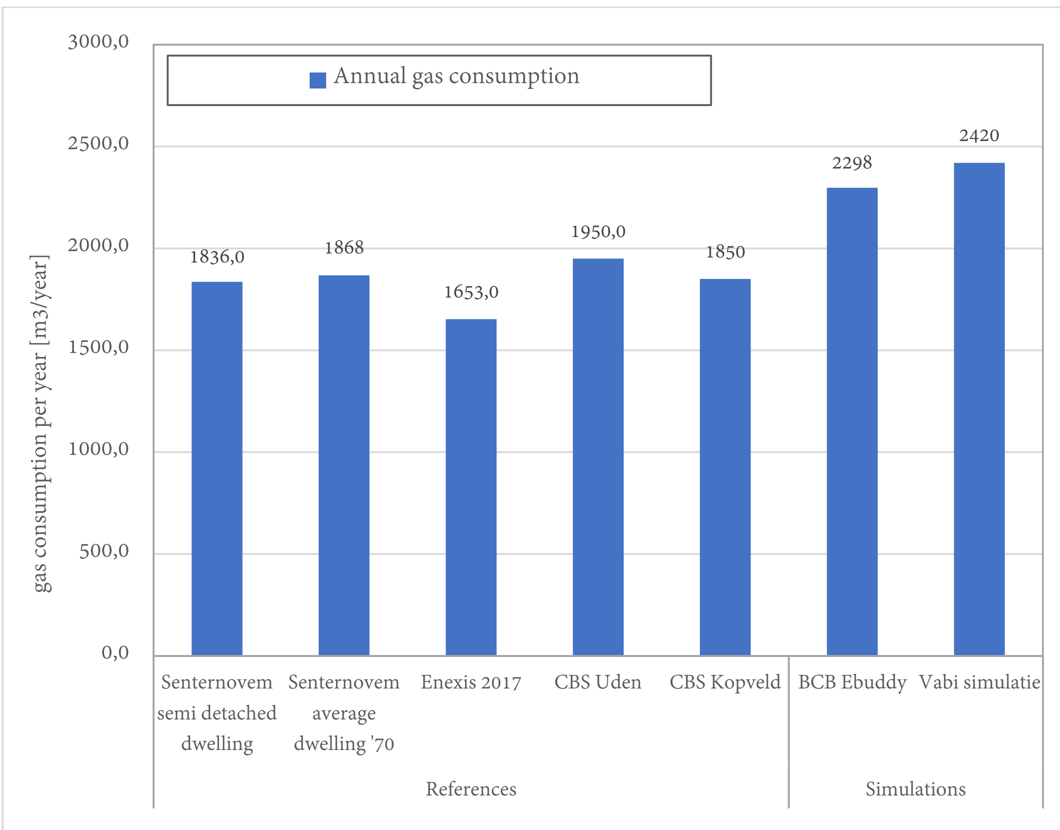


Figure 55: Comparison of the reference data and the output of the calculations models for the annual gas consumption (m3/year).

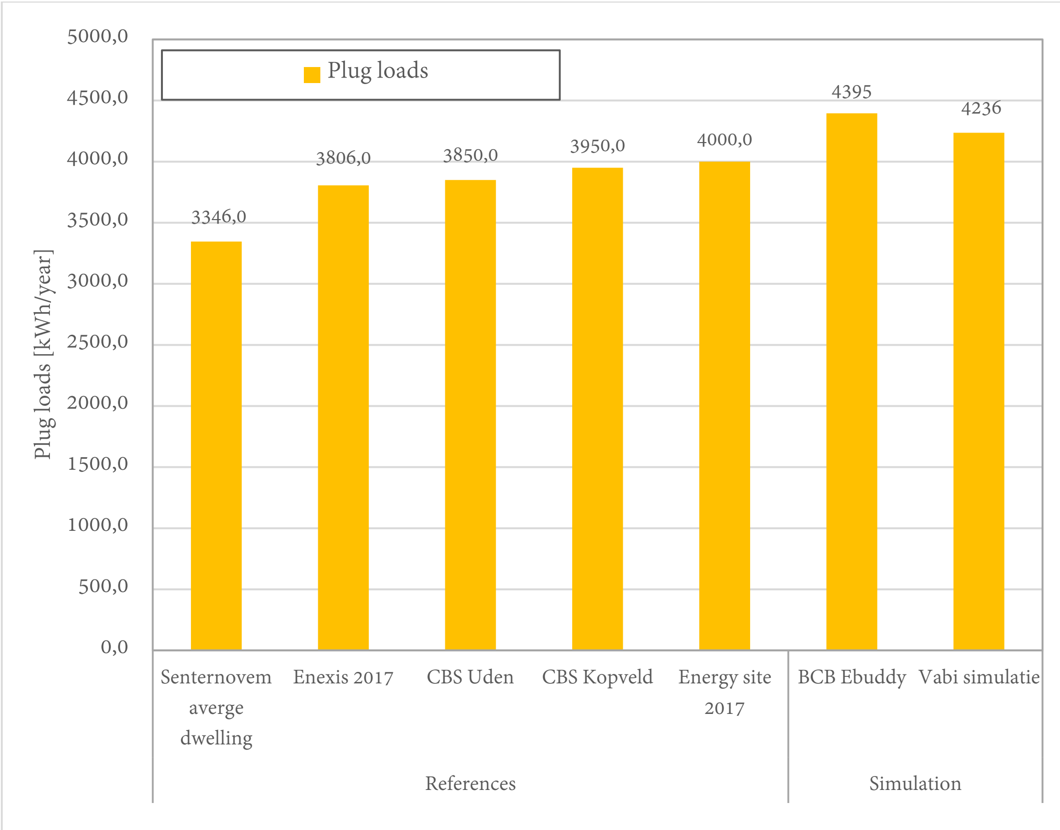


Figure 56: Comparison of the plug loads calculated by the models and the reference data.

Again some differences can be noticed between the calculation models and the reference data. Both calculation models overestimate the gas consumption and plug loads compared to the reference data on site. There are several reasons. First of all, both models calculate with the NEN 5060 [4] weather file and not with a local weather file. Furthermore, although much information was known about the project, we still had to make an assumption on the heating set point, presence, infiltration values and device usage, which have a significant effect on the energy consumption [83], [84]. However, for the testing of the thresholds said differences were considered to have little influence on the simulations as long as they were kept constant for each simulation. The resulting base model was therefore considered to be suitable for the testing of the thresholds.

Simulation of the indoor temperature for different scenarios

For simulating the thresholds, a difference can be made between the scenarios for heating and cooling. For heating and cooling, several scenarios are simulated, one for threshold described in Annex IV. For the resulting output, several criteria were analyzed for how the indoor temperature changes. Additionally, for heating the annual gas consumption and transmission losses were compared to for each threshold. For cooling, the cooling load and summer comfort were compared for each threshold as well. The results of each scenario are shown in the figures below.

Heating

For heating the different scenarios were modeled in the simulation software. For each threshold scenario, the gas consumption (Figure 57), the heat losses for space heating (Figure 58 & Figure 59 and the indoor temperature (for the living room and bedrooms) are plotted below (Figure 60 & Figure 61).

Table 13: Thresholds for the different renovation scenarios simulated.

Objects	F	E	D	C	B	A
Insulation wall	Rc = 1.69 m^2.K/W(existing situation)		Rc = 3.50 m^2.W/k			Rc = 4.50 m^2.W/k
Infiltration Qv10	2.50 dm3/s.Ag	3,36	2,28	1,56	1.2	0.84
Insulation roof	Rc = 0.22 m^2.K/W(existing situation)		3.5 m^2.W/k			Rc = 6,0 m^2.W/k
Insulation floor	Rc = 0.15 m^2.K/W(existing situation)				Rc = 3,5 m^2.W/k	Rc = 3,5 m^2.W/k
Heating system	RC/ VR-system	Hr-100 boiler		HR-107 boiler		
Heat recovery	No heat recovery					Heat recovery present
Ventilation					Mechanical exhaust present	Mechanical supply and exhaust.
Windows	Single sheeted glass U = 5.37 W/m.k	Double glass, U = 2.80 W/m.k				HR++ gas, U = 1.8 W/m.k

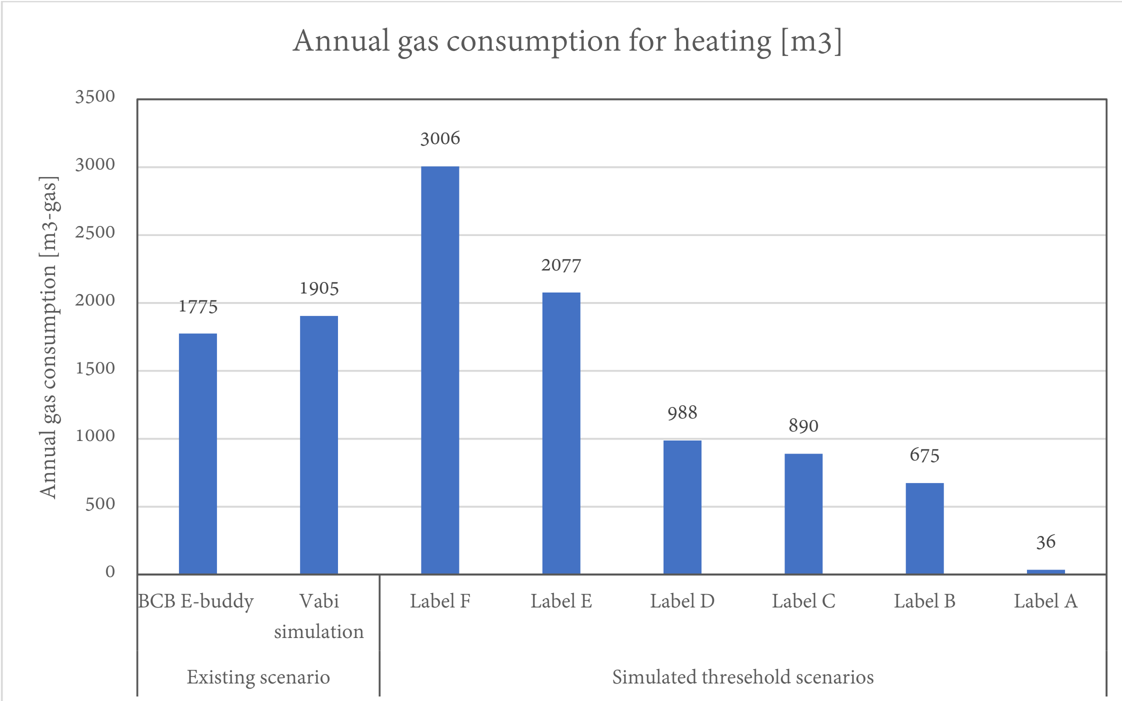


Figure 57: Gas consumption for space heating in m3-gas for each scenario. The value does not contain the gas consumption for cooking and DHW.

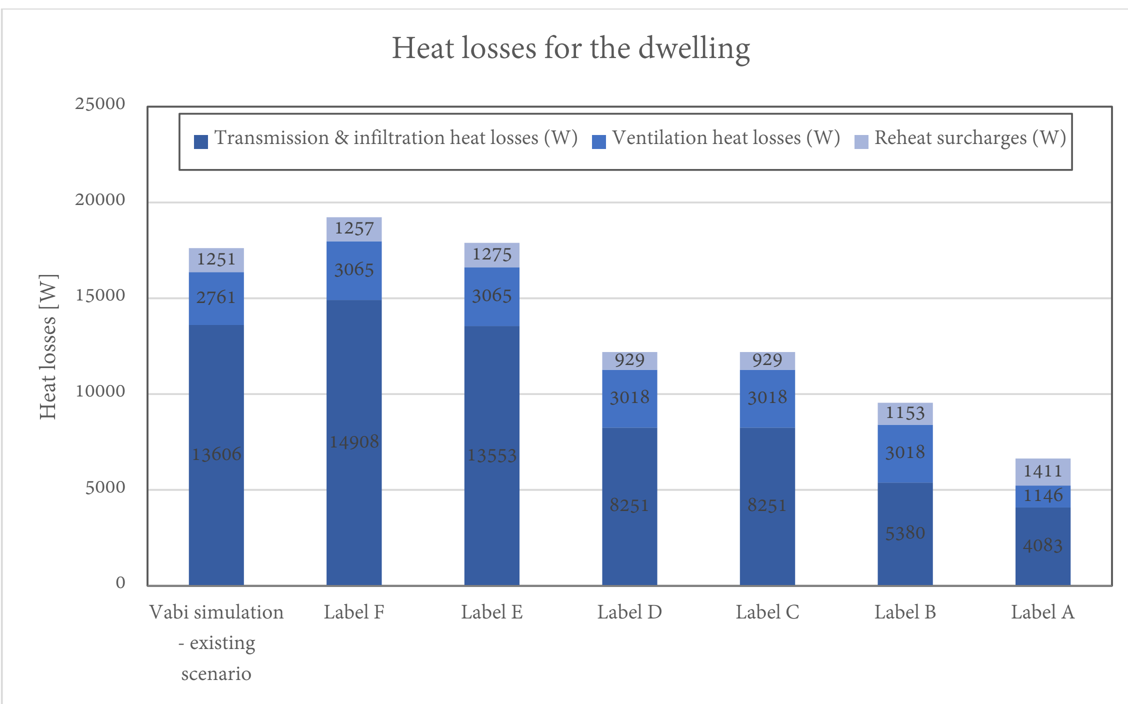


Figure 58: Heat losses calculated for the different scenarios for space heating. In scenario D and C, only the heating system was changed, which has no influence on the heat losses.

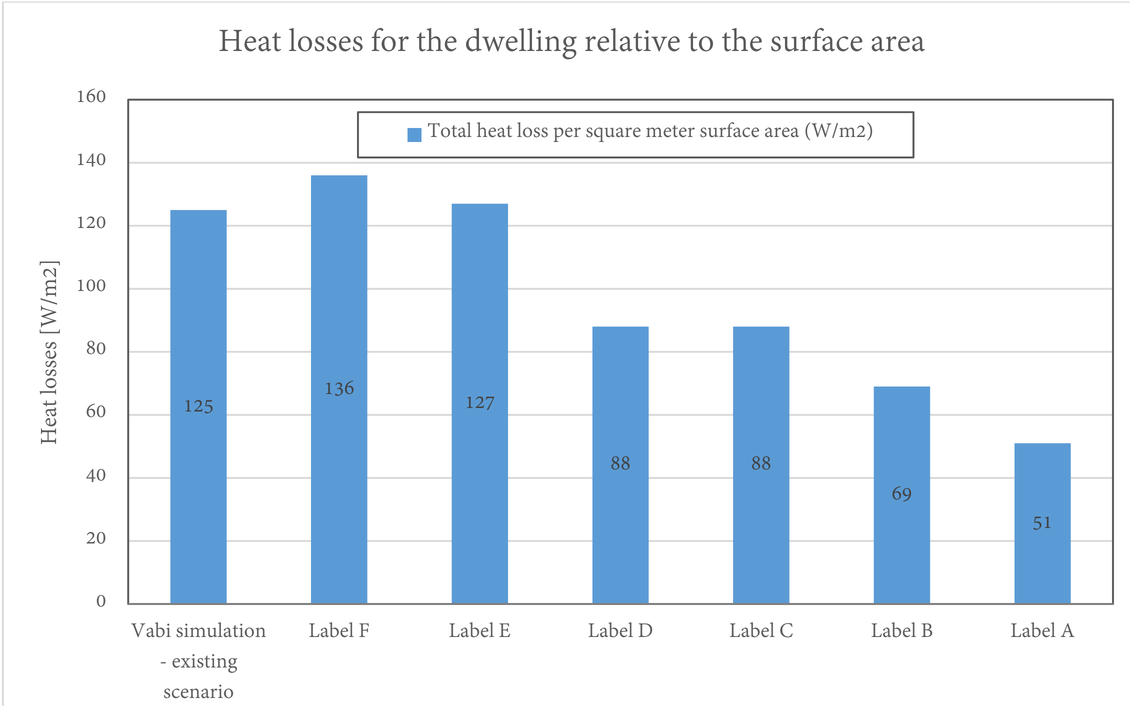


Figure 59: Heat losses for space heating of the building calculated per square meter surface area. The total surface area of the dwelling equals 140 m². In scenario D and C, only the heating system was changed, which has no influence on the heat losses.

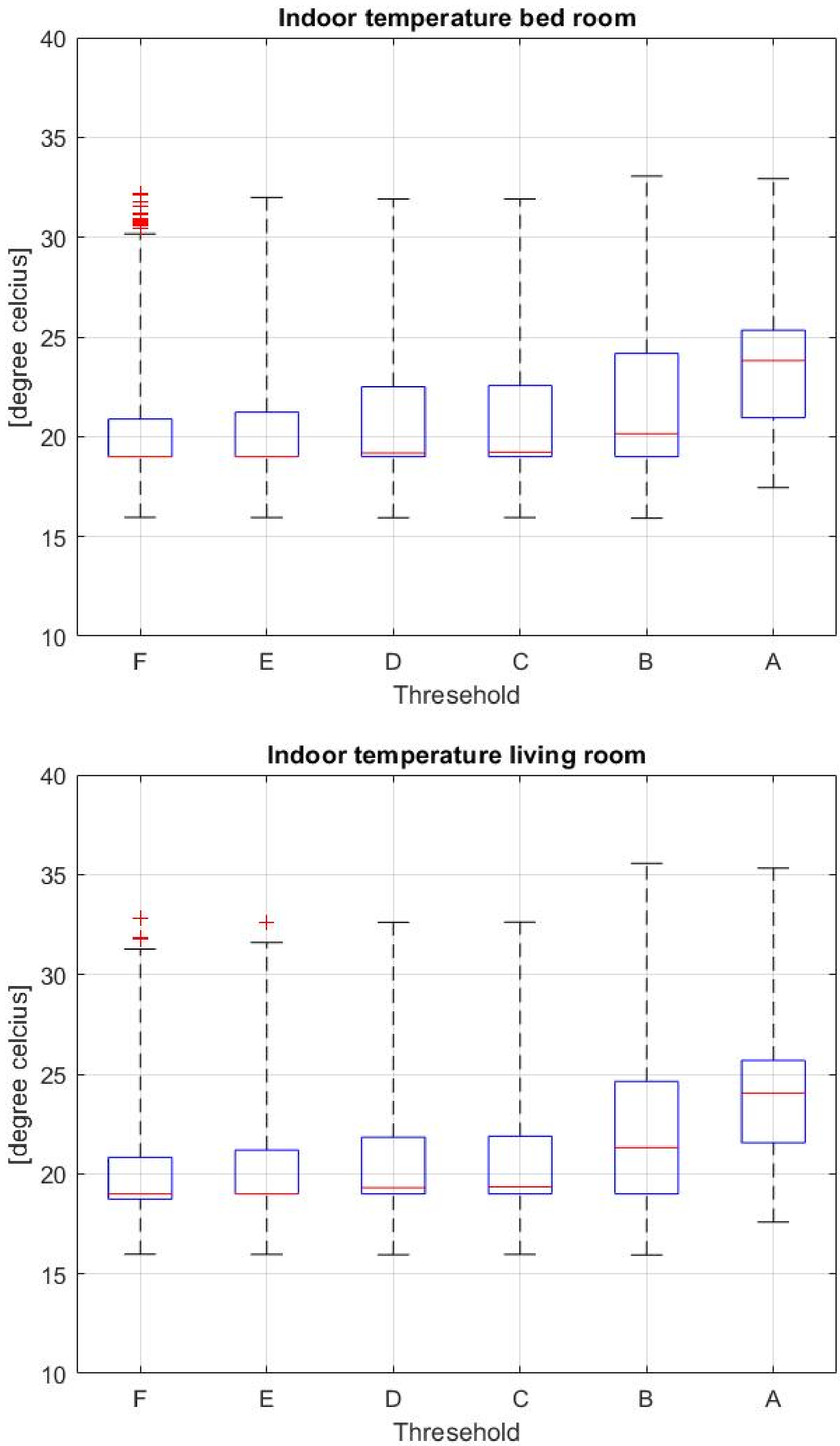
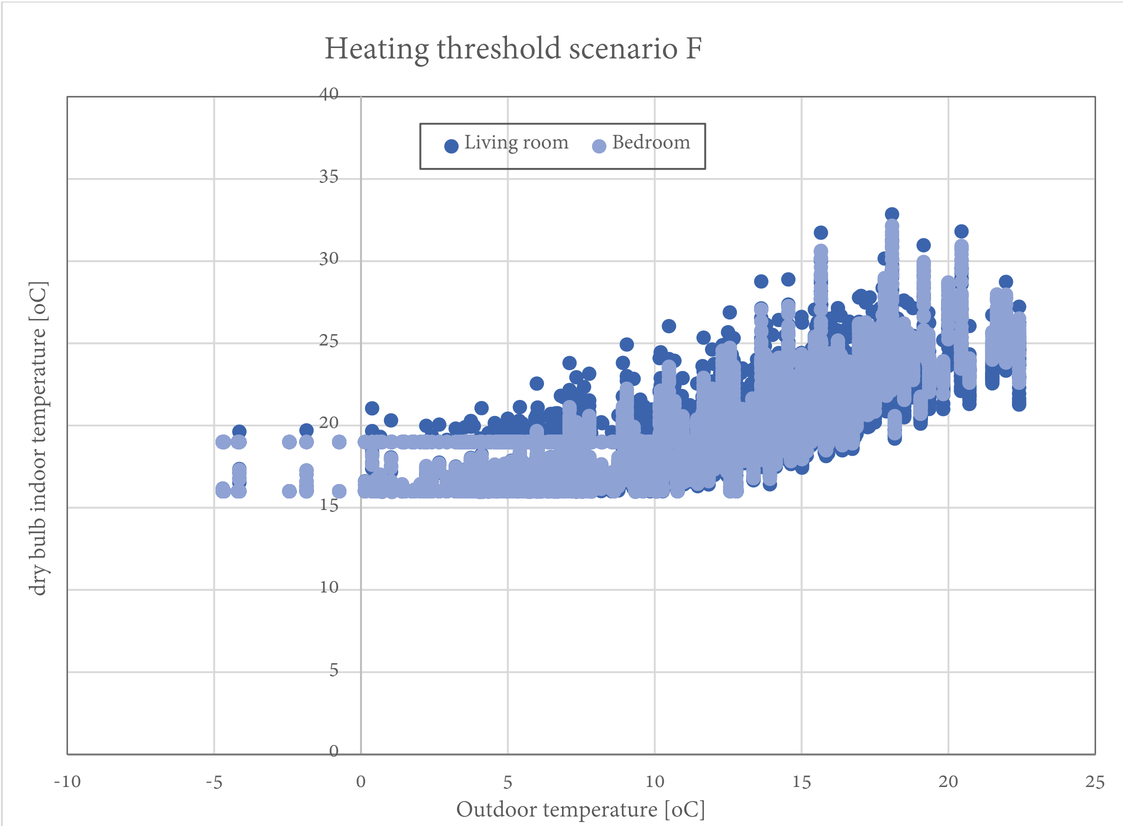
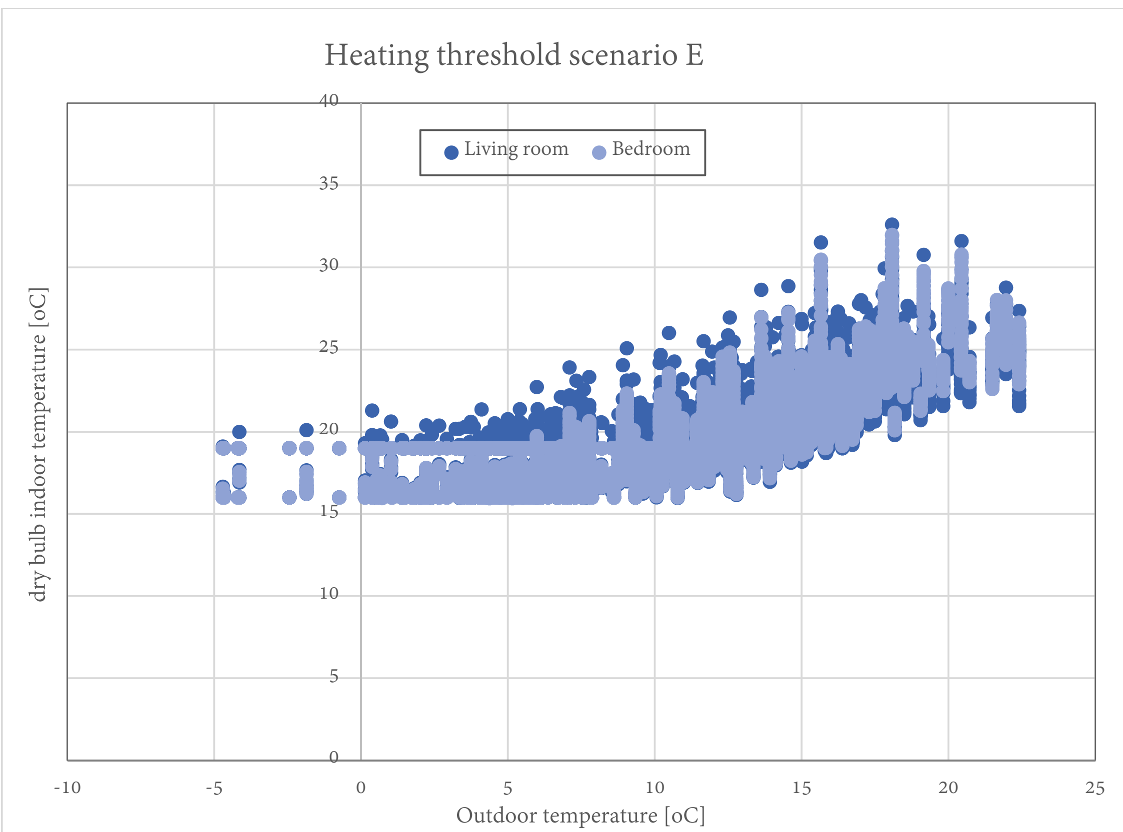
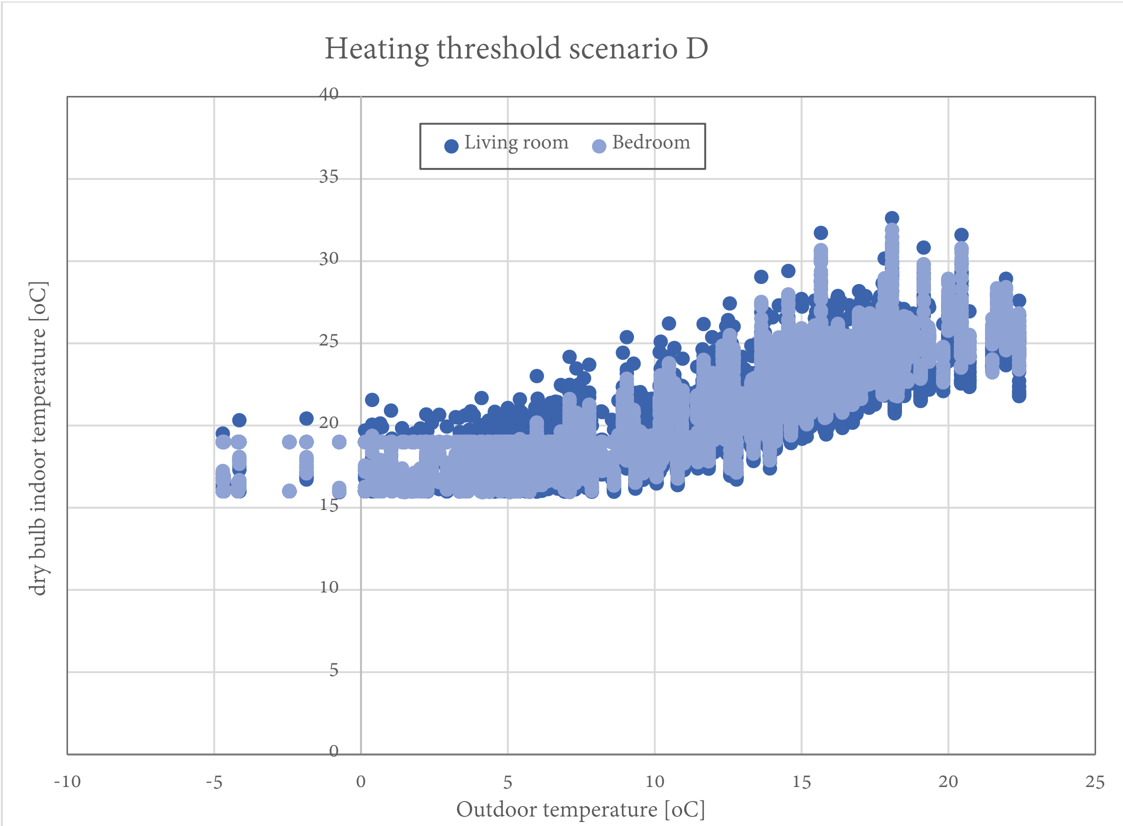
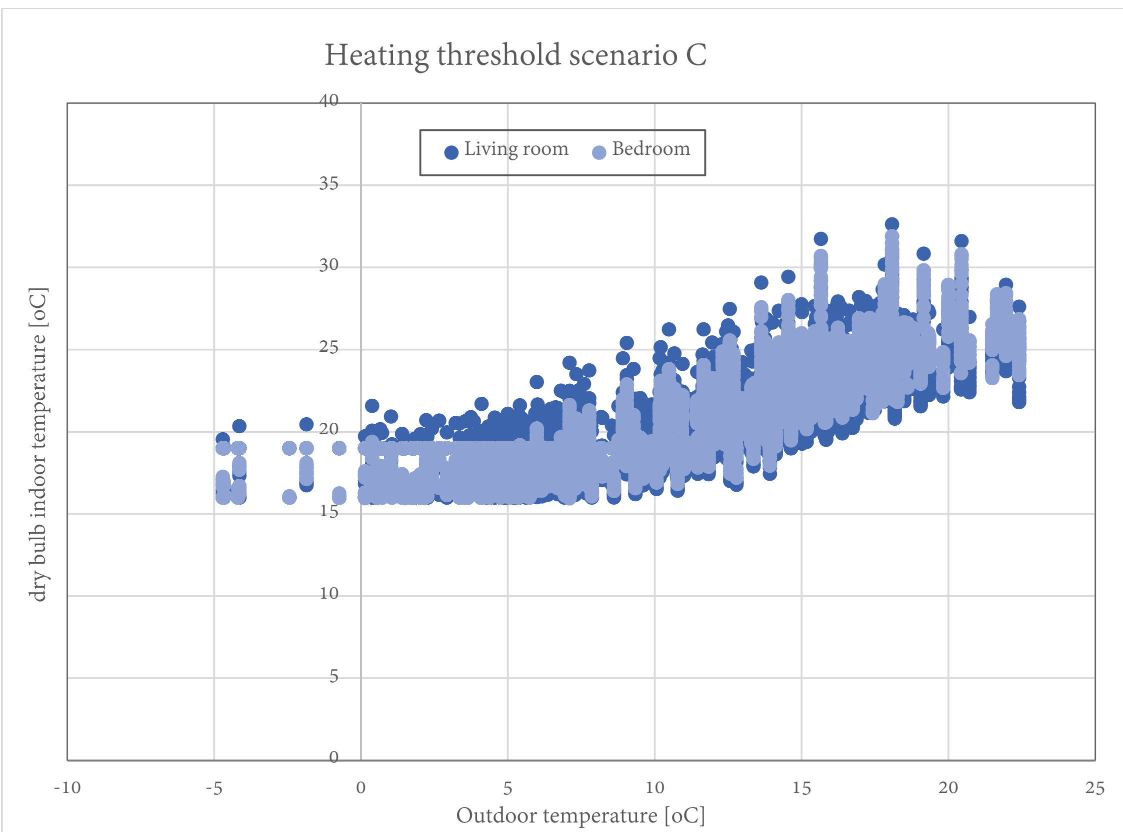


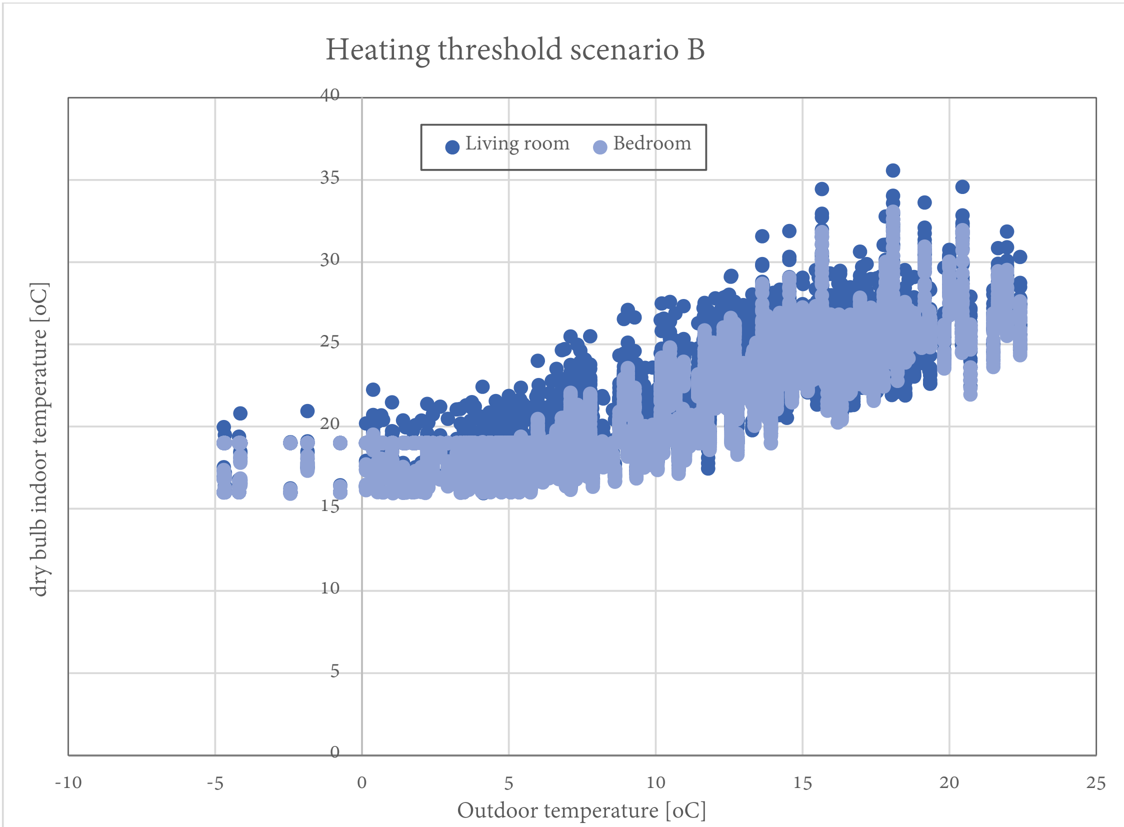
Figure 60: Simulated indoor temperature distribution for each heating threshold scenario. The upper figure displays the simulated temperature at the bedrooms, the lower figure shows the temperature at the living room.


Heating threshold scenario F
Living room
Bedroom
dry bulb indoor temperature [oC]
Outdoor temperature [oC]
0
5
10
15
20
25
30
35
40
-10
-5
0
5
10
15
20
25


Heating threshold scenario E
Living room
Bedroom
dry bulb indoor temperature [oC]
Outdoor temperature [oC]
0
5
10
15
20
25
30
35
40
-10
-5
0
5
10
15
20
25


Heating threshold scenario D
Living room
Bedroom
dry bulb indoor temperature [oC]
Outdoor temperature [oC]
40
35
30
25
20
15
10
5
0
-10
-5
0
5
10
15
20
25


Heating threshold scenario C
Living room
Bedroom
dry bulb indoor temperature [oC]
Outdoor temperature [oC]
40
35
30
25
20
15
10
5
0
-10
-5
0
5
10
15
20
25



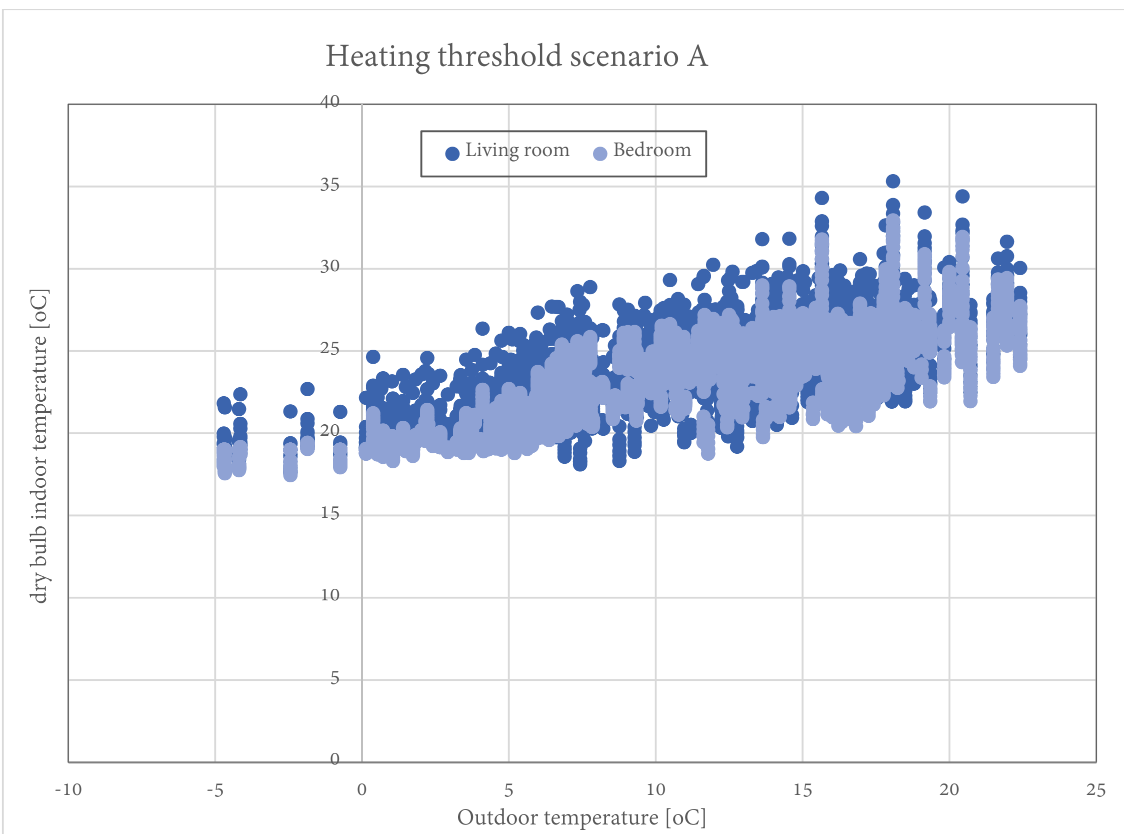


Figure 61: Indoor temperature of the living room and the bedroom simulated for each threshold in function of the outdoor temperature.

Cooling

Similar as for heating, the different cooling scenarios were modeled in the simulation software. For each threshold scenario, the cooling load (Figure 62) and the indoor temperature (for the living room and bedrooms) are plotted below in Figure 64 and Figure 65. Also the variable "*zomercomfort (Mj)*" or summer comfort was plotted at each threshold scenario in Figure 63. "*zomercomfort*" is a variable used by the Dutch EPC method [4] to indicate how much energy would be required to cool the building when a mechanical cooling system is not present. For reducing problems with overheating, it is preferred to keep the value low.

Table 14: Thresholds for the different renovation scenarios for cooling.

Objects	F	E	D	C	B	A
Windows	Single sheeted glass U = 5.37 W/m.k	Double glass, U = 2.80 W/m.k				
Solar shading?	No shading present		Shading present for large windows and south oriented windows			
Ventilation rate (x times building decree)	Insufficient ventilation (0.8 x decree)	Sufficient ventilation (1.0 x decree)		NTA class B (1.3 x decree)		
Ventilation capacity windows (x times building decree)	Insufficient ventilation (0.8 x decree)	Sufficient ventilation (1.0 x decree)				
Bypass system for full mechanical ventilation					Bypass unit present for night cooling. (mechanical ventilation)	
Airco system present						Central air condition present for the living room and bedrooms

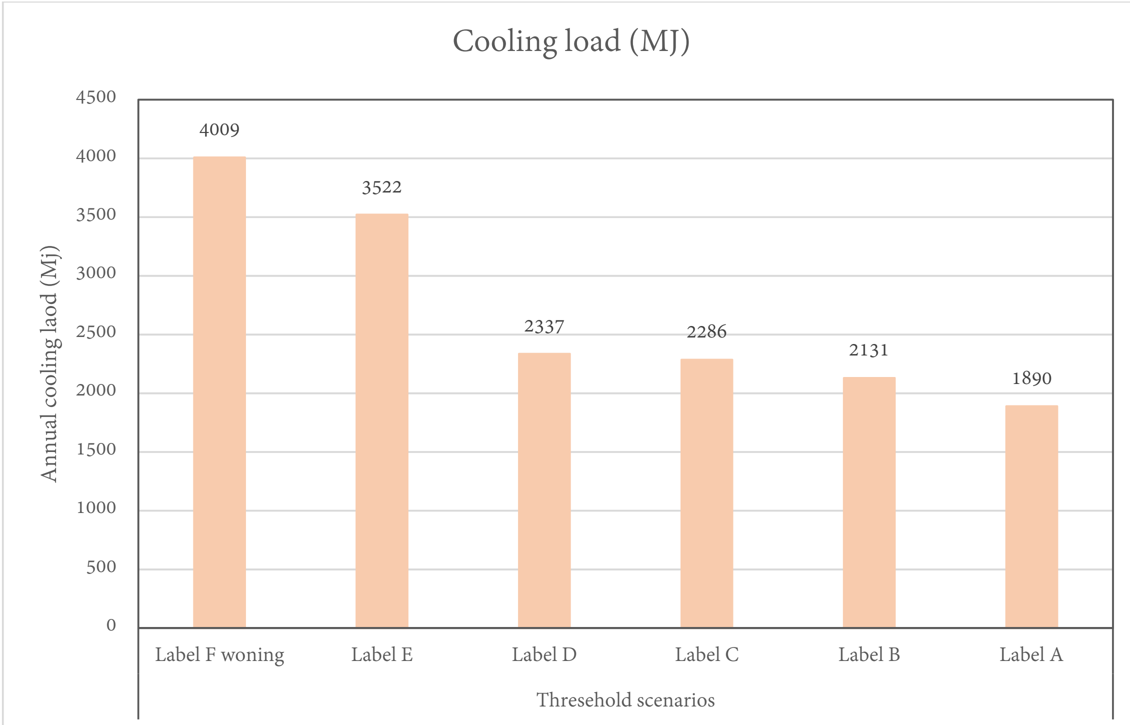


Figure 62: Annual cooling load simulated per threshold scenario.

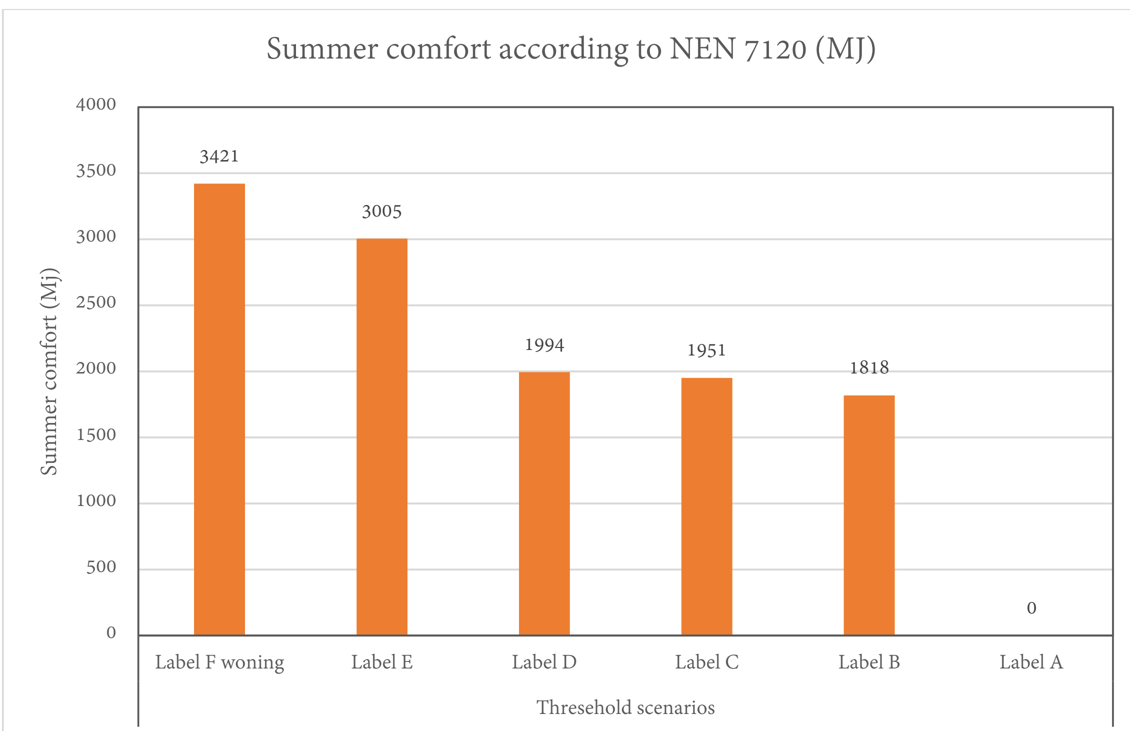


Figure 63: Annual summer comfort simulated per cooling threshold scenario. In case of Scenario A, no value is recorded as a cooling system is present.

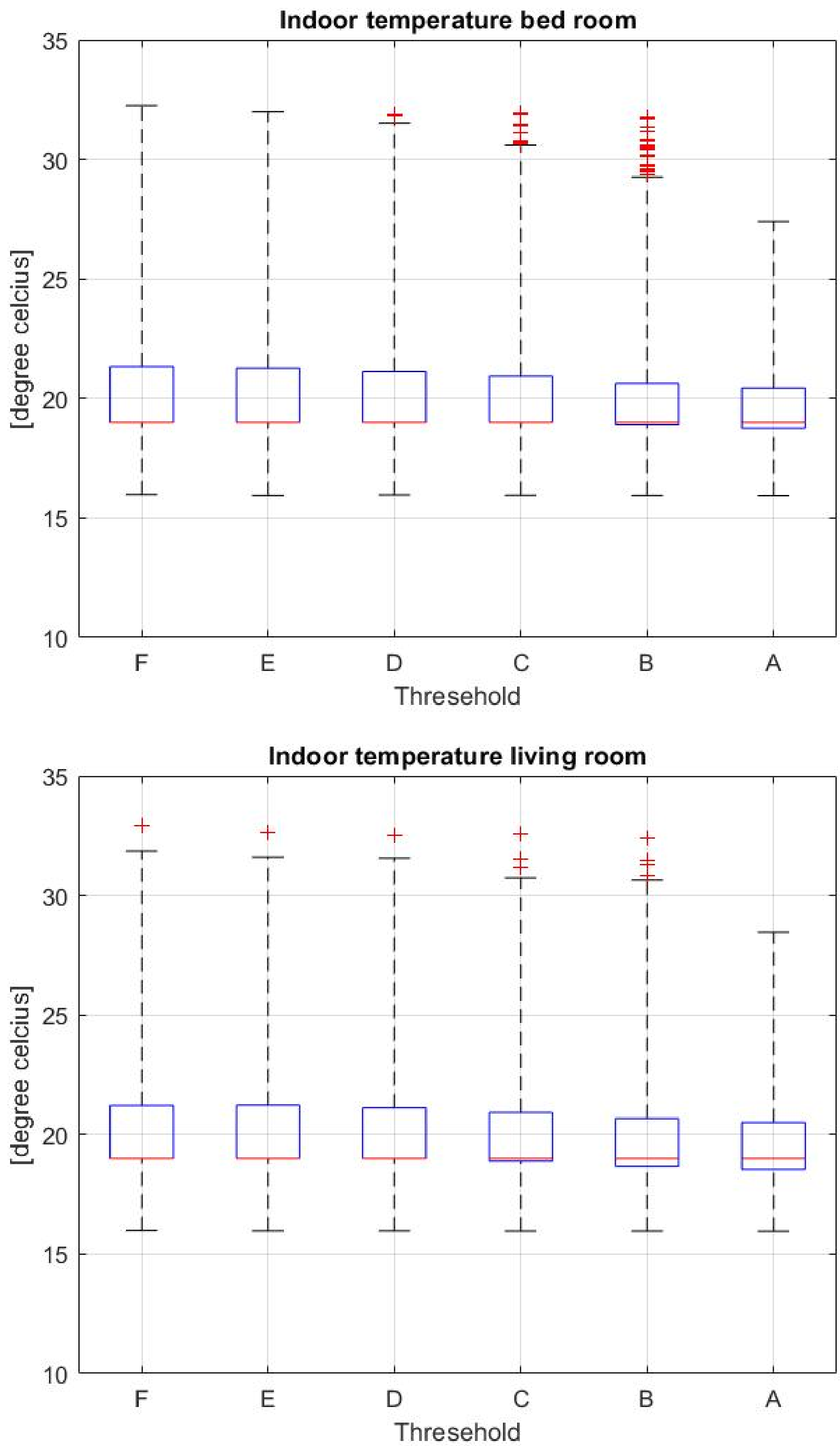
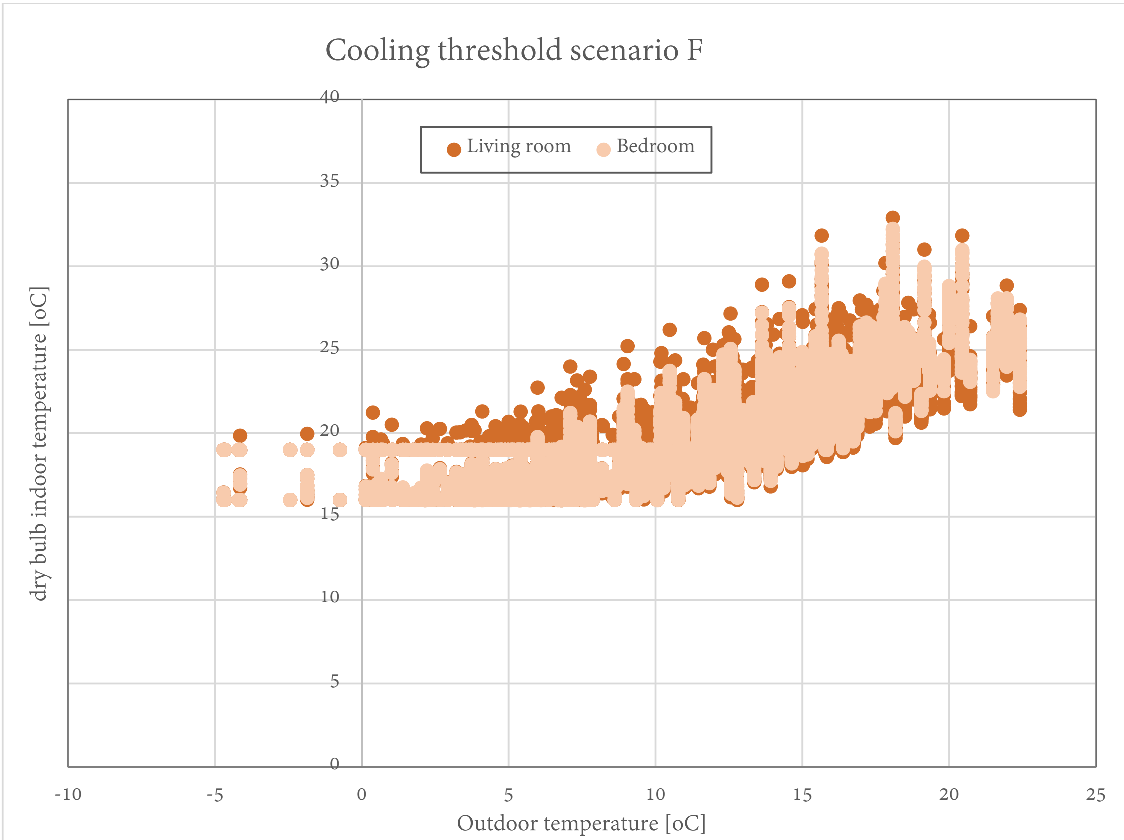
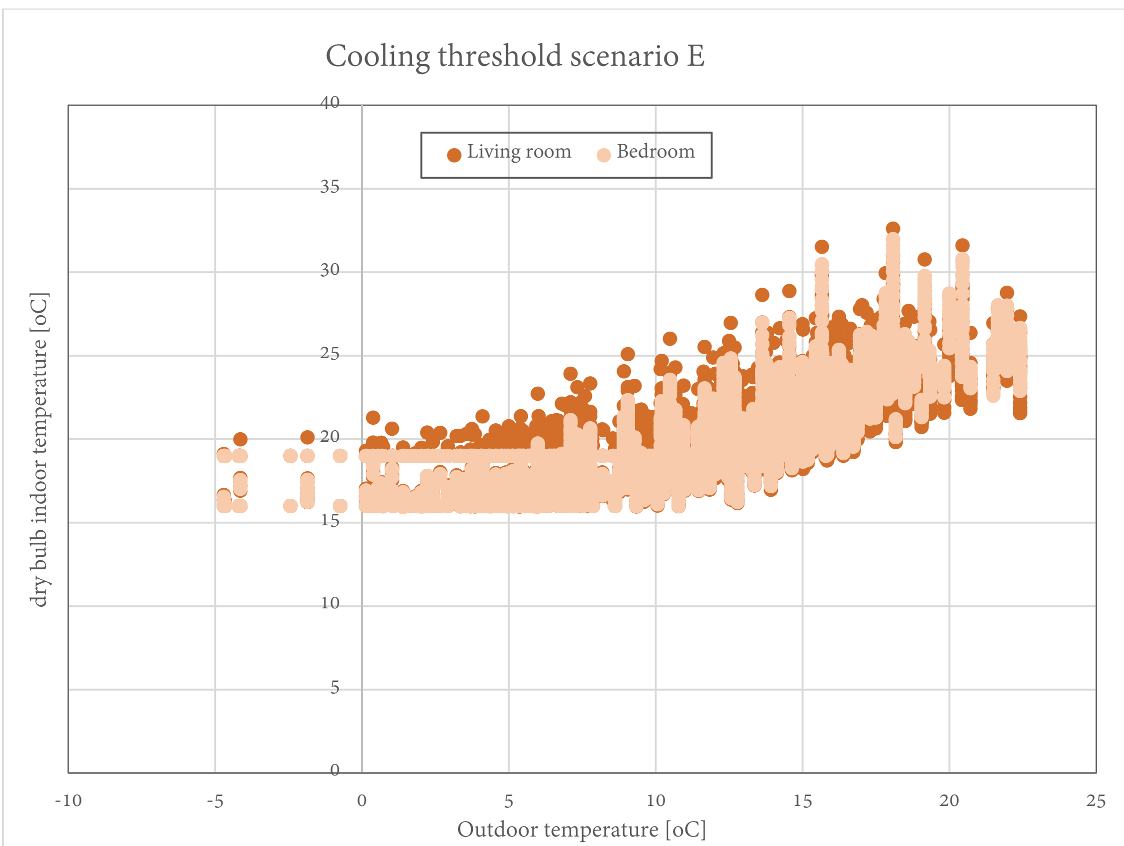
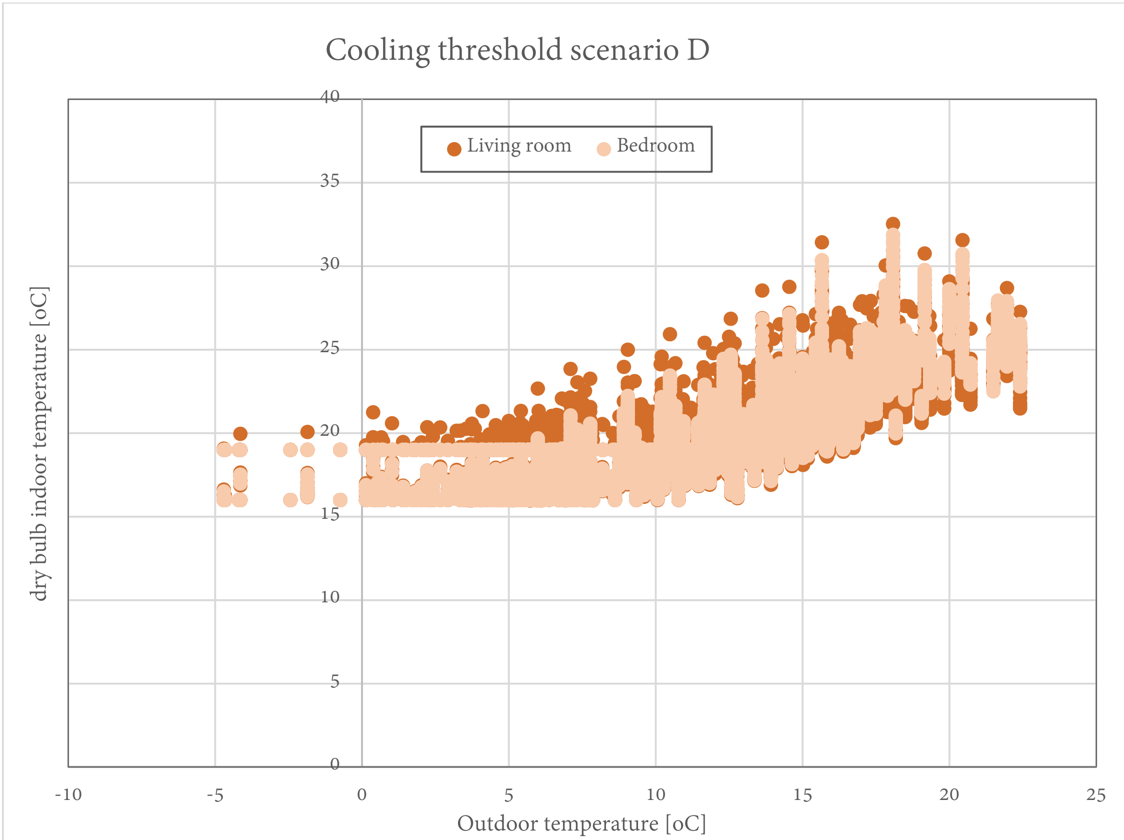
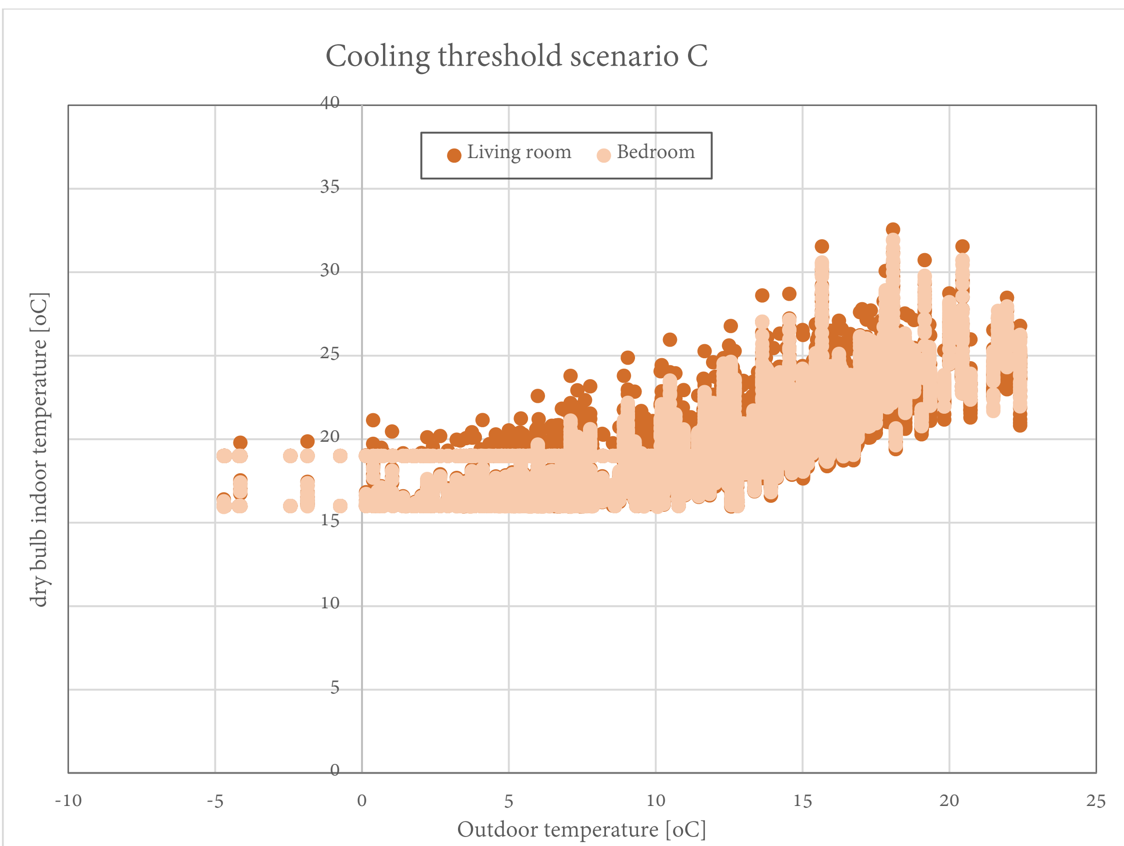


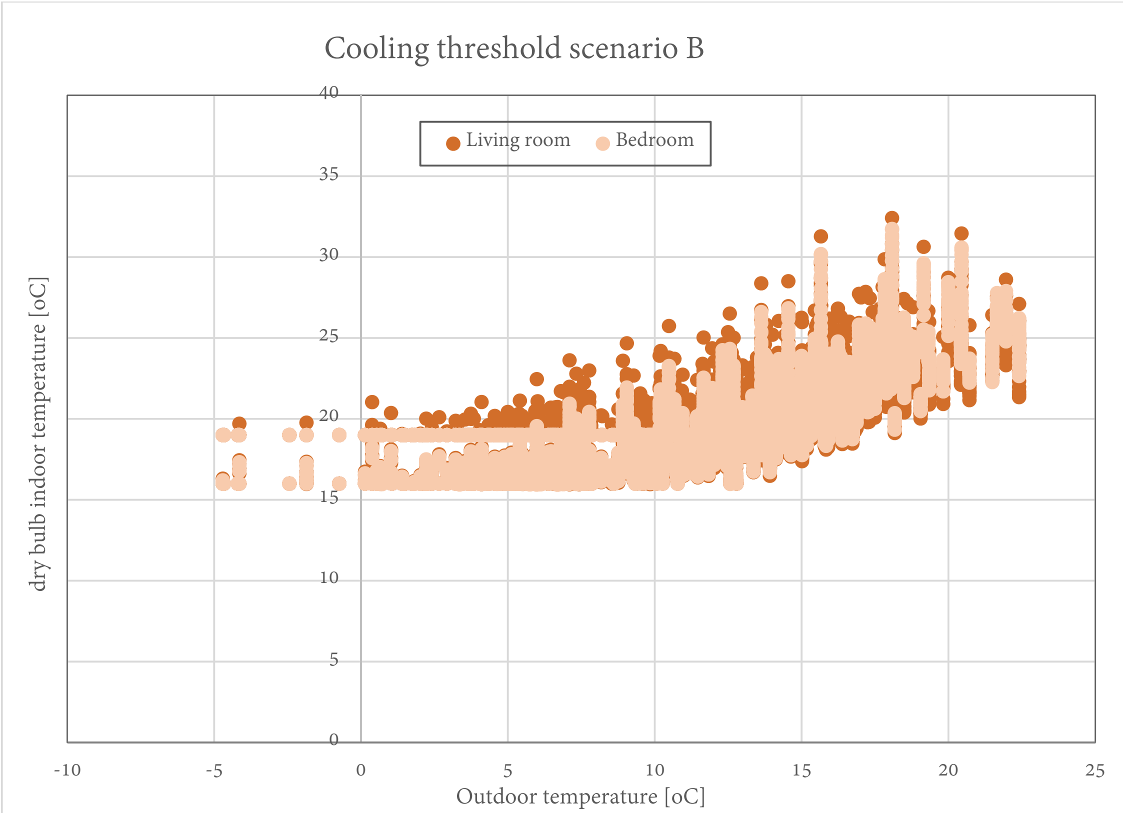
Figure 64: Simulated indoor temperature for each cooling threshold scenario.


Cooling threshold scenario F
Living room
Bedroom
dry bulb indoor temperature [oC]
Outdoor temperature [oC]
0
5
10
15
20
25
30
35
40
-10
-5
0
5
10
15
20
25


Cooling threshold scenario E
Living room
Bedroom
dry bulb indoor temperature [oC]
Outdoor temperature [oC]
0
5
10
15
20
25
30
35
40
-10
-5
0
5
10
15
20
25


Cooling threshold scenario D
Living room
Bedroom
40
35
30
25
20
15
10
5
0
-10
-5
0
5
10
15
20
25
dry bulb indoor temperature [oC]
Outdoor temperature [oC]


Cooling threshold scenario C
Living room
Bedroom
40
35
30
25
20
15
10
5
0
-10
-5
0
5
10
15
20
25
dry bulb indoor temperature [oC]
Outdoor temperature [oC]



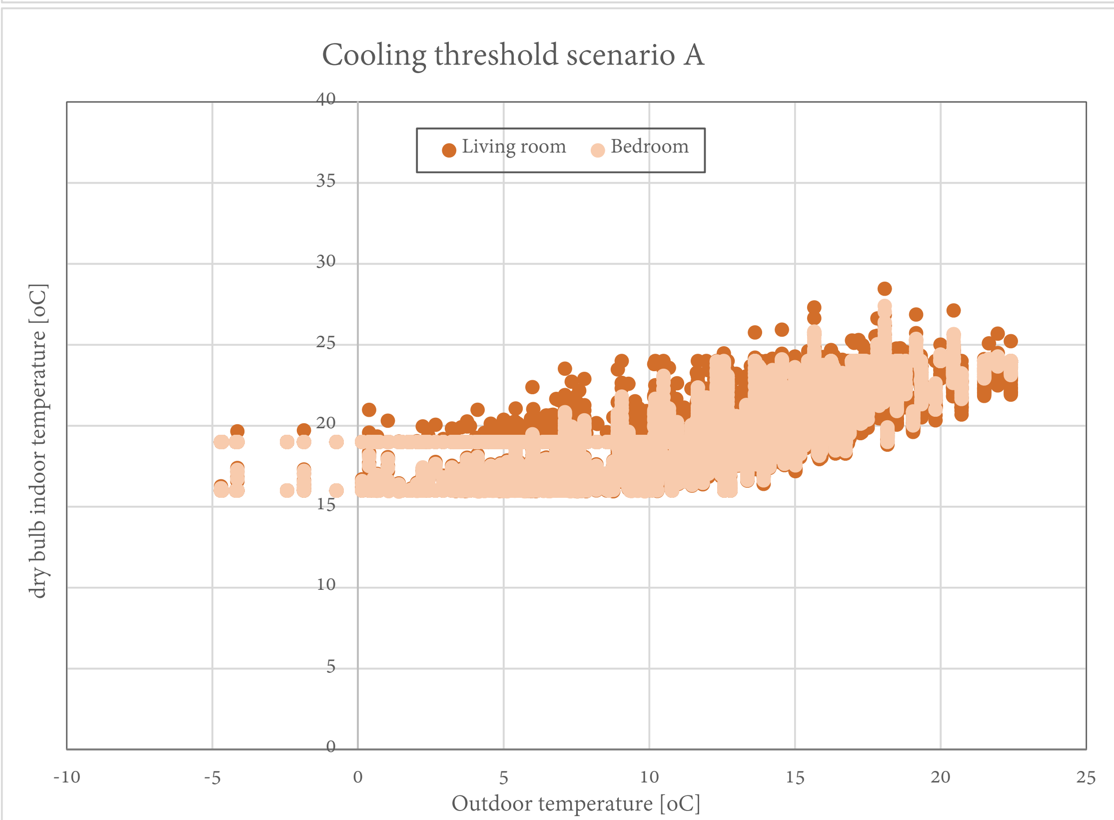


Figure 65: Indoor temperature of the living room and the bedroom simulated for each cooling threshold in function of the outdoor temperature

Annex VI – Usability test

For validating the software, a usability test was performed. The user had to answer several questions or had to perform several tasks. These questions and tasks could be solved by using a paper guide and the prototype. The answers, recreations and questions related to the software were used to form the summary. The test itself is shown in Table 15.

Table 15: Guide used for the usability test.

Step	Question/ task?	Paper/ interface?
1	Question: Name and age	Paper
2	Task: Read introduction about the case study in *Uden*.	Paper
3	Question: Would you be interested in renovating the dwelling? • Yes • No	Paper
4	Question: What would be your main reason for renovating the dwelling • Improve comfort • Reduce energy bill • Increase value of the dwelling • Perform repairs • Other (user must specify)	Paper
5	Question: What renovation options seems interesting to you? The user could select options from a list, including costs. The resulting list would be compared to the same list filled in later.	Paper
6	Task: Log in to the software	Interface
7	Task: Select the different views of the dwelling to gain a good view of how the dwelling looks like.	Interface
8	Task: Start the comfort module	Interface
9	Task: Retrieve the extra information that was given to explain the software	Interface
10	Question: Is the information given sufficient? Is anything missing? • (Open question)	Paper
11	Task: Go to the rating interface and enter the ratings for the different criteria.	Interface
12	Question: What criteria did you find the most important? • (Open question)	Paper
13	Task: Go to the standard complain interface and fill what complaints correspond to your experience of comfort.	Interface
14	Question: Are there any 'standardized' complaints missing? • (Open question)	Paper
15	Task: After filling in the complaints, generate a new "future" scenario.	Interface

16	Task: Select the advice screen and select" our advice". The resulting screen showed the renovation options that fit with the complaints and ratings of the users. The user was then again asked to fill in the options he found interesting.	interface
17	Task: If the user was satisfied with the options he selected, he was asked to download the results. (paper report)	interface
18	Question: Did you choose different then the first time (step 5)? Why? • (Open question)	Paper
19	Question: What were the main criteria that you looked at when selecting the renovation options the second time? • (Open question)	Paper
20	Question: What positive and negative feedback could you give about the interface, design for concept? • (Open question)	Paper
21	Question: Do you have any other questions about the project, interface, design or concept? • (Open question)	Paper

Annex VII – Interface design

The following appendix shows screenshots from version 1.0 of the comfort module for the test study of *Uden*. The following interfaces were also used for the usability test.

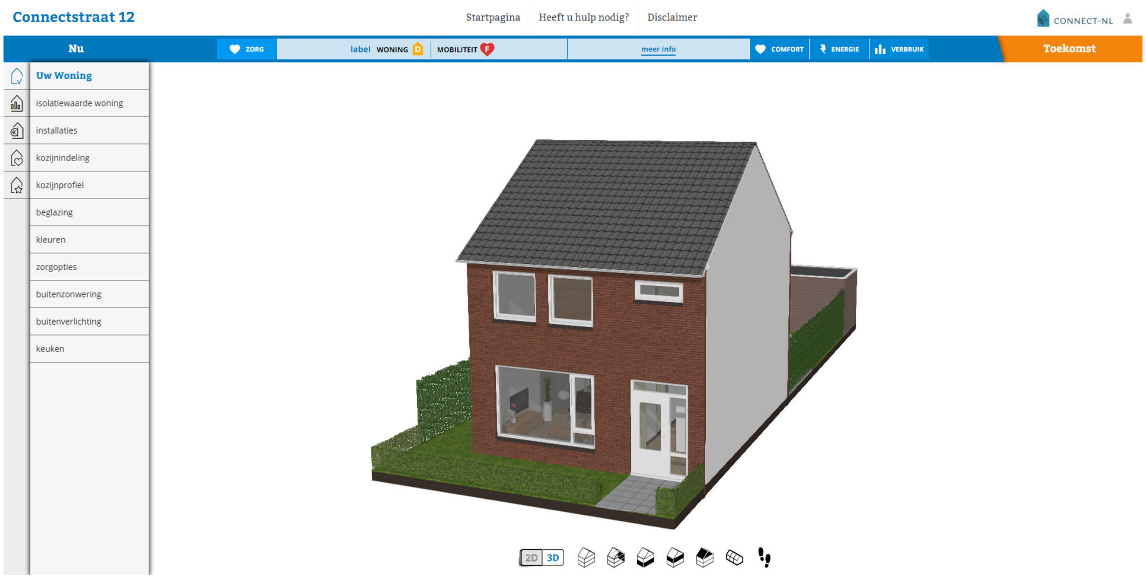


Figure 66: The (existing) interface including the integrated BIM -model. For the comfort module, additional data was added to the BIM - model. For entering the comfort module, the button comfort has to be selected.

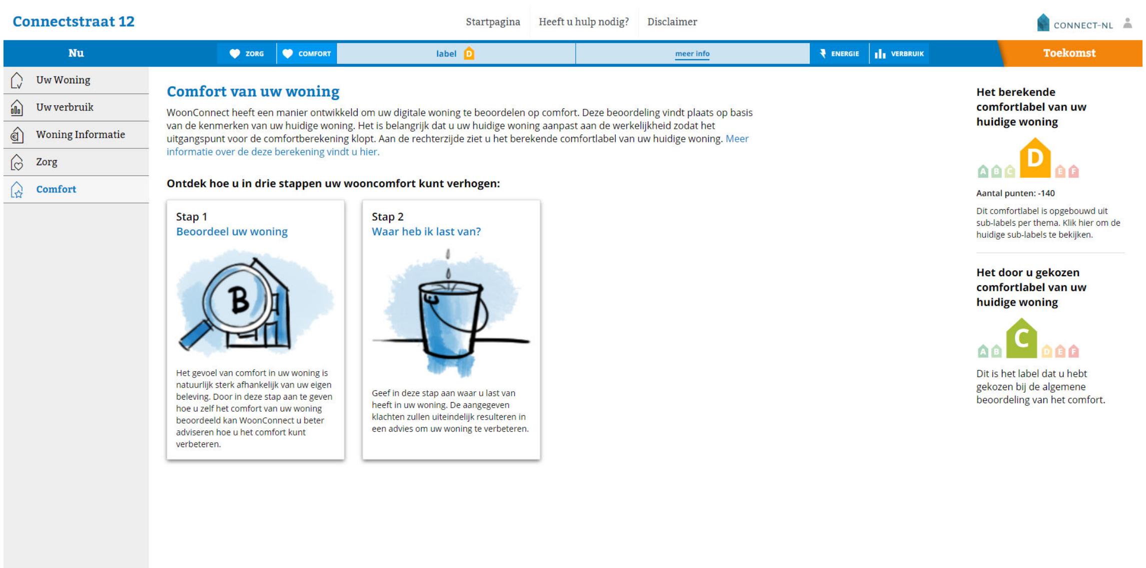


Figure 67: The start screen for the comfort module. The structural assessment is shown as a label D (right upper case). The lower label (C) displays the rating given to the dwelling by the occupant. The occupant can access the rating screen and the complaint screen through "Stap 1" and "Stap 2".

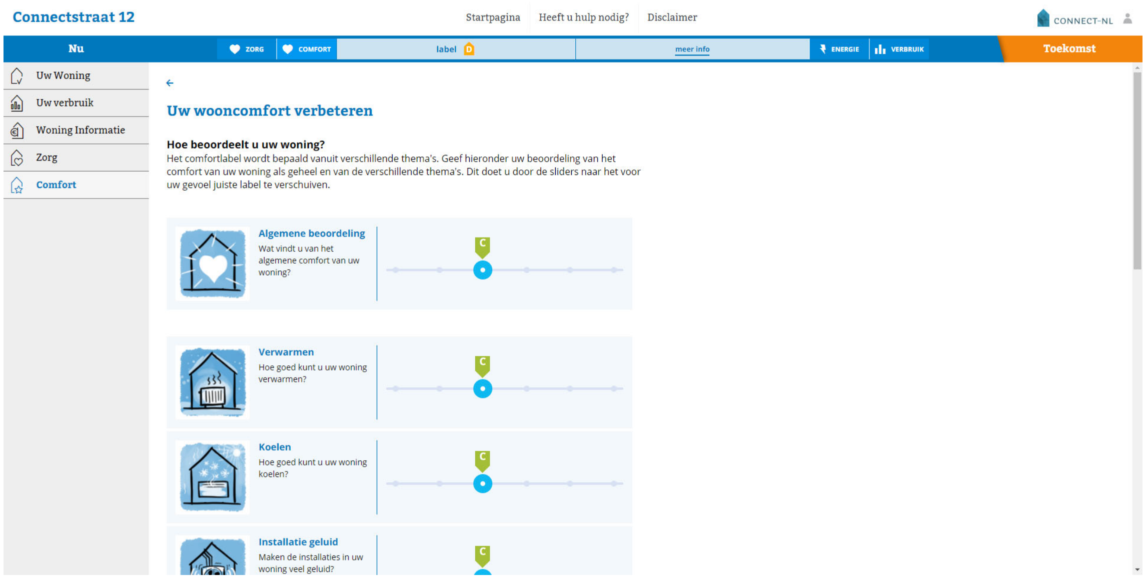


Figure 68: Input screen where people can rate how satified they are for the various comfort criteria n, ranging from F (very bad) till A (very good).

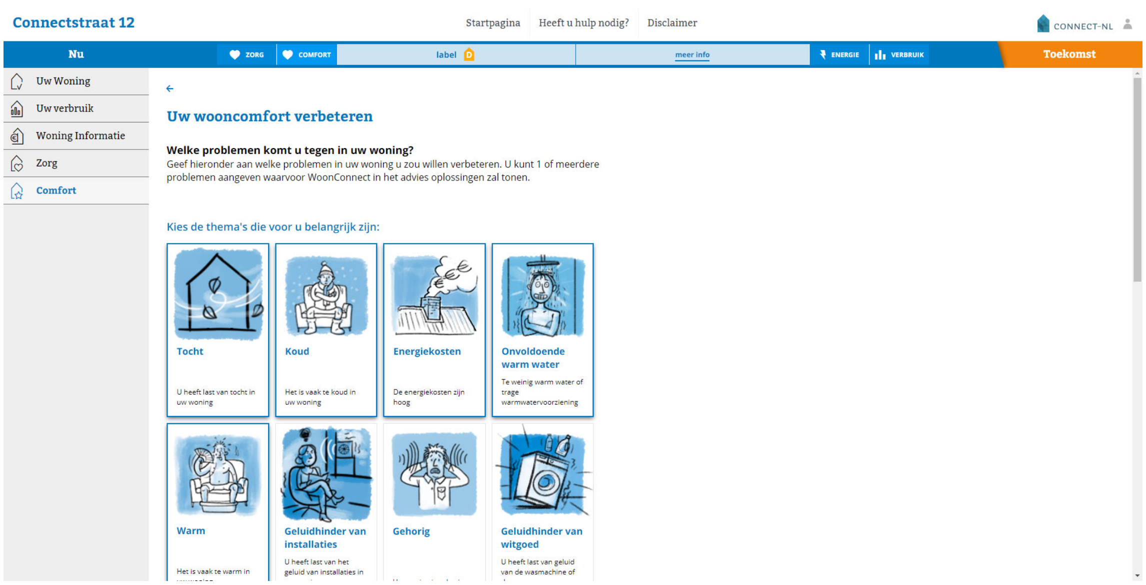


Figure 69: Interface were the user can select standardized complaints.

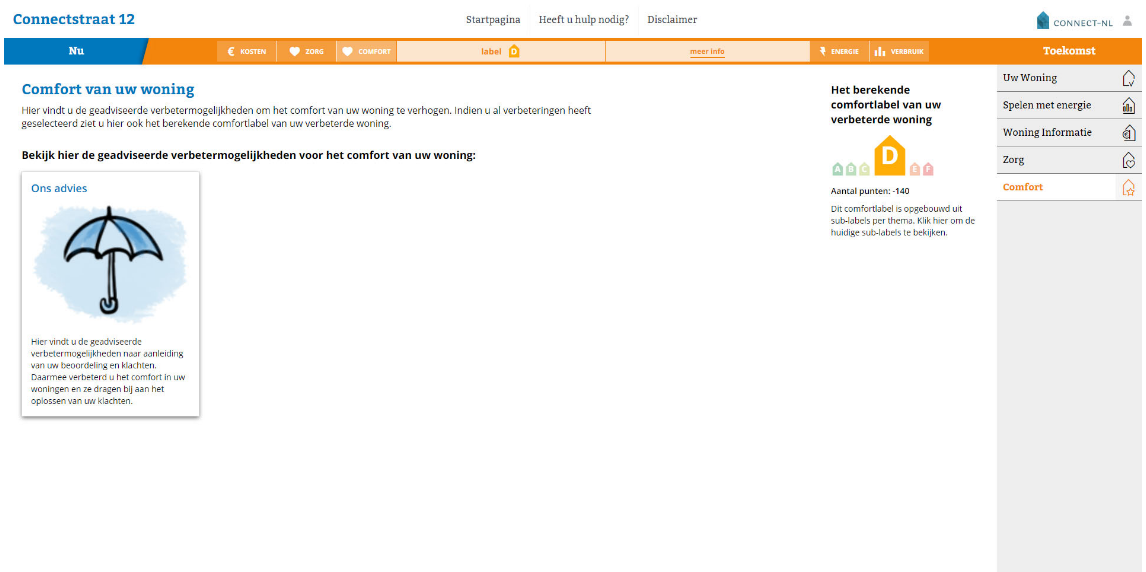


Figure 70: Interface where the user can select to receive extra advice on how to improve their dwelling.

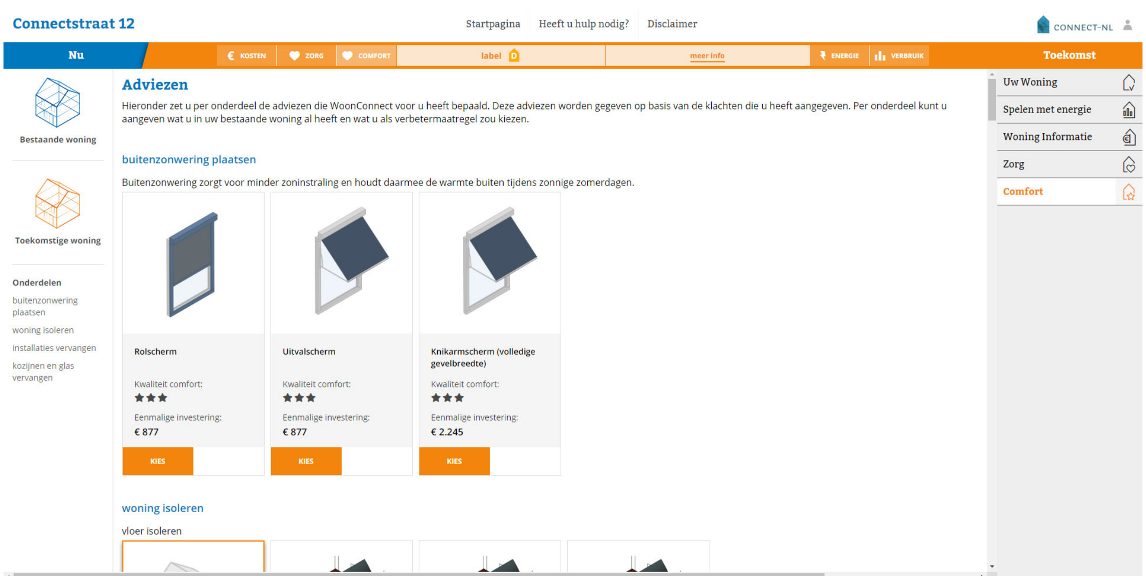


Figure 71: Interface where the user can select renovation options to improve his building. The options displays are triggered based on the complaints and the ratings the occupant filled in. The options are sorted per complaint.