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Deliverable 3.12

Report on user-centric approach for the design and evaluation of smart buildings

Lead authors: Olivia Guerra Santin (TUE)

Co-authors/contributors: Marleen Spiekman (TNO), Vera Lange (HAN)

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EXECUTIVE SUMMARY

This report presents a unified user-centric approach for the design, evaluation, and operation of smart buildings, developed within the Brains4Buildings (B4B) project. While smart buildings increasingly rely on automation and data-driven control to improve energy efficiency and sustainability, insufficient consideration of occupants' needs, preferences, and behaviours can lead to dissatisfaction, discomfort, and reduced system effectiveness. Research consistently shows that occupants' comfort and satisfaction are strongly linked to their sense of control, understanding, and participation in building systems.

The project addresses this challenge by integrating occupant experiences into building design, performance evaluation, and control strategies. Five complementary solution areas were developed: (1) methods for collecting user self-reported data, (2) incorporation of user feedback into building performance evaluation, (3) behavioural models based on building and occupant data, (4) personalised thermal comfort models for control and fault detection, and (5) design and evaluation frameworks for user-building interfaces.

Multiple self-reporting methods were investigated, ranging from anonymous tools (vote boxes and QR codes) to personal tools (comfort apps and smart watches). Anonymous methods proved effective for large-scale building performance assessment due to their low participation threshold, while personal reporting enabled richer data collection suitable for personalised comfort modelling and building control. Each method has distinct strengths and limitations, highlighting the importance of selecting tools based on evaluation goals and managing occupant expectations to sustain engagement.

User self-reports were successfully integrated into building performance assessment through the Indoor Climate Label, which combines subjective comfort data, sensor measurements, and building characteristics to generate an overall indoor climate score. This approach enables real-time evaluation of comfort and health at building or zone level and supports benchmarking and improvement planning for owners, tenants, and facility managers.

In relation to control, the project demonstrated that personalised thermal comfort models based on self-reported data outperform traditional Predicted Mean Vote (PMV) models. Machine-learning models improved comfort prediction accuracy, supported fault detection and diagnosis, and enabled more flexible energy management by identifying acceptable comfort-preserving temperature deviations. Importantly, these models distinguish between system faults and individual comfort preferences, reducing unnecessary interventions.

The project also examined user-building interfaces through the lens of self-determination theory, emphasising autonomy, competence, and relatedness. Findings show that occupant satisfaction increases when interfaces provide meaningful control, clear feedback, and support collective use. A set of design dimensions and practical guidelines was developed to evaluate existing interfaces and guide new designs. A case study at the Philips Campus illustrated that even poorly designed interfaces can be significantly improved through well-designed manuals and usability testing.

Overall, the B4B project delivers a comprehensive, validated user-centric framework that complements sensor-based approaches. By integrating occupant feedback, personalised models, and psychologically informed interface design, the framework enables healthier, more comfortable, and more energy-efficient smart buildings while strengthening trust and engagement between users and building systems.

Deliverable 3.12: Report on user-centric approach for the design and evaluation of smart buildings

In this task, the user-centric design and evaluation approach was defined, with the main goal to inform practitioners on validated methods to incorporate the user needs and preferences into the design of systems. The results and different methodologies, models, algorithms and approaches developed and tested within WP3 are compiled into one single unified approach.

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1 INTRODUCTION

Smart buildings offer many opportunities for more sustainable and healthy buildings. On the one hand, from the point of view of building owners and facilities and building managers, smartness may translate into more efficient control and maintenance, and more possibilities for using renewable energy sources. On the other hand, for the building occupants, **smartness** may translate into more comfortable and healthy working environments, which may be linked to increased productivity and satisfaction. However, as buildings become smarter, they also tend to be more automated. While some smart building strategies assume that a smart **automated** and data-driven control system would result in better indoor environments for occupants, others actively intend to **remove control** from building occupants, in order to reduce behaviour (building control) that are unexpected or (energy) inefficient. However, occupants' behaviour and comfort preferences vary too much among building occupants for smart systems to predict (Zeiler et al, 2014).

Recent research has shown that occupants' satisfaction and comfort is related to the degree of control or participation that the users have on their living/working environment (Levin, 2003). This control can also be indirect.

The need for more efficient and flexible buildings has also increased systems and interfaces complexity, which is the reason for increasing automation. However, fully automated climate systems often result in a high number of complaints from occupants after their agency (actual control to influence their environment) has decreased.

Furthermore, research has also shown that users' adaptive strategies to achieve their required level of comfort, often defined as 'unexpected or inefficient' occupants' behaviour, are a consequence of the lack of understanding of how systems work, as well as of systems not responding to the actual needs of building occupants, and complex interfaces and systems. Examples of such strategies are setting climate systems to a higher or lower temperature than required with the objective of cooling or heating faster, or opening windows as a response to 'polluted air' when in reality, what the users feel is air dryness. In this regard, and as buildings become more automated, user-building interfaces are a key feature to ensure that the needs of the occupants are met, as well as a way to communicate effectively with them.

Thus, although one of the ultimate goals of smart buildings is to improve indoor environmental quality, the **lack of consideration of the occupants** in the design and control of the building may end up in less desirable (indoor) conditions for the user.

Within the Brains4Buildings project, various aspects of user-building interaction were investigated. **The main research questions** were:

How can the actual experiences of occupants be used to evaluate building performance?, How do we incorporate occupants experiences to the design and evaluation of buildings and buildings' systems?, How can we consider occupants behaviour in the control and management of systems?, How can we considered the personal thermal experiences and preferences of the occupants in the systems?, and How do we design better user-building interfaces that support energy efficiency, flexibility and health indoor environments?

This report summarises all knowledge developed in the B4B project to make buildings and interfaces more user-centric. The **strategies and solutions** developed within the project were:

1) User self-reporting methods, intended to different types of evaluation goals.
2) Incorporation of users self-reports in building evaluation.
3) Compilation of models to predict occupants behaviour for building control.
4) Personalised thermal comfort models for building control and FDD through user self-reported data.
5) The role of control and feedback in interfaces for user satisfaction and health in smart buildings.

All these solutions correspond to a complete picture of a user-centric smart building.

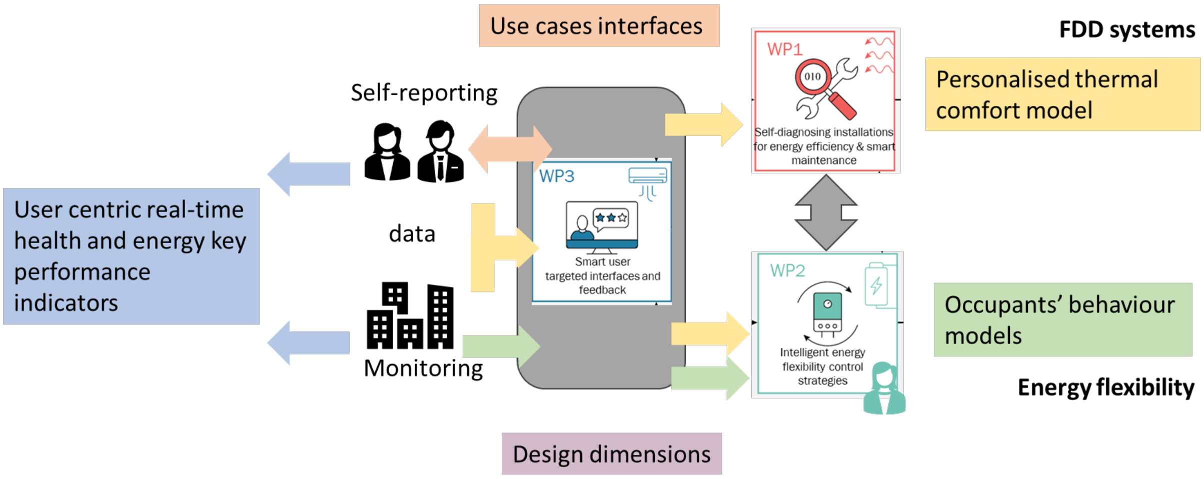


Figure 1 Conceptual figure of a user-centric smart building

In following parts of this report, we summarise the findings of these activities, and link to relevant publications and resources.

2 THE ROLE OF USER SELF-REPORTED DATA: A REVIEW OF METHODS USED IN THE B4B PROJECT

In recent years, the role of self-reported data has become increasingly important in the field due to advances in sensors, meters, and IoT. While self-reporting data are known to have some constraints (such as subjectivity and recall bias), their role in building automation, management and control could increase not only the energy efficiency and flexibility in building, but also build trust among occupants towards the systems, and increase satisfaction in the workplace.

Therefore, within the Brains4Building project, we investigated the role of self-reported data in relation to personalised thermal comfort models for building control and management, as well as in the evaluation of building performance. In this section, we present an overview of the different methods to obtain self-reported data within the project, and summarise the results on the application of self-reported data on building control and management, and building performance.

2.1 Anonymous reporting: QR codes and Vote boxes

Two data collection methods were developed to continuously measure perceived air quality, thermal comfort, light, noise, and control in the workplace, on a 5-point scale. The goal was to determine which methods are more effective at encouraging occupants to self-report for long periods of time, while being minimally intrusive.

The first method developed was a five-point vote box, combined with a short question related to one aspect of indoor quality (Figure 2). Only one question could be added through this method, so if more than one parameter needs to be investigated, the question must be manually changed in the voting box. The vote box, similar to those currently used in airports, allows any visitor to quickly give feedback on one specific question.

The second method consisted of an app for scanning a QR code, developed by Unica (Figure 3). This app asked four questions related to perceived comfort of air, noise, light and temperature.

The B4B study focused on how comparable these two methods were with a traditional survey, which method is better at engaging the occupants to contribute with self-reports, and how reliable these methods are by investigating how the collected data relate to environmental data. The full reports can be found in Deliverable 3.01.

The question behind the QR code was changed every two weeks. A specific aspect of indoor climate was investigated each time. For example, How satisfied are you with the noise and acoustics in your workplace?

The following questions were included on the QR code app:

- How do you feel now?
- How do you like this workspace? A five-point scale was used to rate the following: Temperature, Noise level, Air quality, and Light.
- Are there any other things to mention? A space for occupants to give optional further information was provided.

Figure 2. Left: Box vote and QR code locations during testing. Right: Vote box and question (Deliverable 3.01, Jacobs et al.).

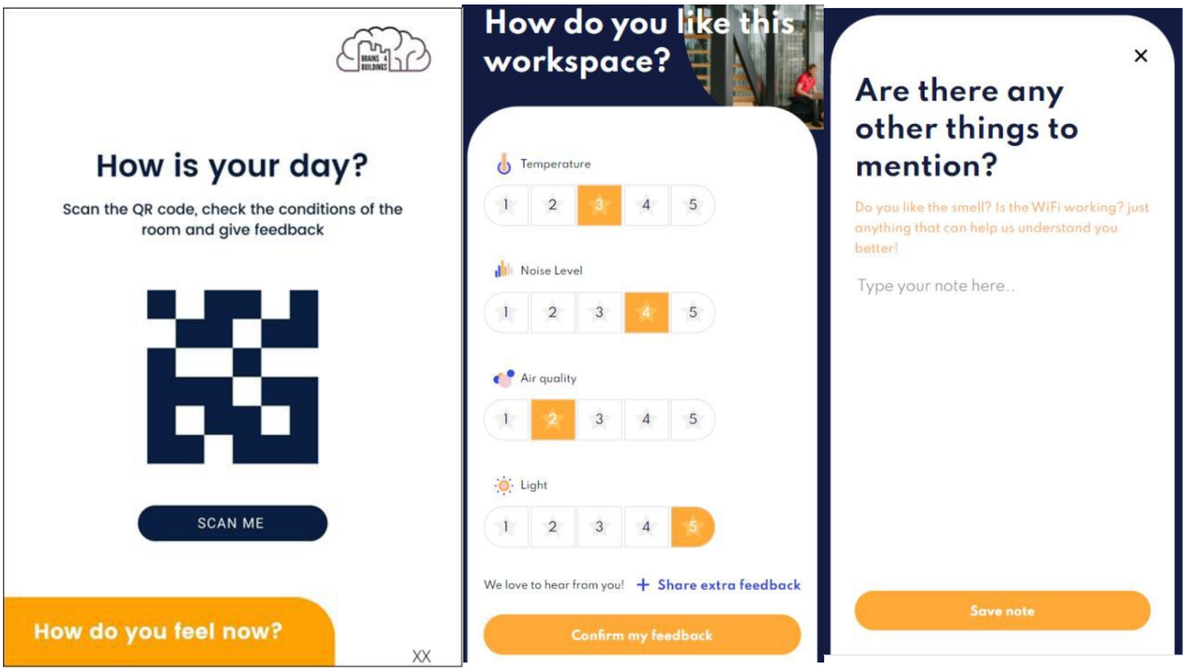


Figure 3. Left QR code, right: two screenshots of Unica's five-point scale comfort app after answering the questions (scale: 1= uncomfortable, 3 = neutral, 5 = comfortable). (Deliverable 3.01, Jacobs et al.).

2.2 Personal reporting: comfort app and smart watch

Within the B4B project, the possibilities to obtain personal feedback from occupants was also investigated. Two different methods were used: via a comfort app based on a previously developed personal reporting tool, and the implementation of the same questions in a smart watch (Upasani et al., 2024). The goal of this research was to investigate the possible incorporation of personal self-responses on personalised comfort models, as well as which methods is less intrusive for occupants to employ. The full report on these methods can be found in Deliverables 3.05, 3.07.

The questions included in the app are shown in Table 1. Figure 4 shows the main screens of the app.

Table 1. Questions included in the app.

Question	Reasoning
How are you feeling today?	Asked to capture the mood of the occupants at the time of self-reporting.
How did you come to the HHS?	Riding a bike or walking will lead to a higher metabolic rate, affecting the occupants' thermal comfort.
Where are you located?	This information is needed to define the location of the self-report.
How long have you been here?	This question is asked to determine whether the person has already acclimatised to the room's conditions (as contrary of for example coming from outside).
How hot or cold do you feel?	A 7-point scale for the occupant to report their thermal comfort from hot to cold.
Do you want to be warmer or cooler?	The thermal preference of the user in asked on a 3-point warm, OK, and cool. This question is asked to make a difference between the thermal sensation reported in the previous question, and the satisfaction/agreement with the thermal sensation.
What do you think about the air quality?	The user can report if they feel the air quality as Humid, Smelly, Suffocating, Dry or All good. Humidity and air quality are combined into a single question because some people find it difficult to differentiate between them.
Have you eaten recently?	The time duration after consumption of food is reported, since this affects metabolic rate.
Have you had a hot or a cold beverage recently?	Beverage consumption is sometimes to cope with discomfort in indoor environments.
What are you wearing?	To know the clothing value of the occupant at the time of self-reporting.

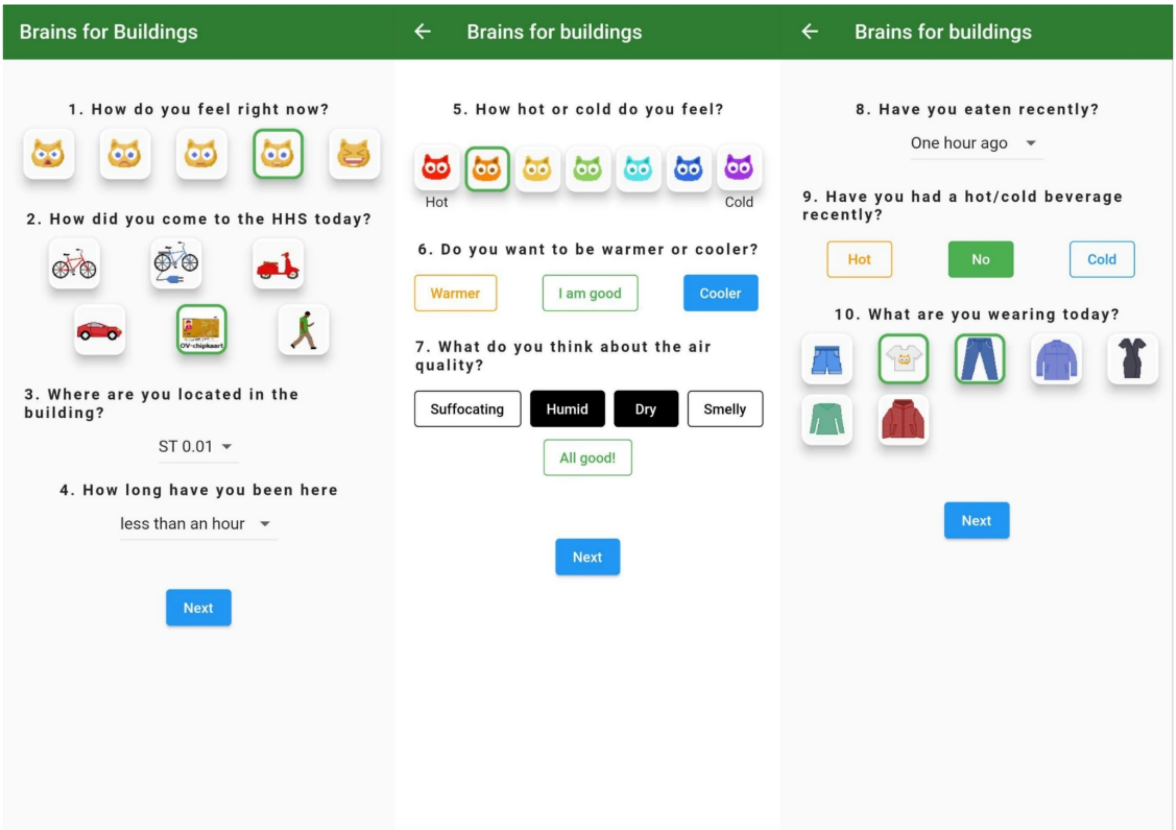


Figure 4. Screenshots of the three main screens of the comfort app (Upasani et al., 2024).

For the application of the questionnaire on the smartwatch, some questions and answers had to be modified to fit the screen. For example, the clothing question was split into two. Figure 5 shows the screens of the smart watch.

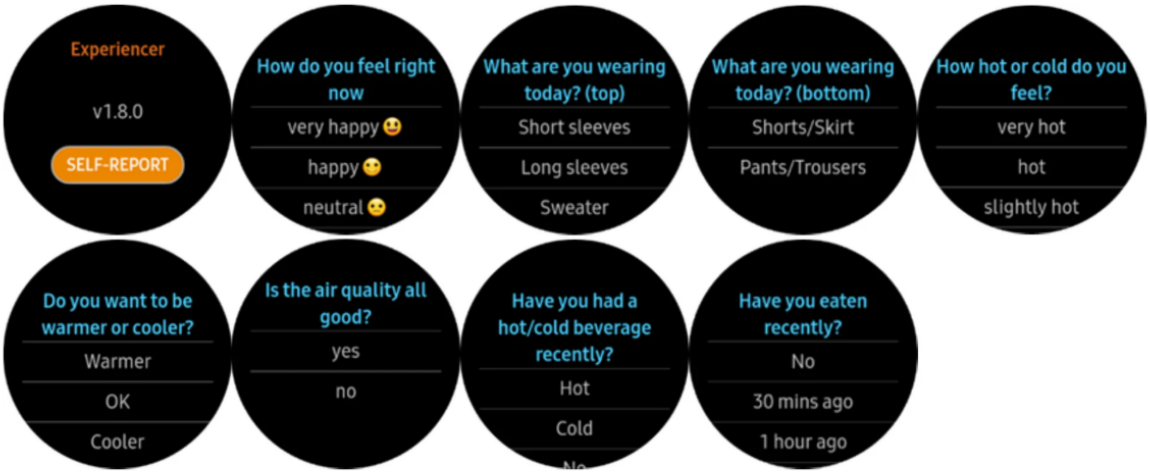


Figure 5. Screenshots of the questions applied in the smart watch (Upasani et al., 2024)..

2.3 Comparison between the methods

The anonymous and personal data collection methods have in principle different goals. The anonymous data is intended to be used in a building evaluation tool. For the performance evaluation of the building, it is not necessary to know who is giving the experience votes. This method allows for the simplification of the questions, with the benefit that more people will provide their votes, ideally for a longer time. This could be seen in the results from the testing of the QR code against the Vote Box. The Vote Box had a lower use threshold than the QR codes, since only one question was asked and it would take only seconds for the occupant to give feedback. In contrast, using the QR code requires using a mobile phone, opening the needed app, scanning the code and answering four questions. The results reported indicated that more people used the Vote Box, and for a longer period (although voting decreased with time for both methods).

On the other hand, the personal self-reporting requires more effort from the occupants. More questions are asked in the app and the watch, since part of the research also included determining how personal factors, such as mood or situational circumstances, could also affect comfort. Furthermore, since the person carries the self-control device, and thus the device is not linked to a particular space, the user also has to report their location.

In Table 2, the main strengths and weaknesses of each method, according to the reported results of the investigations, are summarised.

Table 2. Strengths and weaknesses for each self-reporting method

	Strengths	Weaknesses
Vote Box	– Lowest threshold for use. Can obtain many votes. – These type of boxes is widely use in airports and retail spaces. Thus, people are more use to them. – No privacy issues. – Ideal to be used when wanting to obtain average experiences (satisfaction, comfort), with as many participants as possible. – Ideal for large, open areas with many transients or office workers. – Best for: building performance assessment.	– Only one question can be asked. – Difficult to determine if the votes is really related to the question, or whether it refers to overall satisfaction/comfort. – The position is important. If located in common areas instead of working areas (i.e. offices), the votes given in common areas might actually reflect the working areas, where workers spend most of their time. – Votes difficult to link to measured indoor data. – Since it involves a physical device, there are limitations on how many can be deployed in a building due to costs and space.
QR code	– There is no limit on how many QR code to deploy in a building. – Flexibility to add as few or as many questions as needed. – Flexibility to add follow up questions. – Ideal to use in buildings with many induvial offices. – Best for: building performance assessment.	– Votes difficult to link to measured indoor data. – Might be a higher use threshold for people to use (accessing phone, having right scanning app, etc.). –
Comfort app	– Can track personal comfort in different spaces and over time. – Questions related to other variables affecting comfort can be included. – Ideal to use when understanding sources of (dis)comfort is essential, for example before renovations or when data will be used for building control and management. – Can be used in combination with smart watch. – Responses have been linked to indoor parameters. – Best for: building control and management.	– Users most report also in their location. – Risk that app is used outside of the working ours or other locations. – Users might forget to vote, so notifications are required, thus increasing intrusiveness. – App installation requires allowing notifications. – Different apps are needed for different phone systems (i.e. Android, Apple).

	Strengths	Weaknesses
Smart watch	Can track personal comfort in different spaces and over time. Questions related to other variables affecting comfort can be included. Ideal to use when understanding sources of (dis)comfort is essential, for example before renovations or when data will be used for building control and management. Can be used in combination with comfort app. Responses have been linked to indoor parameters. Best for: building control and management.	Users most report also in their location. Risk that app is used outside of the working ours or other locations. Users might forget to vote, so notifications are required, thus increasing intrusiveness. Since it involves a physical device, there are limitations on how many can be deployed in a building due to costs and availability of devices, or it only works when a large percentage of occupants already have a smart watch. Due to size of the screen, need to adapt questions.

As an overall weakness for all methods, occupants might think that self-reporting will lead to management actions to improve their comfort. If this is not the case, their engagement to participate in the future might be compromised. Therefore, managing expectations and being clear on what is the purpose of their participation is key to keep motivating people to give future feedback.

3 USERS SELF-REPORTS FOR BUILDING PERFORMANCE EVALUATION: THE CLIMATE LABEL

A method to assess occupants' comfort and health levels in real-time during the operational phase of buildings was developed. The method employs building monitoring data and occupants' self-reported anonymised data. This method was in a later stage, incorporated to the Indoor Climate Label from Binnenklimaat Nederland. The method includes three elements: measurement of (self-reported) subjective comfort, measurement of indoor environmental parameters using sensors, and a survey of building characteristics that can impact comfort and health. The three ratings are used to calculate a total score for indoor comfort for a whole building or a section within a building, such as a building floor. The objective of the method is to be able to evaluate complete buildings, or parts of building rented to other companies. Thus ,the method is useful, in addition to facilities managers, both for building owners and building tenants. The full description of the method can be found in Deliverable 3.02

The current version of the Indoor Climate Label uses an online questionnaire (so-called, the healthy building index tool) applied at least once per year. The questionnaire is used to collect occupants' data, on a 7-point scale, regarding their satisfaction with different indoor parameters of the workplace, as well as their own degree of control over these parameters. The questions and scale are shown in Figure 6.

Figure 6. Healthy building index tool questions (Deliverable 3.01, Jacobs et al.).

Indoor Climate

	Satisfaction						
	Very satisfied	Unsatisfied	Somewhat unsatisfied	Neutral	Somewhat satisfied	Satisfied	Very satisfied
How satisfied are you with the temperature in your workplace?	○	○	○	○	○	○	○
How satisfied are you with the air quality in your workspace?	○	○	○	○	○	○	○
How satisfied are you with the light in your workspace?	○	○	○	○	○	○	○
How satisfied are you with the noise and acoustics in your workspace?	○	○	○	○	○	○	○
How satisfied are you with the degree of control in your workspace	○	○	○	○	○	○	○

The scoring is based on a set of predefined criteria on air quality, temperature, humidity, lighting, and noise levels, as define by the Program of Requirements Healthy Offices (Boerstra, 2021). The measured indoor parameters are assessed against these criteria.

The goal of the scoring system is to assess the indoor environment of a building to identify improvement areas to increase the comfort and health of occupants, as well as to evaluate a building, or building area, against others. Figure 7, shows the relationship between the three different aspects of the method within the Binnenklimaat label, from Binnenklimaat Nederland.

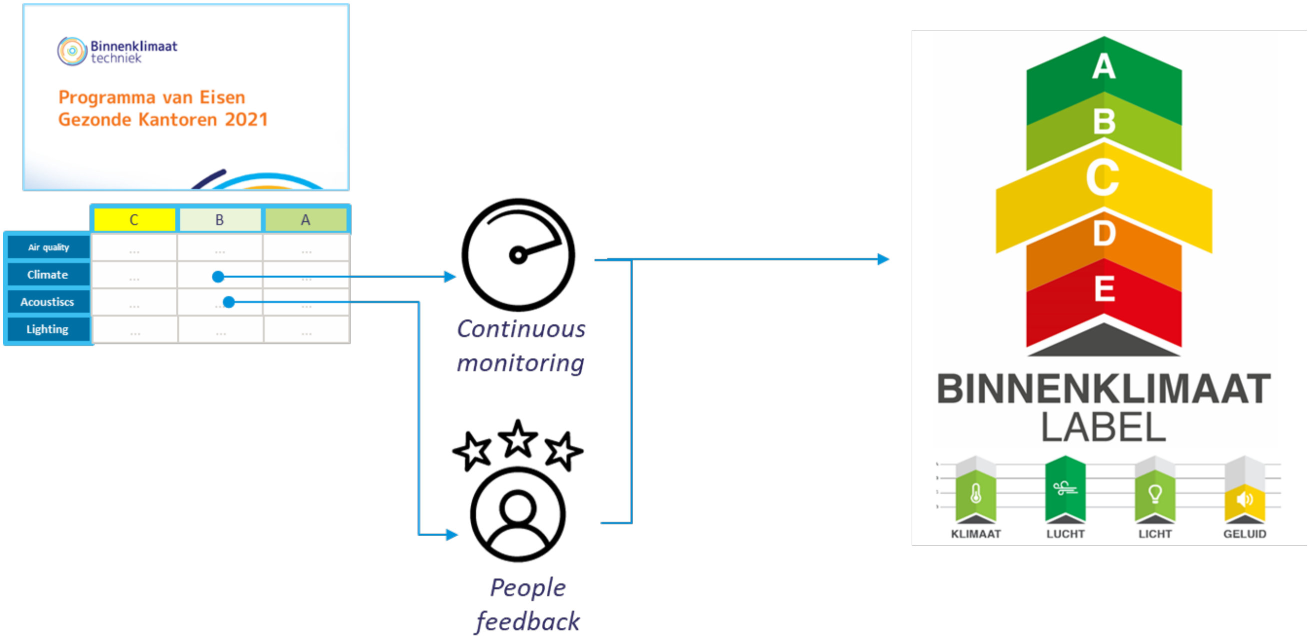


Figure 7. Binnenklimaat label components (slides B4B final presentation, W.Atmar)

4 THE ROLE OF BUILDING DATA AND OCCUPANTS' BEHAVIOUR: COMPILATION OF MODELS

The wide availability of smart meters, IoT (Internet of Things) and sensors have made possible the continuous, almost real-time, monitoring of building indoor parameters, energy production and consumption and building operation. A large amount of research has been conducted on how to use monitoring data to develop occupants' behaviour profiles and patterns.

As reported in Deliverable 3.08, occupants' behaviour in commercial buildings usually refers to the use or interaction with heating systems, cooling systems, lighting, ventilation systems and windows, and the presence of people in the building (occupancy). Diverse modelling techniques, using sensor and meters data, have been used so far to build these occupants profiles. These profiles are designed to provide a more accurate prediction of energy demand in buildings.

While these profiles can be used to predict future demand based on previous occupants' behaviour, these profiles or data cannot always be used to improve the indoor conditions of buildings, nor to identify strategies to increase the energy flexibility of buildings, for which user engagement would be required.

5 USER SELF-REPORTED DATA TOWARDS PERSONALISED COMFORT FOR BUILDING CONTROL MANAGEMENT

In this activity, we looked further into how personal self-reported data can be used as integral part of FDD and smart control and management systems. The objectives were to develop personalised comfort models based on self-reporting data, and to develop a data-driven visualisation strategy for facility managers to take timely and effective decisions.

This work explored the possibilities and limitations of integrating occupant-related data to fault detection and diagnosis systems. For this, self-reporting and sensor data was used to determine the occupants' comfort, taking into account personal and subjective comfort preferences, as well as indoor conditions data. A machine-learning model based on self-reporting of thermal comfort was developed. The model predictions showed to be more accurate that those based on the Predicted Mean Vote model, the current method to establish thermal comfort in office buildings (Upasani et al., 2024). Furthermore, the model also allows for determining which personal and contextual variables have more influence on thermal comfort. More details on the personalized comfort model can be found in D3.05.

The personalized thermal comfort prediction can be used, within FDD systems to determine a discrepancy between a current thermal vote or complaint (that could be understood as a fault in the system or in a sensor), and the (historical) thermal comfort of the specific user. Thus, for example, users who routinely complain of feeling cold, will be identified as a discrepancy between actual temperature and thermal comfort preference, and not as a fault in the system/sensor. Figure 8 shows the research framework for the comfort model.

Furthermore, the identification of personal and contextual variables influencing thermal comfort can be used by the facilities manager to make more sound decisions in the management of the building systems. The goal was to determine data-driven strategies to support flexible energy management by providing feedback to the facilities managers. This is addressed through feedback mechanisms, based on interpretable machine learning to deliver information flows from occupants to facilities managers (and vice versa), to decrease the risks of occupants' discomfort and dissatisfaction and to provide more information and possibilities for the control and management of the buildings. The interpretable machine learning models help users visualize how different factors influence thermal comfort based on the ML-based personalized thermal comfort model, which integrates user characteristics, occupants' behaviour, and environmental factors. This model supports energy flexibility by identifying acceptable deviations in temperature settings that maintain comfort while improving efficiency. More details on the data-driven visualization strategy can be found in (Upasani et al, 2025).

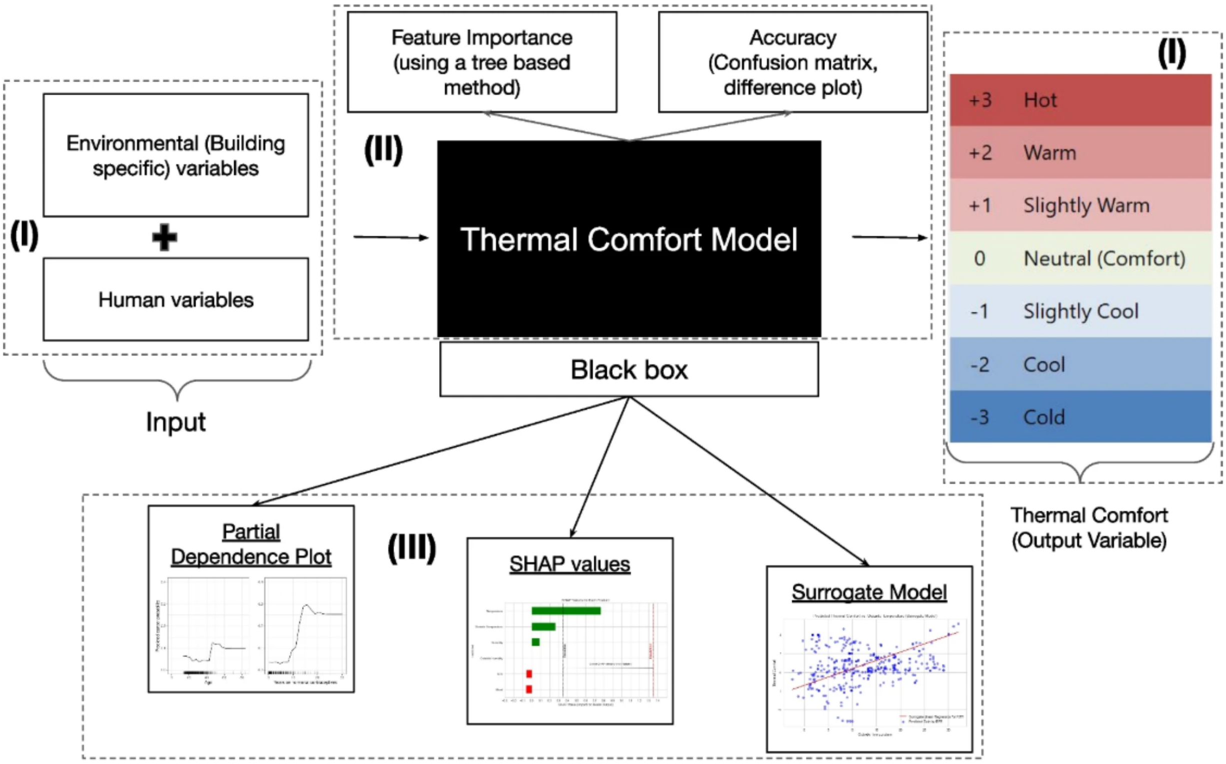


Figure 8. Research framework for ML-based thermal comfort models (Upasani et al., 2024)

6 FEEDBACK AND CONTROL IN BUILDING INTERFACES TO INCREASE SATISFACTION. A DESIGN AND EVALUATION FRAMEWORK.

Within the B4B project, we investigated the relationship between interfaces and building characteristics, as well as the satisfaction of occupants. Based on the literature, a study was developed based on self-determination theory. Self-determination theory tells us that satisfaction and well-being (and other human needs such as motivation, performance, etc.) is influenced by three basic psychological needs: autonomy, competence and relatedness. Autonomy is defined as the need to feel in control of one's own choices and behaviour. Competence is defined as the need to feel effective and masterful in one's everyday practices. Relatedness is the need to feel connected to and cared for by others. These have been applied to the field of building performance as the need to be in control of daily life building control, to have the capacity, skills and knowledge to act as desired, and as the social practices revolving around group control.

In this research, a questionnaire was developed and applied to the occupants of eight buildings in the Netherlands. The results indicate that all psychological needs: autonomy, competence and relatedness influence the satisfaction of the occupants with their working environment (Upasani et al., in progress).

These psychological needs can be translated into specific characteristics of user-building interfaces. Autonomy can be translated into the control that the user has over the building systems and to make changes to regulate their (working) environment; competence can be translated into the occupants understanding on how the building systems and the interfaces work through correct, effective and accurate feedback from the interface to the user; and relatedness can be translated into the group dynamics occurring in working environments to achieve collectively, a comfortable environment for all. However, most user interfaces do not support these needs, as can be seen from the results of the B4B and other projects. Therefore, a framework has been developed that supports the design and evaluation of interfaces, starting with a common language through design dimensions, and defining guidelines to develop user-building interfaces. The guidelines are intended to be used by designers and developers of buildings, systems and interfaces.

A participatory approach in the project Living Labs was conducted to gather insights into the users needs. The results from the investigation (represented graphically in Figure 9) led to the development of the design dimensions.

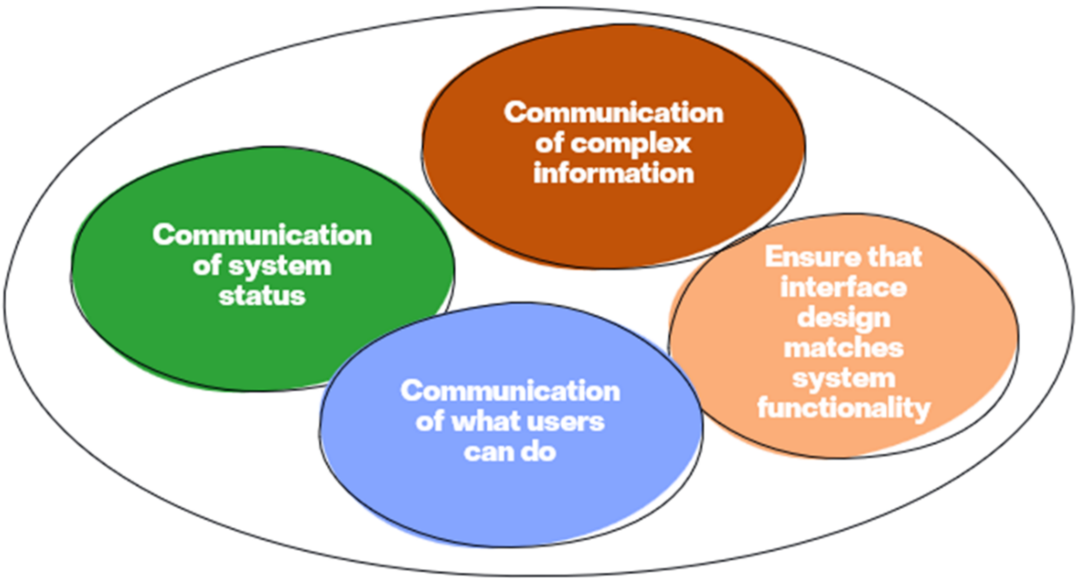


Figure 9: Results from participatory research in Living Labs

The design dimensions focused on feedback given from the system to the user (occupant or facility manager), and the control given to the occupant. The dimensions can be used firstly to evaluate existing interfaces, to select a suitable interface and to generate new interfaces. The dimensions are seen in Figure 10. Some dimensions are defined as binary (e.g. presence/absence of a feature), and others as spectrum. The explanation of the full design dimensions and their development can be found in D3.10.

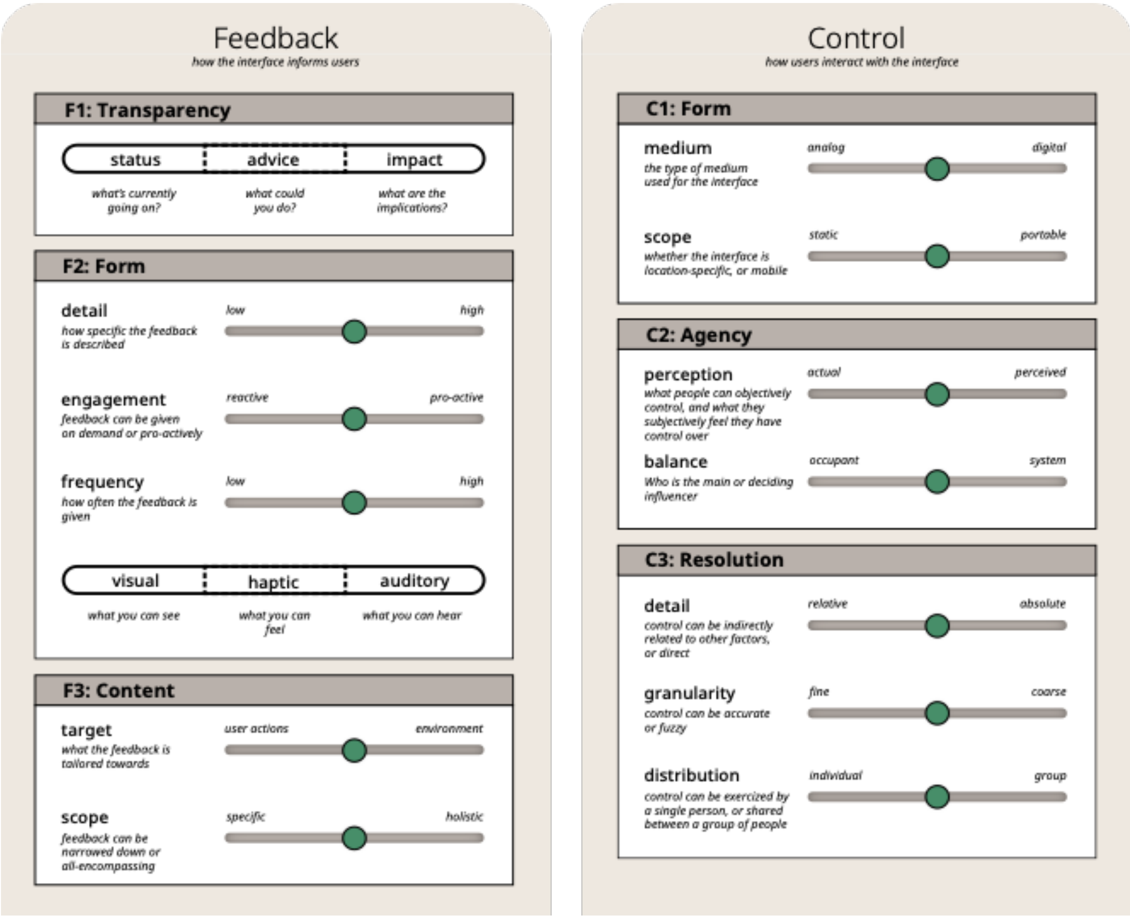


Figure 10: Design dimensions for user-building interfaces

The explanation of the full design approach and an applied example within the B4B project can be found in D3.11. A workbook (Figure 11), explaining how to practically apply the design dimensions in real life projects, is included in the Deliverable.

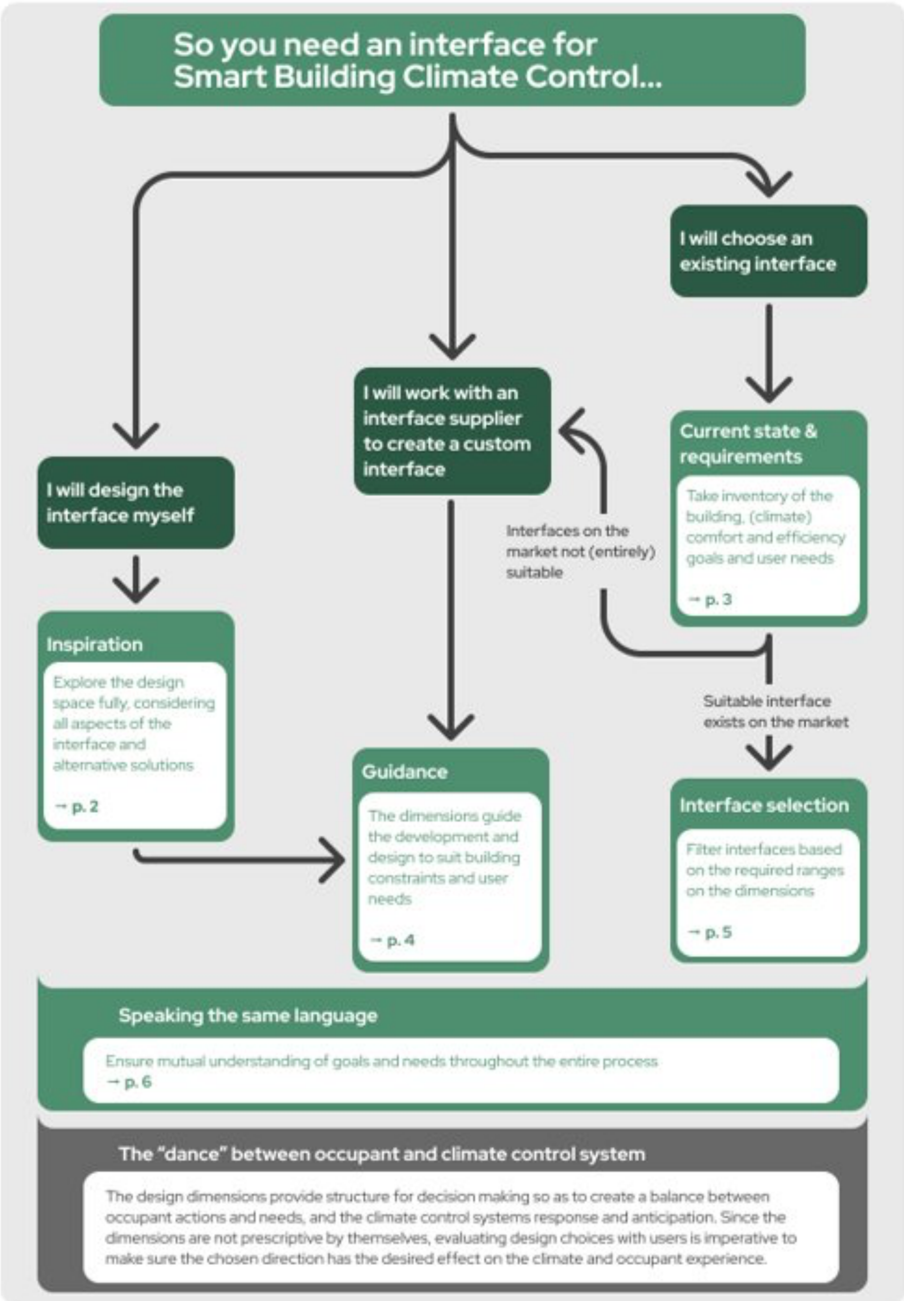


Figure 11. Screenshot of Design Dimensions workbook

An example on how Built Environment students from TU/e employed the design dimensions to re-design the interfaces of the TU/e Atlas building can be found in (Guerra-Santin et al, 2025). Examples of the re-designed interfaces are shown in Figures 12 to 14. Given the clear connection between the design dimensions on feedback and control with the psychological needs competence and autonomy, we have concluded that, self-determination theory is a suitable theory to understand and investigate user-building interfaces. Although dimensions focusing on the third aspect of the theory: relatedness were not separately designed (they are included within other dimensions for example Control > Distribution), it was clear during the design exercises with the consortium partners, that some aspects related to group dynamics should be included in interfaces (see Figures 12 and 15). Thus, further research would aim at the development of such dimensions.

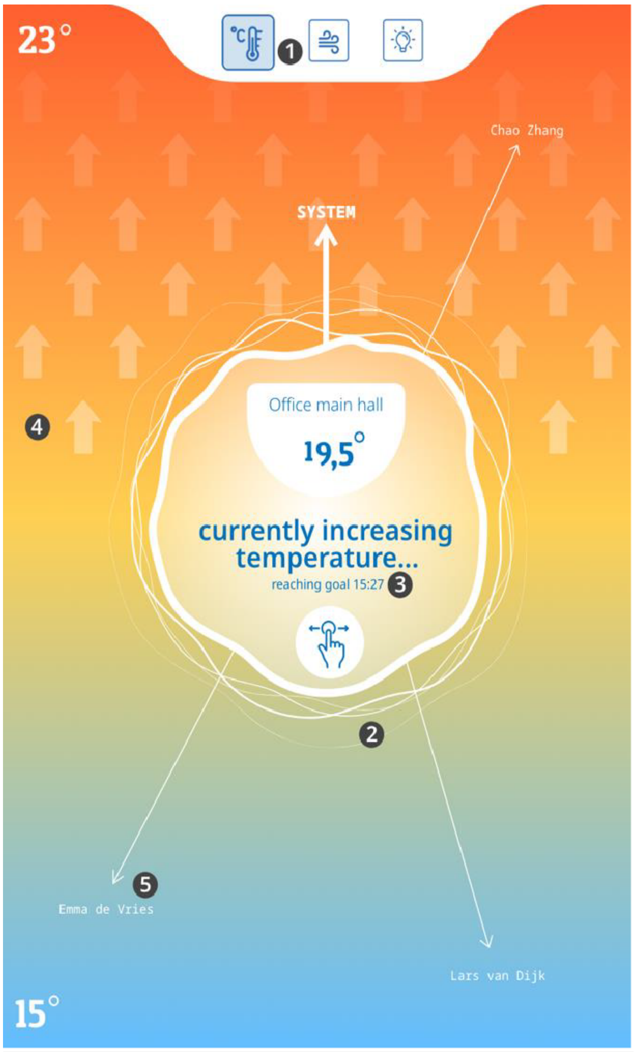


Figure 12. Redesigned interface for Spectral by HAN, showing the temperature preferences of different users (Feedback/ Competence and Relatedness), the current temperature, the action taken by the system, and the time to reach the goal.

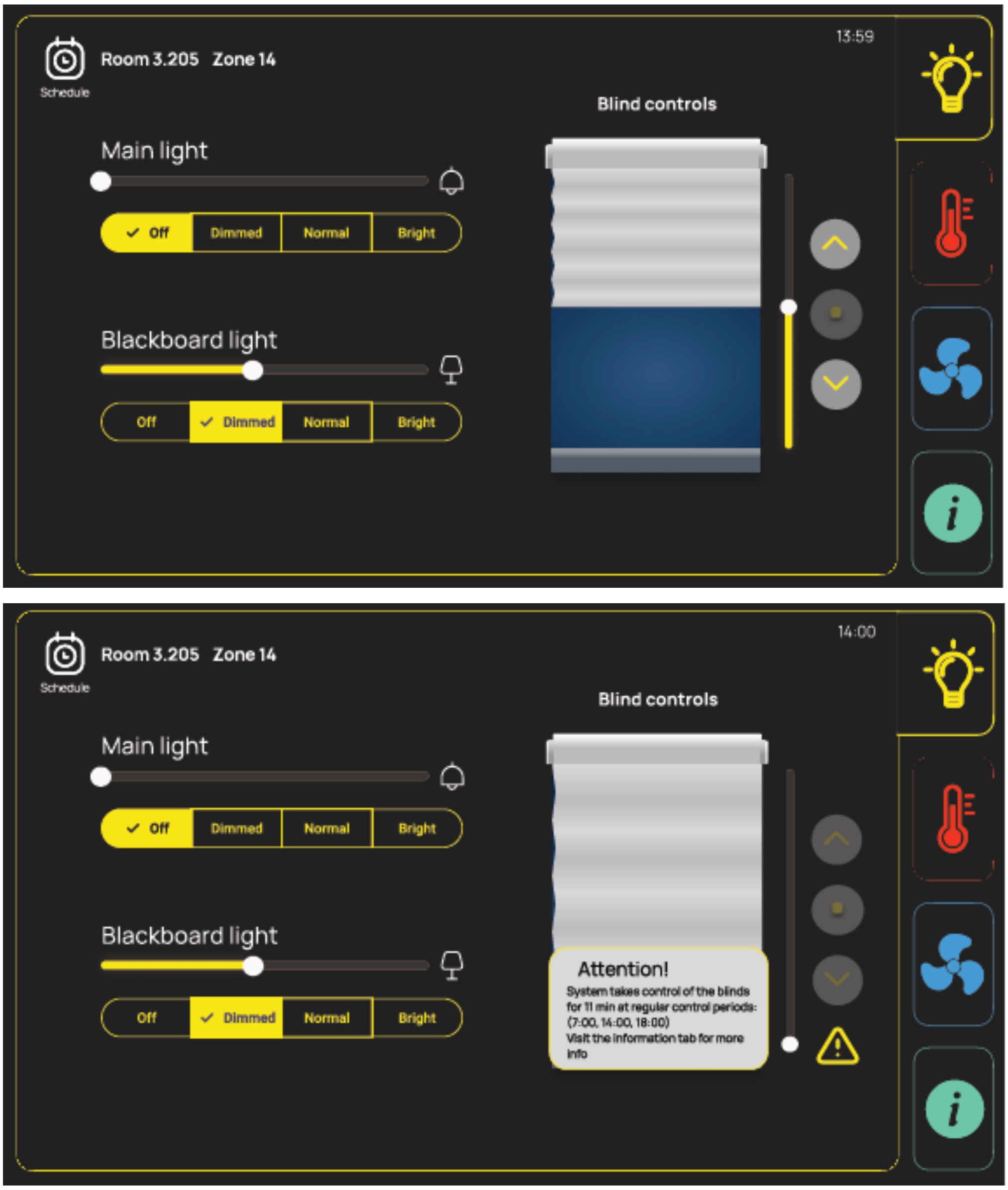
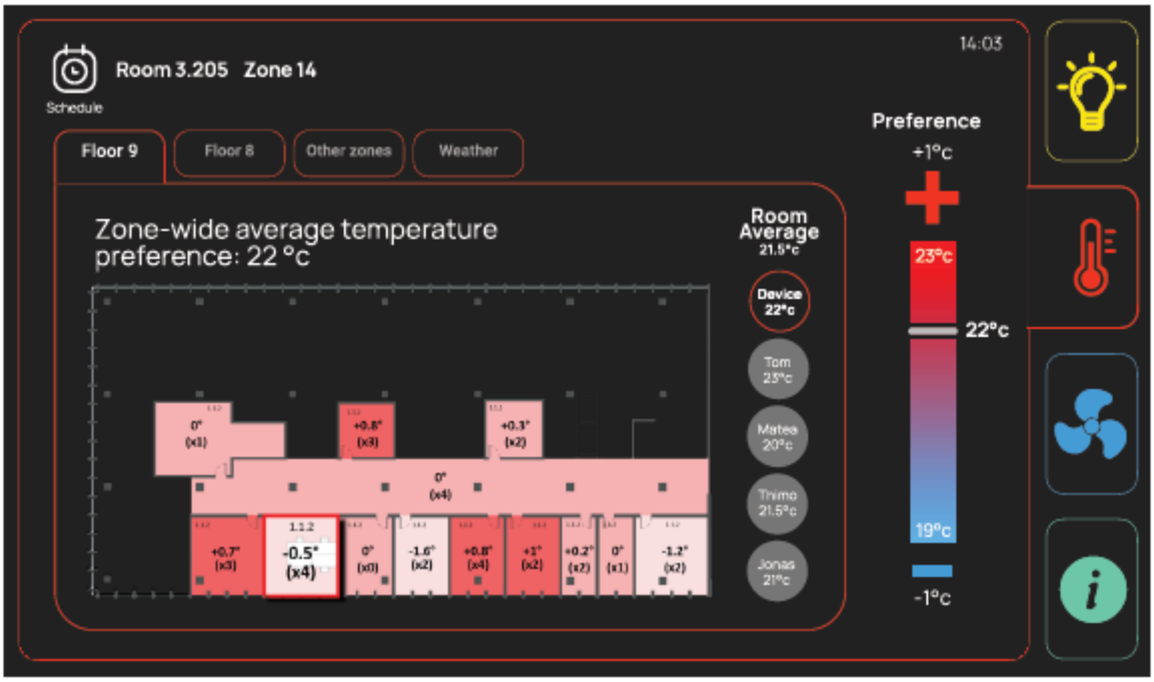


Figure 13. Redesigned Atlas interface by TU/e students, showing the current status of the blinds, and informing users when an action is taken automatically by the system (Feedback/Competence).



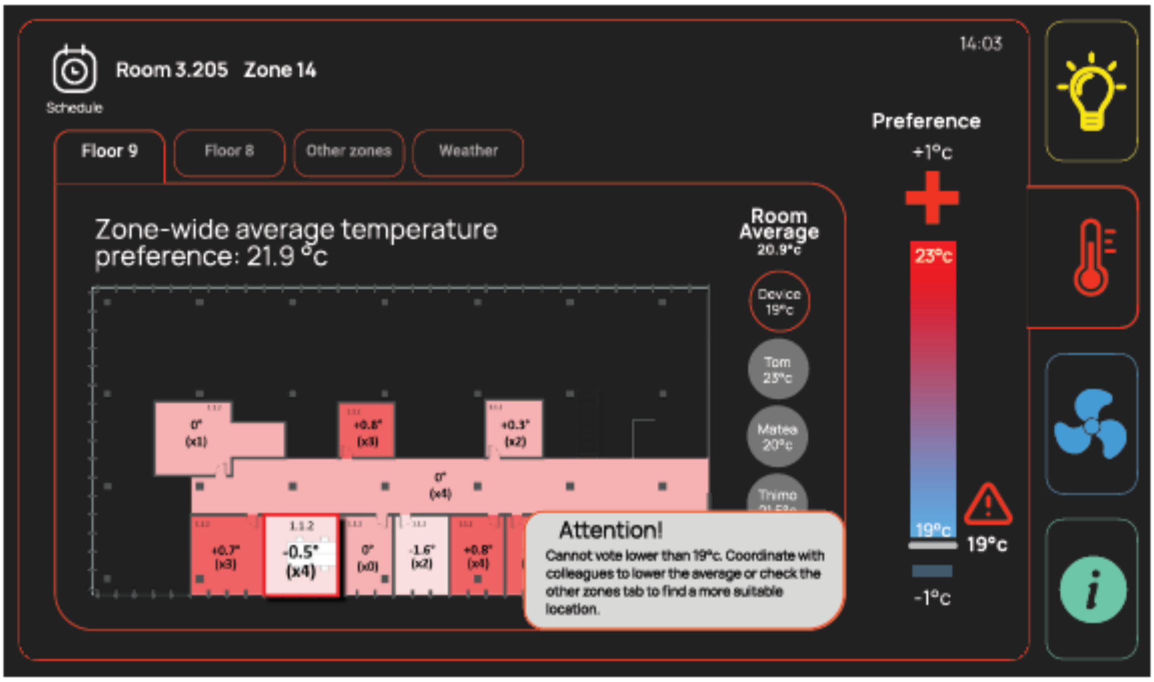


Figure 14. Redesigned Atlas interface by TU/e students, showing the current room temperature, the average temperature preference of the occupants, and feedback given when users preferences cannot be satisfied (Feedback/Competence).

Figure 15. Redesigned Atlas interface by TU/e students, showing the screen where occupants can vote their preferred temperature, and showing the current room temperature, and historical data (Autonomy/Control, Feedback/Competence).

To conclude, we would like to stress that one of the main takeaways from the work in this project is the fact that a standard interface for all buildings cannot be defined. The developed dimensions represent aspects of the interface that should be considered. They are not meant to stipulate an ideal interface. Given the large variety of building typologies, building systems and building occupants, the most suitable interface for a building should be defined based on the requirements for each case, together with relevant stakeholders.

In the following section, we present a case study in a Philips building. This case study demonstrates the application of the design dimensions to improve the use of existing interfaces in cases when the interfaces cannot be modified.

7 USE CASE BUILDING INTERFACES PHILIPS CAMPUS

A study on energy flexibility acceptance among office employees at the Philips Campus in Best revealed that many building interfaces in their buildings were poorly understood and therefore underused. Despite frequent discomfort with the indoor climate, employees often missed the opportunity to improve their comfort through manual control. Interestingly, even at a campus with a highly educated workforce, many struggled to operate the building systems via the available interfaces. This made the Philips Campus a compelling case for examining how interface comprehension can be improved to support both comfort and energy flexibility.

7.1 Aim and Method

Since the interfaces for indoor climate could not be replaced, we chose not to redesign them but to develop simple manuals that could be placed next to the interfaces to support users. While these manuals directly improve system use at the Philips Campus in Best, our main goal was to gain practical experience in studying user-system interaction and to better understand what tends to go wrong in everyday use.

The interview protocol, manuals, results and conclusions are described in detail in Annex 1. A short summary is given below.

The study aimed to evaluate the usability of three different interfaces for building indoor climate control systems that are used at the Philips Campus in Best. The research was conducted in two phases:

Interface usability without manual

Five participants, who were not familiar with the interfaces, were asked to perform tasks via predefined scenario's (e.g., adjusting temperature, turning off lights, reducing ventilation) using each interface without a manual. The goal was to assess the initial intuitiveness and user understanding of the interface.

Interface usability with manual

Twelve new participants (organized in an A/B testing set-up) repeated similar scenarios, but this time with access to a manual. Two different versions of the manual were created for each interface to test the impact of documentation quality on usability. Participants were asked to evaluate both the interface and the manual.

Data collection involved semi-structured interviews after each scenario, focusing on what worked well, what caused confusion, and how participants perceived ease of use. Observations were summarized and categorized into advantages, disadvantages, and recurring issues for each interface. Additionally, feedback on the manuals was gathered to identify strengths and weaknesses in instructional design.

7.2 Results

The analysis revealed several key findings (also see Annex 1 for illustrations of the interfaces and manuals).

Interface usability

The simple, brandless interface was generally perceived as user-friendly; however, participants encountered difficulties interpreting relative temperature values (e.g., “0.0” versus “-1.5”) and noted the absence of feedback following user actions.

The Honeywell simple interface introduced confusion, particularly regarding the confirmation process and the interpretation of specific icons. Many users mistakenly assumed the interface was a touchscreen, as the function buttons were not intuitive. Participants expressed a preference for buttons with single, clearly defined functionalities.

The Honeywell complex interface presented the greatest usability challenges. Participants reported that navigation required an excessive number of steps, and confirmation of successful actions was insufficiently clear. Additionally, the meanings of various icons were ambiguous. Users consistently indicated a preference for interfaces with straightforward navigation that enable rapid task completion.

Impact of user manuals

Manuals improve task completion rates, but the effectiveness of the different manuals varied.

The simple brandless interface required minimal explanation, concise guides were sufficient to enable effective use.

The Honeywell simple interface also required limited explanation. However, clarification of icon meanings and explicit feedback regarding successful actions were necessary to improve usability.

The Honeywell complex interface presented significant challenges and necessitated detailed, visual, step-by-step instructions. Users expressed a clear preference for visual diagrams over text-heavy manuals. Furthermore, the use of cross-references within instructions was discouraged, and overly technical terminology led to confusion and uncertainty among most users.

Methodological insights

A/B testing highlighted the importance of iterative design. It is challenging to design a manual that is understood by the majority of users. It became evident that a badly designed interface can still be used efficiently when supported by a clear manual. Therefore it is recommended to extend usability testing of the interface with

A/B testing highlighted the importance of iterative design in developing user manuals. It is challenging to design a manual that is understood by the majority of users. Achieving broad user comprehension remains challenging, primarily due to the need for clear terminology and anticipating support requirements in combination with intervention moments. The findings indicate that even a poorly designed interface can still be operated efficiently when supported by a well-constructed manual. Consequently, it is recommended to extend usability testing of the interface with supporting materials, such as user manuals. This approach can substantially enhance the overall user experience.

7.3 Conclusions of the case study

The study demonstrates that interface design has a strong influence on usability and the need for supporting documentation. While simple interfaces can be operated intuitively or with simple visual support, complex systems require comprehensive, well-structured step-by step manuals to ensure user success. It is interesting how users clearly prefer simple manuals, while more complex manuals seem to provide better support. The key seems to be finding the middle ground. Furthermore, the research underlines that designing effective manuals is a non-trivial task, demanding attention to clarity, visual aids, and user feedback.

8 CONCLUSIONS

The following conclusions have been drawn from the research activities in WP3. These are:

- The Brains4Buildings project demonstrated that integrating occupants' experiences, preferences, and behaviours into design and evaluation processes leads to healthier, more comfortable, and more efficient indoor environments.
- While sensor data remains critical, occupant feedback provides insights into subjective comfort and satisfaction that cannot be captured otherwise. Methods such as vote boxes, QR codes, comfort apps, and smart watches each serve distinct purposes, from large-scale building performance evaluation to personalized comfort modelling. For this, occupants must understand the purpose of self-reporting and how their input will be used. Without transparency, participation declines and trust in smart systems erodes.
- Regarding the use of self-reporting data as input for personalized comfort models, personalized comfort models seem to outperform traditional approaches. Machine learning models based on self-reported data proved more accurate than the Predicted Mean Vote model, enabling smarter fault detection, diagnosis, and energy-flexible management strategies.
- Occupants' psychological needs (autonomy, competence, and relatedness) must be supported through building interfaces. Clear feedback, meaningful control options, and consideration of group dynamics are key to sustaining engagement and well-being.
- The project's outcomes (self-reporting methods, behavioural models, personalized comfort tools, and interface design guidelines) form a comprehensive user-centric approach. This framework provides practitioners, designers, and facility managers with validated strategies to balance energy efficiency, flexibility, and occupant satisfaction.

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