D2.1

Interactions strategies between users and smart buildings control systems

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Deliverable Lead Partner	TUD
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List of Abbreviations

Acronym	Description
BMS	Building Management System
BT	Building Technology
D	Deliverable
EC	European Commission
EEG	Electroencephalographic
FFM	Five-Factor Model
HBI	Human-Building Interaction
HCI	Human-Computer Interaction
HVAC	heating, ventilation, and air-conditioning
IEQ	Indoor Environmental Quality
IoT	Internet of Things
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
PSSUQ	Post-Study System Usability Questionnaire
SRI	Smart Readiness Indicator
TBS	Technical Building Systems
WP	Work Package

Executive Summary

The objective of this deliverable was to investigate and gain new knowledge on the technical requirements to design and implement satisfactory interaction strategies between users and automated or smart controls in buildings.

First, a taxonomy is proposed to describe the different types of interaction strategies that can take place between users and smart buildings. This taxonomy was developed by expanding the work from Luna-Navarro et al. (Luna-Navarro et al., 2020), which was originally designed for human interaction with smart facades to all the building. This is reported in section 2. Secondly, the taxonomy is used to describe and evaluate the state of the art in industry by interviewing with key market stakeholders in the SMARTeeSTORY project. This is reported in Section 3.

Overall, the main strategies currently present in the market revolves on: (i) applying "direct sensing" of the indoor environmental quality or occupancy to inform automated control strategies (either directly to the actuation system or to the BMS). Most of current technologies are ready to provide information to users in more advanced manners, but this is rarely performed, and usually visual screens are used to present dashboard. Similarly, users are not integrated in control loops, even if the technology is ready for this; (ii) direct control from users is also widely established in the market.

This methodology is then used to describe the interaction strategy in the three demo sites and propose recommendations for the design in Section 4. In Granada, the main interaction strategy is "direct control". In Delft, the main interaction strategies are also related to "direct control" of the users, there are no information strategies as well. Ventilation does not provide any possibility of interaction to users, heating is fully automated with only direct control, only lights and blinds present some degree of "direct sensing" and "direct control", which is currently disruptive and lacking user feedback. Finally, Riga presents a similar situation than Delft, but in Riga the direct sensing is mainly applied to cooling, heating and lighting, while blinds are only based on "direct control". In all demo sites there are not interaction strategies related to information, while the interaction strategies in terms of convenience related aspects are extremely basic. The data from this analysis is confirmed by the results in the participatory workshops in D1.1.

Then, the state of the art in literature was investigated to identify new knowledge on the main drivers that impact user satisfaction and acceptance with interaction in smart buildings. This is reported in section 5. The following drivers were identified: (i) user expectation and definition of smart services; (ii) user preferences on the overall level of automation and personal agency; (iii) information from users and buildings and vice versa; (iv) need for adaptive and flexible interactive solutions that enable personalisation, therefore introduction of archetype or user persona that can effectively describe differences in user needs in terms of interaction. The results from the literature review were aligned with the results from D1.1. The review of technical standards, however, showed that only requirements for personal control and interface design are currently considered. There is an urgent need for expanding user requirements in technical standards and incorporate the knowledge already gathered in literature.

Finally, this deliverable reports in section 6 results from three case studies with human participants. The first study (section 6.1) evaluates the impact of smart services on smart readiness indicator and potentially on user satisfaction, by combining data from SRI calculation with data from workshop and questionnaires with users. This was performed to verify the importance of interaction strategies for user satisfaction. For this, the case of smart building

envelope is considered in the Delft demo site. The analysis highlights that interaction strategies are key to support increase in smart services and the anticipated benefits on comfort and energy described by an increase in the SRI. Secondly, a longitudinal questionnaire at the demo site buildings was employed to identify user needs in terms of interaction strategies (section 6.2). This study demonstrated the importance of applying the Theory of Planned Behaviour when assessing satisfaction of users with information and convenience. In addition, the importance of having direct control to personalise the work environment and the interaction strategies was also confirmed by the data, remarking that specifically for some indoor environmental domains (i.e. heating, lighting, cooling) enabling control to personalise is key. In other domains, larger assistance from automation is instead welcomed. Preliminary profiles of personal preferences in interaction strategy were then introduced. Finally, controlled lab experiments (section 6.3) also showed that personalised profiles or archetypes are needed to describe user requirements with interaction strategy and previous knowledge is key determinant of user preferences and expectations.

To conclude, new recommendations for the design and implementation of satisfactory interaction strategies are provided in this deliverable. This is particularly important to complement and expand on the requirements proposed by the SRI in the impact factors related to "information" and "convenience". It is clear as main conclusion of this deliverable that personal archetypes on preferred interaction strategies, are needed. The highest rate of SRI in convenience and information should therefore not be related to a specific service but to the adequate combinations of services that can best respond to individual requirements. This deliverable paves the way for interaction related archetypes that will be proposed in the deliverable 2.3.

1 Introduction

1.1 Purpose and scope of the document

The purpose of this deliverable is gathering main requirements for the design and implementation of interaction strategies in demo-site buildings and in Europe for user satisfaction and well-being.

1.2 Contributions of partners

Table 1 depicts the main contributions from project partners in the development of this deliverable.

Table 1. Contributions of partners

Participant Short Name	Contributions
TUD	Conceptualisation, writing, data collection, data analysis, evaluation of interaction strategies in the Delft demo site
RINA-C	Review
Pellini	Interview and support in mapping interaction strategies in default systems in the market
SE	Interview and support in mapping interaction strategies in default systems in the market
Tera	Interview and support in mapping interaction strategies in default systems in the market
CUERVA	Support in evaluation of interaction strategies in the Granada demo site
REA	Support in evaluation of interaction strategies in Riga demo site

1.3 Relation to other activities in the project

Table 2 shows the relation of T2.1 to other activities and related deliverables in the project.

Table 2. Relation to other activities in the project

Activity (Deliverable Number)	Description
T1.1 (D1.1)	User requirements from the participatory approach
T2.3 (D2.3)	Data collection of user interaction with existing personalised control strategies.
T2.4 (D2.4)	User preferences regarding the control of available personalised smart controls in buildings.
T2.5 (D2.5)	Evaluation of user centre co-benefits of smart control in buildings.

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T3.3 (D3.4)	Definition of control strategies per demo site regarding the methodology developed in D2.1.
T4.1 (D4.1)	Information on cyber-security aspects.
WP5	Final recommendations for implementing the interaction strategy, which will then be verified during the demonstration phase

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2 Overall approach

This deliverable evaluates user requirements for satisfactory interaction strategy in automated and smart buildings. This is performed by: (i) investigating current state of the art in literature and market; (ii) performing data collection through questionnaire in demo sites buildings and controlled experiments. The all analysis adopts the classification scheme of interaction strategies proposed by Luna-Navarro et al. (Luna-Navarro et al., 2020).

A classification scheme was developed based on the existing classification scheme for human interaction with smart façade as described in (Luna-Navarro et al, 2020). The classification scheme identifies three main physical components: the Occupant (O), as single or group, the control Logic or "Operating system" of the Intelligent automation system (L), and the Building Services (B). "B" includes artificial lighting, heating, cooling and ventilation management systems. A distinction is made between conventional rule-based Logics (L) and learning ones (Lm), which correspond to automation systems without and with AI-enhanced capabilities respectively. Each component can interact with the others and create an alternative interactive scenario. The interaction is represented by an arrow. The proposed classification scheme identifies two main categories of interaction relatively to their level of intrusiveness and aim: Direct Interactions (I) where a direct request of action, feedback or information display is made between two physical components, and Automatic Sensing (S), where there is an indirect interaction between two physical components through sensing devices. The following types of Direct Interactions have been identified: 1) Control action Ia; 2) Feedback request If; and 3) Display of information Id. Similarly, the Automatic Sensing was classified according to the aim of the sensing action: sensing of occupants (such as physiological or facial characteristics) So or monitoring of occupant adaptive actions Sa; sensing of indoor environment Si; sensing of outdoor environment Sext and sensing of the facade Sf. The classification scheme is used to decompose complex Occupant-Facade scenarios into the constituent interactions.

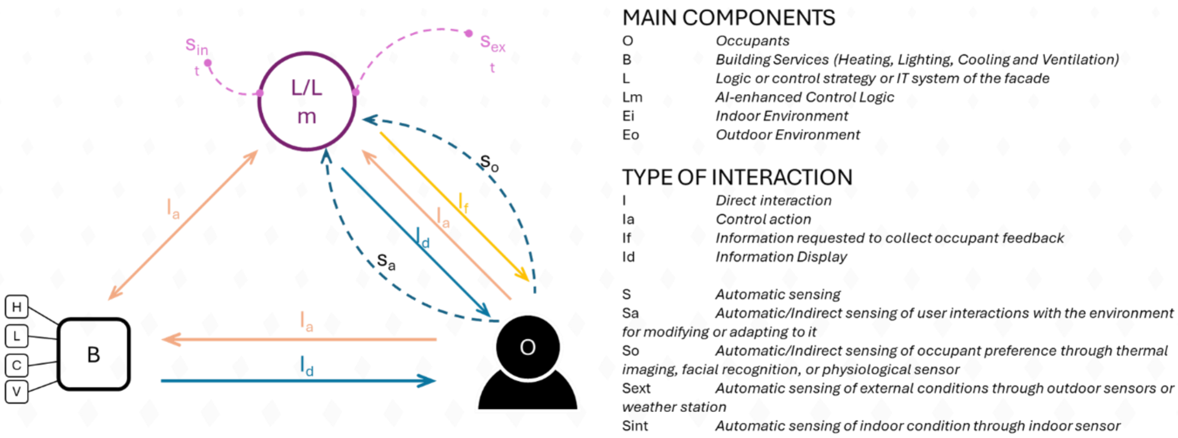

Figure 1. Main classification scheme adopted for this study

2.1 Objectives and expected impact

The task T2.1 had the following objectives:

- Ob1. Mapping interaction strategies in the market;
- Ob2. Mapping of interaction strategies in demo sites;
- Ob3. Review of state-of-art in satisfactory interaction strategies between users and automated systems;
- Ob4. Review of state of the art in user requirements for interaction strategies;
- Ob5. Evaluation of drivers of user satisfaction with interaction strategies

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3 Mapping of user interaction strategies in the market

Based on the previously described classification scheme, we conducted a mapping of interaction strategies available in the market. These strategies were identified within the technology providers participating in the SMARTeeSTORY project (Pellini, Tera, and Schneider Electric) and categorised into five actuation types:

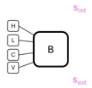
1. **Dynamic Self-Adjustment**: Systems that automatically adjust their operations based on real-time data without direct interaction from occupants or preset control logic.
2. **Direct Interaction without Control Logic**: Systems where users manually control devices directly, without any underlying automated logic or algorithms.
3. **Logic with Environmental Sensing without Occupant Interaction**: Systems that use environmental sensors to automatically adjust operations without any interaction from occupants.
4. **Logic with Automated Sensing of Occupants**: Systems that automatically detect the presence of occupants and adjust operations accordingly without requiring direct interaction from those occupants.
5. **Logic with Direct Occupant Interaction**: Systems that allow occupants to interact directly with control interfaces, with adjustments made based on this input combined with predefined logic.

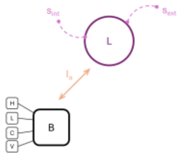
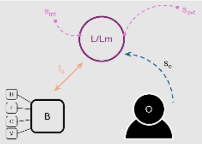
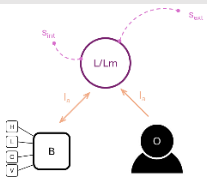
Additionally, a description, example, and available technology are provided for each actuation type to illustrate the range of options currently available.

3.1 Pellini – User interaction strategies

Pellini offers a diverse range of interactive shading systems categorized into various actuation types. These systems leverage both automated and manual controls, utilizing advanced sensor technologies and traditional mechanisms to enhance occupant comfort and energy efficiency. The interaction strategies mapped are described in Table 3.

Table 3. Description of interaction strategies and technologies available in Pellini

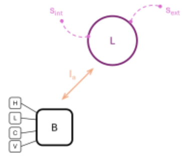
Actuation type	Name of interactive scenario	Pictogram of the interactive scenario	Description and examples	Technology
Dynamic self-adjustment	$E_{i/o}$ B		Automated control based on sensors and schedules. **Example:** Pellini BMS	- BMS. - Environmental sensors. - IoT hubs.
Direct interaction – No control logic	O I_a I_a B		The shades are actuated by an external knob fixed to the window frame. **Example:** P System Manual Knob. Force produced by two coupled rotational magnetic devices to raise and lower	- Analogic switches and knobs. - Digital switches and knobs. - Manual blind cords.

			(and tilt, in venetian models) the blind using a cord loop. **Example:** C System Cord. Push buttons actuate the shades. **Example:** M System with an internal motor. The shades are actuated using a magnetic knob placed on the glass. **Example:** B System Manual Bottom.	
Logic with environmental sensing – No occupant interaction	$S_{i/e}$ L I_a B		The shades are actuated by conditions detected inside and outside the building. **Example:** M System with internal motor The shades are actuated by simulations continuously calibrated by conditions detected inside and outside the building. **Example:** Pellini BMS	- IoT Hubs. - BMS.
Logic with automated sensing of occupants	$S_{i/e/o}$ L I_a B		The shades are actuated by sensing the occupant. Example: Occupancy sensors.	- Occupancy sensor. - BMS.
Logic with direct occupant interaction	$S_{i/e}$ L I_a B O I_a B		People override and after a certain time the automated mode comes back (wall, remote control and app / on and off of automation - on and off privacy). **Example:** BMS configuration. Glare assessment for blind control. Occupants override	- BMS. - App. - Remote control. - Wall smart switches.

3.2 Tera – User interaction strategies

TERA focuses on integrating environmental sensing into their building service controls. Their solutions primarily monitor indoor conditions to optimise building performance, reflecting a strong emphasis on automated, sensor-driven adjustments without requiring occupant interaction. The interaction strategies mapped are described in Table 4.

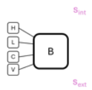
Table 4. Description of interaction strategies and technologies available in Tera

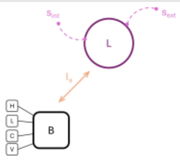
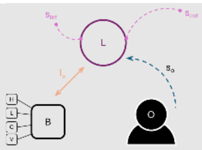
Actuation type	Name of interactive scenario	Pictogram of the interactive scenario	Description and examples	Technology
Dynamic self-adjustment	-	-	-	-
Direct interaction – No control logic	-	-	-	-
Logic with environmental sensing – No occupant interaction	$S_{i/e}$ L I_a B		Indoor environmental conditions are monitored to control building services available. **Example** Beeta Boxx	- Environmental sensor
Logic with automated sensing of occupants	-	-	-	-
Logic with direct occupant interaction	-	-	-	-

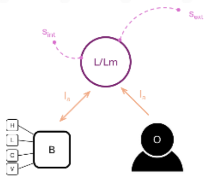
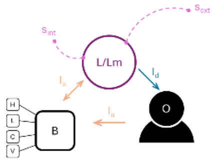
3.3 Schneider Electric – User interaction strategies

Schneider Electric provides comprehensive building management solutions that span all five actuation types. Their offerings include sophisticated systems that automatically adjust based on real-time data, as well as manual control devices. These systems aim to improve energy efficiency, occupant comfort, and overall building management through advanced sensing and interactive technologies. The interaction strategies mapped are described in Table 5 .

Table 5. Description of interaction strategies and technologies available in Schneider Electric

Actuation type	Name of interactive scenario	Pictogram of the interactive scenario	Description and examples	Technology
Dynamic self-adjustment	$E_{i/o}$ B		Systems automatically adjust their operations based on real-time data without direct interaction from occupants or preset control logic. **Example:** EcoStruxure™ Building Operation: This integrated building management system	- Integrated building management system.

			dynamically adjusts HVAC, lighting, and other building systems based on real-time data from sensors and other sources to optimise energy usage and comfort.	
Direct interaction – No control logic	$O\ I_a\ I_a\ B$		Users manually interact with devices to control them directly without any underlying automated logic or algorithms. **Example:** Simple Switches and Dimmers: Basic light switches or dimmers that require manual operation by the user to turn lights on/off or adjust brightness.	- Basic switches and dimmers.
Logic with environmental sensing – No occupant interaction	$S_{i/e}\ L\ I_a\ B$		Systems use environmental sensors to adjust their operations automatically without any interaction from occupants. **Example:** Com'X 510 Energy Server: Collects data from electrical distribution panels, environmental sensors, and meters, then uses this data to optimise energy consumption without occupant intervention.	- Environmental sensors - Energy meters - BMS
Logic with automated sensing of occupants	$S_{i/e/o}\ L\ I_a\ B$		Systems automatically detect the presence of occupants and adjust operations accordingly without requiring direct interaction from those occupants. **Example:** Wiser Energy Management System: Uses motion sensors to detect occupancy and adjust lighting, HVAC, and other systems to improve comfort and energy efficiency.	- Motion sensors - Energy sensors - Room controllers

Logic with direct occupant interaction	$S_{i/e}$ L I_a B O I_a B S_a L I_d O	 	Systems allow occupants to directly interact with control interfaces, and the system adjusts based on this input combined with predefined logic. **Example:** SpaceLogic Insight-Sensor: Allows occupants to adjust settings via a user interface or mobile app, while also using embedded sensors to fine-tune operations.	- Smart switches - Wall touch screen - App

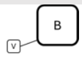
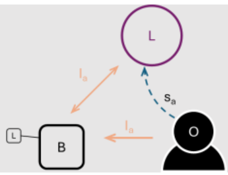
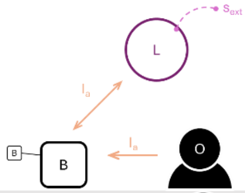
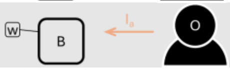
From the information provided for each technology provider involved on user interaction strategies within the market, we conclude the following:

- Integration of Advanced Technologies: Technology providers Pellini, Tera, and Schneider Electric incorporate advanced sensor technologies, building management systems (BMS), Internet of Things (IoT) hubs, and environmental sensors into their solutions. These technologies enable dynamic self-adjustment, environmental sensing, and automated detection of occupants.
- Limited Direct Occupant Interaction: While some systems allow for direct interaction from occupants through manual controls, wall switches, remotes, or apps, this aspect appears less emphasised compared to automated or sensor-driven strategies.
- Potential for Enhanced Personalization: Despite the advancements in automation and sensing, there seems to be room for enhancing personalisation and customisation of user experiences within these systems. Integrating more direct occupant interaction options and adaptive learning algorithms could further improve user comfort and satisfaction.

4 Mapping of user interaction strategies in the demo sites

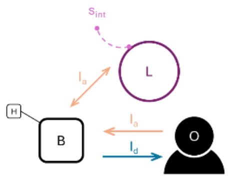
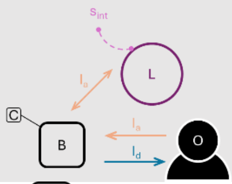
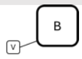
The following section details the user interaction strategies in the three demo sites in Delft, Riga, and Granada. Each table outlines the building services, user interfaces, sensors, types of control, and interaction strategies employed within these locations. The comparison across these sites reveals diverse approaches to managing heating, cooling, ventilation, lighting, blinds, and windows, reflecting the control access for each setting.

Table 6. Description of the user interaction strategies in the Delft demo site

Building service	User Interface	Sensor associated	Type of control	Interaction strategy
Heater	Thermostatic valve	-	Manual	
Cooling	-	-	-	-
Mechanical Ventilation	-	-	Fixed-rate	
Lighting	Switch	Motion sensor	Manual with automatic on/off based on occupant motion.	
Blinds	Switch	Outdoor solar irradiance	Automatic with override option.	
Windows	Window handle	-	Manual	

In Delft, the heating system is manually controlled via a thermostatic valve, while lighting integrates motion sensors to enable a hybrid manual-automatic strategy. Blinds are automatically adjusted based on outdoor solar irradiance but can be overridden manually.

Table 7. Description of the user interaction strategies in Riga demo site

Building service	User Interface	Sensor	Type of control	Interaction strategy
Heater	Thermostatic valve The thermostat screen on the wall	- Thermometer to control split unit.	Manual for radiators. Automated control to keep the set thermometer.	
Cooling	The thermostat screen on the wall	Thermometer	Setpoint	
Mechanical ventilation	-	-	Fixed-rate	

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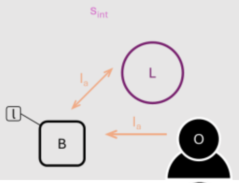
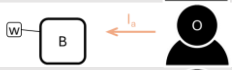
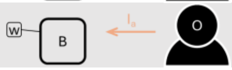
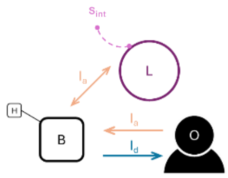
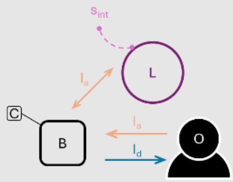
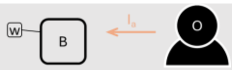
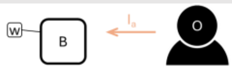
Lighting	Switch Desk light switch	Motion sensor	Manual with automatic on/off based on occupant motion.	
Blinds	Cord	-	Manual	
Windows	Window handle	-	Manual	

Riga employs a more integrated setup, where heating and cooling are regulated through a thermostat screen that automates temperature control delivered by the split units. The radiators for heating on the walls are controlled manually. Lighting in Riga also benefits from motion sensors, whereas blinds and windows are manually operated.

Table 8. Description of the user interaction strategies in Granada demo site

Building service	User Interface	Sensor	Type of control	Interaction strategy
Heater	Personal heater on/off The thermostat on the wall	- Thermometer to control split and fan coil unit.	Manual for radiators. Automated control to keep the set thermometer.	
Cooling	Personal ventilation on/off The thermostat on the wall	Thermometer to control split and fan coil unit.	-	
Lighting	Switch Desk light switch	-	-	
Shutters	Handle	-	Manual	
Windows	Window handle	-	Manual	

Granada's configuration uses personal control mostly to control the indoor environment with individual heaters, and manual operation for lighting, shutters, and windows.

The demo sites, despite showcasing automated control, sensing technologies, and multidomain approaches encompassing visual, thermal, acoustics, and indoor air quality domains, still exhibit certain deficiencies in terms of personal control and interaction strategies. Primarily, there appears to be a limited integration of personalized user preferences into the automated control systems. While the sites demonstrate automated temperature regulation and motion-sensing capabilities for lighting, they lack mechanisms for users to customize their environments based on individual comfort preferences or specific tasks. Additionally, there seems to be a gap in real-time feedback mechanisms that would allow occupants to understand and adjust their energy usage patterns in response to environmental conditions or system operations. Moreover, the absence of seamless interoperability among different building systems may hinder the holistic optimisation of indoor environmental quality and energy efficiency. Overall, enhancing personal control and interaction strategies in these demo sites could involve incorporating more user-centric interfaces, integrating adaptive learning algorithms, and fostering interoperability among diverse building systems to provide occupants with autonomy and comfort customisation options.

5 Review of state of art in satisfactory interaction strategies

This chapter summarises the main findings of previous work on user requirements with automated controls, in particular on drivers of user satisfaction with automated controls.

To this purpose a systematic review was conducted with the following keywords: (user OR occupant) AND (smart OR intelligent OR automat*) AND building AND (satisfaction OR comfort OR acceptance OR preference) AND (experiment OR "field study" OR monitoring OR survey OR questionnaire OR interview) AND (participant OR volunteer OR subject). A total of 132 papers were identified from 1646 papers in Scopus. Figure 2 shows the publications per year. The body of literature published per year in this field has steeply increase by 2013. It is also noticeable the impact of the COVID-19 pandemic on the publication trend.

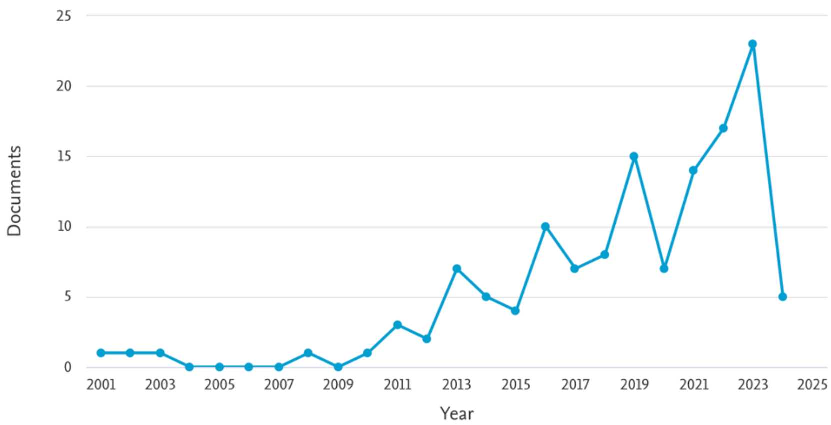


Figure 2. Publications per year on the field of human-smart building interaction

The existing publications on this topic delved into the following aspects of human interaction with smart buildings: (i) role of information; (ii) individual requirements on the desired level of automation and personal agency; (iii) personalization of interaction strategies; (iv) design of interfaces; (v) ethics and privacy issues.

5.1 Perception of smart buildings in end-users

Existing literature highlighted that users have personal preconceptions, definitions and perspectives on the purpose and importance of smart buildings. Fakhrhosseini et al. (Fakhrhosseini et al., 2023) reported users are generally positive about smart buildings.

In terms of benefits for instance, Tuzcuoğlu et al. (Tuzcuoğlu et al., 2023) conducted semi-structured interviews and reported users anticipate that smart office environments will offer improved interaction with their social and physical surroundings and help them understand the smart technology through practical experiences. Another aspect observed in a study (Berrocal et al., 2023) is the tendency to qualify the term “intelligent” or “smart” as “simple”, referring to the idea that even if there are sophisticated, sensor-based automation services widely present in smart buildings they should ultimately be very simple for the user.

Conversely, users may be less inclined toward unfamiliar and futuristic ideas that featured high levels of integration and automation, such as advanced energy services, companion and informative homes, and robotic agents. As mentioned by these authors, acceptance of advanced home technologies can differ based on behavioural and attitudinal factors, of which some are also contextual, as well as demographic and socio-economic backgrounds. This highlights the importance of understanding future users of smart technology products and services beyond easily measurable traits. It suggests that a variety of tools and approaches may be necessary to comprehensively identify and target these users.

In this sense, Bresa et al. recently explored the willingness of users to provide feedback by using the theory of planned behaviour (Bresa et al., 2023) The following user-related influencing factors were described(Yang et al., 2017):

- **Attitude:** this include the behavioural beliefs, perceived ease of reporting, importance of energy-saving, environment and social responsibility, current knowledge on building performance and role of smart buildings; how the performance of the smart building is evaluated, whether in terms of comfort, cost savings or energy savings for the environment;
- **Subjective norms:** this includes normative beliefs, which are mainly revolving on social influence of people that share the space, and the motivation to comply to social norms or rules;
- **Perceived Behaviour control:** perceived level of personal control, importance of personal control;
- **Generalised intention:** the overall intention to cooperate with the smart building, for instance in reporting information;
- **User trust:** privacy issues and trust on the system performance;
- **User preference on agency and level of automation:** personal requirements in terms of balance between automation and personal control.

Among these factors, the results indicated that the impact of Attitude (the intrinsic values and beliefs of the target group, such as thinking that reporting feedback will improve comfort and save energy) is greater than that of Social Norms (social impact) and Perceived Behavioural Control (the ability to report feedback, such as the ease of reporting feedback). Additionally, User Trust was a significant factor in the intention to interact with the smart building. On the other hand, user preferences regarding control, the willingness to engage in grid flexibility actions, and comfort preferences do not directly impact the intention to interact but do influence the occupant's Attitude. Lastly, age and gender do not affect the willingness of occupants to interact with the controller. In Yang et al. (Yang et al., 2017), it was shown that attitude, subjective norm and perceived behavioural control are three key factors that affect the intention to use smart services.

Knowledge on smart technologies, both considering their functioning and benefits, was recognised by previous studies as important factor on user adoption and acceptance of smart technologies (Sovacool et al., 2021; Zimmermann et al., 2018). Individuals knowledgeable about smart technologies perceived significantly more positive benefits, such as saving time, money, energy, and emissions, as well as enhancing leisure, comfort, security, and overall quality of life. They also felt safer, more empowered, and in control of their homes. Conversely, those with little knowledge were more likely to feel unsafe or ambivalent about the technology. Data protection was also a driving factor of user willingness to adopt and interact with smart buildings (Zimmermann et al., 2018). It is worth noticing that most literature on these aspects focus on smart homes rather than smart offices.

In terms of user perception of smart buildings, we can summarise that literature has focused on the following aspects of user perception:

a. **Acceptance and adoption**. In 1989, Davis proposed a theoretical model of user acceptance of technology, the "Technology Acceptance Model" (Davis, 1989). For acceptance, this model already highlighted these two drivers: (i) perceived usefulness or namely "Performance and effort expectancy", and (ii) social influence, in terms how users perceive others expecting them to use a technology. Other aspect that influence acceptance have also identified: perceived benefit, trust, reliability, privacy, cost, and ease of use (Wilson et al., 2015). Key factors such as performance expectancy, effort expectancy, habit, and interaction adequacy are crucial in shaping users' intentions to adopt this technology (Tak et al., 2023). Additionally, privacy and transparency have a greater impact on trust than perceived control, emphasizing the need for attention to trust-building, as it directly influences adoption intention (Tak et al., 2023).

b. **Preferences.** This considers the preference of users among different features of automation and level of interaction. (Ahmadi-Karvigh et al., 2017)

c. **Satisfaction** with overall automation and control strategy.

A previous review from Luna-Navarro et al. (Luna-Navarro et al., 2020), proposed the following recommendation to design satisfactory interaction strategies:

- **There are no one-size-fits-all design solutions for satisfactory interaction strategies** (Ahmadi-Karvigh et al., 2017). Design principles for satisfactory interaction scenarios are challenging to generalize because they are individual and contextual. Achieving satisfactory interaction levels necessitates bespoke design solutions that account for local occupant expectations and contextual factors such as building typology. Therefore, flexible or adaptive solutions tailored to each specific scenario are necessary to ensure a high level of personalization.

- **The holistic effects of interactive scenarios on occupant satisfaction are yet to be fully-captured.** The comprehensive effects of interactive scenarios on occupant satisfaction have yet to be thoroughly explored, indicating a need for further research. Utilizing methods from Human-Computer Interaction (HCI) and Human-Building Interaction (HBI) can aid designers in addressing these emerging demands. During the design phase, employing "Personas" and techniques to map the spatial context of interaction can enhance usability. Once prototypes are available, task analysis, interviews, and focus groups are valuable tools for evaluating occupant responses. In the absence of prototypes, virtual reality and advanced computational design classification methods can be employed to gauge responses to new interactive systems. Additionally, various techniques, such as video recording, physiological response monitoring, and eye movement tracking, can be used to study occupant reactions in different interactive scenarios.

- **Interfaces play a key role in ensuring occupant satisfaction with interaction strategies.** Existing research widely acknowledges that a well-designed interface is crucial for occupant satisfaction in various interaction strategies. In particular, it is paramount to provide users with means for overriding and exercise personal control on the environment. More interdisciplinary research is needed to define ease-of-use and enhance both functional and psychosocial compatibility with users. The level and mode of interaction should be tailored to the context, user, and function. Efforts have been made to expand the concept of "usability" from Human-Computer Interaction (HCI) studies to "user experience," which better addresses the diverse needs of occupants interacting with intelligent facades. The application of novel interfaces in the built environment is still

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emerging. Research into wearable technologies and affective human-computer interaction suggests several innovative interface designs. For instance, facial expressions can detect emotions or environmental satisfaction in a contactless manner, though they may not always be reliable. Studies have also indicated that a single arm can indicate thermal sensations, and facial skin temperature can serve as a bio-signal for comfort preferences. Other physiological signals such as heart rate, peripheral temperature, and skin conductivity have been explored for environmental control and emotion detection. While brain-computer interfaces, such as electroencephalographic (EEG) signals, offer extensive information on occupants, they may be too invasive for everyday environmental control strategies. A recent study show that young people are very keen in interfaces based on voice recognition for instance.

- Interactive strategies have ethical and privacy consequences that need to be addressed. Automated control and sensing raise issues related to ethics, privacy, surveillance, and datafication, particularly when collecting large datasets on individual preferences, physiological responses, mood, productivity, or well-being. These ethical concerns have prompted the creation of new governmental guidelines and a growing body of research addressing these issues. Main concerns include ensuring occupant awareness and consent in data collection, securing personal data storage, and restricting data access to authorized personnel to prevent confidentiality breaches. Consequently, developing effective, non-intrusive methods for occupant data collection must address these ethical challenges. Further research is required to tackle the new ethical questions posed by the unprecedented intimacy between occupants and automation controls. Understanding the benefits and advantages of embedded computing in buildings is essential to outweigh potential privacy and security drawbacks.

5.2 Role of information in occupant-building information

5.2.1 Information from users to building control logics

Gathering feedback on user preferences is key in smart building controls for achieving high performance in terms of user comfort, satisfaction and acceptance of the overall control strategy. However, providing feedback can also be very disruptive to users since providing feedback can be time-consuming or cognitive intense (Luna-Navarro et al., 2019). Existing literature has focused either on demonstrating the potential of personalised controls when including the user feedback in the control loop (Nagy et al., 2023), or in devising less intrusive strategies for gathering user feedback in the least disruptive manner (Luna-Navarro et al., 2019; Ramsauer et al., 2022). The most recent advances are based on detecting and recognising human activity and infer feedback from user behaviour (Najeh et al., 2022), or physiological measurements (Bogatu et al., 2023; Kar et al., 2019).

5.2.2 Information from building control logics to users

One of the most important features of smart buildings is the possibility to provide information to users. This is important for: (i) user acceptance of smart technologies (Cho et al., 2019); (ii) improve user behaviour for energy efficiency, climate adaptation, health. Similar to research looking into the role of information from users to control logics, research on information from logics to users has focused on: (i) developing effective strategies for interacting and informing the user; (ii) demonstrating the benefits of information for the user and the energy performance of a building.

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Information has been provided to user by: (i) mobile-app, also embedded in smart watches; (ii) desktop computer web-interfaces; physical signalling systems.

Overall, there are two approaches in informing users: (i) providing information in a static manner, by giving user access to a platform where data is continuously stored; (ii) prompting users with dynamic information, to nudge behaviours and adopting "Just in Time" strategies, this is performed by real-time feedback either through mobile phones (vibration, text messages etc.) or visual or acoustic signals in buildings. It is important to remark that the consideration of users with impairments is key when selecting interfaces for informing users.

5.3 User of clustering and persona to describe user requirements

Overall, the existing literature highlights that users have different preferences in terms of control and automation (Malekpour Koupaei et al., 2020). **It is therefore crucial to design interaction strategies to be able to accommodate and respond to different expectations and preferences in terms of preferred level of automation and personal control**. These studies uncovered differing perspectives on control and autonomy. Some users are content to relinquish control, while others are hesitant to embrace automation. This indicates a need for a variety of control options, allowing users to select according to their preferences (Tak et al., 2023), and it was also confirmed by SMARTeeSTORY participatory study presented in the D1.1.

5.4 Recommendations from technical standards

In addition to the SRI, the following standards containing information related to user interaction with smart controls have been identified:

- ISO 9241:2019 (Ergonomics of human-system interaction).

  This standard is aimed at the professionals that design interfaces for human-system interaction. In particular, it provides strategies to design interfaces that can enhance human experience and ergonomics.

  EN 15232-1:2017 (Energy performance of buildings - Impact of Building Automation, Controls, and Building Management).

  This standard defines minimum requirements or any specification regarding the control, building automation and technical building management functions.

- BS EN 12464-1:2021 (Light and lighting - Lighting of work places - Indoor work places).

  Provides recommendations for lighting design in workplaces, emphasizing the role of automated lighting controls. Recommends to allow users to easily adjust lighting conditions to suit their needs.

- ASHRAE Standard 55-2020 (Thermal Environmental Conditions for Human Occupancy).

  Sets comfort criteria for designing and operating heating, ventilation, and air-conditioning (HVAC) systems to achieve acceptable thermal comfort.

  Highlights the benefits of providing personal control for enhancing thermal comfort adaptation.

- ISO 7730:2005 (Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria):

  Provides a method for predicting the thermal comfort of occupants using PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices.

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Suggests that personal control of heating and ventilation can improve thermal comfort by addressing individual needs and preferences.

- REHVA Guidebook No. 15: Indoor Climate Quality Assessment:

  This guidebook offers comprehensive methods for assessing indoor climate quality, covering thermal comfort, indoor air quality, lighting, and acoustics. It emphasizes the importance of providing occupants with personal control over HVAC systems to enhance comfort and satisfaction.

6 Results from workshops, questionnaires and controlled experiments on user interaction with automated systems

6.1 Questionnaires and workshop: Impact of dynamic facades on Smart Readiness Indicator and users' satisfaction

The Smart Readiness Indicator (SRI), introduced by the European Union in 2018, assesses a building's capacity to effectively accommodate smart-ready services. This evaluation focuses on optimizing energy efficiency, aligning operations with occupant needs, and responding to signals from the grid. Previous studies have evaluated SRI feasibility in various locations and retrofit scenarios, estimating the costs associated with implementing smart technologies in existing European buildings. However, the specific impact of digitizing distinct building services on SRI scores remains unexplored. Particularly, adaptive façade technologies show potential in enhancing overall building performance, being worthy to understand how these services influence the smart readiness rating of a buildings. This study aims to investigate the impact of adaptive façade technologies on SRI scores and user satisfaction. As a case study the demo site building in Delft (The Netherlands) was selected to assess the impact of smart technologies on energy efficiency and comfort. This section shows preliminary results from the pre-intervention phase, where the SRI was calculated for both the baseline condition and a scenario with the highest possible level of smart services for the building envelope. The results from the SRI methodology, showed an increase of approximately 4% in energy efficiency and 15% in terms of energy flexibility. In addition, the SRI also predicts similar improvements on user convenience, information and health & well-being, but only 4% on user comfort. This was confirmed by the assessments on user perception and preferences. Users reported to be "slightly satisfied" with the several comfort domains. In addition, several users considered very important better control of the external shadings, which was currently reported as very disruptive by users. This preliminary finding shows then potential for smart services applied at the façade level to improve user satisfaction if aspects of interaction and convenience are adequately addressed. The data on the post-intervention phase is now required to confirm these preliminary findings.

6.1.1 Methodology

6.1.1.1 Case study

The building of the TU Delft Faculty of Architecture was used as a case study for this study (as shown in Figure 3). The building was built in 1918 and it is listed as monument building. Therefore, no deep renovation of the building envelope is possible. The building is currently in energy class F. The case study relates to six open-space office environments located at the first and second floor on the south-east façade. The façade has a window to wall ratio of approximately 60% and external automated black roller blinds. The blinds are currently programmed to be lowered to reduce solar gains and glare when the sun is in the field of view. Users have always access to override by means of wall-mounted switches. The opening of the vents is only manually controlled, while there is mechanical ventilation to maintain healthy indoor air quality levels. The lighting systems is also automated by movement sensors and users can manually override the system by means of wall-mounted switches. Every user has also access to task lighting. The smart readiness of the building with the current existing smart services is approximately 22% by using the detailed calculation method "B" as for the Smart Readiness Methodology [12]. A higher smart readiness level reflects a "smarter" implementation of the service, which generally should increase the benefits for users, energy efficiency and grid. In the proposed method, the smart readiness score of a building or building unit is expressed as a percentage which represents the ratio between the smart readiness of the building compared to the maximum smart readiness that it could reach. In the context of the "SMARTeeSTORY" EU-funded research project, this building will be integrated with additional smart services that will tackle all the nine domains of the SRI. The increase in smart readiness is projected to be approximately 78%.

Figure 3. Images from the case study: a. Interior view of the office; b. external view of the building façade; c. overview of the building site.

6.1.1.2 Smart readiness indicator assessment

For this study, the smart readiness of the building was assessed by using the pre-calculated spreadsheet based on the multi-criteria assessment method defined in Commission Delegated Regulation (EU) 2020/2155 [12]. This spreadsheet provides weights to evaluate the influence of smart services on the seven different impact areas considered by the SRI. The weights vary depending on the building typology, year of construction and climate.

For this study the average weights provided in the spreadsheet were used. For the baseline scenario, the current level of smart services where considered. Then, to evaluate the impact of smart services associated to the building envelope, the following smart services related to the integrated control of lights, blinds and vents were considered, here reported with the corresponding code from the SRI methodology: (a) control for indoor lighting based on occupancy (L1); (b) control of artificial lighting power based on daylight levels (L2), (c) window solar shading control (DE-1); (d) window open/closed control combined with HVAC system (DE-2); (e) reporting information regarding performance of dynamic building envelope system (DE-4); (f) detecting faults of technical building systems and providing support to the diagnosis of these faults in relation to the building envelope control (MC-4); (g) occupancy detection: connected services (MC-9); (h) central reporting of TBS performance and energy use (MC-13); (i) reporting of information regarding demand side management performance and operation (MC-28); (l) override of DMS control (MC-29); (m) single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather, and grid signals (MC-30).

6.1.1.3 User assessment

A workshop with end-users and facility managers was organized on the 16th of October in Delft. The results were provided in the deliverable D1.1. Follow-up interviews were also held consequently to the workshop to engage with the participants that were not present during the workshop. The participants of the workshops were all the users of the intervention area. Their participation in the workshops was requested by e-mail or face-to-face on both demo-sites. A total of 22 participated to the interview and workshop in Delft. All participants received an information consent sheet, where information about the project, workshop description and data privacy concerns were reported. Each participant was explicitly asked for consent to attend the workshop. In addition to the workshop and the interviews, users were also asked to fill in a questionnaire on their level of satisfaction with the indoor environmental quality, the building control and interaction strategies.

6.1.2 Results and Discussion

6.1.2.1 Influence on smart readiness indicator

As shown in Figure 4, by only adding to this case study only smart services related to the building envelope and the integrated control of lights, the SRI methodology predicts increases in impact scores in the range of 4-20%. No impact is considered on energy efficiency, while a small impact is calculated for energy flexibility (increasing of 13%). Similarly, only 4% increase in user comfort is predicted, while the largest impact on the users seems to be on related to convenience (15%), health & well-being (17%), and information (19%). The maintenance and fault prediction is the domain with largest improvement (20%).

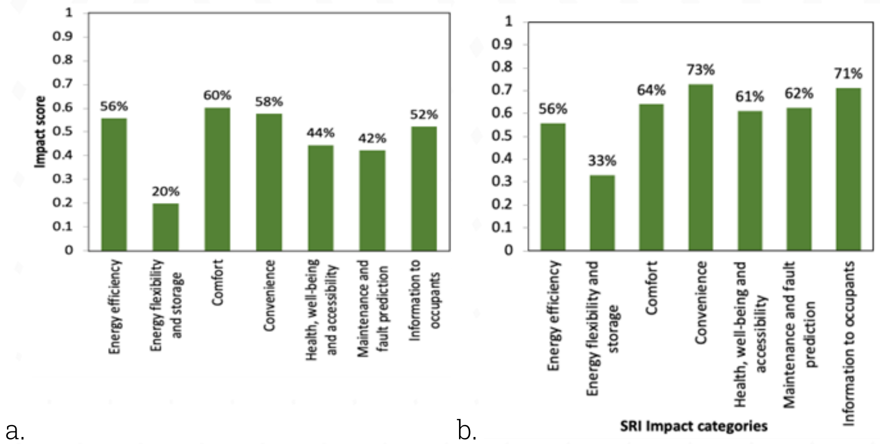

Figure 4. Impact scores on the smart readiness indicator for: a) the baseline condition in Delft, b) condition with highest level of smart services applied at façade level.

6.1.2.2 User satisfaction and requirements with adaptive facades

As shown in Figure 5, **the users from the case study attributed large importance to the several indoor environmental aspects that are closely related to the building envelope.** In particular, the importance of satisfaction with glare mitigation, satisfaction with daylight access, satisfaction with lights, satisfaction with personal control of shades, satisfaction with personal control of light and window vents. Privacy through the window was considered less important, while access to outdoor view was also considered important for users. This indicates that improvements in the control of the building envelope can noticeably affect users. Overall, in Figure 6, it can be seen that users were slightly satisfied with the indoor environmental quality in the office space. The satisfaction with outdoor view access was the highest, while several users indicated that there is space for improving several aspects related to the building envelope, namely: daylight access, view clarity, glare mitigation and temperature. This figure shows that better controls of the building envelope could potentially also improve several aspects of users satisfaction with indoor environmental quality. During the workshop, several users reported being strongly dissatisfied with the current control of the blind system. The automated control of the blinds was perceived disruptive and not logical, since users could not understand the reasons behind the control strategy. This was claimed when users did not see a consistent behaviour between the control of the blinds and the observed weather conditions. In terms of view clarity, users reported the current blinds to be excessively dark, thereby considering the space to be either excessively bright when blinds were raised or excessively dark when blinds were lowered. The fact that lights could not be dimmed depending on the daylight levels indoor was also considered as a negative aspect. In addition, users were asked to rate several smart services in terms of their perceived level of necessity for the smart service and their perceived level of importance. As shown in Figure 7, smart window vents were not considered either important or necessary by the users, while smart lights were considered moderately important and necessary. Smart blinds were considered very important and necessary.

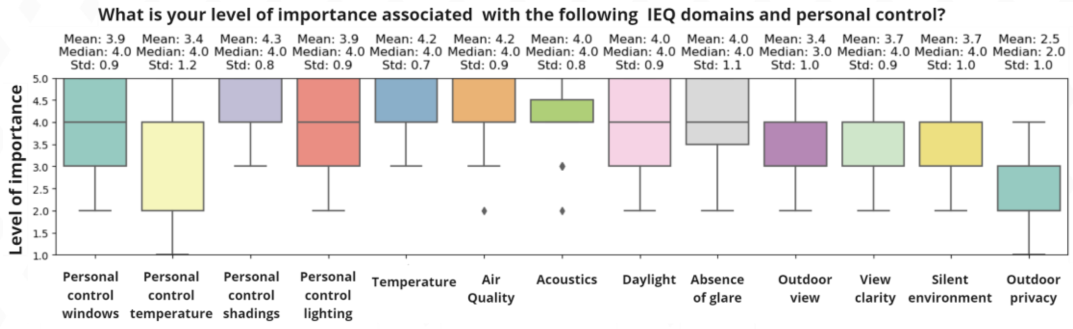

Figure 5. Level of importance associated with the satisfaction with domains of indoor environmental quality and personal control, while being at the office space

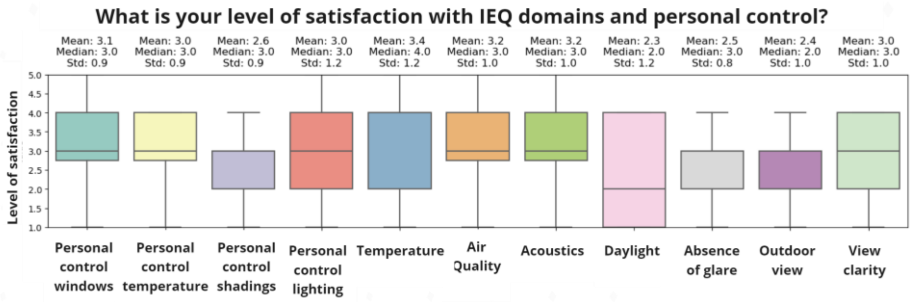

Figure 6. Current level of user satisfaction with several domain of indoor environmental quality. The question was phrased as: "To what extent do you agree to this statement: "I feel satisfied with…". The users could then express from 1 to 5 their level of agreement, as 1- strongly disagree, 2 – slightly disagree, 3 – neither agree or disagree; 4 – slightly agree and 5 - strongly agree.

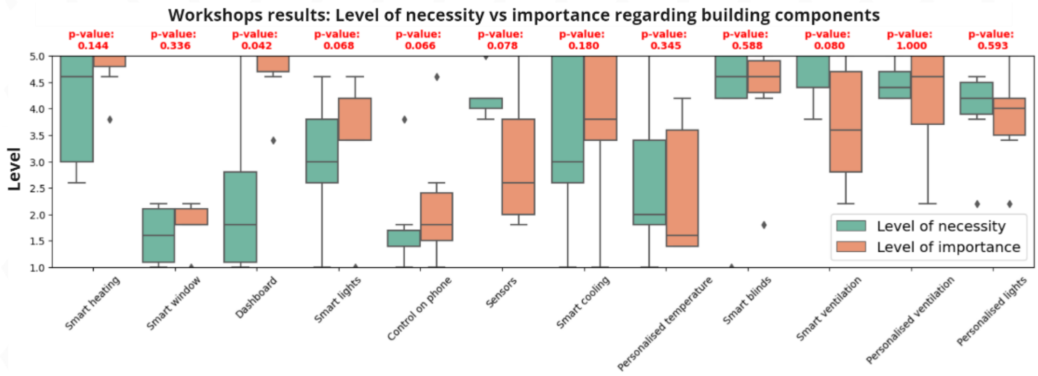

Figure 7. Distribution of necessity and level of importance for each of smart building items asked for during the workshop activity in Delft demonstrator site.

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6.1.3 Conclusion

This section shows preliminary results on the impact of smart controls and technologies (here referred to as smart services) on energy efficiency and user satisfaction in an office building in The Netherlands. The aim of the work was to gain preliminary knowledge on the potential impact of smart services related to the building envelope on energy efficiency and user satisfaction according to the EU Smart Readiness Methodology. In addition, qualitative and quantitative user assessments were performed to investigate user perspectives on smart building envelopes. Applying smart controls in an integrated manner to building envelope and lighting seems promising especially for user satisfaction and energy flexibility according to the SRI methodology. However, this is highly dependent on the interaction strategies that were highlighted by the users as a very disruptive factors in the automated control of the blinds.

6.2 Questionnaires: Identification of factors influencing satisfaction with interaction strategies

Control systems in buildings that prioritise occupant preferences have gained attention recently. aiming to enhance the acceptability of automated systems. However, effective human-building interaction strategies remain challenging to design due to the lack of understanding of building occupant preferences. **This section identifies factors influencing occupant satisfaction with building interaction strategies aiming to offer recommendations for improvement**. Questionnaires conducted in Latvia and the Netherlands collected data on satisfaction with indoor environmental quality (IEQ), building controls, productivity, control importance, and subjective norms. Analysis categorised respondents into high and low satisfaction clusters and identified significant factors influencing IEQ satisfaction through non-parametric tests. Logistic regression and coefficient analysis were used to assess the relationship between satisfaction and these factors. Findings suggest the need for improvements at the Delft demo site, including enhancing personal control, providing heating system performance information, identifying user archetypes, improving shading efficiency, and reducing noise. In Riga, priorities include user-friendly interfaces, accessible heating settings, scheduled heating control, and optimised shading systems. Further research is necessary to evaluate these strategies and understand how insights into human-building interaction dynamics can lead to higher satisfaction levels.

6.2.1 Case studies

Two demo-site buildings were investigated: The Faculty of Architecture and the Built Environment (ABE) of the Technical University of Delft (TU Delft) located in Delft, The Netherlands, and **the Riga City Hall** located in Riga, Latvia.

ABE (Figure 8 - Left) is a 30,000 square meters historical building. In this study, the Department of Architectural Engineering and Technology (AE+T), in particular the section on Building Technology (BT), was considered as the investigated area. BT is a space of 200 square meters composed of 40 desks on two floors, in which 30 people work as professors, assistant professors, and researchers. The schedules of occupancy may vary over time due to the lack of fixed routines. Every office is heated by radiators as part of a central heating system, regulated manually by thermostatic valves. There is no cooling. A fully automated mechanical ventilation system supplies air in most of the offices. The façade is composed of windows with manual control, and semi-automatic roller blinds. The roller blinds control logic is centralized based on solar irradiance. Lighting is semi-automated with occupancy sensors and task lights at every desk with manual control.

The Riga City Hall is the main administrative building of the Riga City Municipality, located in the Historic Centre of Riga (Figure 8 - Right). The area of intervention has three floors, with around 30 desks of office workers. The occupancy patterns follow mostly fixed schedules. Heating control is primarily manual with thermo-static valves. Cooling systems operate with basic on/off control, and there's no interlock to prevent simultaneous heating and cooling. The lighting relies on manual switches, and the building envelope, including window shading and operation, is manually controlled. The building has a glazing facade orientated towards the south, providing views of the City and the Daugava River.

Figure 8. Demo sites front view (Left: Delft, Right: Riga)

6.2.2 Questionnaire design

We surveyed occupants from both demo sites to collect information on (i) profile (age, level of education, type of tasks performed), (ii) their level of importance for indoor temperature, view outside, acoustic environment, air quality, daylight, acoustic environment, artificial lighting, glare and privacy; (iii) their intention of interaction with the building services regarding perceived behavioural control, attitudes toward control and the social norms following the theory of planned behaviour (Yang et al., 2017); and their satisfaction levels per domain and personal and automated control of those services. All questions were answered by rating statements on a Likert scale from 1 to 5.

6.2.3 Data Analysis

6.2.3.1 Descriptive statistics

Firstly, this section aims to describe both demo site user profiles in terms of age, working days per week and number of hours per day. Then, **the data analysis included several steps to understand the factors influencing occupants' satisfaction and the direction of this influence**. Initially, respondents were grouped into two clusters based on their satisfaction levels: those with high satisfaction and those with low satisfaction (Figure 9, a). Next, among different factors potentially explaining satisfaction IEQ, such as automated and personal control, we identified the statistically significant ones by using a non-parametric test, specifically the Mann-Whitney U Test, due to the non-normal distribution of our sample (Figure 9, b). This helped to explain the variability between the two satisfaction clusters. Subsequently, we conducted a logistic regression analysis to determine the relationship between satisfaction and these influential factors, focusing on the satisfaction objective variable (Figure 9, c). Finally, we analysed the magnitude and direction of coefficients to understand how changes in the influencing factors impact satisfaction levels (Figure 9, d).

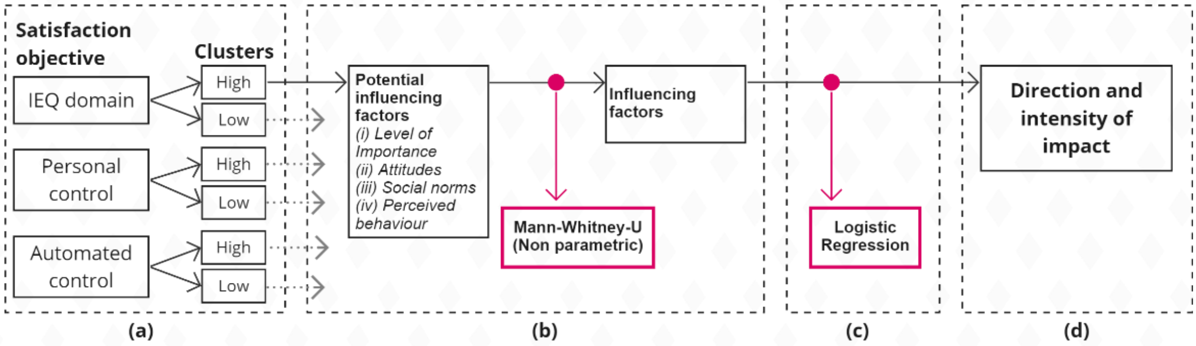

Figure 9 Workflow of data analysis to identify factors influencing occupant satisfaction with IEQ, personal control and automated building operation.

6.2.4 Results

6.2.4.1 Delft demo site occupants present more dynamic occupancy schedules than the ones' in the Riga demo site

We got 29, and 34 responses for Delft Demo and Riga Demo, respectively. The profiling results of both demo sites, Delft and Riga, present differences in the typology of work and occupants. In Riga, 6% of respondents are aged 18-30, 21% are aged 31-40, 29% are aged 41-50, and 44% are aged 51-60, whereas in Delft, 10% are aged 18-30, 41% are aged 31-40, 31% are aged 41-50, and 17% are aged 51-60. Regarding work patterns, Delft respondents work an average of 4.7 hours per day and 3 days per week, while Riga respondents work 7.8 hours per day and 4.1 days per week. Regarding the office environment, 45% of Delft occupants sit 0 to 2 meters from a window, 48% sit 2 to 4 meters away, and 7% sit 4 to 6 meters away, compared to 63%, 20%, and 17% in Riga. Both demo sites have 90% of occupants always working at the same desk and 10% practicing flexible desking. These findings highlight notable differences in occupancy schedules, where Delft is more dynamic and flexible, and Riga occupancy follows clearer schedules. The expectation regarding interaction strategies with building systems of both demo sites might differ due to the age range.

6.2.4.2 Satisfaction with Building Control Systems and IEQ

The results are organized Table 9 and Table 10 which show the influence of factors on satisfaction levels of different aspects of building components for the Delft and Riga demo sites, respectively. The column "description" provides a direct interpretation of the results.

In Delft (Table 9), social norms such as approval-seeking and the significance of diverse opinions (when others' opinions impact individual actions) influence most of the satisfaction objectives, for instance, personal control of the window, Indoor temperature, daylight, and absence of glare. The satisfaction level with automated heating is influenced by both personal control with HVAC and the acoustic environment, while time schedules for the windows operation influence satisfaction with the acoustic environment.

Table 9. Results for the statistical analysis on the influencing factors affecting satisfaction with IEQ, personal control and automated building operation in the Delft demo site.

Satisfaction objective	Cluster	Influencing factor	P-Value	Coeff	Description
	L - 35%		0.046	1.32	

Personal control of window	H - 65%	Approval-seeking for operating windows			(a) Increasing seeking of approval for window operation is positively correlated with personal window control satisfaction.
Automated heating	L - 67% H - 33%	Personal control of HVAC	0.038	0.90	(b) Increasing the perceived personal control increases satisfaction with automated heating control.
Indoor temperature	L - 76% H - 24%	Approval-seeking for operating heating	0.009	1.60	(c) Increasing seeking approval for operating the heating system increases satisfaction with indoor temperature.
Daylight	L - 68% H - 32%	Significance of diverse opinions for operating shadings	0.015	-1.66	(d) Decreasing the significance of diverse opinions in operating the shadings results in higher satisfaction with daylight.
Absence of glare	L - 68% H - 32%	Significance of diverse opinions for operating shadings	0.077	-1.16	(e) When having more diverse opinions for operating the shadings decreases the satisfaction with the absence of glare.
Absence of glare	L - 71% H - 29%	Outside View	0.015	-2.21	(f) Having less importance of having outside views enhances satisfaction with the absence of glare.
Acoustic environment	L - 60% H - 40%	Time schedules for window operation	0.076	-0.76	(g) Decreasing the dependency on time schedules for window operation increases satisfaction with the acoustic environment.

In Riga (Table 10), social norms and perceived behavioural control towards the control are influencing the satisfaction level with personal control of temperature and automated heating operation. Interestingly, lowering the level of importance of indoor temperature and the absence of glare improves satisfaction with automated cooling and absence of glare.

Table 10. Results for the statistical analysis on the influencing factors affecting satisfaction with IEQ, personal control and automated building operation in the Riga demo site.

Satisfaction objective	Cluster	Influencing factor	P-Value	Coeff	Description (The letter is used for the discussion)
Personal control of temperature	H - 47% L - 53%	Approval-seeking for operating heating	0.036	1.01	(a) Increasing seeking of approval for adjusting the temperature increases satisfaction with personal temperature control.
Personal control of temperature	H - 44% L - 56%	Perceived behavioural control in operating the cooling system	0.069	1.07	(b) Increasing the perceived behavioural control in operating the cooling system is positively correlated with personal temperature control satisfaction.
Personal control of temperature	H - 41% L - 59%	Approval-seeking for operating cooling	0.098	0.84	(c) Increasing seeking approval for operating the cooling system increases satisfaction with personal temperature control.
Automated heating	H - 33% L - 67%	Perceived behavioural control in operating the heating system	0.042	1.23	(d) Increasing the perceived behavioural control in operating the heating system is positively correlated with automated heating automation satisfaction.
Automated heating	H - 39% L - 61%	Time schedules for heating operation	0.017	0.98	(e) Increasing the time-based operation for heating systems is positively correlated with automated heating automation satisfaction.

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Automated cooling	H - 50% L - 50%	Indoor temperature	0.072	-1.72	(f) Having a lower level of importance of indoor temperature levels is correlated with cooling automation satisfaction.
Absence of glare	H - 32% L - 68%	Absence of glare	0.022	-2.11	(g) Having a lower level of importance of glare is correlated with daylight satisfaction.
Indoor air quality	H - 27% L - 73%	Acoustic environment	0.058	1.09	(h) Having a higher level of importance of the acoustic domain increases satisfaction with indoor air quality.
Indoor air quality	H - 27% L - 73%	Silent work environment	0.077	1.04	(i) A silent work environment correlates positively with indoor air quality satisfaction.
Acoustic environment	H - 27% L - 73%	Silent work environment	0.031	1.48	(j) Having a higher level of importance to a silent work environment increases satisfaction with the acoustic domain.

6.2.5 Conclusions

The influencing factors on the level of satisfaction in different building services described in the results section allow us to infer several recommendations for improving the human-building interaction strategies for both the Delft and Riga demo sites.

The suggestions for improving the interaction control strategy for the Delft demo site are as follows:

1) *Increase personal control strategies* over the thermostat, such as making thermostats more accessible and enabling control from tables. This will improve perceived personal control (Table 9, b), and enhance acceptance of automated control logic.
2) *Provide Information on heating system performance and IEQ* will benefit decisions based on approval-seeking tendencies, allowing users to take more reasonable actions (Table 9, c).
3) *Identify user archetypes* that can inform the creation of a dynamic, rule-based control system that accommodates different opinions or needs when operating shadings (Table 9, d and e).
4) *Provide Information on shading operation* when glare is present can improve overall user satisfaction and understanding (Table 9, f).
5) *Address Noise from Blind Operation* might have an effect on users' satisfaction level with the blind operation (Table 9, g). The actual blind control system in Delft has been identified as noisy and disruptive to users.

The suggestions for improving the interaction control strategy for the Riga demo site are as follows:

1) *Implement user-friendly control interfaces* with improved accessibility for operating the cooling system (Table 10, b).
2) *Provide accessible configuration for heating system setpoints* according to their personal preferences. This customisation can improve user control, and therefore their satisfaction with the automated system (Table 10, d).
3) *Incorporate a schedule-based control strategy for heating* to make it more understandable

for occupants. This can enhance the predictability of the automated heating and improve satisfaction (Table 10, e).

4) *Analyse and align automated cooling system control logic with occupants' preferences.* It is necessary to understand why automated systems may not align with occupants' preferences. Further exploration is needed to optimize system performance (Table 10, f).
5) *Review and improve the shading system for glare reduction*. It should be reviewed, analysed, and improved to enhance occupant comfort and satisfaction (Table 10, g).

The recommendations for the Delft and Riga demo sites differ based on their specific contexts. In Delft, the emphasis is on enabling users with personal control over building systems like thermostats, while providing information on heating system performance and shading operation. Identifying user archetypes informs the creation of a flexible control system, and addressing noise from blind operation is crucial. In Riga, the focus shifts towards developing user-friendly interfaces, especially for the cooling system. Additionally, there's an emphasis on the accessibility of heating system settings and aligning control logic with occupants' preferences. Improving heating control through scheduling and optimising the shading system for glare reduction are specific areas of interest in Riga.

Overall, these customised recommendations strive to enhance human-building interaction strategies at each demo site, ultimately improving satisfaction levels with automated systems and fostering improvements in energy efficiency within the buildings. Further research should assess the effectiveness of these strategies and test the framework in the buildings to gain insights into how the understanding of human-building interaction dynamics can lead to high satisfaction levels.

6.3 Lab experiment: Impact of location, type of interface and information on users' satisfaction with interaction strategies

This section describes the experiment conducted in a living lab to determine the impact of interaction strategies on occupant satisfaction with automated controls. In particular, it investigated how different interface configurations impact occupants' satisfaction, preferences, and control perception when controlling lighting and roller shades in an office setting.

The objective of this study was to collect information on the impact of different positions, types, and interface information on occupant-perceived control and usability of the tested setup. The experiment was conducted in the MOR building, located at The Green Village, TU Delft campus (Figure 10).

Figure 10. MOR building. The facility is located at The Green Village in the TU Delft campus. This building was utilised for experimenting.

6.3.1 Experimental Design

The experiment involved testing three aspects of control interfaces available to building users: position, type of interface, and the information provided. These aspects were evaluated through a series of scenarios that are described in Table 11.

Table 11. Description of control interfaces aspects tested and the different scenarios proposed.

ASPECT TESTED	SCENARIO
Position of Interfaces (Figure 11)	1. Lighting switches on the desk and roller shades switch on the desk. 2. Lighting switch on wall and roller shades switch on the desk 3. Lighting switch on the wall and a roller shades switch on the wall. 4. Lighting switches on the desk and roller shades switch on the wall.
Type of Interface	5. Physical switches for lighting and roller shades 6. Touchscreen control for lighting and roller shades
Information Displayed	7. Digital interface without system status information 8. Digital interface with system status information (on/off status, percentage of shading opening, and percentage of dimming lights)

Each participant experienced six different sessions, with the scenarios randomized to avoid order effects.

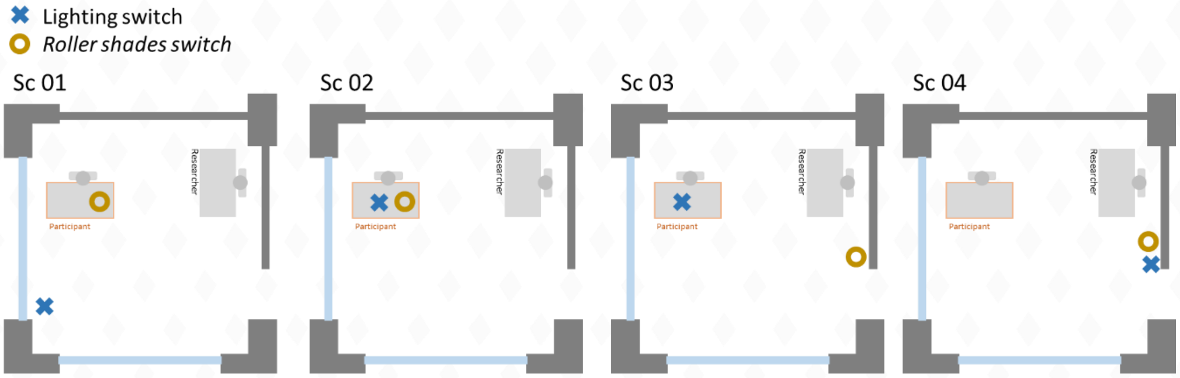

Figure 11. Describes the positions for lighting switches and roller shade interface tested.

6.3.2 Data Collection

Data collection was conducted through questionnaires and observations during the experiment. The collected data included personal information, personality test results, and usability assessments.

6.3.2.1 Personal information

Participants provided personal information through a questionnaire, which is described in Table 12.

Table 12. Participants personal information collected during the experiment.

Participants information	Question
Personal Characteristics	Age
	Gender
	Highest level of education
	Origin
Level of familiarity	Smart roller shades
	Manual roller shades
	Dimmable lights
	Smart lights
	Analogue control interfaces
	Digital control interfaces

6.3.2.2 Personality test

Participants completed the IPIP-NEO Short Form personality test to assess their personality traits. Different personality types may have varying preferences for interface styles. In addition to that, personality traits can influence how users perceive and interact with technology. The IPIP-NEO Short Form is a psychometric assessment tool designed to measure personality traits based on the Five-Factor Model (FFM) of personality. The Five-Factor Model includes five broad domains, often referred to as the "Big Five" personality traits. The IPIP-NEO Short Form includes items that assess these five domains and their associated facets.

6.3.2.3 Questionnaire per each interaction scenario

After completing each scenario, participants filled out the Post-Study System Usability Questionnaire (PSSUQ). This questionnaire included 16 questions divided into four categories Table 13.

Table 13. Questionnaire answered by participants after each of the interaction strategy scenarios tested.

Categories	Questions
System Quality (Questions 1-6)	- Overall satisfaction with the system interface - Ease of use - Task completion efficiency - Comfort in usage - Learning curve - Productivity potential
Information Quality (Questions 7-12)	- Information clarity and helpfulness - Error recovery - Ease of finding necessary information - Effectiveness of information for task completion - Information organization
Interface Quality (Questions 13-15)	- Pleasantness of the system combination - User preference for the system combination - Functionality and capability of the system combination
Overall Satisfaction (Question 16)	General satisfaction with the system combination

6.3.3 Experimental Procedure

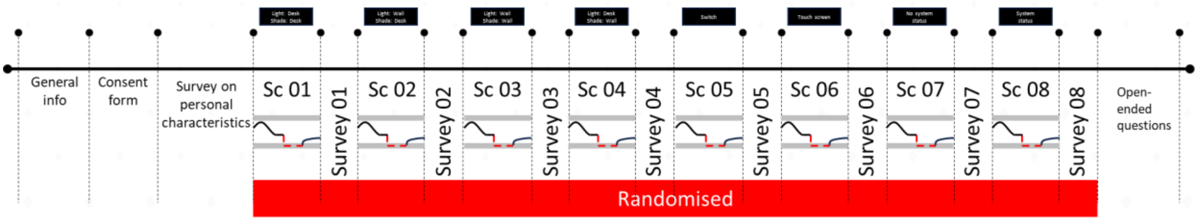

Figure 12. Graphic overview of the experimental procedure. The full span of the experiment is 1 hour.

Participants are welcomed and briefed on the study's purpose, which is to evaluate the effectiveness, efficiency, and overall user experience of interfaces for controlling smart lighting and roller shades. The session duration is 40-60 minutes, and participants are assured that all data collected will be kept confidential and used solely for research purposes Figure 12.

Next, participants are asked to read and sign an informed consent form. This step ensures that they are fully aware of the study's nature, their role, and the confidentiality of their data, thereby obtaining their explicit agreement to participate.

Before beginning the main tasks, participants complete a kick-off questionnaire and a personality test. These preliminary activities gather baseline data and contextual information about the participants, which may help in analysing the usability test results.

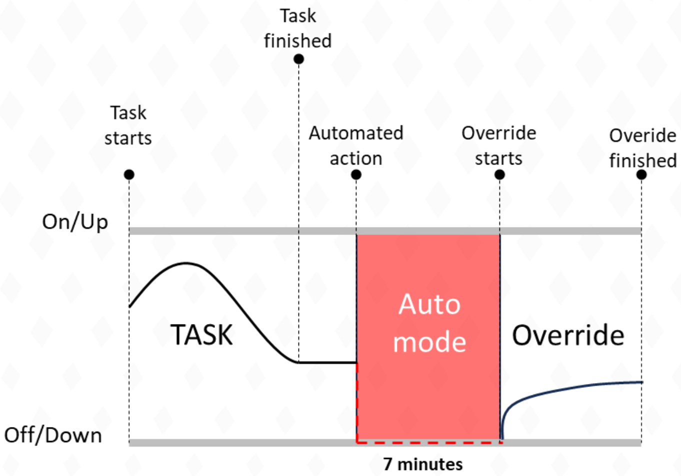

Figure 13. Graphic description of the activity performed for each participant in every scenario tested. When the scenario starts, the participant enters the room, adjusts the visual environment and sits. Then, an automated action is triggered, and the participant is asked to reset the visual condition as it was before the automated action.

The core usability test involves a series of tasks designed to assess the interfaces Figure 13. Participants first identify the interface used to control the roller shades and lights upon entering the room. They then set the shades and lights to their preference and inform the researcher when satisfied. After this setup, they wait for an automated adjustment of the lighting conditions, which they must override using the interface to readjust to their preferred settings. Once satisfied with the override, they again inform the researcher. This sequence simulates real-world use of smart building systems and captures both initial and adaptive interactions with the interface.

Throughout the tasks, researchers observe and take notes on participants' interactions. They document the steps taken to complete each task, any errors or difficulties encountered, hesitations, verbal feedback, and non-verbal cues such as facial expressions and posture. The start and end times of each task are recorded to track how long participants take to complete each step. These observations provide detailed insights into the usability of the interfaces and highlight areas for improvement.

The above tasks and observations are repeated for each interface scenario being tested, ensuring a comprehensive evaluation across different contexts. This repetition helps in comparing how different interface designs perform under similar conditions.

Finally, participants answer a series of open-ended questions. These questions explore various aspects of their experience, including the effectiveness and satisfaction with different interface positions, challenges faced, and their preferences regarding the intuitiveness and user-friendliness of the interfaces. Additionally, participants reflect on how their physical location within the office space influenced their interaction and express their preferences for interface configurations in different scenarios, such as private or shared offices.

6.3.4 Results

Profiling

The questionnaire included six participants aged between 24 and 34 years. Five participants held Master's degrees, and one held a Doctoral degree. The participants came from diverse countries: two from Italy, and one each from India, Saudi Arabia, Mexico, and Malta. In their office environments, three participants used analogue control interfaces, two used manual roller shades, and one used smart roller shades. The Figure 14. Level of familiarity with smart devices represents their level of familiarity with several devices; overall users were not very familiar with smart interfaces, but largely more familiar with manual and analogue ones.

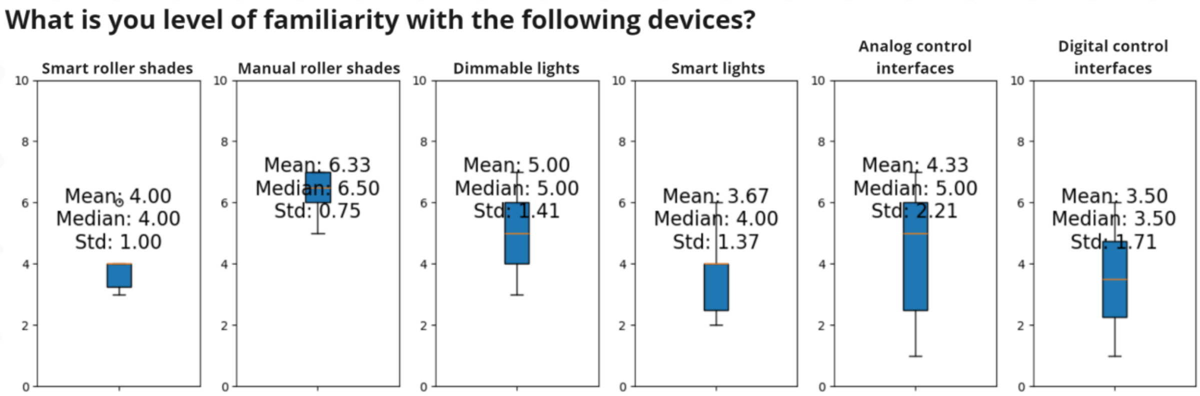

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Figure 14. Level of familiarity with smart devices

Analysis of position, type of device and information

From the six scenarios of the experiment, we evaluated the impact of position (wall vs desk), type of device (switch vs tablet), and information displayed in case of the tablet.

The influence of the position of lighting (Figure 15) on the desk vs wall does not present any statistical significance after testing the responses of the usability test. It should be noted the wide variance obtained in all the questions denoting the need of increasing the sample size of the experiment conducted.

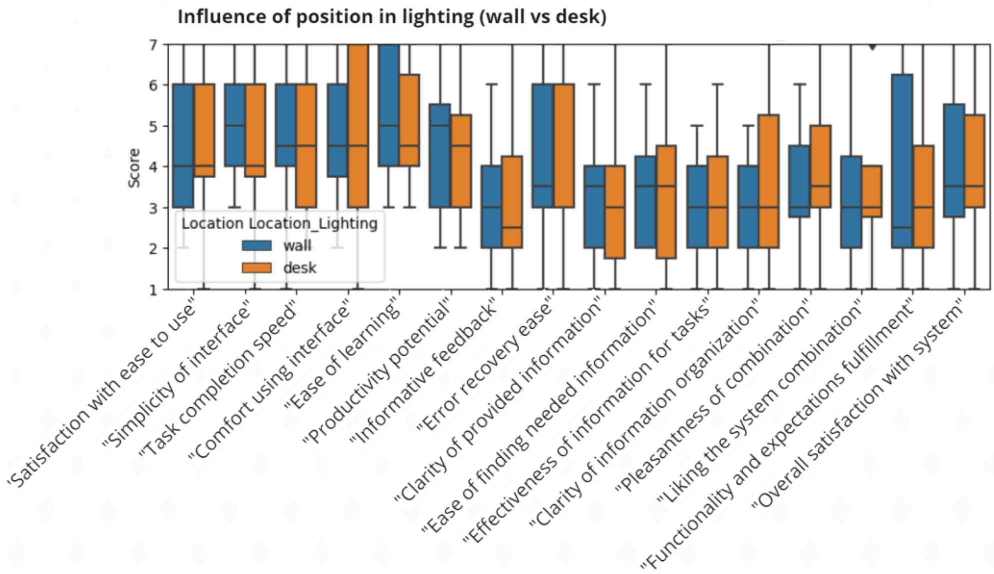

Figure 15. Influence of position in lightning control.

The influence of the position of shadings on the desk vs the wall (Figure 16) follows similar patterns, not presenting any statistical significance after testing positions. The standard deviation results present different influences of such variables of the usability test. The variables concerning the system quality (satisfaction, ease of use, simplicity of interface, task completion speed, comfort using interface, ease of learning, productivity potential) rank strong influence (above 4 overall).

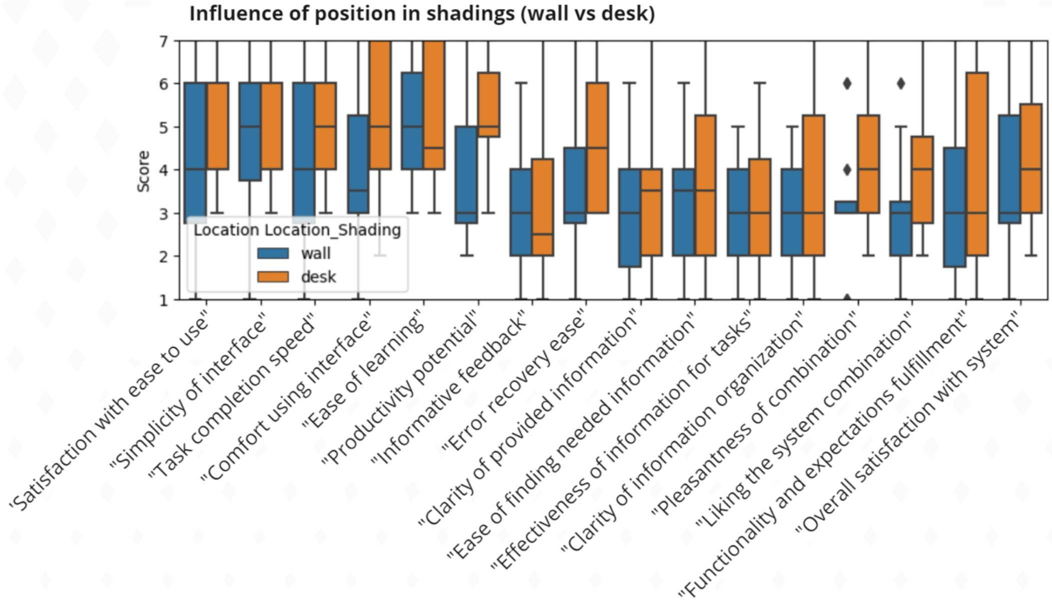

Figure 16. Influence of position in shadings control.

Mayor differences are seen when comparing the type of interface, switch vs screen (Figure 17). The use of a screen is statistically significant, ranking higher than the switch, in all the main domains of the usability test questions (System quality, information quality and interface quality)

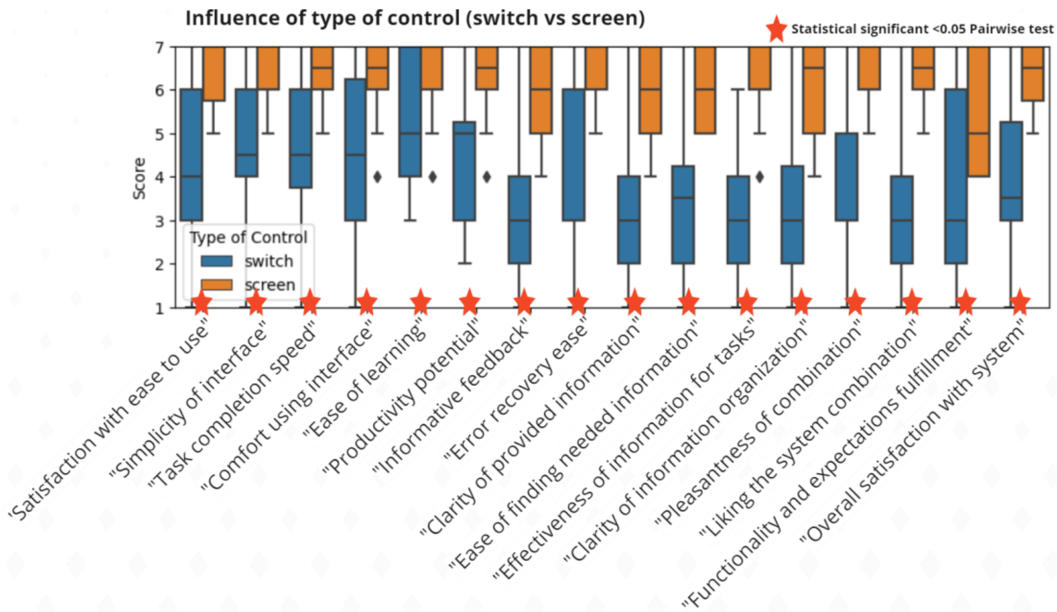

Figure 17. Influence of type of control (Switch vs screen)

The comparison of the influence of having information (Figure 18Figure 18) when using a screen shows no statistical difference. Raking in both cases, having and not information, suggests the favourable impact of using a screen over a switch as seen before.

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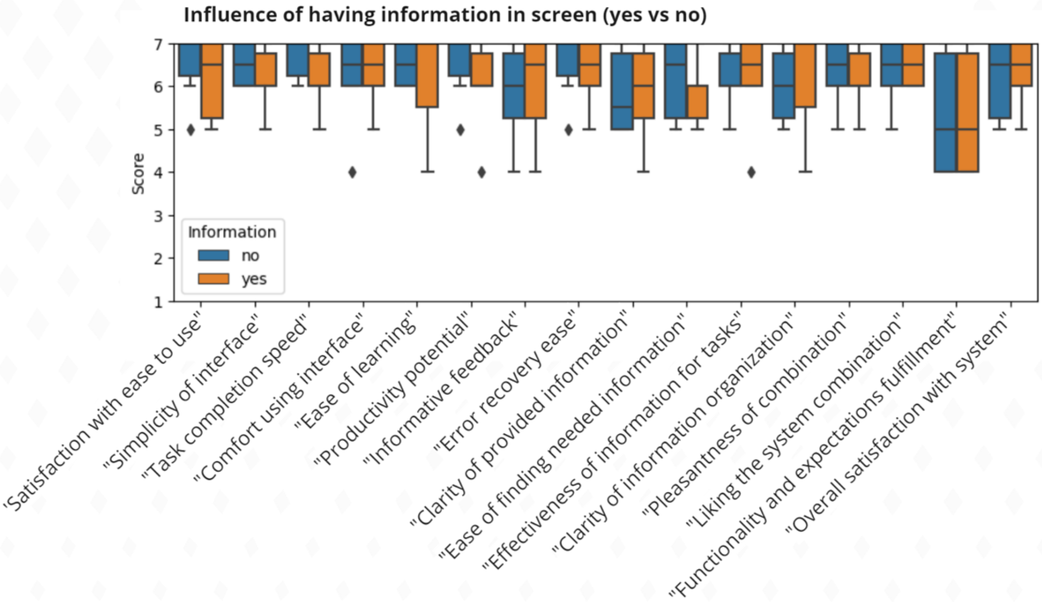

Figure 18. Influence of information in tablet display

6.3.5 Conclusions

<u>Position of Shading and Lighting</u>
The results show no statistical differences between type of location for shadings and lighting. However, during the qualitative responses we identify a need for both devices being always together. It is noticeable that in those responses we see high standard distributions, such high variance on responses suggest the need of increasing the sample size.

<u>Preference for Device Type – Switch vs. Screen</u>
When comparing type of device, switch versus screen, screen seems to be preferred among the sample, which is statistically significant. This result is understandable under the sample profile, which is young users between 24 and 34 years old. Further research should explore other age gaps to identify better relationships between user profiles and the type of interface preferred.

<u>Effectiveness of Information Display</u>
The screen showed a more favourable influence when operating the visual environment. Nonetheless, the effect of information about the status displayed seems to not be significant with reduced standard deviation, which suggests that by increasing the sample size, we would not expect different results.

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7 Overall conclusion and technical recommendations

Interaction strategies between users and smart buildings are key to enhance user satisfaction, comfort and well-being but also energy efficiency in smart buildings. Satisfactory interaction strategies are already considered in the SRI in the impact factor "convenience' and "information". However, recommendations and technical requirements for satisfactory interaction strategies are currently missing in current standards. This deliverable aimed at evaluating main technical requirements of satisfactory interaction strategy. This was performed by: (i) proposing a classification scheme for describing all the existing possible interaction strategies; (ii) applying the classification scheme to analyse market and real demo sites in terms of interaction strategies; (iii) review key findings from scientific literature and technical standards; (iv) perform qualitative and quantitative data collection on user requirements through workshops, questionnaires and controlled experiments.

The classification scheme proposed in Section 2 proved to be an effective tool to analyse interaction strategies in buildings and in the market. The analysis reveals two main approaches: The first strategy utilizes automated control based on direct sensing. Here, sensors measure factors like indoor environmental quality (IEQ), which refers to the occupants' thermal comfort, air quality, and lighting levels. Additionally, occupancy sensors can be used to detect presence. This data is then directly fed into automated control systems, either Building Management Systems (BMS) or actuation systems, which optimise building operations based on real-time conditions. While current technologies offer the capability to provide more sophisticated user interfaces, the typical approach remains limited to dashboards displayed on visual screens. Furthermore, despite advancements allowing for user integration into control loops, this potential remains largely untapped. The second well-established approach is direct user control. This strategy empowers building occupants to directly control systems like lighting and temperature through interfaces like buttons or thermostats. This approach offers a more immediate level of control for users.

There is a large extent of knowledge in literatures of drivers that impact user satisfaction with interaction in smart buildings. Key promising trends are: (i) to consider holistically user requirements by adopting the Theory of Planned Behaviour; (ii) to avoid generalisation of drivers and requirements and utilise user profiles or archetypes that can effectively describe user requirements with interaction strategy. Key drivers of satisfactory interaction strategies were confirmed to be: (i) meeting inherent expectations and definition of smart buildings in users by embracing a diversity of requirements, in particular for what concerns the balance between automation and personal control; (ii) providing strategies for information between users and buildings and vice versa; (iii) addressing privacy and trust concerns.

These findings were confirmed and expanded by the data collected by means of workshops, longitudinal questionnaires and experiments in Section 6. Well-designed interaction strategies are key to maximising user satisfaction and building efficiency (Section 6.1). Longitudinal studies (Section 6.2) reveal user desire for control, especially overheating, lighting, and cooling. User archetypes can inform flexible control systems (Section 6.2). Experiments confirm screen preference for users and highlight the value of grouped controls (Section 6.3).

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8 Deviations

The deliverable respected the expected outcomes. The only deviation to mention is the number of participants in the controlled laboratory study, which will be increased in the following months to increase the statistical significance of the results.

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