Comfort & Renovatie:

de studie naar een comfortlabel als pull factor voor duurzaam renoveren

Publicatiedatum: 6 februari 2019

TU/e DE TWEE SNOEKEN

Inhoudsopgave

1 Algemeen

1.1 Gegevens project

- Projectnummer: TESN118004
- Projecttitel: Comfort & Renovatie
- Penvoerder: De Twee Snoeken Holding b.v.
  Medeaanvrager: Technische Universiteit Eindhoven.
- Projectperiode: 1 mei t/m 31 december 2018
- Contactpersoon voor meer informatie: Henk van Evert, henk.van.evert@tweesnoeken.nl
- Dit rapport is in digitale vorm gratis op te vragen bij bovenvermelde contactpersoon.

1.2 Uitvoering van het project

- Er hebben zich geen technische of organisatorische problemen tijdens het project voorgedaan.
- Er zijn geen wijzigingen ontstaan tijdens de uitvoering ten opzichte van het projectplan.
- Er zijn geen verschillen tussen de begroting en de werkelijk gemaakte kosten.
- Voor kennisverspreiding is dit rapport openbaar toegankelijk en gratis digitaal te verkrijgen bij bovenvermelde contactpersoon..
- Dit onderzoek en het resultaat zal in bijeenkomsten over dit onderwerp vermeld worden.

1.3 Subsidie

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

1.4 Bijdrage van het project aan de doelstellingen van de regeling

De projectactiviteiten en de uiteindelijke resultaten van de ontwikkelingen vallen binnen de doelstellingen zoals is omschreven in de Topsector Energiestudies. Het past daarbij specifiek bij de volgende programma's:

Programma 4: Urban Energy

Dit programma richt zich specifiek op de invulling van duurzame energie en de invloed op de gebouwde omgeving. Concreet wordt het volgende beschreven: "Energieverbruik en de invulling van die vraag met veelal lokaal opgewekt duurzame energie zijn van invloed op het uiteindelijke beeld van de gebouwde, op techniek en infrastructuur en ook op gedrag en vice versa". De doelstelling van het project sluit naadloos aan bij de doelstellingen van deze programmalijn, namelijk de transitie naar gasloze wijken. Daarbij sluit het project concreet aan bij de volgende programmalijnen:

Programmalijn 4.2: Warmte- en koude installaties

Het systeem moet bewoners stimuleren en enthousiasmeren om te verduurzamen. Hiermee kunnen de nodige voorbereidingen getroffen worden tijdens alomvattende renovaties van wijken. Comfort op het gebied van warmte is daarbij een belangrijk uitgangspunt. Daarbij moet dan ook concreet blijken of warmtepompen, zonnecollectoren, koudeopslag, etc. een bijdrage leveren aan het comfort. Daarbij moet eveneens doorgerekend worden wat de energiefoodprint gaat zijn en wat de kosten hiervan zijn.

Programmalijn 4.3: Integratie in de bouw

De tool wordt uiteindelijk aangeboden aan alle stakeholders, hieronder zitten eveneens aannemers en woningcorporaties die het comfort en de duurzaamheidswensen zo goed mogelijk kunnen vertalen en integreren in de woningen. Uiteindelijk levert het hiermee een bijdrage om kostprijsverlaging, efficiënt ruimtegebruik, aantrekkelijkheid verhogen, snelheid en gemak, esthetica, rendementsverhoging en prestatiegaranties te integreren.

Programmalijn 4.4: Flexibele energie-infrastructuur

De tool moet worden ingezet voor onder andere monitoring & control van de behoefte van de stakeholders. Daarbij levert het een bijdrage aan de volgende ambities: inzicht in en optimalisering van kosten en baten, inzicht in de conditie, flexibele componenten, beheersbare verstoringen en investeringen voor een duurzame energievoorziening, betaalbare betrouwbare producten en methoden voor snelle duurzame warmtetransitie in bestaande bouw.

2 Aanleiding en doelstelling van de studie

2.1 Aanleiding

De Nederlandse overheid zet in op een transitie naar aardgasloze wijken. Vanuit deze gedachte worden er eveneens een groot aantal aanvullende maatregelen genomen. Om dergelijke gasloze voorzieningen aan te bieden is het van belang dat alle woningen binnen een kort tijdsbestek aardgasloos ready worden gemaakt.

Deze transitie kan daarbij gekoppeld worden aan renovatieprojecten. De Twee Snoeken werkt al enkele jaren aan de ontwikkeling van Woonconnect; een tool die gebruikt maakt van onder andere bouwinformatie model software (bim-software) en digitale berekeningsmethodes (bijvoorbeeld NEN 7120). Deze webtool kan worden gebruikt door corporaties, architecten, gemeentes en bewoners.

Voor de bewoners van de wijken betreft een dergelijke transitie veelal een grote impact. In de praktijk blijkt bewoners eerder genegen zijn om duurzame renovaties door te voeren, als het leidt tot comfortverhogingen en kosten (reducties). Op dit moment is het echter nog niet inzichtelijk in hoeverre de energiebesparingen leiden tot kostenreductie en wat het effect is van de verduurzaming op het comfortniveau van de bewoners.

2.2 Doelstelling

De doelstelling van de studie is om te bepalen of het mogelijk is om de kostenreductie en de verhoging van comfort door te rekenen, binnen de bestaande criteria. Daarbij moet er eveneens worden onderzocht wat de richtlijnen zijn van comfort en hoe dit te definiëren is. Uiteindelijk wil men het hiermee mogelijk maken om renovaties uit te kunnen drukken in termen die de bewoners en woningcorporaties aanspreken, en ook toegankelijk zijn voor technici. Hiermee zullen renovaties sneller van de grond komen, omdat het belang voor de gebruikers beter inzichtelijk wordt gemaakt, op basis van een tool die voor alle gebruikers toegankelijk is en eenduidig communiceert. Bewoners krijgen inzicht in de comfortverhoging van hun woning, terwijl andere stakeholders zicht hebben op het energieverbruik en de gasloos readyness van de woning en de wijk. De effecten op energiebesparing zullen in een label doorgerekend worden en zijn het gevolg van de voorgestelde comfortverbetering. De studie moet het inzichtelijk maken of het mogelijk is om een dergelijke tool te ontwikkelen en wat voor berekeningen, algoritmes, koppelingen en overige innovaties in een vervolgproject gerealiseerd moeten worden.

2.3 Samenwerkende partijen

De Twee Snoeken Holding b.v.

De Twee Snoeken ontwikkelt BIM-software waarmee woningen ontworpen en doorgerekend kunnen worden, waarbij de systemen -online- toegankelijk zijn voor architecten, aannemers, toeleveranciers en eindgebruikers en alle processen digitaal afgehandeld kunnen worden. Producten van De Twee Snoeken als Het Digitale Huis, WoonConnect en de BouwConnect Bibliotheek zijn in de wereld van de bouw (architecten en projectontwikkelaars, woningcorporaties) een standaard geworden. Binnen dit project is De Twee Snoeken dan ook verantwoordelijk voor het onderzoeken naar de haalbaarheid van de software technische aspecten (databases, algoritmes en koppelingen).

Technische Universiteit Eindhoven

De Technische Universiteit Eindhoven (TU/e) is een onderzoek gedreven en ontwerpgericht op het terrein van de Engineering Science & Technology in onderwijs, onderzoek en kennisvalorisatie. Hiermee leveren ze een grote bijdrage aan de ontwikkeling van het innovatieve karakter van Nederland. Een van de speerpunten van de TU/e is de ontwikkeling Smart Building and Cities. Uit een van de eerdere onderzoeken kwam duidelijk naar voren dat comfort één van de belangrijkste speerpunten bij bewoners is om wel of niet te verduurzamen. In dit project is de rol van de TU/e het in kaart brengen van de specificaties die de stakeholders belangrijk vinden bij duurzaam bouwen en het onderbouwen daarvan door middel van een comfort label.

3 Beschrijving van het onderzoek

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 1 shows the conceptual design of the new module. The principle of the comfort module consist of three parts: the personal assessment, the structural assessment based on the bim environment and the summary of said data within the existing project overview of *WoonConnect.*

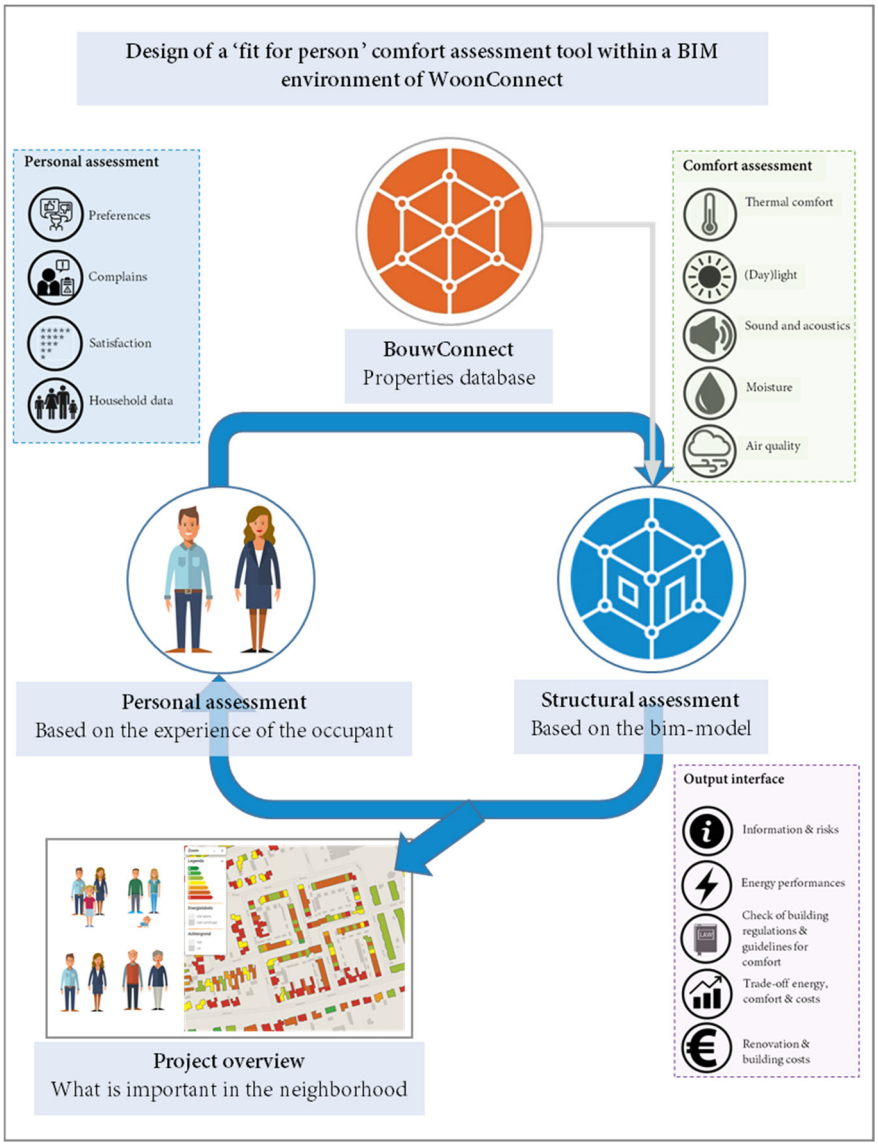

Figure 1: Conceptual design of the comfort module.

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 a better fitted solution for the occupant.

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. 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. 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.

For explaining the design, an information process model was built (Figure 2 next 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 green, blue and purple colored parts 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 an in detail description of the software. However, before explaining these sub models, chapter 3.2 and chapter 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* will assess comfort based on the structure of the existing bim model. Within the process model displayed in Figure 2 these are represented by the green actions. Next, chapter 3.5 addresses the personal assessment from the occupants. These actions are represented by the blue actions within the process model. Last, Chapter 3.6 will explain what adjustments are made to the main interface. These are represented by the purple actions of the process model.

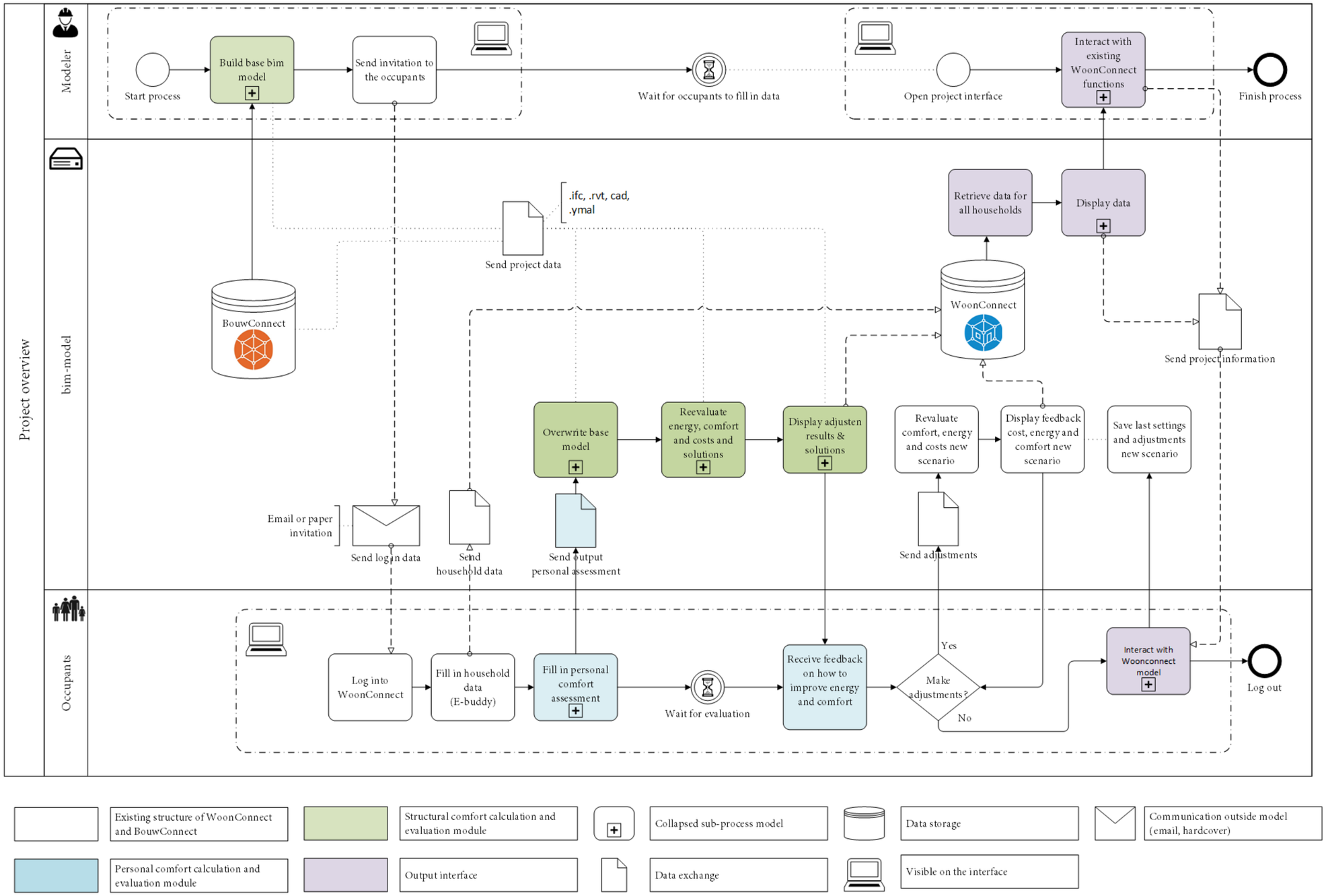

Figure 2: Information process model for a WoonConnect project. For the development of the new comfort module, the colored areas are adjusted for the model. The green actions are addressed in chapter 3.4, the blue actions are addressed in chapter 3.5 and the purple actions are addressed in chapter 3.6.

3.2 Definitions for comfort

For defining comfort first an overview was made of how different tools define comfort. Overall there is no single definition of comfort. Therefore this chapter looks at several international recognized sources, including the definitions of BREEAM, LEED, GPR, the Dutch building code and the Perfection-framework. Annex 3 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 (DGBC, 2016). 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 documents and assessments as proof.

LEED

LEED is an international green building framework and rating system (USGBC, 2009a). 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 environments also work to improve the building's value, enhance productivity, decrease absenteeism and reduce liability for building designers and owners*". For Table 7, the input was derived from (Alyami & Rezgui, 2012).

GPR

GPR is a communication tool used for sustainable assessment (W/E Adviseurs, 2017). 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 coordination action between academic institutes and the industry, including the TU/e (Lupisek, Antonin; Botsi, Sofia; Hajek, Petr, Sakkas, Nikos; Hodkova, 2009). 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 of both comfort and health related metrics. The desired purpose of PERFECTION is to help enabling 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 code also indicates how several aspects of comfort should be calculated according to Dutch regulations.

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 ones comfort (Vischer, 2004). 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. (Mallory-hill, 2004, pp. 125–162). For example, (Leaman & Bordass, 2001) shows that there is a relation in experiencing comfort and the ability of occupants to self-operate windows. As a result (Leaman & Bordass, 2001) 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-regulations, the ability to determine the criteria within the bim-model of *WoonConnect* and the expected expertise to understand the criteria. 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. This 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 and lighting, 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) (Normcommissie 351 074, 2011). 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 reasons 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 (See Chapter 2.1). Having a separation between both parts will help to better personalize the advice given to the user. I.e. possible actions to take when the occupant has

problems with heating are different then when the indoor climate is too hot. Based on this principle, also air humidity is 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 this in the bim environment would be hard to obtain. For both criteria, the required information is often not available within many (internal) projects and can therefore not be addressed in the bim-environment.

In summary, the above discussion has led to the following comfort criteria being assessed in *WoonConnect* (Table 1). The exact documents used to calculate these criteria are further explained in "*Chapter 3.3.3 Overview of the documents for calculating and* evaluating comfort*"*. Although the first version will focus on these criteria, additional criteria such as usability and home health care can still be considered in the future.

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

Temperature related comfort criteria		
1	Heating	The ability for the dwelling to heat and regulate the building to 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 and infiltration	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 installations like HVAC-systems and common household equipment.
6	Sound restriction between rooms	Restriction of sound in the room and between rooms, including the sound propagation in 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 quality of the interior and building size	Size of the building and the quality interior
12	Home health care	Ability of the dwelling to support elderly or disabled people

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. For designing the assessment tools, the same factors were considered. These factors are:

- Minimum required accuracy and the model complexity needed to sufficiently assess a design situation for the given purpose
- 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, (Brooks & Tobias, 1996; Enk, 2016; Trčka & Hensen, 2010; Zeigler, Praehofer, & Gon Kim, 200AD) 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) (Zeigler et al., 200AD).

To describe accuracy of a calculation model, (Zeigler et al., 200AD) often describes complexity as the relation between the resolution of the model, the scope and the size (number of components or variables). Figure 3 provides a visual overview of how (Zeigler et al., 200AD) describes the relation between the resolution, the scope and size of the model. Overall, any combination can be made with these variables. However, traditional, tools often are solution oriented and have therefore a narrower scope and resolution. They often focuses on one discipline within (static) extreme conditions (worst case scenario) or average situations (Loonen, n.d.). Advanced tools often consider a higher complexity and often integrate several disciplines together whilst focusing more at understanding the problems (Loonen, n.d.).

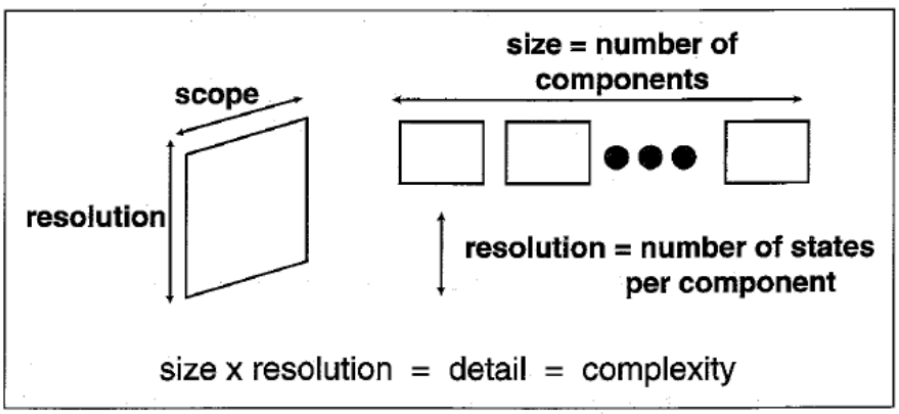

Figure 3: Model complexity visualized according to (Zeigler et al., 200AD) *, which shows the relation between the resolution, the scope and the number of components.*

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 work contradicting on the quality of the model, as low quality or over simplified data can cause errors as well. Therefore, when building model, 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 4, which shows the relationship between the model complexity and the uncertainty caused by the low skill user and uncertainty in the data.

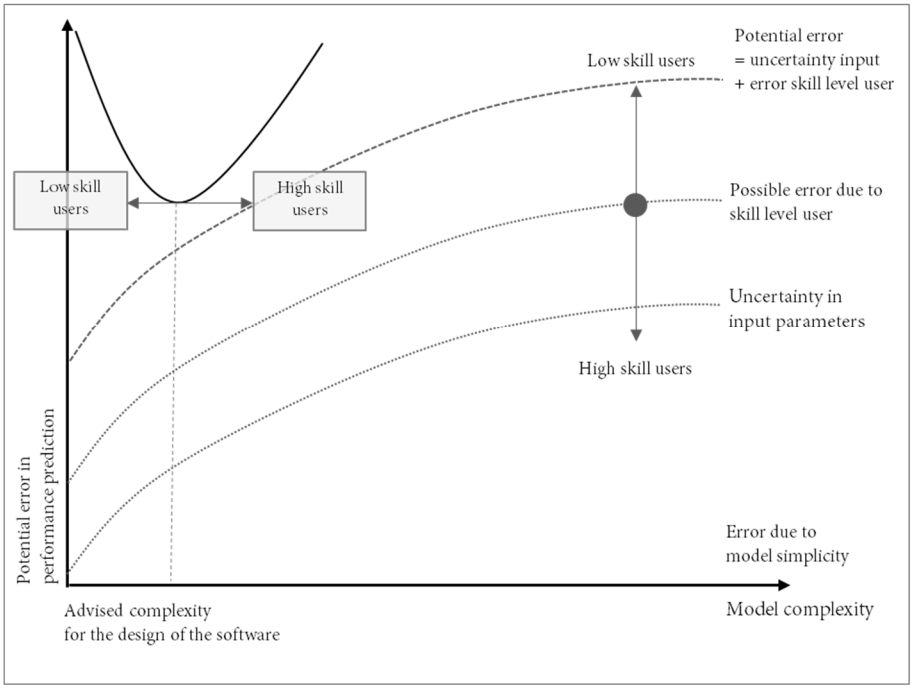

Figure 4: Trade-off between the model complexity and uncertainty of the input data adopted from (Trčka & Hensen, 2010). *For this project we considered an additional factor, the skill level of the (intended) user. The intended user can influence the advised trade-off. A low skill user will likely make 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 wrong 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 (Enk, 2016; Trčka & Hensen, 2010). 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 requires additional data from the user.

A large part of the required data to build this model can however 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. 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 short-comings of a simpler model when evaluating a model

A low skill user is unlikely able to do this. A low skill user has therefore a larger possibility to provide wrong input data. This likelihood will increase when dealing with more advanced models as the amount of required data also increases. A low skill user us 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*, intended users are often municipalities, housing corporations and occupants. Based on the interviews, it was clear that this group had less experience with these tools then engineers. (See Annex II – Interviews with the *WoonConnect* users).

A practical example of a situation where the skill level of the user often caused problems in the past are with Computer Fluid Dynamics calculations (*CFD-calculations*) (Hensen, 2002). 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 are unrealistic, inaccurate or completely incorrect. Because if this problem, the software is sometimes called ‘Colors For Directors’ by experts (Hensen, 2002).

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 depended on the complexity on one side. It is also depended on the intended communication platforms for the software. For *WoonConnect*, the intended medium a website. This web tool can be accessed through a different mobile platforms and aims to provide direct feedback to the user for costs and energy. Due to this approach, the expected computational power and time should be low.

This 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 this project advanced computational models for comfort are radiance and HAMbase were tested, [47], [48]. To a large extent *WoonConnect* should be able to run these calculations in an integral package, as most data could be added within the BouwConnect Bibliotheek or was already present. This possibility could already be seen within a master thesis project with regards to coupling radiance to a BIM-model based on .IFC-files (*Industry Foundation Classes*) (Claus, 2015).

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 (Claus, 2015), 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 to long for the company and costumers. 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. As a result, the information needed for building these advanced models is summarized in Annex IV – Overview of the sources used for the calculation and assessment of the criteria.

3.3.2 Design considerations for *WoonConnect*'s new modules

For the design of the new comfort module, the following design consideration were made.

- 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 that the documents stated are supported by regulations or other international sources. 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 payed 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 can be stored in the BouwConnect library and the bim-model. This library ensures that (average) data is available for each calculation. Since the physical properties are bound to these objects, changes made to the model will be reflected in each assessment. For example, insulation effects 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 require a more specific evaluation. It is however preferred to keep the questionnaire short to limit the amount of date required form 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 calculation are better fitted for the situation.
- DTS considers that, due to the low skill users, attention should be payed to the design of the interface. A well designed interface should help reduce the change 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*. An overview of these sources is given in "*Annex IV – Overview of the sources used for the calculation and assessment of the criteria"*. This annex also displays which assessment methods are mandatory for the Dutch regulations and which assessment methods are optional. Additional limits of these sources are also addressed and described in this annex. Since DTS might consider to implement more advanced comfort calculations in the future, the required sources to build the complex models are also added. DTS can use these documents as a starting point for these developments.

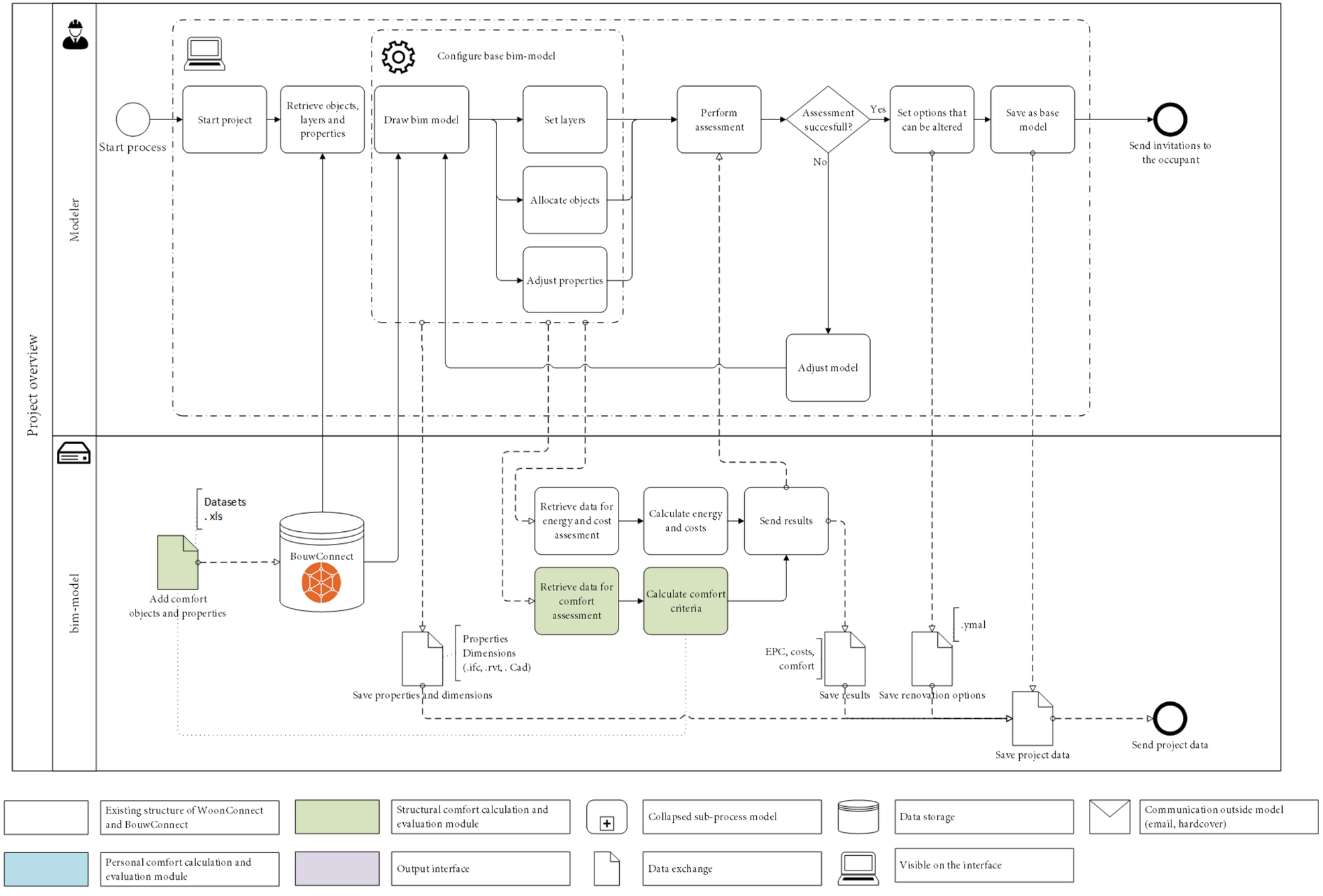

Figure 5: Overview of how a WoonConnect base model project is built by the modeler (collapsed sub process model for "build base model). The green parts show what has been altered for assessing comfort within the existing structure.

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 is used.

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 5 (previous page) displays the sub process model of how a *WoonConnect* project is built and how the comfort calculation are added (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.

Explanation of the existing structure behind WoonConnect

Figure 6 shows how the structure behind a model looks like. The existing structure consists out 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 area's (*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, 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.

After the layer is specified, the user can allocate "objects" to the layer. Figure 7 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'. Additional properties are also stored according to a standard template. For the different products variants, BouwConnect uses information from the factory, licenses and dimensions and nen-document. A modeler can overwrite these properties with own values, however, he cannot not alter the template behind each object.

Figure 6: 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.

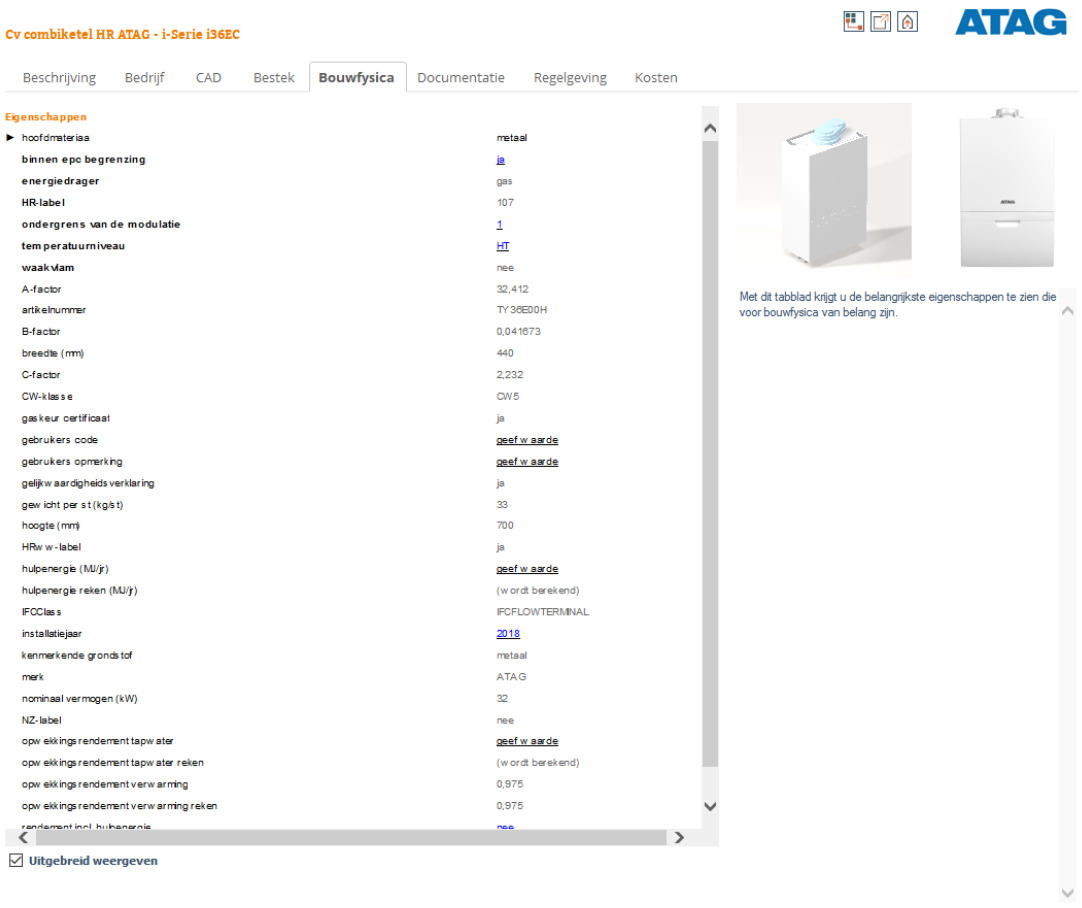

Figure 7: Example of a heating boiler as object and the template containing all properties.

An overview of the resulting bim-model is shown in Figure 8. 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 need 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 8: 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 floors plan 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 9 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 9 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.

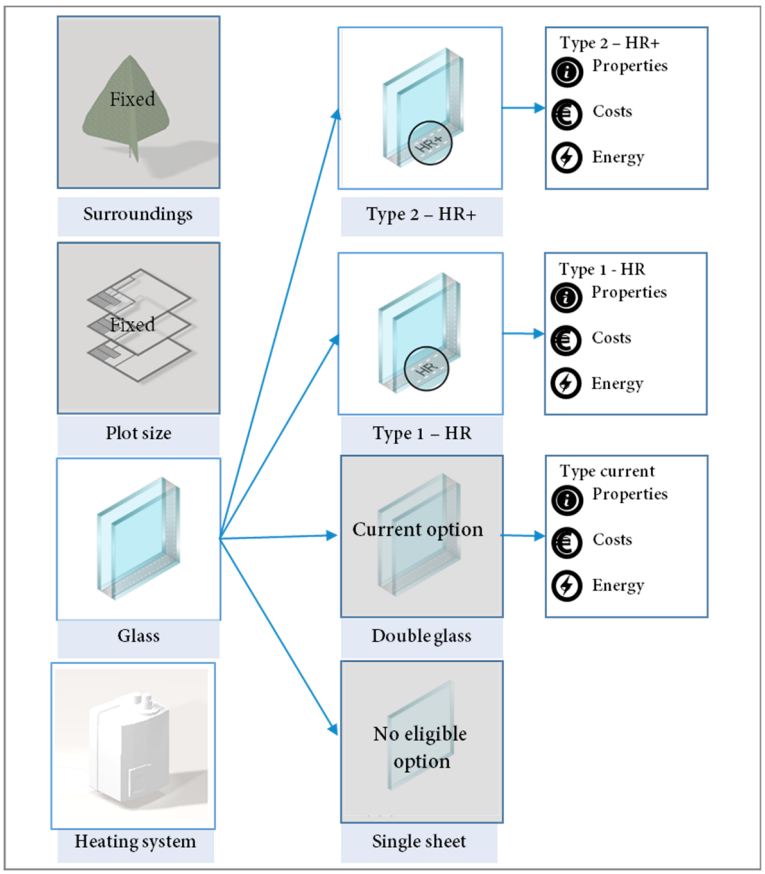

Figure 9: Example of a choice process displaying the different objects that the occupant later on can alter.

Adding new objects and properties in BouwConnect for calculating the comfort criteria
The previous sections described how the existing structure of *WoonConnect* looks like and how a model is built. The first design requirement from Chapter 2 was that the new comfort module fits within the existing structure.

To meet this requirement, BouwConnect (De Twee Snoeken, 2018) was expanded with new objects (and properties) that contribute to comfort. These 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. A complete list of the new options is added in **Fout! Verwijzingsbron niet gevonden.**.

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 for each criteria based on 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 *WoonConnect* in the period of 2017-2018 (De Twee snoeken, 2018; Morcus, 2015).

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 (Morcus, 2015). The resulting score was divided into a total 'home healt care label' ranging from F (very bad, cannot support elderly people) till 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 have 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 till 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 2. 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.

To fit the scores to the existing structure, each question is allocated to one of the different layers described in Figure 10 (next page). Based on the type of layer, the score is determined slightly addressed 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 residue area. The score gained for an object marked with 'room, residential area or residue 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).

Table 2: Example of a data set built for the object 'windows'. The object effects 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

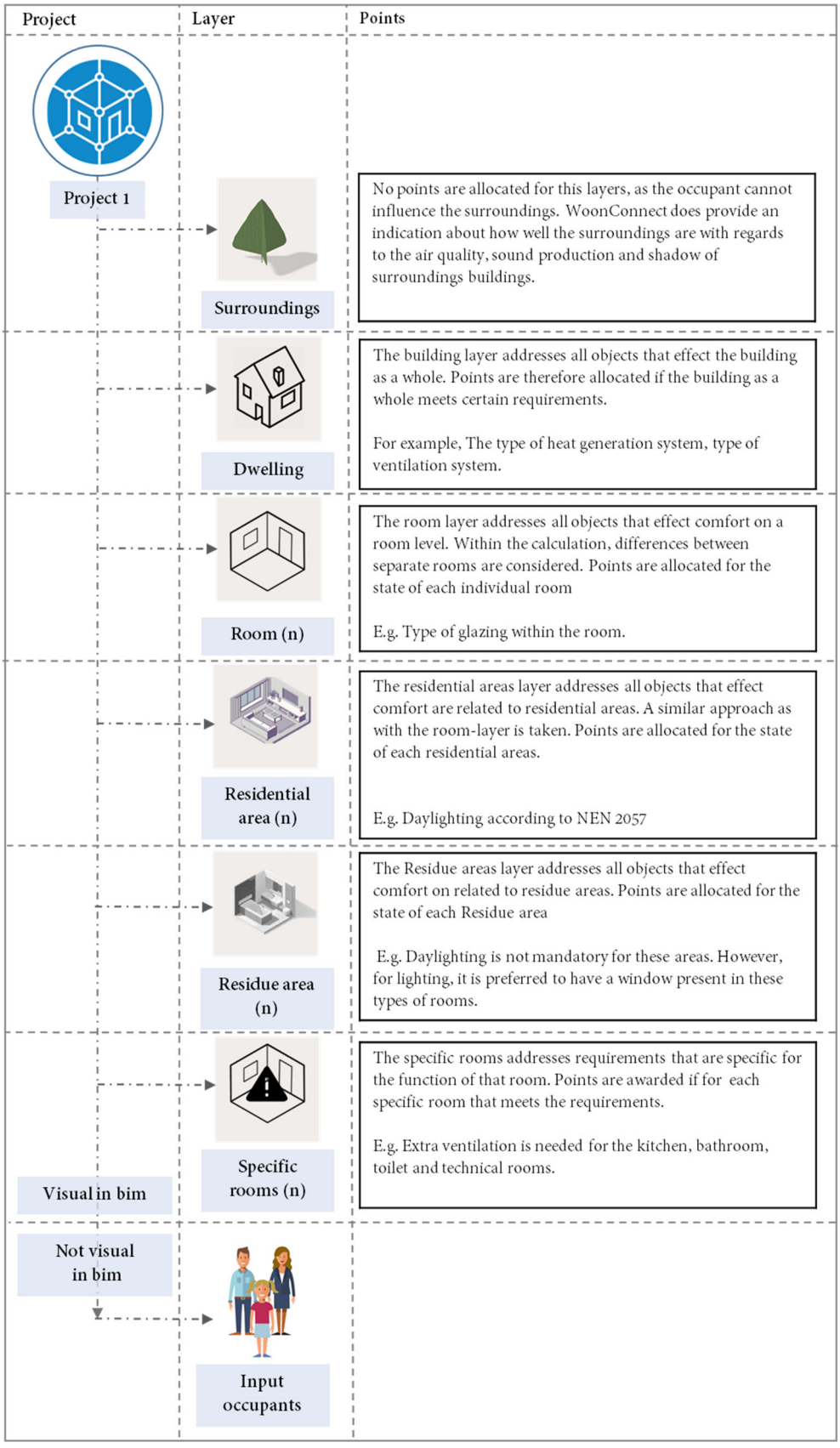

Figure 10: Graphic explaining how the scores are related to each layer, including examples. All questions/ scenarios are allocated to one of these layers and points are awarded accordingly.

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 of 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). Within the assessment, it is advised to resolve these points first.

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 TU/e 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) or only in certain situations.
- 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 3.2.3 Comfort assessment criteria for WoonConnect.*

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) till 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)

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

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

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

In which:

L_{min_n} = Minimum achievable score for comfort criteria n.

L_{max_n} = Maximum achievable score for comfort criteria 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 criteria n at given layer.

L_{Qmin_layer} = Minimum score achievable for every question at given layer (dwelling, residential, residue or specific room).

L_{Qmax_layer} = Maximum score achievable for every question at given layer (dwelling, residential, residue or specific room).

The resulting range, defined by L_{min_n} and L_{max_n}, represents the potential score to be gained for the model for one comfort criteria. 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.

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

In which:

$L_{scenario(m),n}$ = Total score for comfort criteria n for given model scenario (m)

L_{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 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. The total score given for the question addressing the layer '*dwelling*' has only one answer or 'model state'. Table 3 displays an example for how the score is determined at dwelling layer. 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 3: Example for how the score is determined for a question at the layer 'dwelling'.

Question asked from the model	**When is the roof insulated?**	
Layer within *WoonConnect*?	Dwelling layer	
$Q_{dwelling\_1}$	**Possible state of the model**	$L_{Q\_dwelling\_1}$
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.

$$L_{Q\_room} = \sum_{p_{room}=1}^{q} (L_{Room\_1} + L_{Room\_2} + L_{Room\,p})$$

In which:

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

L_{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 3 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 11 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) till 'A' (very good). Figure 12 shows how the resulting labels are printed on the interface for each individual comfort criteria. As part of the verification criteria, the assessment can be printed as a hard copy document ("*comfortrapport downloaden*"). The document contains a more in detail description behind the model, including the provided scores, corresponding physical model properties and thresholds behind the model.

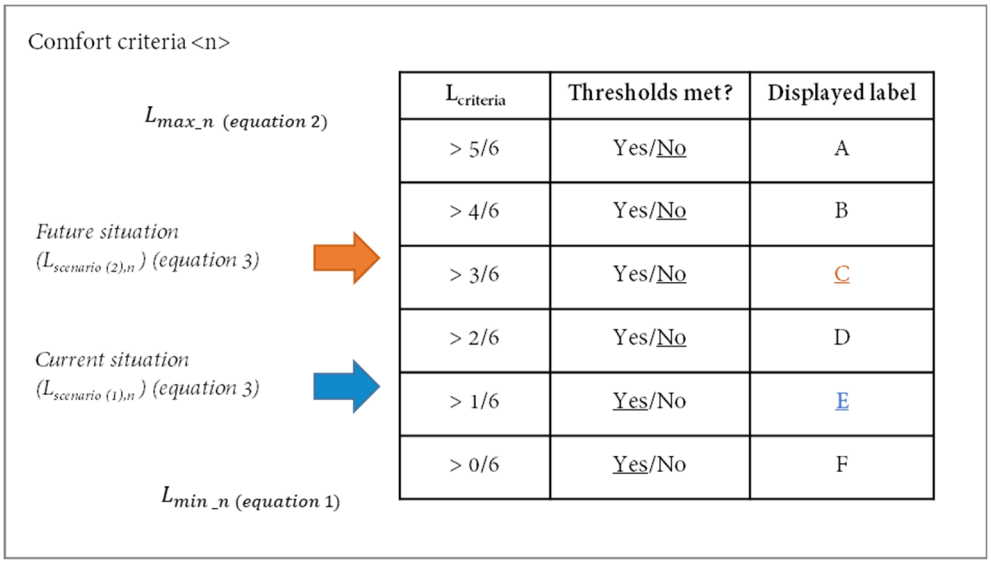

Figure 11: Graphic explaining how the displayed label is determined within WoonConnect's interface.

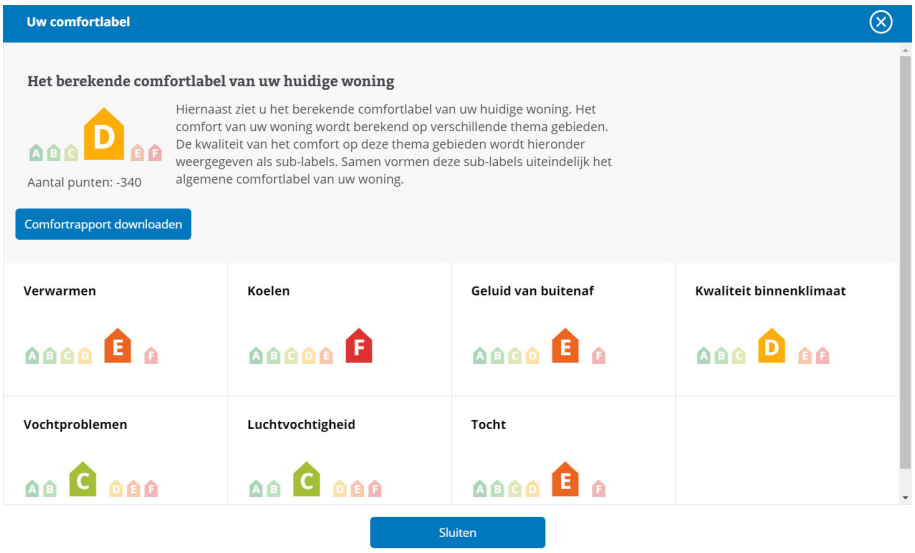

Figure 12: Screenshot of the interface displaying the individual structural assessments for each comfort criteria.

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 14 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 take is 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 build earlier on by the modeler. For example, in Figure 13, the modeler assumed that the building has double glass 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 glass '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 (see Figure 9) to the current settings. Based on the remaining options, *WoonConnect* will display the results to the user. In the example of Figure 13, the advice will be to install HR glass or better.

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

Figure 13: 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.

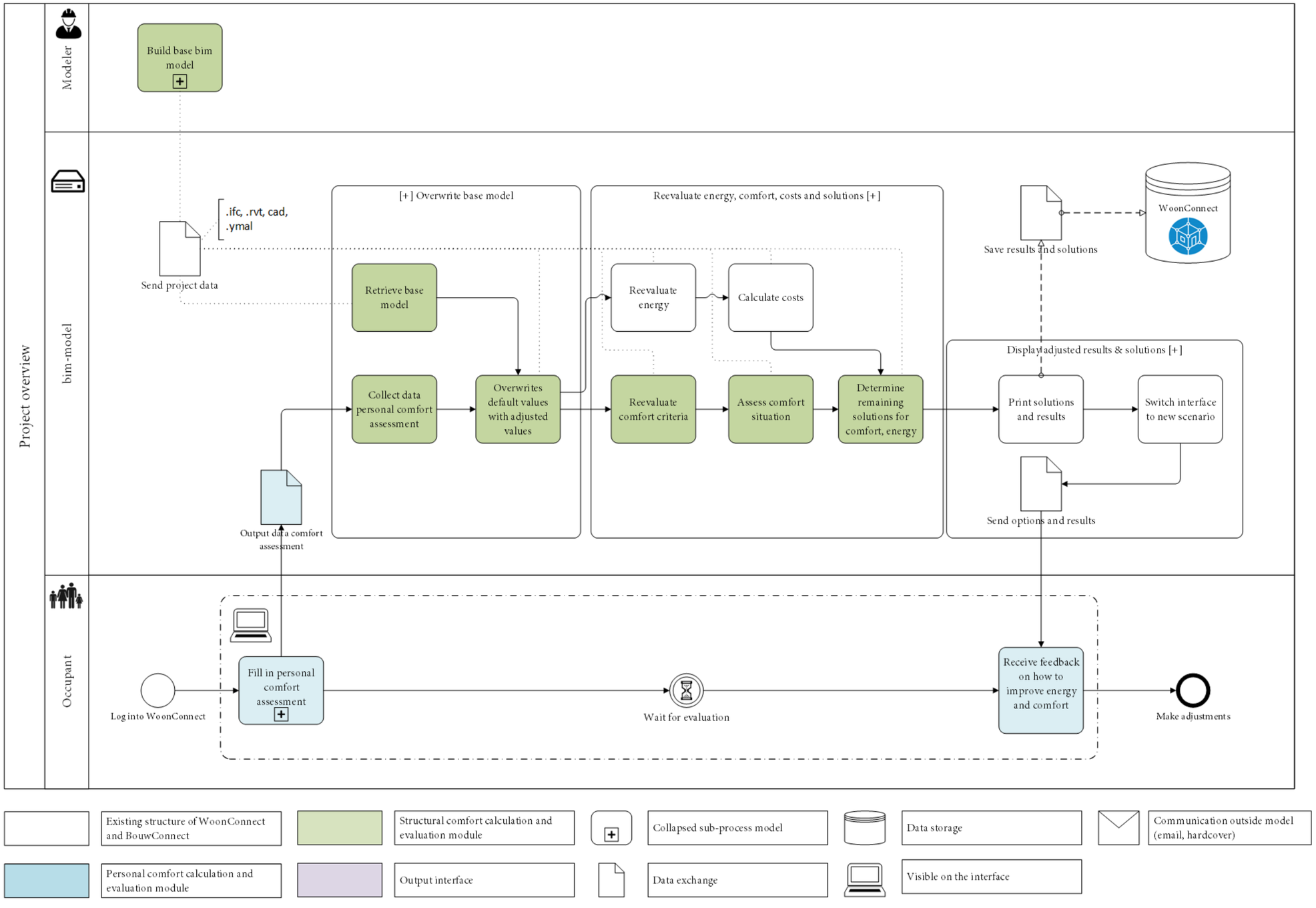

Figure 14: Process model for how the personal comfort assessment (blue) is being used to overwrite base model values in WoonConnect (green). The resulting output is printed and visible to the

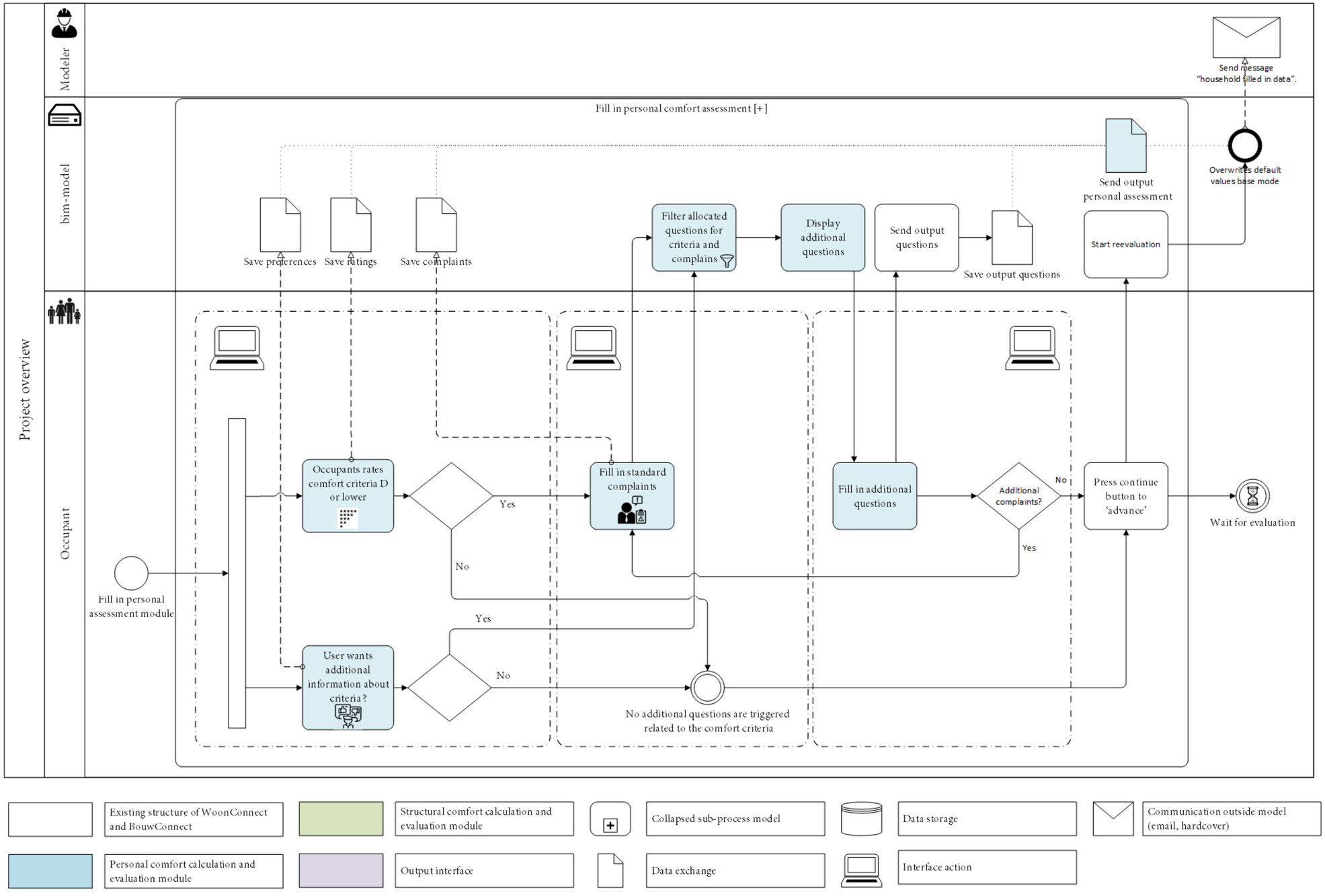

Figure 15: Process model used for the personal assessment. This personal assessment is based on the ratings, preferences, complaints and additional questions filled in by the occupant. The exact information shown at each blue step is shown in Figure 16

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, complains 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 15 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 parts of information (see Figure 16). The first part focuses on rating the building with regards to comfort and by asking if the occupant wants to improve said criteria. For the rating, a similar A till F scale is used as in the structural assessment ("S*ection: 3.4.2 Assessment for comfort based on the bim* model *of WoonConnect").*

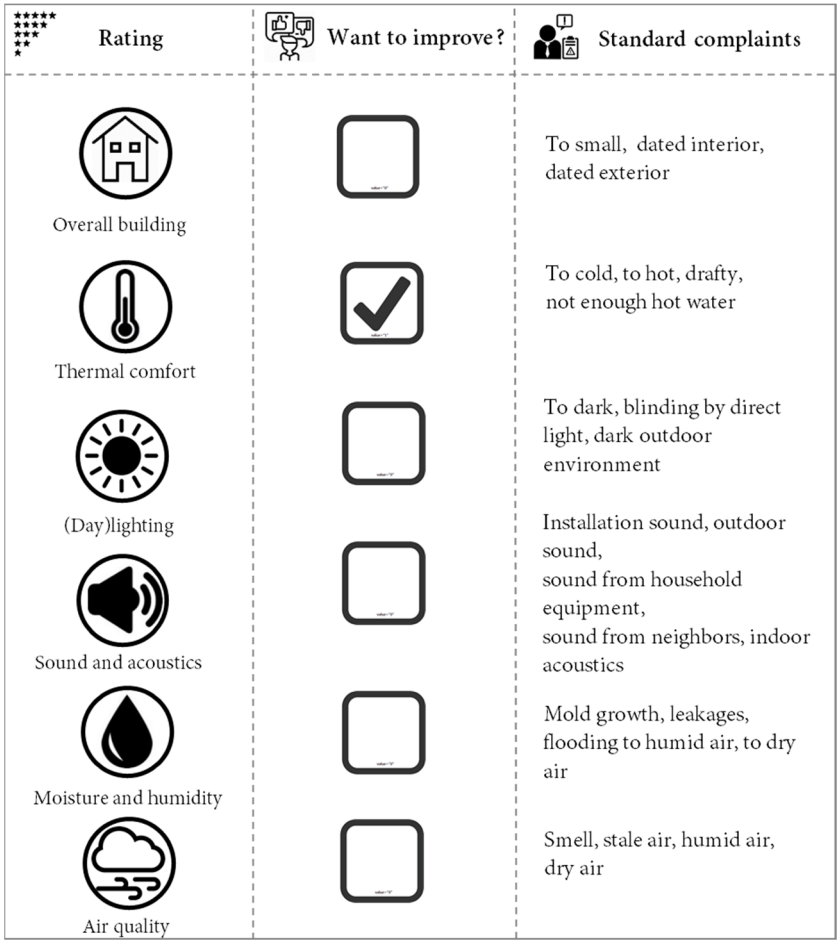

Figure 16: Overview of how the people can make their preferences known in the software. The list of standard complains can still be extended.

An explanation of what each scale means is displayed in Table 4 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 the options to act against discomfort.

Table 4: 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, however, it only happens sparsely. If the user experiences discomfort, the dwelling provides sufficient options to act against the problem.
D	The user experiences discomfort regular 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 do 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 do act against the problem.
F	The user experiences discomfort on a daily or weekly base. The user is unable to do 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. Which complaints are marked first are depended on the rating, as only when the rating is D or lower will trigger the related complaints. Through filtering the rating and complaints in advance, *WoonConnect* aims to limit the information required from the occupant. When the occupant has filled in his complaints, the interface will switch to a third interface.

3.5.2 Limiting the amount of questions needed

Figure 17 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 to 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 15 to reduce the information burdening 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 values remains default.

Comfort criteria	Thermal comfort	
Rating	E	
	**Standard complaint**	
	Drafty, To 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 glass • Additional glass front • Single sheeted glass	• Triple glass • HR ++ glass • HR + glass • HR glass • Double glass • Additional glass front ✓ Single sheeted glass	• Triple glass • HR ++ glass • HR + glass ✓ HR glass • Double glass • Additional glass front • Single sheeted glass

Figure 17. 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 "to cold", "drafty", "to hot" and "not enough warm water" are shown on the second interface. In this example, the occupant filled in the standard complaints "drafty" and "to 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 this 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 18). The shown adjustments are limited to the options set and determined by the modeler and the previous step. In the existing structure, *WoonConnect* can already shows 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 (For example, Figure 18).

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 modeler will receive a notification that this household has filled in the information and the latest settings at that are saved for the modeler to use.

Figure 18: 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.

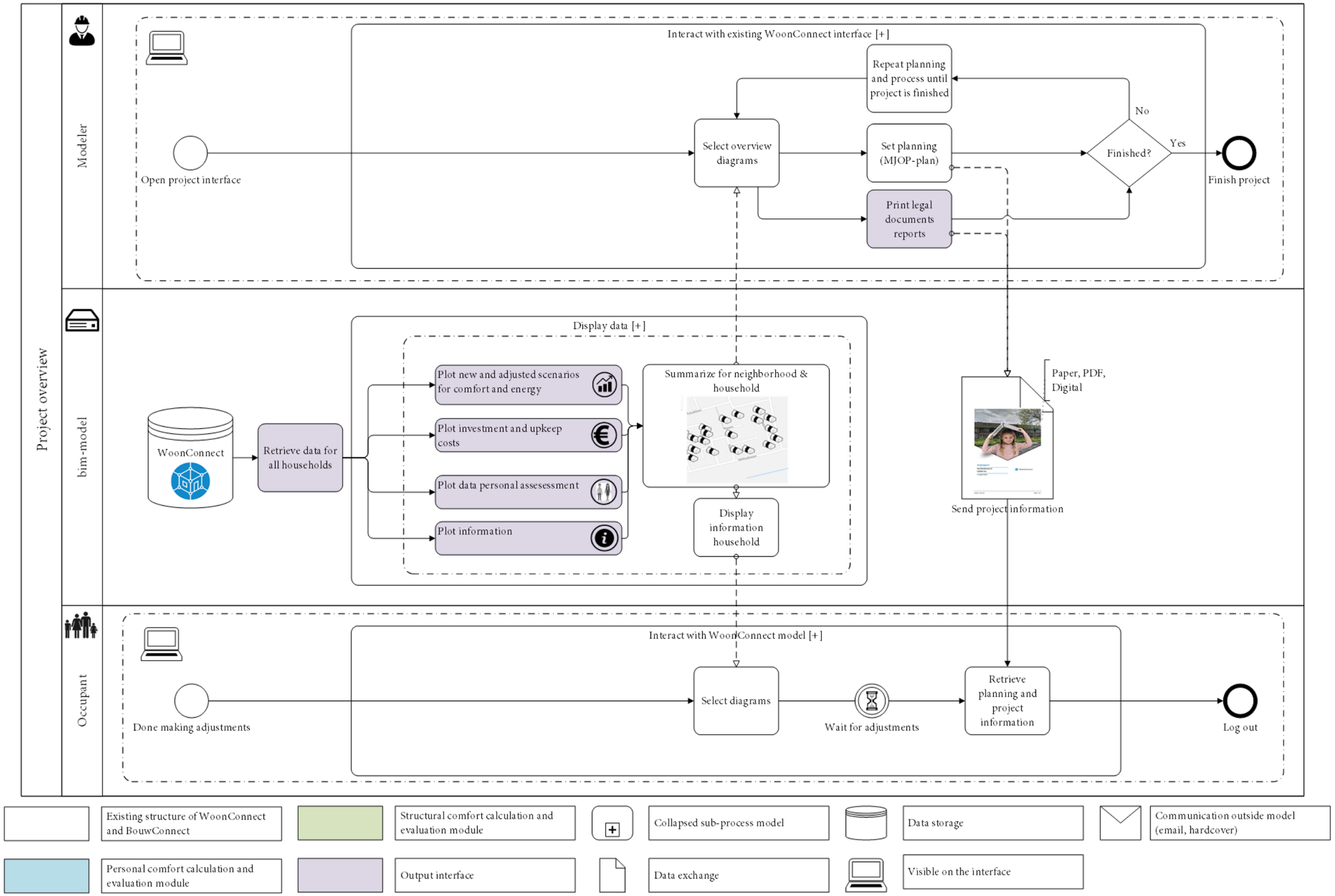

Figure 19: Process model for how the information of WoonConnect is translated to the output interface for both the occupants and the modeler. The information of each household is combined into a site plan of the neighborhood.

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 functions of *WoonConnect*. Similar 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"*) displayed at 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 criteria 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 the modeler wishes to increase the personal assessment label of the building, he has to address these points first.

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

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

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

Personal comfort assessment label building	= Total score of the building considering the personal and structural assessment of the building for scenario m
X_n	= Weight factor derived from the personal comfort assessment for each comfort criteria n
$L_{Scenario(m),n}$	= Structural assessment for criteria n 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 modeler and occupant

The same system as used for the energy and costs calculations is reused for the comfort module. The modeler 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 modeler can then use the data in analyze the data on a neighborhood scale, to summarize and to identify common complaints within the neighborhood. Additionally, the model assures that user can estimate costs for the renovation. The calculation output can also be printed into an personal report. The report (Dutch*: "persoonlijk maatwerkadviesrapport"*) provides advice on what renovation options are best suited to decrease costs and to counter discomfort.

4 Advice for the further development of the software

4.1 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 perform this task.

4.1.1 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 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 effect on the experience on thermal comfort, as shown by a literature review by [79]. A household with more female members might therefore experience more discomfort that a predominantly male household. Another example, noise pollution (caused by bad insulation) can have more negative effects on children [80]. Household with young children might therefore value sound 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 people might give a personal score of E (not satisfied) for the same dwelling. The difference could lay 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.

4.1.2 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 is shown Table 5 below.

Table 5: 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?
Ho	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?

4.1.3 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 23 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.

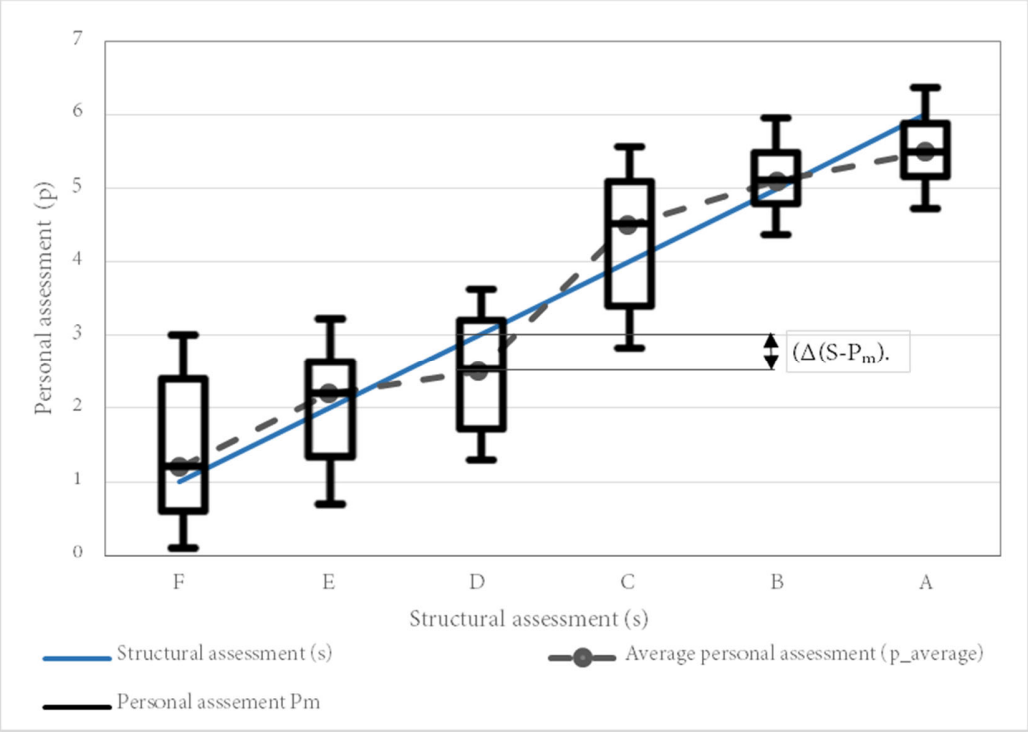

Figure 20: Example of how the data can be plotted for a comfort criteria n

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 (Δ(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 negative. If the difference between both variables is too large; for example, $\Delta(S\text{-}p) > 1$ or -1, then the difference between the structural assessment and the personal assessment is too large. In case of $\Delta(S\text{-}p) < -1$, the structural assessment is too low. On the other hand, if $\Delta(S\text{-}p) > 1$, than 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.

4.1.4 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 5 can be used to form different groups

To form these groups, a cluster analyzes carried out in *SPSS* could provide an option. The output of a cluster analyzes 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 21 below.

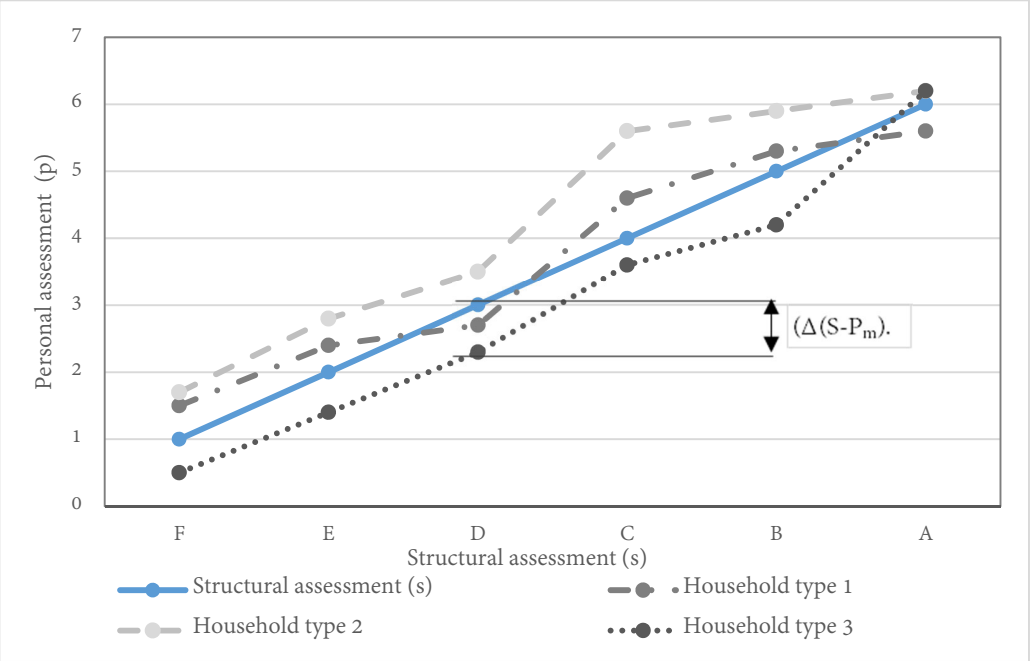

Figure 21: Example where the data is filtered it no different clusters.

The resulting data can be processed through a similar method as in step on: 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 "*chapter* ***Fout! Verwijzingsbron niet gevonden.***".

4.2 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 simper methods for providing renovation advice.

The main reasons 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 what 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. The accuracy of said methods compared to the real life is lower due to the lower resolution or for using abstractions for different variables 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 were therefore considering implementing advanced calculation methods as well. The calculation methods that can be used for performing these advanced calculations were summarized in appendix IV.

However, due to the differences in usability and simulation time, *De Twee Snoeken* might consider using the advanced calculations methods different in a *WoonConnect* project than the simpler methods. Figure 22 below 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.

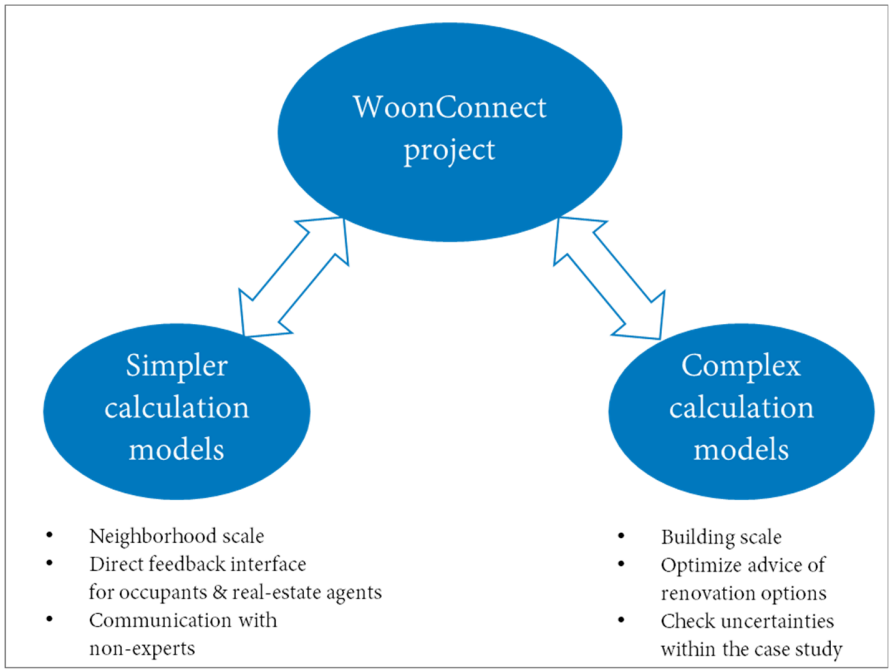

Figure 22: Overview of how De Twee Snoeken can consider implementing more complex calculation methods within a WoonConnect project.

For example, a discrepancy in actual energy performances and simulated energy performances is an uncertainty found within some *WoonConnect* projects. 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.

5. Conclusies en aanbevelingen

Het is gelukt om een prototype te bouwen waarin verschillende comfort criteria samenkomen. Het prototype wordt aangestuurd door een bim model. De Twee Snoeken zal het model verder uitbreiden in de toekomst.

Het is mogelijk om comfort integraal te berekenen binnen een bim-model. Dit vergt echter een grootte hoeveel extra informatie van het bim-model die (nu nog) niet beschikbaar is in de huidige bim-programma's. Indien wij willen werken naar integralen pakketten voor zowel comfort, energy, bouwkundige details enzovoort, dan zal een centrale gegevens/eigenschappen database nodig zijn voor de bim-omgeving.

Het huidige bouwbesluit is vooral gericht op het gebouw en diens energieverbruik. Gestelde eisen uit het bouwbesluit zijn vaak minimaal met betrekking tot comfort en zijn vooral opgericht op het onderwerp energieverbruik en veiligheid. Andere tools kijken naar comfort in een breder pakket en hebben meer betrekking op de desbetreffende type gebruiker. Bijvoorbeeld, eigenschappen zoals de thermostaat setpoints en de hoeveelheid (natuurlijke) ventilatie zijn afhankelijk van de bewoner, maar hebben in het bouwbesluit vaak een bouwkundige basis.

Voor het bouwbesluit kan het een meerwaarde hebben om extra advies te geven ten voor hoe wij de bewoner beter kunnen meenemen in de ontwerpberekeningen. Bijvoorbeeld, het bouwbesluit kan extra advies geven voor de voorkeuren van verschillende doelgroepen aan bewoners ten aanzien van thermostaat setpoints, ventilatiehoeveelheden etc. Een betere betrekking van de bewoner als uitgangspunt in de bouweisen kan ook leiden tot accuratere resultaten tussen de rekenmodellen en de werkelijkheid.

Gebruikersgedrag, ofwel de bewoner, is namelijk een grootte onzekerheidsfactor in energieberekeningen. Vooral bij gebouwen met een zeer laag energieverbruik wordt de invloed van de gebruiker op het totale energieverbruik steeds belangrijker [bron – Hoes]. Extra aandacht voor de bewoner in het bouwbesluit kan daarom leiden tot comfortabelere gebouwen voor de bewoner maar ook tot accurate energieschattingen voor de ontwerpers. Het bouwbesluit kan deze adviezen eventueel toelichten in een apart document.

Tot slot blijkt dat er al een breed pakket aan (losse) rekentools beschikbaar zijn voor het berekenen van comfort. De bestaande tools hebben een groot verschil in nauwkeurigheid, gebruiksvriendelijkheid, aandachtsgebieden, vereiste kennis en rekenkracht etc. Dit maakte het erg moeilijk om zelf een pakket samen te voegen, aangezien er geen totaaloverzicht beschikbaar is. Omdat comfort steeds belangrijker wordt binnen de bouw is het raadzaam dat er een centraal punt komt met een overzicht van welke

rekentools geschikt zijn. Het centraalpunt kan dan ook aantonen welke tools gebruikt kunnen worden voor bepaalde criteria. Deze criteria hoeven niet alleen betrekking hebben tot comfort, maar ook tot het energieverbruik, materiaalgebruik, brandveiligheid etc. Dit overzicht maakt het makkelijker voor de bouw om geschikte middelen te vinden voor het toetsen van het ontwerp.

Het centrale punt hoeft echter niet onderdeel te zijn van het bouwbesluit. Dit kan eventueel een apart document zijn. Wij adviseren wel dat dit document wordt samengesteld door een klankbord. Dit klankbord moet bestaat uit o.a. leden die het bouwbesluit beheren, overheid en partijen zoals de KIWA die de kwaliteitsgarantie kunnen controleren.

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Annex I – Market analysis

For the comparison of the tools from a usability point of view, the table suggested by (Lee, 2013) was used as a starting point. Within this article, a comparison was made between BREEAM (DGBC, 2016), LEED (USGBC, 2009b) and several other tools.

Table 6: Comparison of the tools according to the literature of (Lee, 2013).

	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	Points Overall grade Certified Silver Gold	Number of points for each category with 1 being very bad and 10 being	-

	Outstanding	Platinum	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

For determining which aspects *WoonConnect* could focus on, interviews were held with different types of *WoonConnect* users and costumers. These users consists of occupants (including home owner associations), real-estate employees and municipality's employees and technical specialists (engineers, contractors and architects). In total 42 people were interviewed (Figure 23). An overview of the ratio of different people and their output is shown below. The questionnaire itself is also added.

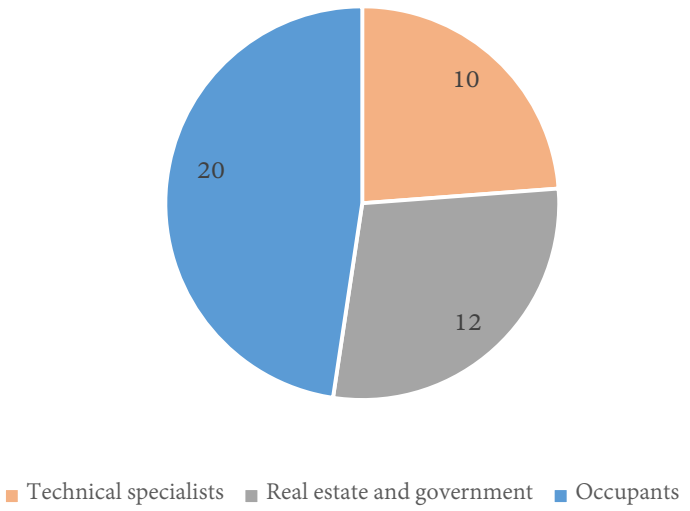

Figure 23: Ratio of the different participants within the interview. In total 42 people were interviewed, divided under the categories technical specialists (engineers, architects, contractors), real-estate and government employees and occupants (includes home owner associations).

Figure 24 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 25 displays the output from the third question. Here, the average score of the different participants displays where people would put their priority when constructing a building. Last, Figure 26 shows if the participants have experience with (sustainable) assessment tools or not.

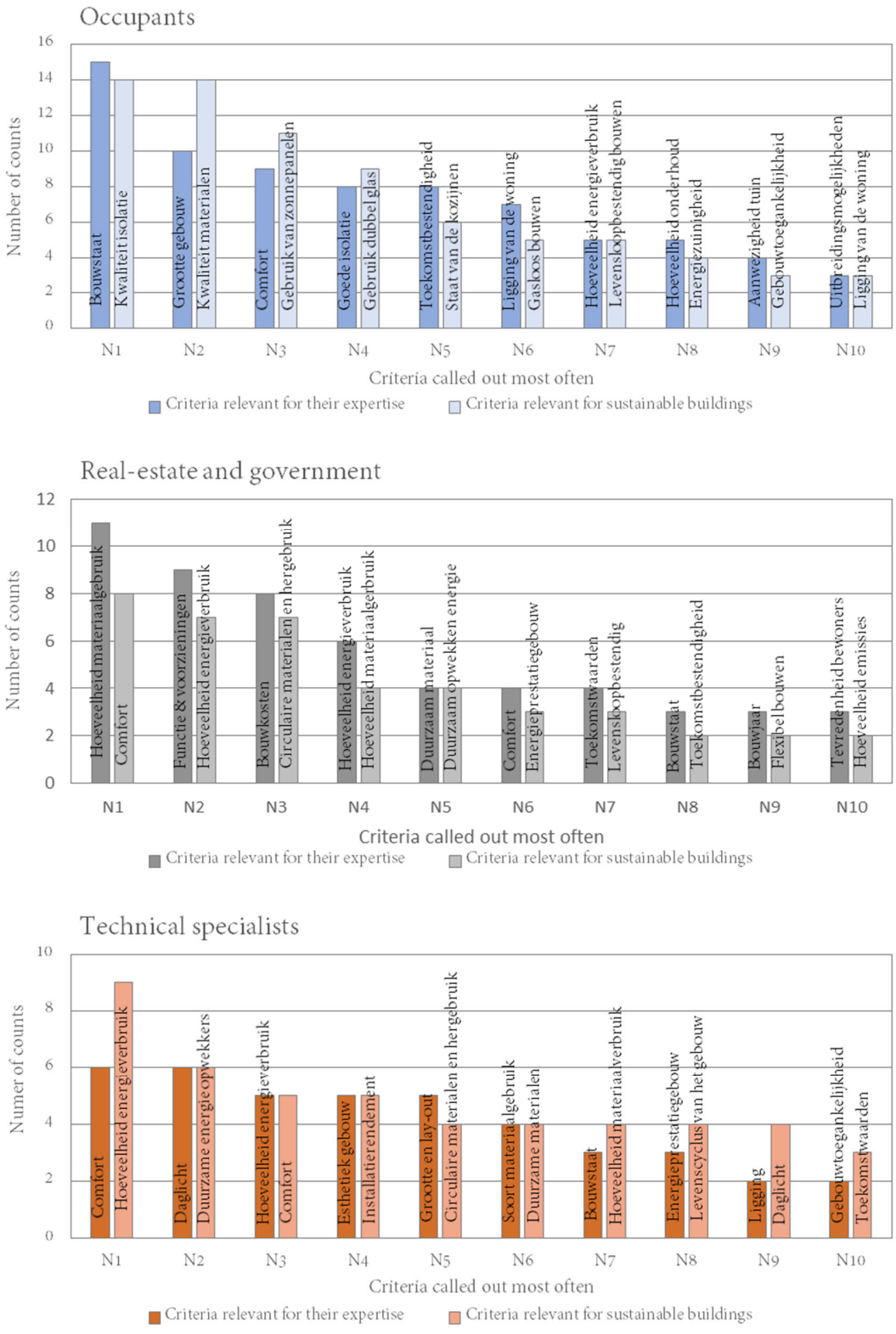

Figure 24: Overview of the output for the different users for both the first and second question (Dutch).

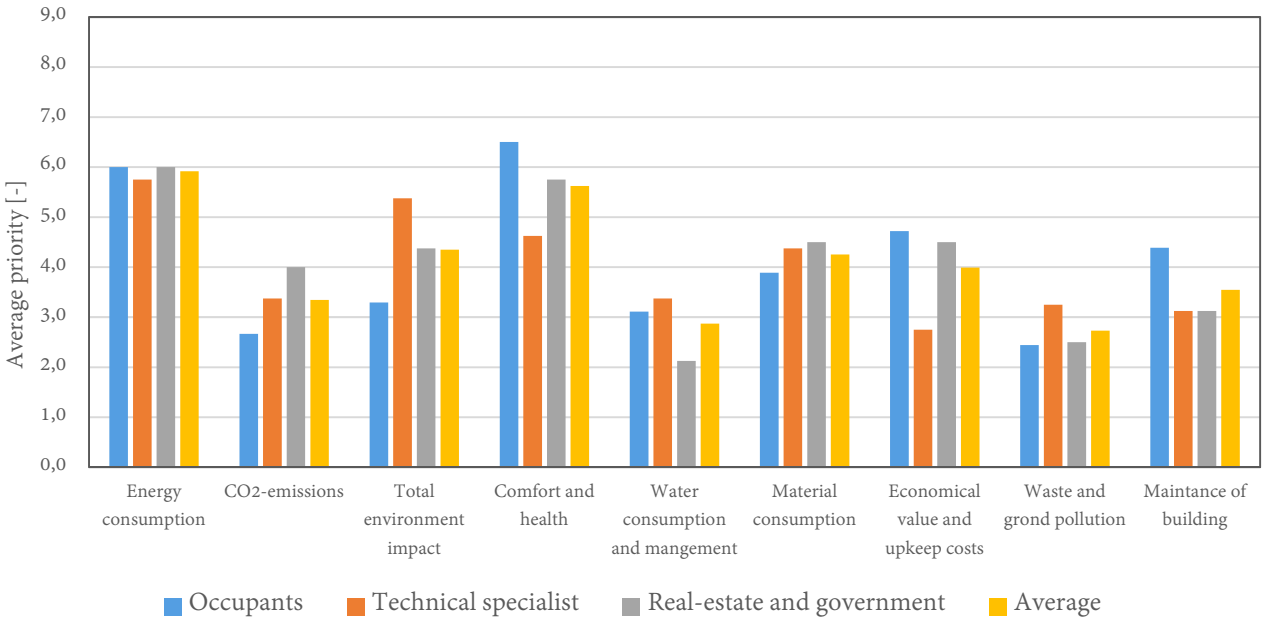

Figure 25: Average score of the output of the third question, divided over the different participants.

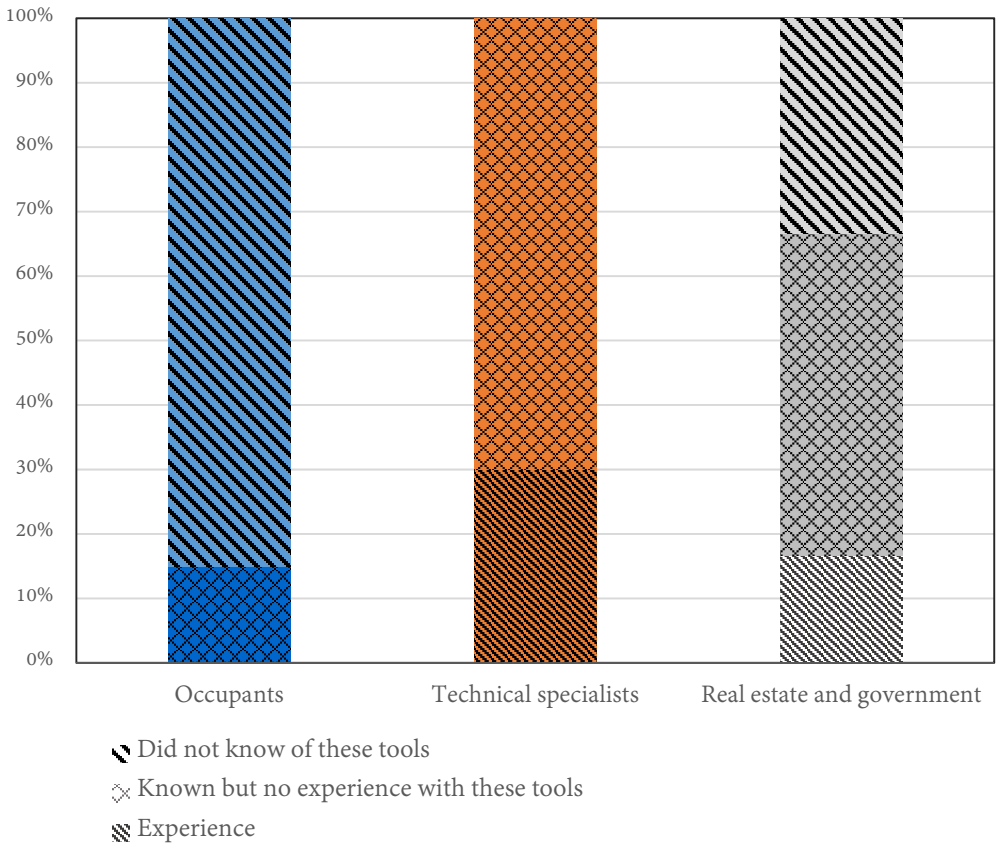

Figure 26: Output to the question: Are you familiar with assessment tools and do you have work experience with these assessment tools?

Annex III – Comparison of comfort categories for the different tools

Table 7 below gives an overview of the different comfort criteria that are being addressed in the different tools.

Table 7: 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	• Thermal comfort • Temperature control (zoned control)	• Thermal comfort Thermal control	• Thermal comfort • Infiltration and draft	• 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 criteria was to provide an overview of the used sources. This annex shows the following information per comfort criteria.

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, 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 is the preferred situation to improve comfort?

Evaluation

- Reference table which *WoonConnect* uses to evaluate comfort based on the output of the bim-model.

Data and score table for each object, layer of situation

The data set for the assessment is allocated into an Excel-file. The Excel file contains all possible answers, the allocated scores and which complains are attached to each question.

1 Thermal comfort - Heating

Main documents	
WoonConnect aims to assess heating through looking at the ability of the system to heat the building to a certain temperature set point. This temperature set point is set by the occupant themselves through the questionnaire and can therefore by variable based on the occupant's preferences and per household. This temperature can be reached by either having a proficient heating-system or other sides by reducing the heating demand required of this system. This later can be achieved through added insulation, preventing leakage and draft or using mechanical ventilation with heat recovery.	
Main documents	**Dutch building code**
NEN 7120 – Energie prestatie gebouw (Normcommissie 351 074, 2011)	Mandatory
NEN 7120 – Achtergrond document ter ondersteuning van de norm NEN 7120 (Van Dijk et al., 2011)	Mandatory
Building physics handbook – part 2 heating, ventilation and cooling (Bakker, F.E ; Schellen, Henk; Hak, 2008b)	Optional
Future documents	
nen-EN-ISO 52017-1 Energieprestatie van gebouwen - Voelbare en latente warmtebelasting en binnentemperaturen - Deel 1: Algemene berekeningsmethode (Nederlands-Normalisatie-instituut, 2017)	Optional
ISSO-publicatie 32 - Uitgangspunten temperatuursimulatieberekeningen (ISSO, 2010)	Optional
ISSO-publicatie 51 - Warmteverliesberekening voor woningen en woongebouwen Bepaling benodigd vermogen per vertrek en totaal (ISSO, n.d.)	Optional
HAMbase Part 1 and Part 2 (Wit, 2009)	Optional
Isso 7730, isso 74 (European Committee for standardization, 2018; isso, 2014),	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. These can cause local discomfort
Type of window usage	Glass with a higher insulation value decreases the heating demand.
Type of window frames	Window frames with a higher insulation value decrease the heating demand.
Type of heating system and the capacity	Newer heating systems have a higher efficiency and can provide heat faster. This heating system should have sufficient capacity to heat the building as assed through 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 higher, more evenly distributed heating capacity.

Mass density of the building (kg/m2)	Heavier mass buildings tend to have higher heat capacity compared to light weighted structures.
Use of smart meters with wi-fi control	Ability to monitor the temperature and control the heating set point from different locations.
Use of separate thermostats for different floors	Ability to regulate the temperature and heat supply from different floors.
Placing of radiators near windows	Prevents draft and local discomfort for heating as a result of downdraught.
Use of mechanical ventilation including heat recovery	Usually more ventilation means a higher heating demand. However, mechanical ventilation prevents the need for fully natural ventilation. Combined with heating recovery this allows a more stable supply of air.
Usage of infiltration prevention around window frames	Prevents unwanted infiltration from the outside.

Thresholds for the assessment	
Label	**Threshold requirements to improve thermal comfort (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 glass 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	• Insulation of the floors = (Rc > 1,3 m2.K/W) • 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)
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

Main Documents	
WoonConnect assesses cooling through looking at the ability of the building to prevent a high cooling demand, risk of overheating (NEN 7120) and having sufficient supply to fresh air. The preference is to first reduce the cooling demand and to prevent high indoor temperatures through other means then a cooling system as a cooling system will contribute to an increased electricity consumption. For the cooling set point, a variable set point given by the occupants can be used. This cooling demand is derived from the same documents as for heating. For the future, the same documents as for heating can be used.	
Main documents	**Dutch building**
NEN 7120 – Energie prestatie gebouw (Normcommissie 351 074, 2011)	Mandatory
NEN 7120 – Achtergrond document ter ondersteuning van de norm NEN 7120 (Van Dijk et al., 2011)	Mandatory
Building physics handbook – part 2 heating, ventilation and cooling (Bakker, F.E ; Schellen, Henk; Hak, 2008b)	Optional
NTA 8778:2012 nl Harmonisatie Begrippenkader - Binnenmilieu in woningen (Nederlands-Normalisatie-instituut, 2012)	Optional
Future documents	
nen-EN-ISO 52017-1 Energieprestatie van gebouwen - Voelbare en latente warmtebelasting en binnentemperaturen - Deel 1: Algemene berekeningsmethode (Nederlands-Normalisatie-instituut, 2017)	Optional
ISSO-publicatie 32 - Uitgangspunten temperatuursimulatieberekeningen (ISSO, 2010)	Optional
ISSO-publicatie 51 - Warmteverliesberekening voor woningen en woongebouwen Bepaling benodigd vermogen per vertrek en totaal (ISSO, n.d.)	Optional
Heat Air and Moisture model for Building And Systems Evaluation Part 1 and Part 2 (Wit, 2009)	Optional
Isso 7730, isso 74 (European Committee for standardization, 2018; isso, 2014),	Optional

* Replaced NEN 7120 as of 01-09-2018

Objects, layers and properties considered in *WoonConnect*'s bim-model assessment	
Building/system part	**Description**
Risk of overheating general building	Risk for the building to overheat, based on calculation of NEN 7120 – Chapter 17.8
Ventilation system and air change rate	The ability to add fresh air more rapidly (1.3 and 1.5 times regulations). This reduces the impact 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.
Ventilation system has access to a CO2 regulator	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 inlet is placed in full sun light, the sun can heat the air that enters the building.
Presence of a cooling system	A cooling system is present to provide cooling when required
Thick insulation of walls, roofs and floors and windows.	High insulation of walls, roofs, windows and floors is positive for heating, but can cause problems during summer. If tick 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 more easier during the evening/ night
Use of smart meters with wi-fi control	Ability to monitor the temperature and control the heating set point from different locations.
Use of separate thermostats for different floors	Ability to regulate the temperature and heat supply from different floors.
Acces to (outdoor) sun screens	Prevents solar radiation from entering the building. Overheating can be bigger problem with large glass surfaces on a southern oriented side.
Mass density of the building (kg/m2)	Heavier mass buildings tend to have higher heat capacity compared to light weighted structures. The building will keep a more constant temperature.
Use of glass with a high ZTA value (> 40%)	Glass with a high ZTA value prevents solar radiation from entering the dwelling.
Usage of infiltration prevention around window frames	Prevents unwanted infiltration from the outside.

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) • Large south, west, east oriented glass surfaces, Aeq/Aeq_room > 20% have no access to sunscreens.
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 and should be CO2-regulated
A	• A airco of central cooling system is present (negatively effects electricity consumption)

3 Thermal comfort - Draft

Main documents	
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 (Normcommissie 351 074, 2011)	Mandatory
NEN 7120 – Achtergrond document ter ondersteuning van de norm NEN 7120 (Van Dijk et al., 2011)	Mandatory
BENG regulations NTA 8800. (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties;, 2017)*	Mandatory
Building physics handbook – part 2 heating, ventilation and cooling (Bakker, F.E ; Schellen, Henk; Hak, 2008b)	Optional
NEN 1087 (Normcommissie 351 074, 2006)and NEN 8087 (Normcommissie 351 074, 2001)	Mandatory
NEN 2778 (Normcommissie 351 074, 2015)	Mandatory
Woning checklist (Nellis, De Haas, & Mak, 2018)	Optional
Future documents	
No documents available	-

*Replaced NEN 7120 as of 01-09-2018

Parts considered in *WoonConnect*'s assessment	
Building/system part	**Building/system part**
Placing of radiators near windows	Prevents draft and local discomfort for heating as a result of down draught (*Dutch = "koudeval"*)
Open connection between different floors (e.g. chair cases)	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	Preferences from regulations, reduces draft as a result of fresh (cold) air that enters the building.
Draft prevention mailbox	Draft prevention for the mail box prevents unwanted infiltration.
Insulation value of the roof, floors and outer walls	Higher insulation decreases the heating demand and keeps the building at a more stable temperature. This also prevents down draught from non-insulated building parts.
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.
Type of window usage	Glass with a higher insulation value decreases the heating demand and will prevent down draught near windows
Type of window frames	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	Prevents unwanted infiltration from the outside.

Evaluation	
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 sheeted glass 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. NEN 5077.	
Main documents	**Dutch building**
NEN 5077 (Nederlands-Normalisatie-instituut, 2008)	Mandatory
GGG 97	Optional
NEN 12354 part 3 (Normcommissie ISO/TC 43, 2017)	Optional
Sound maps (Rijksinstituut voor Volksgezondheid en Milieu, 2015)	Optional
Bouwkunde tabellen boek (Bone, A; Kemps, T; Peters; A; Post, 2010)	Optional
Future documents	
Unknown	-

Parts considered in *WoonConnect*'s assessment	
Building/system part	**Description**
Outdoor environment	Measured sound production based on sound maps is used for the assessment. These sound maps are available for rail roads, traffic and air traffic.
Sound insulation of the wall according to NEN 5077 and GGG 97	Overall assessment method for sound calculating the sound insulation, expressed in the sound insulation from the wall and the indoor sound level
Application of sound-proof natural ventilation shafts	Application of sound insulation for natural ventilation inlets above the window
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 of the insulation material has higher sound absorption properties.
Cracks around window and door frames	Large openings nearby cracks in the window and door frames contribute to the sound insulation of the façade as well. Making sure that these cracks are prevented helps to reduce sound.
Type of window usage	Thicker glass or double glass has an overall higher sound insulation value then single sheeted glass.
Use of outdoor sun screens	Certain types of outdoor sunscreens can contribute to the sound insulation when lowered.

Evaluation	
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 common household equipment such as a washing machine and dryer. The method looks at two parts. The first parts assess the quality of the systems to reduce 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.	
Main documents	**Dutch building code**
NTR 5076:2015 (Normcommissie 351 003, 2015)	Optional
Woningchecklist (Nellis et al., 2018)	Optional/ Mandatory
Nen 5077 (Nederlands-Normalisatie-instituut, 2008)	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 assessment	
Building/system part	**Description**
Build-up boiler system	Placed in a sound proof closet or housing. Use of silencers for ventilation exhausts and inlets Low power systems Direct currency
Build-up heat pump system	Placed in a sound proof closet or housing. Use of silencers for ventilation exhausts and inlets Low power systems Direct currency
Build-up ventilation system	Placed in a sound proof closet or casing. Use of silencers for ventilation exhausts and inlets Low power systems Direct currency
Location of the installations	Preference is that the installations are placed in a separate room away from the bedrooms
Location of the household equipment	Preference is that household equipment is placed in a separate room away from the bedrooms.
Sound insulation of the walls and floors of the room where these systems are located.	Quality of the walls and floors in which the installation system is located. A heavier wall/ floor is preferred over a light weight wall.

Evaluation	
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 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 bedroom, kitchen or living room and is placed on a sound absorbing underground.
A	• HVAC-Installations are placed in a designated installation room or sound proof closet within the residue area. • Household equipment is placed in a separate designated residue area

6 Sound – sound reduction between rooms

Main documents	
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) and walls (sound reduction between two adjacent rooms). This part also cover the sound reduction between two adjacent dwellings either horizontal or vertically.	
Main documents	**Dutch building code**
Tabellenboek (Bone, A; Kemps, T; Peters; A; Post, 2010)	Optional
NPR 5086 Noise control in dwellings – noise control of lightweight partition walls between dwellings. (Normcommissie 351 003, 2006)	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 (Normcommissie 351 003, 1981)	Optional
Nen 1070: Noise control in buildings – specifications and rating of quality (Normcommissie 351 003, 1999)	Optional
Building physics handbook – part 3 Sound (Bakker, F.E ; Schellen, Henk; Hak, 2008a)	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 assessment	
Building/system part	**Description**
Location staircases	For sound reduction between different floors it's preferred to have the staircase in a separated room. This to reduce air sound 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.
Quality indoor walls	No gaps or holes should be present. It is preferred to have heavier constructions which have a higher sound insulation value. Light weight constructions (example wood with plaster board) require different solutions to reduce sound problems between the rooms.
Quality indoor floors	No gaps or holes should be present. It is preferred to have heavier construction (concrete) which have a higher insulation value. In case of a lightweight wooden floor, a floating screed or floor can be used.
Quality dwelling separation wall	No gaps or holes should be present. It is preferred to have heavier construction (concrete) which have a higher sound insulation value. For a dwelling separation wall, a cavity is preferred.

Quality dwelling separation floors	No gaps or holes should be present. It is preferred to have heavier construction (concrete) which have a higher insulation value. In case of a lightweight wooden floor, a floating screed or floor can be used.
Use of a front wall or second wall for dwelling separation walls	If no cavity is present, a front wall can provide an alternative to reduce sound between two adjacent dwellings.
Surface of (wooden) staircases	Wooden staircases can contribute to discomfort from contact sound. Upholstery of the staircase can prevent this by providing a softer material.
Use of acoustical plaster	Use of acoustical plaster of finishing can help to reduce the echo in the room if preferred.

Evaluation – the main evaluation is based on the sound reduction values of standardized walls	
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 o The wall separating the dwelling contains a cavity. o 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. o Stair case connecting the separate floors is located in a separate room or hallway o The chair case has a soft surface to reduce contact sound • For structures (floors and walls) that separate two dwellings o No demands
A	• For different rooms inside the same dwelling. o Internal walls are made from concrete or stone material o If the walls are a light weighted wooden structure, tit contains sound insulation. o Internal floors are from concrete, > 300 mm • For structures (floors and walls) that separate two dwellings o The floor separating the structure is made from concrete, thickness > 300 mm and is disconnected from the structure

7 (Day)light

Main documents	
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 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 with simplified daylight simulations.	
Main documents	**Dutch building code**
NEN 2057 (Normcommissie 351 005, 2011)	Mandatory
Building physics handbook – part 1 design with light (Bakker, F.E ; Schellen, Henk; Hak, 2010)	Optional
IESNA lighting handbook (DiLaura, Steffy, Mistrick, & Houser, 2011)	Optional
Future documents	
Average daylight factor: a simple basis for daylight design, Information Paper 15/88, Building Research Establishment, Watford, UK. (Littlefair, 1988)	Optional
Development of advanced daylight calculations BIM automated coupling with radiance, accordance to the ray-trace methodology (Claus, 2015).	Optional

7- Considered factors in *WoonConnect*'s BIM- calculation	
Building/system part	**Description**
Aeq both in m2 and % per room	The amount of surface area for day light to enter the building
User of (solar) blinds or outdoor sunscreens per room	To prevent blinding, the building should have access to indoor or outdoor sunscreens. Especially with larger openings (Aeaq/Asurface)
Window dimensions per room	Good room dimensions ensure that the light enters the dwelling in an equal matter. For this 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). Other sides, based on NEN 2057, the windows should have at the very least have a lower frame height of 800 mm.
Use of window stickers and positions of windows for sensitive rooms	Use of windows stickers or place the window above a height of 1800mm to prevent privacy problems.
Amount of windows within a room and the orientation	More lights windows in different orientations bring a more dynamic form of lighting in the building
Use of bright colors instead of dark colors	Usage of bright colors improves the amount the amount of light within room by having a higher reflective value
Use of glass panel doors or skylights for internal rooms	Delivering of day light to internal rooms, even if they have no direct access to the outdoor environment (indirect daylight)
Use of outdoor lighting near entrances for safety reasons	Use of external lighting near the entrances of the building for during the night or evening.
Skyline factor	Considers how much of the skyline is visible from a window or room. A low skyline factor indicates that the buildings is surrounded with a lot of high rise buildings.
Type of light switches	Besides standard light switches, light dimmers can be used to regulate electric lighting. This allows the user to have more flexibility to in regulation the artificial lighting.
Use of windows for non-mandatory rooms	Non all rooms types are required to have access to direct sunlight according to the Dutch regulations. Yet it is better if they do have (sun)light.

7– (Day) lighting	
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 entrance have access to an outdoor window • Bathroom has direct access to daylight • Entrance area has direct access to 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

Main documents	
To increase the air quality in the dwelling WoonConnect considers the air change rate due to infiltration and from windows, the air change due to ventilation and the quantity and how the building is ventilated. To improve the indoor quality, sufficient air change is crucial and if possible, it is preferred to have a large air change rate then advice 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. 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 to safety operate.	
Main documents	**Dutch building code**
NTA 8778: Harmonized Conceptual Framework – indoor environment in residential buildings. (Nederlands-Normalisatie-instituut, 2012)	Optional
NEN 1087: Ventilation in buildings – Determination methods for new estate (Normcommissie 351 074, 2006)	Mandatory
NEN 8087: Ventilation in buildings – Determination methods for existing buildings (Normcommissie 351 074, 2001)	Mandatory
Air quality maps Netherlands (Rijksinstituut voor Volksgezondheid en Milieu, 2015)	Optional
Buildings physics handbook part 2 – heating, ventilation and cooling (Bakker, F.E ; Schellen, Henk; Hak, 2008b)	Optional
Future developments	
No document available	-

Table 8: 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 m^3/uur/m^2	3.2 m^3/uur/m^2	2,5 m^3/uur/m^2	Minder dan 2,5 m^3/uur/m^2
Keuken	Hoogstand 400 m^3/uur	Hoogstand 300 m^3/uur	75 m^3/uur	Minder dan 75 m^3
Toilet	25 m^3/uur	25 m^3/uur	25 m^3/uur	Minder dan 25 m^3
Badkamer	70 m^3/uur	70 m^3/uur	50 m^3/uur	Minder dan 50 m^3

	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 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?
Ventilation rate of the system	The amount of air that can be that can be supplied/removed based on the NTA classes. Overall, the more air that can be supplied, the better the air quality.
CO2 controlled system	Co2-systems can detect the quality of the indoor environment and adjust the air change rate accordingly.
Type of heating distribution system (radiator, floor heating)	Traditional radiators can more difficult to clean and due to the higher temperature dust can more easily burn. 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 reduce 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).
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*)	A dwelling has sufficient access to ventilate the dwelling through the openable windows.
Height of ventilation inlets > 1800mm	The preferred height of the ventilation inlets is higher than 1800 mm to prevent draft or discomfort from the inlet air.
Separation of kitchen and the living room	Prevents smell from food or from the furnace to enter the 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. This 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.
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 ventilation the building through the windows, the preference is to have multiple windows in different orientations or locations for each residential area.
Presence of windows in residual area's (toilets, hallways)	It is not mandatory for these rooms to have openable windows. For the air quality it is preferred that these rooms also have access to openable windows. This helps to increase the ventilation rate of these rooms when required.
Insulation material not 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.

Evaluation	
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 CO2 regulated for each exhaust point

9 Moisture problems related to the structure.

Main documents	
The assessment to restrict problems with moisture in the structure are based on two parts. The first part is whether the occupant has complains or problems with structural damage as a result of moisture. 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 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 advices. *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 (Normcommissie 351 074, 2015)	Mandatory
Buildings physics handbook part 2 - heating, ventilation and cooling (Bakker, F.E ; Schellen, Henk; Hak, 2008b)	Optional
Future documents	
NEN 2778 – Thermal bridge calculation	Optional

* Advice in accordance with the regulations

Parts considered in *WoonConnect*'s 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.
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.
Does the occupant have problems with leakages?	*WoonConnect* ask occupant if they are having problems with leakages and where these are located.
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.
Insulation	Insulation helps to prevent thermal bridges when applied correctly. New regulations also require that there are preemptive moisture 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 wooden beams. This can cause problems over a longer period of time
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 rot of the wood.

Evaluation	
Label	**Threshold requirements for structural moisture problems**
F	• The occupant states that he has problems with moisture, leakages or flooding as a standard complaint.
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

Main documents	
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). As input, the same documents are used as for ventilation.	
Main documents	**Dutch building code**
NTA 8778: Harmonized Conceptual Framework – indoor environment in residential buildings. (Nederlands-Normalisatie-instituut, 2012)	Optional
NEN 1087: Ventilation in buildings – Determination methods for new estate (Normcommissie 351 074, 2006)	Mandatory
NEN 8087: Ventilation in buildings – Determination methods for existing buildings (Normcommissie 351 074, 2001)	Mandatory
Nen 2778: Moisture control in buildings (Normcommissie 351 074, 2015)	Mandatory
Future documents	
Hambase model (Wit, 2009)	Optional

Parts considered in *WoonConnect*'s assessment	
Building/system part	**Description**
Are there any moisture of leakage problems present?	Before being able to improve the indoor air humidity, moisture or leakage problems have to be resolved first as these provide an uncontrollable source of moisture production.
Ventilation system and air change rate	The ability to add fresh air more rapidly (1.3 and 1.6 times regulations). This ensures that moisture is removed more quickly
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. This 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.
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 has sufficient access to ventilate the dwelling through the openable windows.
Height of ventilation inlets > 1800mm	The preferred height of the ventilation inlets is higher than 1800 mm to prevent draft or discomfort from the inlet air.
Windows in different building	To improve the ability to ventilation the building through the windows, the

orientations	preference is to have multiple windows in different orientations or locations for each residential area.

Evaluation	
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.

Main documents	
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 (Huurcommissie, 2017)	Yes
Future documents	
Woonkeur (SKW Certificatie, 2015)	Yes

Parts considered in *WoonConnect*'s 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	A larger size of the residual area's 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.

Evaluation	
Label	**Threshold requirements to improve usability**
F	• Combined surfaces for residential area < 30m² • Bathroom area < 3 m² • Combined surfaces for residue area < 10 m² • 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 m² • Bathroom area >= 3 m² • Combined surfaces for residue area >= 10 m² • 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 m² • Combined surfaces for residue area >=30 m²

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