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Interface design for lighting and shading controls: device type, position, and system cues influencing user preference and acceptance

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HIGHLIGHTS

- PSSUQ adapted to evaluate lighting and shading control interfaces.
- Desk-mounted digital controls yielded the highest perceived usability across tasks.
- Adding system-state cues improved usability ratings compared to no-cue interfaces.
- Results support reachability and system cues as key design levers for acceptable controls.

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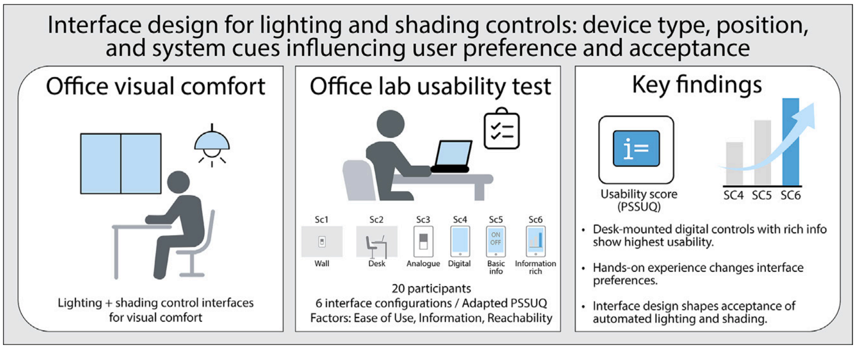
GRAPHICAL ABSTRACT



ABSTRACT

The integration of smart control systems in office buildings can be disruptive when individual preferences and expectations for control interfaces are overlooked. Understanding how human–building interaction influences environmental comfort and acceptance is essential for creating user-centered designs. This study aimed to evaluate the effectiveness of usability testing as an innovative method for assessing building system control interfaces and user interaction with automation. Specifically, we examined user preferences for shading and lighting controls in a controlled office laboratory, varying by “Type of Device” (analog vs. digital), “Position” (wall, desk, or split), and “System Cues” (information richness). In an experimental setting involving 20 participants, we investigated how these factors influence satisfaction and acceptance of automation. Using an adapted Post-Study System Usability Questionnaire (PSSUQ), we evaluated satisfaction with *Ease of Use*, *Reachability*, and *Information*. Findings show that while participants’ initial expectations favored simple analog controls, preferences shifted toward digital, information-rich systems after hands-on interaction. Ordered logistic regression confirmed that *Reachability* ($\beta = 2.317$) and *Ease of Use* ($\beta = 1.831$) were the strongest predictors of Overall Satisfaction ($p < 0.001$), placing interface position as the primary design characteristic. However, preferences varied by office type: in shared offices, users preferred wall-mounted controls to facilitate shared access and visibility. These insights offer actionable guidance for designing smart control interfaces that enhance user satisfaction, support personal control, and promote greater acceptance of building automation.

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1. Introduction

Recent advancements in information technology have facilitated the integration of automation and building control systems, improving user experience and energy efficiency [1]. Realizing this potential depends on how occupants perceive, respond to, and interact with these systems [2]. This dependence is particularly evident for lighting and window shading controls, which are among the primary building services through which users regulate their immediate environment [3]. Accordingly, interaction with lighting and window shading has been widely studied because it directly affects visual comfort, thermal comfort, and building energy use. Across this evidence, occupants are consistently shown to intervene in building operation (e.g., opening windows, switching lights, or adjusting roller shades) rather than passively accepting automated or default system behavior, especially when building control strategies conflict with individual needs or expectations [4,5]. In particular, lighting actions are closely linked to occupancy dynamics, daylight availability, and task demands [6,7]. Building on these observations, researchers have increasingly translated field evidence into probabilistic frameworks that aim to anticipate and represent these interactions in building performance assessments [8,9].

Several scholars have provided detailed empirical evidence of interaction drivers in real office contexts. Da Silva et al. [10] found that lighting and window shading actions were driven more by the act of arriving or leaving the office than by continuous changes in environmental variables, highlighting the role of context and daily routines. Similar studies suggest that acceptance of building services depends on whether automation is experienced as compatible with user requirements and sufficiently transparent. Sadeghi et al. [11] reported frequent interventions and preferences for accessible, customizable building controls, showing that interface accessibility can shape user interaction frequency and perceived acceptability of available building services. Meerbeek et al. [12] similarly documented widespread deactivation of automated exterior window shades in Dutch offices despite available manual overrides, indicating that override availability alone may be insufficient when automation is perceived as inconvenient, opaque, or misaligned. Together, these findings suggest that automation is more likely to be accepted when occupants remain informed and retain a sense of agency over their environment [13].

Review studies have synthesized current evidence, concluding that while environmental drivers of window shades use (e.g., solar radiation and glare) are well established, occupant behavior remains highly context-dependent [14,15]. This variability is frequently attributed to differences in building design, control strategies, and the degree of occupant access to controls [3]. Importantly, Galasiu and Veitch [16] already highlighted that user satisfaction in daylit offices depends not only on luminous conditions but also on building control availability and the quality of control systems, while documenting substantial inter-individual variation in preferences. Despite this evidence, much of it relies on in-situ monitoring and post-occupancy surveys [10,11]. These approaches provide validity, but their dependence on specific layouts and organizational contexts makes it difficult to isolate the influence of specific interface characteristics, such as device type, interface position, or information cues.

Beyond observed actions, perceived control is a key psychological construct influencing comfort and satisfaction [17,18]. Adaptive comfort research indicates that greater perceived personal control is associated with higher satisfaction and wider tolerance of indoor conditions [19]. Importantly, perceived control is tied to system interpretability and feedback. Human-Building Interaction (HBI) frameworks argue that building control interfaces must bridge the gap between system status and user understanding to build trust and acceptance of automation [20]. Evidence from smart thermostat users similarly shows that interface design shapes how people conceptualize system operation: when system status is poorly communicated (e.g., where temperature is measured), users may develop incorrect beliefs that hinder effective interaction [21,22]. Similar evidence from personal environmental control studies further shows that the initial (pre-set) state influences subsequent adjustments and preferred settings, underscoring that “preferred conditions” are not independent of how control is framed and presented [23]. These findings, together with work by Hellwig [24] and Meerbeek et al. [13], connect perceived personal control to the acceptance of automation, showing that systems are often disabled when system behavior is experienced as opaque or misaligned with user requirements.

Despite these insights, perceived building control is still rarely linked to measurable usability attributes of control interfaces, such as learnability, clarity of system state, or reachability. Emerging evidence indicates that these concrete interface characteristics can shape occupant interaction. Van Someren et al. [25] showed that inconsistent interface locations and unclear mappings between switches and fixtures undermine usability and can lead users to abandon control attempts. Moreover, digital interfaces must address potential accessibility barriers to ensure inclusive control [26]. Social dynamics further complicate interaction. In shared offices, occupants may avoid using wall-mounted controls to prevent social conflict, suggesting advantages for personal, desk-based interfaces [27]. Similar preferences are observed in residential contexts, where users often prefer remote or app-based control over wall-mounted interfaces due to ease of use [28]. Finally, extensive evaluations of programmable thermostats demonstrate that usability flaws (e.g., hidden menus, confusing terminology, and lack of feedback) can prevent users from engaging with energy-saving features and can contribute to persistent manual overrides [29,30].

Building on this evidence, this study examines how interface design influences perceived usability, perceived personal control, and the acceptance of automated lighting and shading systems. While existing literature has characterized when interactions occur, a key gap remains in isolating the impact of specific design attributes, such as device type, interface position, and information cues. To address this gap, we introduce a controlled, task-based usability testing approach adapted from Human-Computer Interaction (HCI) research [31]. The primary novelty of this work lies in its experimental design: rather than only recording the frequency of occupant actions, it tests how interface characteristics shape user experience under standardized tasks. By triangulating quantitative usability ratings from the PSSUQ with qualitative insights from questionnaires and interviews, we assess how these attributes relate to perceived Ease of Use, Information Clarity, Reachability, and Overall Satisfaction. This methodology aligns with recent recommendations to systematically compare personal control strategies to better understand how design supports occupant engagement with building automation [32].

2. Methodology

We conducted our experiment in a controlled laboratory designed as a simple office setting (the “office lab”), focusing on three key variables: the “Type of Device” (analog or digital), “System Cues” (no cues, basic system state cues, and system state with task completion cues), and “Position” (wall, desk, and split, i.e., controls distributed between wall and desk). Twenty participants took part in the experiments, which assessed their interaction with various control configurations. Through a combination of questionnaires and interviews about preferences, we collected both quantitative and qualitative data to gain insights into how the tested variables influence *Ease of Use*, satisfaction with *Information*, *Reachability*, and *Overall Satisfaction* with the control system interface. Below is a detailed description of the methodology, including the experimental setup, procedures, and data analysis techniques.

The office lab is located at The Green Village, a living lab affiliated with Delft University of Technology in the Netherlands (Fig. 1(a)). Measuring 2.45 × 2.95 meters, the office lab is southwest-facing and equipped with dimmable LED ceiling lights (Fig. 1(c)) and a motorized

Fig. 1. The office lab at The Green Village, Delft University of Technology. (a) Interior view showing the seats of the participant and researcher; (b) Top-down schematic of the layout including systems, participant, researcher, and entrance; (c) Front view of the window with the roller shade set to the mid position; (d) Lighting system used in the experiment; and (e) Exterior view of the Office Lab. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

roller shade (Fig. 1(d)) on the outer side of the window. Both the lighting and roller shades are connected to a control system powered by the Home Assistant platform [33], which enables integration with the interfaces being tested. Inside the room, we placed a desk with a computer to mimic an office environment. A separate table was positioned in the corner for the researcher, who was responsible for assisting participants as needed and noting any important observations (Fig. 1(b)).

The participants were recruited via email and social media. In total, 20 participants took part in the experiment (9 females and 11 males; age range 23–40, mean = 30, SD = 4.48). Participants worked in technical fields other than building science. The experimental plan was reviewed and approved by the Human Research Ethics Committee of Delft University of Technology under ID 3752.

2.1. Experimental procedure

Fig. 2 shows the timeline of the experimental procedure. First, participants received an introduction to the experiment and signed the consent form. The test started with a questionnaire and an interview about the participants' expectations for controlling artificial lighting and window roller shades in an office space. Participants then completed six randomly ordered scenarios, with the PSSUQ administered after each scenario. Upon completing all six scenarios, participants were interviewed and asked to complete a questionnaire about their experiences with the interfaces. The entire usability test lasted approximately 60 minutes per participant. The experiment is explained in detail in the following sections.

2.1.1. Scenarios

We designed six scenarios to evaluate the impact of three key variables: "Type of Device" (analog switches vs. digital touchscreen), the interface "Position" (wall-mounted vs. desk-mounted, or split position), and the level of "System Cues" provided (no system cues, system state, or system state and cues for supporting the task completion). The split position consisted of positioning the lighting control interface on the wall in proximity to the entrance and the blind control interface on the wall in the proximity of the window. A detailed description of these scenarios is presented in Table 1. Each participant experienced the scenarios in a random order. The six scenarios represent targeted contrasts (not a fully factorial design), a choice made to manage participant fatigue. Therefore, some combinations were not tested (e.g., digital wall-mounted control). Cue-related effects are interpreted within the tested scenario set, primarily through comparisons among the desk-mounted digital scenarios (Scenarios 4–6).

We placed interfaces in three positions: on the wall next to the entrance (switches only), split across the wall next to the window and

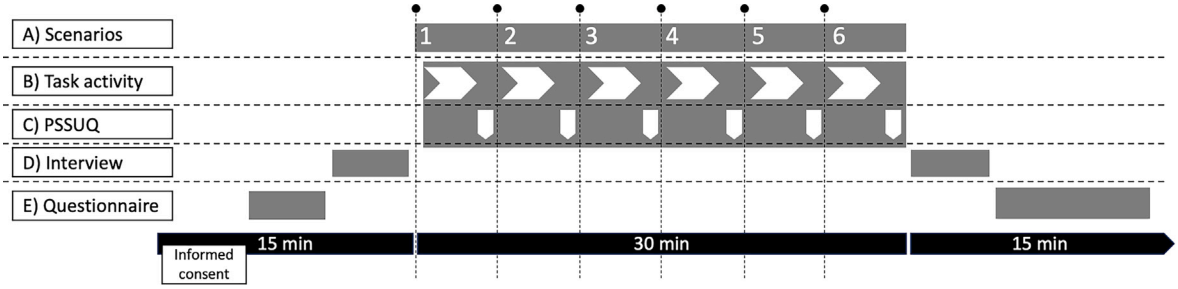

Fig. 2. Experimental procedure timeline.

Table 1

Overview of the six scenarios, which consider different “Types of devices”, “Positions”, and “System cues”.

Scenario	Type of device		Position		System cues	
	Light	Roller shade	Light	Roller shade	Light	Roller shade
SC1	Analog	Analog	Wall/entrance	Wall/entrance	No cues	No cues
SC2	Analog	Analog	Desk	Desk	No cues	No cues
SC3	Analog	Analog	Wall/entrance	Wall/Window	No cues	No cues
SC4	Digital	Digital	Desk	Desk	No cues	No cues
SC5	Digital	Digital	Desk	Desk	System state	System state
SC6	Digital	Digital	Desk	Desk	System state + task completion	System state + task completion

entrance (shading and lighting switches, respectively), and on the participant’s desk (either switches or a tablet). Fig. 3 illustrates the control interface positions within the office lab.

The scenarios utilized two types of control devices: a switch as the analog interface (Fig. 4a and b) and a tablet as the digital interface (Fig. 4(c)). All three types of devices were capable of controlling artificial lighting and the window roller shade. The tablet featured three visual interfaces (Fig. 5): one with no system cues (Fig. 5(a)), one with system state cues (Fig. 5(b)) and one with system state plus task completion cues (Fig. 5(c)).

2.1.2. Control task activity

The task activity in this study was designed to simulate realistic interactions with the different building control interfaces being tested, as outlined below:

(a) *Entering the Room and Initial Setup:* Participants were asked to adjust the lighting to 50% brightness and set the roller shades to a halfway position using the control interface. This step evaluated how intuitively and effectively participants could interact with the system to achieve these specific settings.
(b) *Seated Work Simulation:* After completing the initial setup, participants were instructed to sit at a desk and use a computer, simulating a typical work scenario. This setup established a context for the upcoming automated system actions.
(c) *Automated System Action:* While participants were engaged in the computer-based task, an automated system action was triggered, causing the lights and roller shades to adjust automatically. This phase assessed how participants reacted to the system taking control and their comfort in the situation.

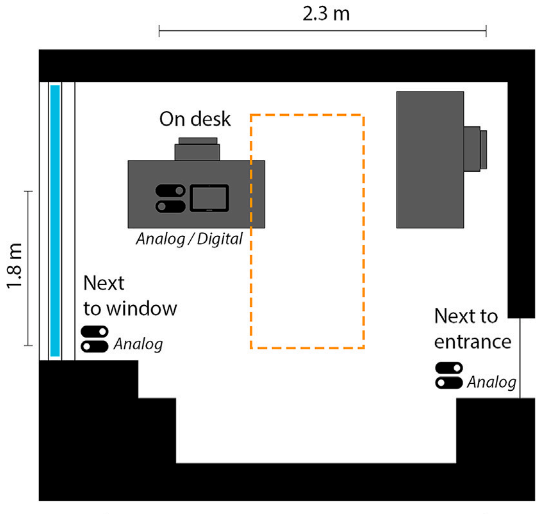

Fig. 3. Top view of the office lab indicating the positions where the interfaces were placed during the tested scenarios.

(d) *Recovering Control:* Following the automated action, participants were instructed to reset the lights and roller shades to their original settings. This step tested their ability to quickly and accurately reassert control over the system.
(e) *Completion and Feedback:* After the system was restored to its initial state, the task scenario concluded. Participants then completed the Post-Study System Usability Questionnaire (PSSUQ), providing feedback on their experience with the control interface.

2.1.3. Post-study system usability questionnaire

To assess participants’ satisfaction with their perceived personal control over the office environment, we employed the Post-Study System Usability Questionnaire (PSSUQ) as a psychometric instrument. Originally developed to evaluate users’ satisfaction with computer systems and applications [31], the PSSUQ demonstrates strong reliability. All categories (system quality, information quality, and interface quality) report Cronbach’s alpha values above 0.80, indicating good internal consistency and supporting its suitability as a standardized measure of usability.

Although PSSUQ is often used for digital systems (e.g., websites or software), its focus on general usability categories makes it suitable for evaluating the control interfaces in this study. The main categories measured were:

(a) *System usefulness:* How well the system helps users achieve their goals.
(b) *Information quality:* Clarity and usefulness of the system’ information.
(c) *Interface satisfaction:* Users’ overall satisfaction with the system’s design and interaction.

Since the standard PSSUQ does not cover the impact of interface reachability on users’ satisfaction, we added four customized items. The original statements were also modified to refer specifically to the control interfaces being tested (Table 2).

2.1.4. Interviews

We conducted two interviews during the experiment:

(a) *Pre-Experiment Interview:* Aimed at understanding participants’ expectations regarding control interfaces in a typical office environment. Questions focused on preferences for “Type of Device” (analog vs. digital), interface “Position”, the desired level of “System Cues”, and acceptance of automation.
(b) *Post-Experiment Interview:* Participants provided feedback on the control interfaces they used during the six scenarios. The same topics were revisited, enabling a comparison between participants’ initial expectations and their actual experiences.

2.1.5. Familiarity and preferences questionnaires

At the start of the experiment, participants completed a questionnaire to assess their familiarity with and experience with various devices, both at home and in the office, including smart roller shades, manual roller shades, dimmable lights, smart lights, analog control interfaces

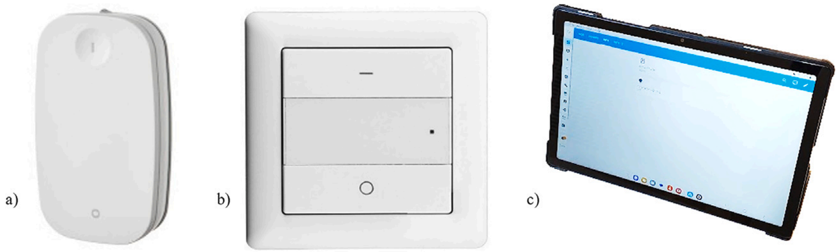

Fig. 4. Types of device interfaces used in the experiment: (a) analog light switch, (b) analog roller shade switch, and (c) tablet interface controlling both lights and roller shades.

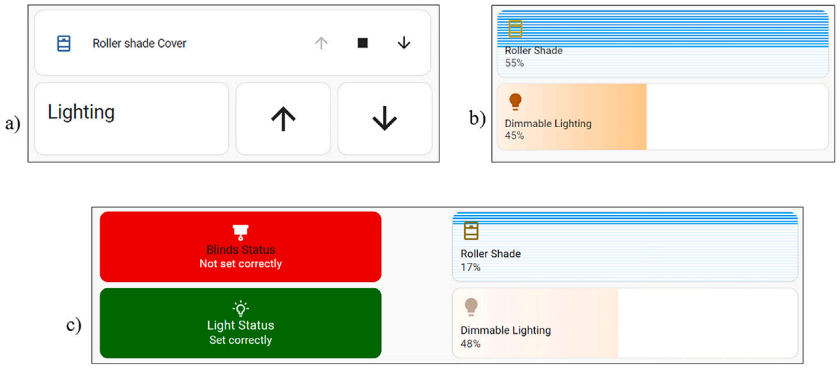

Fig. 5. Various types of digital control interfaces displayed on the tablet interface screen: (a) no system cues, (b) system state cues, and (c) with system state plus task completion.

(e.g., switches, dials), and digital control interfaces (e.g., touch screens). Familiarity was rated on a Likert scale ranging from 1 (not at all familiar) to 7 (extremely familiar). Additionally, a multiple-choice format was used to determine which of these devices were present in their typical office environment.

At the end of the experiment, participants completed a preference questionnaire consisting of three sections. Section 1 focused on personal preferences in the office lab setting, using single-choice questions and one ranking task to assess preferences for the three interface characteristics tested in the study. Participants were asked to indicate where they preferred the interface to be located (e.g., on the desk or by the entrance), what type of feedback they found most helpful (e.g., system status), and whether they preferred analog or digital controls. Section 2 explored how these preferences might change in a shared office context, using Likert-scale statements to evaluate trade-offs between convenience, user responsibility, and feedback clarity. Section 3 examined how these interface characteristics influenced the acceptability of automation, focusing on whether specific design elements might make participants feel comfortable with automated lighting and shading systems. The structure and content of the questionnaire are summarized in Table 3.

2.2. Data analysis

Our data analysis consisted of six steps: (1) summarizing participants' familiarity ratings; (2) validating the PSSUQ via exploratory factor analysis and Cronbach's α; (3) isolating interface effects with Bonferroni-adjusted pairwise tests; (4) modeling *Overall Satisfaction* using ordered logistic regression; (5) examining post-test preferences and automation acceptance; and (6) analyzing interview data to contrast initial expectations with actual experiences.

2.2.1. Level of familiarity distribution

We summarized participants' self-reported familiarity with manual and smart devices and control interfaces (1–7 Likert) by computing means, standard deviations, and interquartile ranges, and displayed them as boxplots. Counts of device availability (e.g., manual, smart, and dimmable lighting) are presented to characterize the participants' prior exposure.

2.2.2. Suitability of the post-study system usability questionnaire

We tested the suitability of the PSSUQ questionnaire by conducting an Exploratory Factor Analysis (EFA) [34]. By performing this analysis, we aimed to identify the key factors for which the survey was designed: *Ease of Use, Information,* and*Reachability*. For a preliminary analysis, we checked the factorability of the sample using Bartlett's test of sphericity ($\chi^2 = 77.70$, $p < 0.001$) [35] and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (0.914) [35], both of which confirmed that the number of participants was appropriate for the factor analysis. After confirming the suitability of performing the EFA, we calculated the Kaiser's eigenvalues of the correlation matrix to determine the number of factors, selecting all eigenvalues greater than one [33]. Before selecting the rotation, we analyzed correlations to decide on the matrix rotation method. We opted for the Oblimin rotation [36], which is appropriate when factors are assumed to be correlated. We tested the internal consistency of the variables summarized in every factor [37] and calculated the factor scores using the refined method of regression, which maximizes validity [38]. Finally, we assessed the reliability of the obtained results by calculating Cronbach's alpha as described in Sauro and Lewis [31] and comparing their reported values with those derived from our modified PSSUQ questionnaire.

2.2.3. Usability scores and interface characteristics impact

We report usability scores for each factor identified, along with the *Overall Usability* score, calculated as the average of the first 16 modified PSSUQ items. To examine how usability factors varied across the six interface scenarios, we conducted Bonferroni-adjusted pairwise statistical comparisons of scenario ratings for *Ease of Use*, *Reachability*, and *Information*. These comparisons isolated the effect of each variable

Table 2
Modified PSSUQ developed for testing building control interfaces. The items were adjusted to match the aim of this usability test, focusing on assessing *Ease of Use*, *Reachability*, and *Information*. “How strongly do you agree or disagree with the following items” – Strongly disagree (1) to Strongly agree (5).

Number	Item	Category
1	Overall, I am satisfied with how easy it is to use this control interface.	Ease of use
2	It was simple to use this control interface.	Ease of use
3	I was able to complete the tasks and scenarios quickly using this control interface.	Ease of use
4	I felt comfortable using this control interface.	Ease of use
5	It was easy to learn to use this control interface.	Ease of use
6	The control interface was pleasant to use.	Ease of use
7	I liked using this control interface.	Ease of use
8	This control interface has all the functions and capabilities I expect it to have.	Ease of use
9	The control interface provided information that helped me to use the light and roller shade.	Information
10	The information provided by this control interface was clear.	Information
11	The information on the control interface was effective in helping me complete the tasks.	Information
12	The organization of information on the control interface was clear.	Information
13	I found it easy to access the control interface in its current position.	Reachability
14	The position of the control interface was convenient for me.	Reachability
15	The control interface’s position was appropriate for the tasks I needed to perform.	Reachability
16	The control interface’s position allowed me to interact with it without causing discomfort.	Reachability
17	Overall, I am satisfied with the control interface (position, information, and type).	Overall satisfaction

(“Type of Device”, “Position”, and “System Cues”) while controlling for the others, enabling a clearer interpretation of their individual impacts. At the same time, the set of scenarios covered all three levels of each variable, allowing for group-level analysis (Table 4).

2.2.4. Influence of factors on overall satisfaction

We performed a regression analysis to assess the ability of the identified factors to predict the *Overall Satisfaction* with the interface, as measured by the item 17: “Overall, I am satisfied with the control interface (position, information, and type of device)”. Since the dependent variable, *Overall Satisfaction*, was measured on a Likert scale (ordinal), we employed an Ordered Logistic Regression model [39].

2.2.5. Personal interface preferences after the experiment

We summarized participants’ preferences for interface characteristics by reporting frequencies and percentages for each option within the office lab setup. To identify which pairwise differences in preference were statistically meaningful, we applied chi-square tests of independence with Bonferroni-adjusted post hoc comparisons (adjusted $\alpha = 0.05$), allowing us to isolate specific contrasts (e.g., desk vs. wall) while controlling the family-wise error rate.

To examine the consistency of preferences across contexts, we compared each participant’s selections in the office lab setup with their responses to a follow-up questionnaire describing a hypothetical shared office scenario. For each interface characteristic (“Position”, “Type of Device”, and “System Cues”), we defined a match as a participant choosing the same option in both contexts. We then calculated a *match rate*, expressed as the proportion of participants whose choices were consistent across the two contexts. This participant-level comparison provided a descriptive measure of context dependency, indicating how stable preferences remained when moving from a controlled, individual lab setting to an imagined, socially shared office environment.

For the automated lighting and shading acceptance questionnaire, we treated each interface characteristic rating (“Position”, “Type of Device”, “System Cues”) as a within-subject comparison of ordinal 5-point Likert scores. We first described this data using medians and interquartile ranges. We then conducted Wilcoxon signed-rank tests for all relevant within-subject pairings ($\alpha = 0.05$) to determine whether median differences were unlikely under the null hypothesis of no preference. Finally, we tallied each participant’s single top-ranked attribute to complement these inferential analyses with a measure of peak preference.

2.2.6. Interviews

We analyzed the interview data using structured data analysis. The analysis focused on participants’ expectations versus their actual experiences with interface positions, the type and level of system cues provided, interface preferences, and attitudes toward automation. We used a comparative approach to assess shifts in participants’ perceptions by contrasting participants’ initial expectations with their post-interaction experiences.

3. Results

3.1. Level of familiarity with lighting, shading and control interfaces

This section examines participants’ self-reported familiarity with manual and smart lighting, shading, and control interfaces. Fig. 6

Table 3
Structure and content of the post-experiment questionnaire assessing participants’ preferences for interface characteristics related to lighting and shading control. The questionnaire was divided into three sections: (1) baseline preferences in a private office setting, (2) preference shifts in a shared office context, and (3) influence of interface characteristics on the acceptability of automation.

Section	Focus	Question type	Interface characteristics examined
Section 1: personal preferences in the office lab	Identifying preferences for control interface characteristics in a private office setup after the experiment	Single choice; ranking (attribute importance)	- Preferred location of the control interface for lighting and shading. - Preferred level of system feedback. - Preferred type of control device (analog/digital). - Relative importance of interface characteristics: position, system cues, and type of device.
Section 2: preferences in shared office context	Exploring how preferences shift in a shared office setting	5-point Likert-scale agreement (strongly disagree to strongly agree)	- Preferred location of controls in a shared office (desk, entrance, separate). - Preference for analog vs. digital controls. - Importance of system feedback. - Desire for simplicity vs. information-rich interfaces.
Section 3: automation acceptability and interface design	Assessing which interface features improve user acceptance of automation	5-point Likert-scale agreement (strongly disagree to strongly agree)	- Interface types that enhance comfort with automation (analog vs. digital). - Interface location (desk, door, distributed). - Degree and clarity of feedback from the automated system.

Table 4
Pairwise comparisons by variable, controlling for other factors.

Variables	Level comparison	Scenario A	Scenario B	Constant variables
Interface Position	Wall vs. Desk	1 – Analog – Wall – No cues	2 – Analog – Desk – No cues	Analog, No cues
Interface Position	Wall vs. Split	1 – Analog – Wall – No cues	3 – Analog – Split – No cues	Analog, No cues
Interface Position	Desk vs. Split	2 – Analog – Desk – No cues	3 – Analog – Split – No cues	Analog, No cues
Type of Device	Analog vs. Digital	2 – Analog – Desk – No cues	4 – Digital – Desk – No cues	Desk, No cues
System Cues	No cues vs. State cues	4 – Digital – Desk – No cues	5 – Digital – Desk – System state	Digital, Desk
System Cues	State vs. Full cues	5 – Digital – Desk – System state	6 – Digital – Desk – Feedback	Digital, Desk
System Cues	No cues vs. Full cues	4 – Digital – Desk – No cues	6 – Digital – Desk – Feedback	Digital, Desk

compares what participants know versus what they have experienced in their office environments. Specifically, Fig. 6(a) shows the responses of the participants in terms of their perceived familiarity with different types of lighting, shading and control interfaces in office spaces, while Fig. 6(b) shows the number of participants reporting the presence of one or more of these items in their office space. The majority of participants (84%) reported being familiar with analog control interfaces and indicated having experience with them in their office space. In line with this, when asked specifically about manually controlled roller shades (typically operated through analog interfaces), participants also reported high familiarity and frequent availability in their office environments. Smart automated lights or manually controlled dimmable lights were less frequently available in the office spaces (5.3% and 10.5% of participants, respectively), even though participants reported being highly familiar with dimmable lights (implying exposure outside of their office environments). In the middle of the available options, smart automated roller shades were present in the office spaces of 37% of participants.

3.2. Suitability of the PSSUQ

This section examines the psychometric suitability of the modified PSSUQ to evaluate usability in lighting and shading control interfaces. After interacting with six interface scenarios, participants completed the questionnaire, providing quantitative measures of satisfaction across sixteen usability items. To verify whether the instrument reliably captured distinct aspects of participants' responses, we conducted factor analysis and reliability testing.

We performed a factor analysis of participants' responses to the 16 PSSUQ items, which resulted in three main factors: (1) *Ease of Use*, (2) *Reachability*, and (3) *Information*. These three factors collectively explained 80.01% of the variance in the dataset, indicating that these domains offer a good representation of the whole dataset of participants' responses, and exceed common thresholds for explained variance in scale development [37].

Table 5 reports the factor loadings for each item, indicating their relative contribution to the identified factors. Factor 1 (*Ease of use*) clustered items related to satisfaction (*item 1* = 0.70), simplicity (*item 2* = 0.82), comfort (item 4 = 0.82), and ease of learning (*item 5* = 0.70). It also included items addressing quickness (*item 3 = 0.51*), pleasantness (*item 6 = 0.54*), liking (*item 7 = 0.66*), and expectation of functionality (*item 8 = 0.65*), which showed weaker loadings (<0.70). Factor 2 (*Reachability*) was defined by items addressing position and access to the interface, with particularly strong factor loadings for appropriateness of position (item 14 = 0.95), ease of access (*item 13* = 0.88), and absence of discomfort (*item 16* = 0.80). Factor 3 (*Information*) gathered items related to "System Cues", with high loadings for helpfulness (*item 9* = 0.97), clarity (*item 10* = 0.94), and organization (*item 12* = 0.80). These results validate that the modified PSSUQ differentiates between *Ease of Use*, interface *Reachability* (or ease of access), and *Information*, thereby validating its structure for evaluating lighting and shading control systems in this study.

To assess the reliability of the modified PSSUQ in capturing its underlying factors, we calculated Cronbach's alpha and evaluated three scoring models: (1) the original PSSUQ v3 subscales, (2) the modified version with equal item weights, and (3) the modified version weighted by factor loadings. As summarized in Table 6, the modified questionnaire achieved high internal consistency across all configurations, comparable to the original PSSUQ. The *Overall factor* showed excellent reliability in both the original and equal-weighted modified versions (α = 0.94), with a slight improvement when factor loadings were applied (α = 0.95). The *Ease of Use* factor, aligned with the original *System Quality* subscale, also showed high internal consistency, achieving α = 0.90 in the original and equal-weighted models, and α = 0.93 with factor loadings. The *Information* factor improved slightly in the modified versions

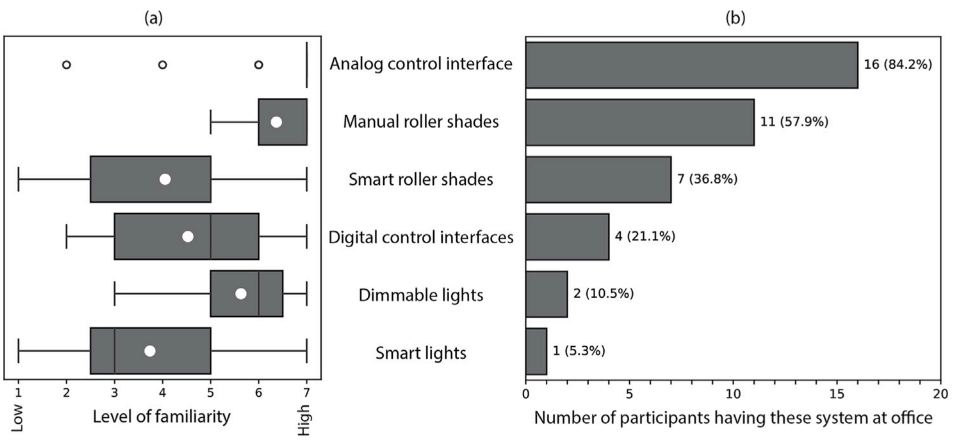

Fig. 6. Overview of participants' familiarity with and availability of different lighting, shading, and control interfaces in office spaces. (a) Participants' self-reported familiarity with manual and smart roller shades, dimmable and smart lighting, and analog or digital control interfaces. (b) Number of participants who reported having these systems in their office.

Table 5
Factor loadings for each item in the factor analysis. Factor 1 represents the items related to *Ease of Use*, Factor 2 to *Reachability*, and Factor 3 to *Information*.

Category	Num.	Item	Factor 1	Factor 2	Factor 3
Ease of use	1	Overall, I am satisfied with how easy it is to use this control interface	0.70	0.17	0.05
Ease of use	2	It was simple to use this control interface	0.82	−0.19	0.07
Ease of use	3	I was able to complete the tasks and scenarios quickly using this control interface	0.51	0.35	0.15
Ease of use	4	I felt comfortable using this control interface	0.82	0.11	−0.11
Ease of use	5	It was easy to learn to use this control interface	0.70	−0.28	0.13
Ease of use	6	The control interface was pleasant to use	0.54	0.35	0.12
Ease of use	7	I liked using this control interface	0.66	0.19	0.08
Ease of use	8	This control interface has all the functions and capabilities I expect it to have	0.65	0.28	0.00
Information	9	The control interface provided information that helped me to use the light and roller shade	−0.05	0.00	0.97
Information	10	The information provided by this control interface was clear	0.04	−0.08	0.94
Information	11	The information on the control interface was effective in helping me complete the tasks	−0.02	0.17	0.85
Information	12	The organization of information on the control interface was clear	0.09	0.00	0.80
Reachability	13	I found it easy to access the control interface in its current position	0.08	0.88	−0.07
Reachability	14	The position of the control interface was convenient for me	−0.01	0.95	0.06
Reachability	15	The control interface's position was appropriate for the tasks I needed to perform	0.04	0.92	0.01
Reachability	16	The control interface's position allowed me to interact with it without causing discomfort	0.06	0.80	0.14

Table 6
Comparison of Cronbach's alpha values between the original PSSUQ (version 3), the modified PSSUQ questionnaire with equal weighting across items, and the modified PSSUQ questionnaire incorporating factor loadings.

Subscales	Cronbach's α (PSSUQ v3)	Cronbach's α (Modified PSSUQ, equal item weights)	Cronbach's α (Modified PSSUQ, factor loadings)
Overall	0.94	0.94	0.95
System quality (ease of use in this study)	0.90	0.90	0.93
Information quality	0.91	0.95	0.95
Interface quality	0.83	(Not evaluated)	(Not evaluated)
Reachability (new factor in this study)	(Not applicable)	0.96	0.96

($\alpha = 0.95$) compared to the original *Information Quality* subscale ($\alpha = 0.91$), indicating enhanced coherence within this dimension. Finally, the newly introduced *Reachability*factor demonstrated excellent reliability ($\alpha = 0.96$), confirming it as a stable and meaningful construct in this study and supporting its inclusion as a distinct usability dimension for evaluating lighting and shading control interfaces.

3.3. Usability score per level of reachability, ease of use, and information

This section reports usability scores for each factor identified previously, along with the *Overall Usability* score, calculated as the average of all 16 items. We conducted pairwise comparisons between scenarios to identify statistically significant differences. Fig. 7 presents these results, displaying scores for *Ease of Use* (a), *Reachability* (b), *Information* (c), and the *Overall Usability* score (d).

As shown in Fig. 7(a), *Ease of Use* increased from Scenario 1 (analog, wall, no cues) to Scenario 6 (digital, desk, with cues). Overall, digital interfaces (Scenarios 4–6) were rated higher than analog interfaces (Scenarios 1–3). This effect is illustrated by the desk-mounted no-cue contrast between Scenario 2 (analog) and Scenario 4 (digital), which isolates the benefit of switching device type while holding position and cue level constant.

For *Reachability* (Fig. 7(b)), wall-mounted (Scenario 1) and split-position interfaces (Scenario 3) were rated lower than desk-mounted configurations (Scenarios 2, 4–6). The improvement from Scenario 1 to Scenario 2 (both analog, no cues) highlights the influence of interface position. Reachability ratings were consistently high for desk-mounted interfaces across both analog and digital device types, suggesting that position is a primary determinant of this factor.

Information scores increased when system cues were provided (Fig. 7(c)). Scenarios without cues (1–4) were rated lower than cue-enabled scenarios (5–6). The contrast between Scenarios 4 and 5 (digital, desk; no cues vs. state cues) isolates the positive effect of adding feedback. No meaningful difference was observed between Scenario 5 (state cues) and Scenario 6 (state + task-completion cues), suggesting diminishing returns once key state information is available.

Fig. 7(d) summarizes *Overall Usability*. Pairwise comparisons showed significant differences ($p < 0.01$) between Scenarios 1–3 and Scenarios 5–6 (i.e., 1–5, 1–6, 2–5, 2–6, 3–5, 3–6). Overall usability was lowest for wall/split configurations and highest for the desk-mounted, cue-enabled scenarios. The contrast between Scenarios 4 and 5 further indicates that adding system cues can yield a substantial usability gain even when device type and position are held constant.

3.4. Influence of position, ease of use, and information on participants' overall satisfaction

In this section, we examine how the three usability factors relate to *Overall Satisfaction*, as measured by *item 17* of the modified PSSUQ (*"Overall, I am satisfied with the control interface—position, information, and type"*). We do this to assess whether *Ease of Use*, *Reachability*, and *Information* also explain participants' overall satisfaction with the interfaces. As shown in Fig. 8, we found strong and statistically significant positive correlations between all three factors and *Overall Satisfaction* (all $r > 0.65$, $p < 0.001$), with particularly high associations for *Ease of Use* ($r = 0.84$) and *Reachability* ($r = 0.80$). These results indicate that participants who rated these domains highly were more likely to report greater overall satisfaction with the control interfaces.

We then performed an ordered logistic regression model to examine the relationship between *Ease of use*, *reachability*, *information*, and *overall satisfaction*(*Item 17*). The analysis indicates that *Ease of Use* ($\beta = 1.831$, $p < 0.001$) and *Reachability* ($\beta = 2.317$, $p < 0.001$) are significant predictors of *Overall Satisfaction*, while *Information* ($\beta = 0.597$, $p = 0.020$) had a comparatively smaller but still significant contribution. The full regression results are presented in Table 7.

3.5. Participant preferences for interface variables after the experiment

In this section, we report the results of the post-experiment questionnaire. After completing the usability test, participants answered a three-part questionnaire designed to capture different aspects of interface design for lighting and shading control (see Table 3).

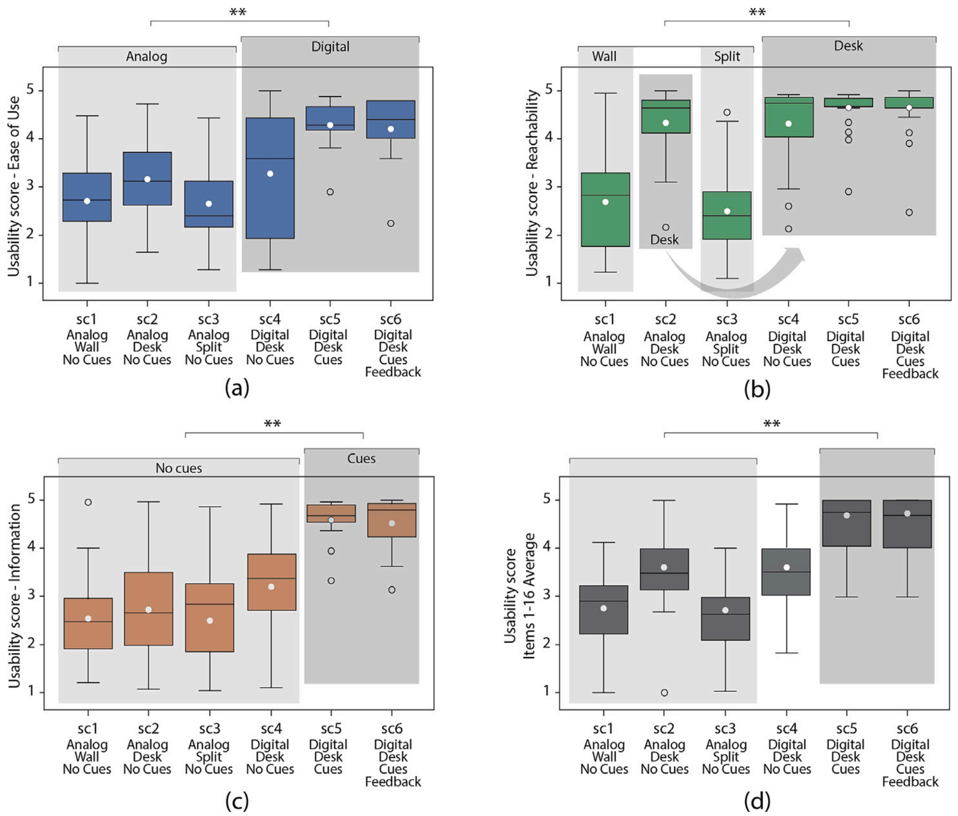

Fig. 7. Usability scores for *Ease of Use* (a), *Reachability* (b), *Information* (c), and *Overall Usability* score (d) across interface scenarios tested. ** = ($p < 0.01$).

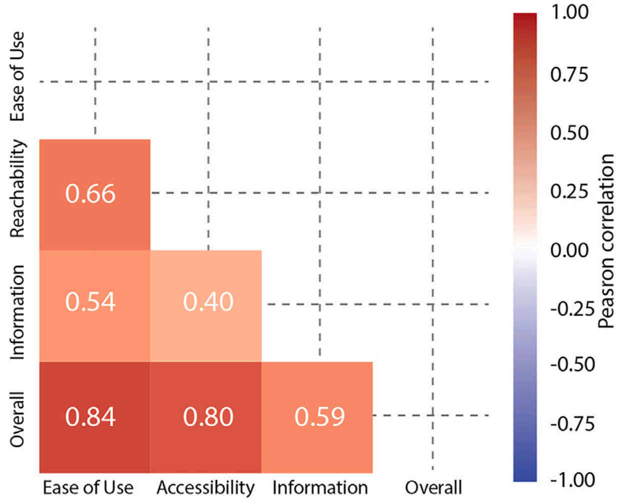

Fig. 8. Pearson correlation matrix showing relationships between the three usability domains, Ease of use, *information*, and *reachability*, and *overall satisfaction*.

Table 7
Ordered logistic regression results for *Overall Satisfaction*. The rows represent the independent variables: *Ease of use*, *reachability*, and *information*, as well as the threshold coefficients (1/2, 2/3, 3/4, and 4/5) indicating satisfaction category boundaries. The columns display the estimated coefficients (Estimate), standard errors (SD err), z-values (z), p-values (P>|z|), and 95% confidence intervals ([0.025, 0.975]).

Parameter	Estimate	SD err	z	p
Ease of use	1.831	0.430	4.26	< 0.001
Reachability	2.317	0.512	4.53	< 0.001
Information	0.597	0.256	2.33	0.020
1/2 threshold	6.944	1.435	4.84	< 0.001
2/3 threshold	1.668	0.225	7.41	< 0.001
3/4 threshold	1.702	0.207	8.21	< 0.001
4/5 threshold	1.260	0.207	6.10	< 0.001

Accuracy on test set: 0.722

3.5.1. Laboratory setup preferences

Fig. 9 presents participants' preferences for interface "Position", "System Cues", and "Type of Device". Regarding the preferred position for the lighting control interface (Fig. 9(a)), the majority of participants (n = 12) preferred having the interface on their desk, compared to the wall (n = 6), while no participants selected placement near the lighting fixture.

For shading controls (Fig. 9(b)), preferences were more diverse. Although the desk remained the most preferred position (n = 10), close to the window was also selected (n = 7), and the wall was least preferred (n = 1). A pairwise comparison revealed a statistically significant preference for the desk over the wall for the roller shades interface ($p < 0.05$).

In terms of "System Cues" (Fig. 9(c)), the most chosen configuration was system state with task completion feedback (n = 10), followed by system state only (n = 7). *No cues* configuration was least preferred (n = 1), and the difference between the most and least preferred options was statistically significant ($p < 0.05$).

Lastly, "Type of Device" preferences (Fig. 9(d)) showed a relatively balanced distribution between touchscreens (n = 10) and physical switches (n = 8), with no statistically significant difference.

Participants rated the importance of three interface attributes ("Position", "System Cues", and "Type of Device") on a three-point scale (Not Important, Somewhat Important, Very Important). Fig. 10 shows a bubble chart. Bubble size reflects the number of respondents

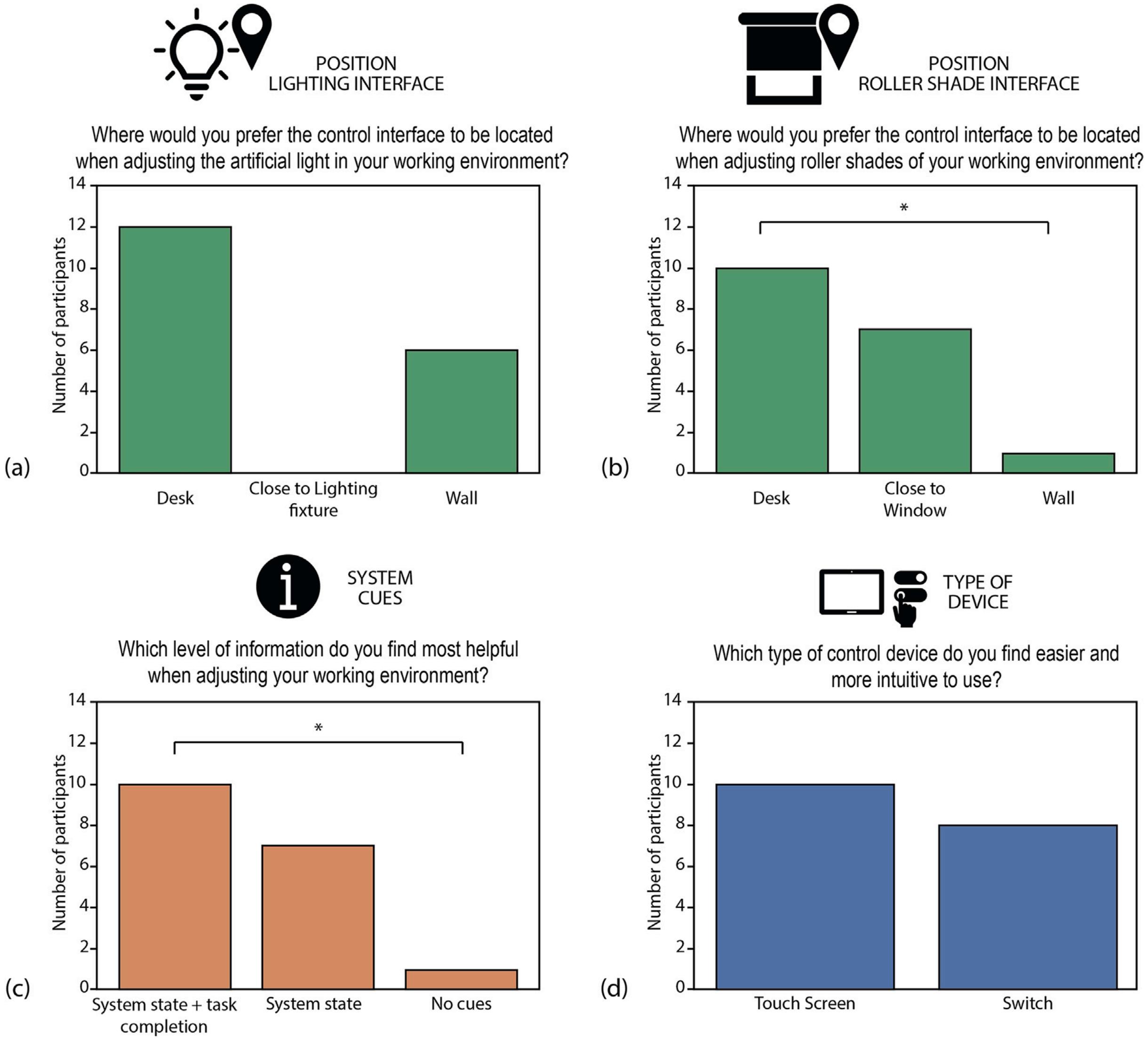

Fig. 9. Participant preferences for interface variables after the experiment. (a) Preferred position of the lighting control interface; (b) Preferred position of the shading control interface; (c) Preferred level of system feedback; (d) Preferred type of device. Bars indicate the number of participants; significance brackets represent Bonferroni-adjusted pairwise Chi-squared comparisons. * = ($p < 0.05$).

at each attribute-by-importance cell, labels show counts (n), and colors indicate respondent groups that share the same ranking profile across attributes. The pattern concentrates at Very Important for “Position” (most participants placed it at the top), while “Type of Device” tilts toward lower importance (many chose Somewhat/Not Important and only a few marked it Very Important). “System Cues” sits between these extremes, with responses split mainly across Somewhat and Very Important. For context, in the underlying rankings, 14/18 participants placed “Position” first, 10/18 placed “Type of Device” last, and “System Cues” was divided (6/18 first, 6/18 s).

3.5.2. Differences in preferences for interface characteristics for single and shared office setups

To further examine how participants’ preferences might shift across different social contexts, the final questionnaire included items related to potential shifts in preferences when multiple users are present in the same office space. Fig. 11 summarizes the distribution of preferred interface characteristics in the office lab setup (which mirrors a single office condition) and compares them to preferences expressed in a shared office context. Preferences are grouped by the interface “Position”, “Type of Device”, and “System Cues”, along with the percentage of participants whose selections matched in both contexts.

For the interface “Position”, most participants preferred a desk-mounted control in the single office setup (56%), whereas in a potential shared office context, preferences shifted toward wall-mounted interfaces (44%). The overall match rate for “Position” preferences was 38.9%, indicating that context significantly influenced participants’ preferred interface “Position”.

“Type of Device” preferences remained relatively consistent. Analog controls were selected by 44% of participants in the laboratory and increased to 61% in the shared office setup. Despite this shift, the match rate between contexts was high (83.3%), suggesting that participants’ preferences regarding the “Type of Device” (e.g., analog vs. digital) are less dependent on social context.

Preferences for “System Cues” were highly consistent: 95% of participants selected interfaces that provided system state and feedback cues in both the laboratory and shared office scenarios, while only one participant (5%) preferred no information. The resulting match rate of 88.9% reflects a strong and stable preference for “System Cues” across contexts.

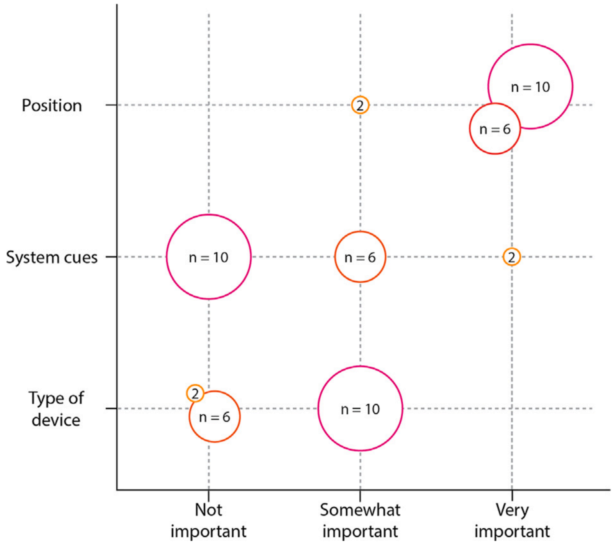

Fig. 10. Participant importance ratings for interface attributes. Bubbles show how many participants rated each attribute (Position, System cues, and type of device) at each importance level on the x-axis (Not important, Somewhat important, Very important). Bubble area is proportional to the number of respondents; labels show counts (n). Color encodes respondent groups that share the same importance ranking profile across attributes (equal ranks). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.5.3. *Influence of interface characteristics on acceptance of automation*

To assess which interface characteristics might promote a higher acceptance of automated lighting and roller shade controls, participants rated their agreement with statements shown in Table 8 about each characteristic on a 1–5 Likert scale (1 = strongly disagree, 5 = strongly agree). Fig. 12 illustrates the distribution of these scores. Desk-mounted controls were viewed as most preferred, with a median of 4.0, whereas wall-mounted controls registered a median of 3.0, and the split layout (lighting at the entrance wall, shades by the window) scored lowest with a median of 2.0. In terms of “Type of Device”, both digital displays and analog dials achieved medians of 4.0, indicating equal overall acceptance. Finally, among system cues, system-state and feedback cues each reached a median of 4.0, while the no-info option lagged behind at 3.0. Altogether, these results suggest that users prefer interfaces that are within easy reach, employ familiar control formats, and provide clear system feedback.

To assess the likelihood that observed differences arose by chance, we applied Wilcoxon signed-rank tests to each within-subject pairing. Only the comparison between desk-mounted and split layouts reached statistical significance ($W = 5.0$, $p = 0.039$), confirming a reliable preference for desk placement over the split configuration. None of the other pairs, such as desk versus wall ($p = 0.359$), digital versus analog ($p = 0.512$), or any pairing among system-state readouts, generic feedback cues, and the no-info condition (all $p > 0.37$), attained the $\alpha = 0.05$ threshold.

3.6. *Interview results*

This section presents qualitative insights from the pre- and post-experiment interviews. The interviews explored participants’ expectations of control interfaces before the usability test and their perceptions after interacting with the six scenarios.

3.6.1. *Type of position*

The examination of participants’ expectations versus experiences with control interfaces for lighting and roller shades reveals notable shifts in perception. Participants expected that the interfaces would be located near the entrance for lighting and close to the window for roller shades, with the expectation that these positions would significantly impact their satisfaction. One participant expressed this view, stating, *“I would expect the switch next to the entrance for lights. The same for the shading, next to the entrance.”* One participant mentioned this preference was related to convenience in reducing the number of items on the desk, *“I like being closer to the door. I don’t think I need to interact regularly with the system. Having too many things on the desk is not convenient.”* However, some participants also expressed that proximity to the interface was key for comfort and efficient interaction. For example, a participant noted that *“…on the desk is the best position due to convenience, but in a shared office, I would prefer the controls at the entrance.”*

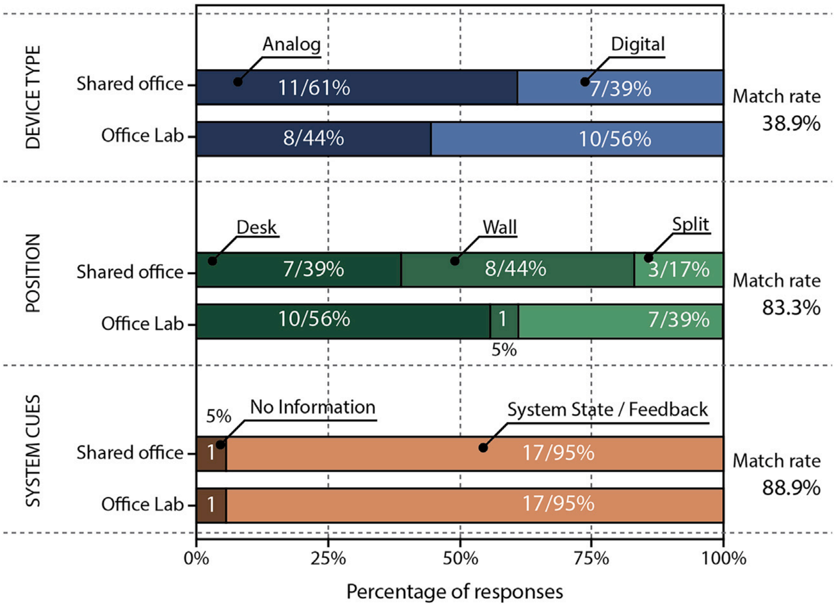

Fig. 11. Comparison of participants’ interface preferences in office lab versus shared office settings across three attributes: “Position”, “Type of Device”, and “System Cues”. The figure presents the number and percentage of participants who preferred each option in both settings (match rate).

Table 8
Statements used in Section 3 of the post-experiment questionnaire on automation acceptance. Participants rated their agreement on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Variables Tested for their impact on automation acceptance	Statements
Analog interface	I'd be less bothered by automation if it had a simple analog switch interface—like a familiar physical switch—giving quick, intuitive control of lights and roller shades without extra learning or mental effort.
Digital interface	I'd be less bothered by automation if it included a responsive touchscreen—enabling fluid interaction with lights and roller shades, and seamlessly integrating into the workspace.
Desk position	I'd feel less bothered by automation if lighting and roller shade controls were positioned on my desk within easy reach.
Wall position	I'd feel less bothered by automation if lighting and roller shade controls were mounted by the door, letting me set lights and roller shades as I enter the room.
Separated (split) position	I'd feel less bothered by automation if lighting and roller shade controls were separated—light switches by the door and shade controls by the windows—so I stay aware of each system throughout the room.
No information	I'd feel less bothered by automation if it were intuitive enough to need no status indicators or performance feedback for lighting and roller shades.
System information	I'd feel less bothered by automation if I could easily check its current state—like the shades' position or the lights' status.
System information and feedback	I'd feel less bothered by automation if it displayed its ongoing actions for lighting and roller shades and let me know once they're complete.

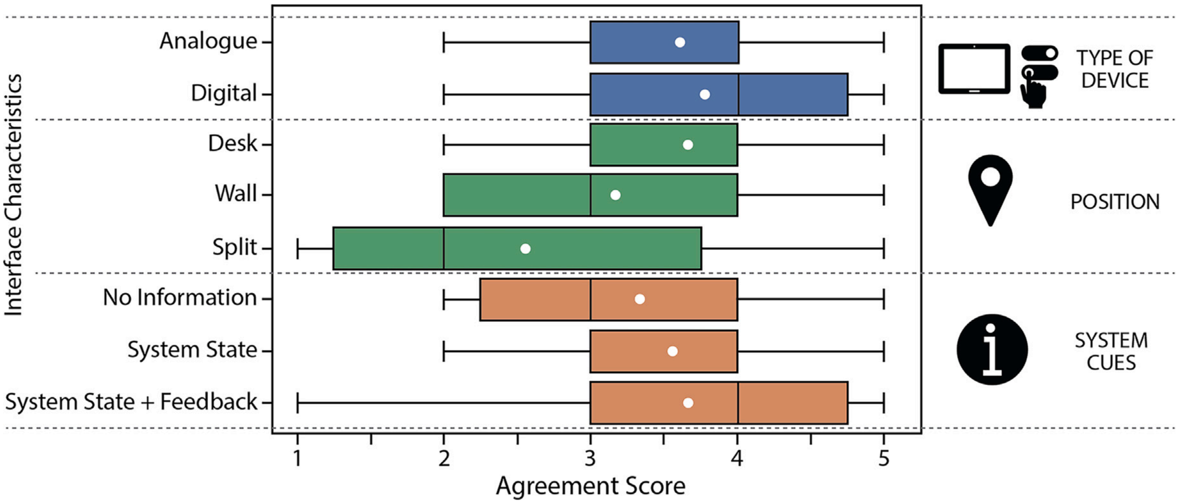

Fig. 12. Boxplots of 1–5 agreement scores for each interface feature (n = 18). Each panel shows the full distribution of participant ratings for (top to bottom) desk-, wall-, and split-mounted positions; digital versus analog devices; and system-state read-outs, feedback cues, or no information. Boxes show the interquartile range, whiskers the full range, and white circles the means. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.6.2. Level of information

At the start of the experiments, participants expected minimal information on control interfaces, such as basic directional cues (e.g., up/down, increase/decrease brightness). One participant shared this expectation, stating, *"I was expecting no information, only icons telling me what I am supposed to do. Maybe information about the system state, such as light brightness can be conveyed by the dial position easily."* However, their experience during the experiment demonstrated to a few of them that higher information levels and cues can enhance their overall experience. For instance, one participant noted, *"I liked it when the system told me when I achieved the control task goal. I would like to have information on the impact of my behavior on the building's performance."* Another participant supported this, saying, *"I like the information about the system state. I feel I have more control if I have that information."* Additionally, some participants expressed a preference for further details on how their behavior influenced the building's performance and indoor environment. As one participant commented, *"I would prefer building performance information combined with my personal preferences."*

3.6.3. Type of interface

Regarding the type of interface, participants preferred analog devices initially, such as switches for lighting, and manual cords or switches for blinds. One participant reflected this preference, stating: *"I would expect a blind controlled by a cord. If it is remotely controlled, I expect information on up and down state."* After using the interfaces during the experiment, a few participants reported preferring digital interfaces, because they offer interactive features and detailed feedback. As one participant commented, *"I liked the percentages and the extra information about my task performance. With this information, I can set up my environment as I want."* Despite these comments, some participants continued to appreciate the simplicity of analog systems. One participant noted, *"I liked the sliders, but I don't like accuracy at that level. Every 10% adjustment option is better for me"*. Furthermore, while simplicity was favored, participants found that having access to detailed information, despite its complexity, was beneficial. Another participant emphasized this, stating, *"I liked having access to information. The better the information, the better my perception of control." Overall, information is appreciated by users, but they* *also remarked several times that the level of information should be simple and useful, according to their expectations.*

3.6.4. Acceptance of automation

Concerns about automation were also noted, with participants seeking systems that were understandable and controllable. One participant expressed this clearly, stating, *"Automation might be frustrating if I can't understand it."* This underscores the need for interfaces that are both intuitive and integrative. Another participant highlighted the desire for control, remarking, *"If I could understand the logic behind the automated control, I would accept it more."* Overall, the transition from expectation to experience demonstrated that while participants anticipated certain features, their actual satisfaction was significantly influenced by practical experience with the interfaces. One participant reflected this sentiment, saying, *"I like the information. The better the info, the better my perception of the control."*

4. Discussion

This study demonstrates the applicability of the PSSUQ in the built environment domain by successfully adapting it to evaluate building control interfaces. The high internal consistency and robust factor structure, comprising *Ease of Use*, *Reachability*, and *Information*, indicate that usability in environmental control interfaces can be reliably measured using this approach. This aligns with earlier findings in human-computer interaction domains [31] while extending the utility of PSSUQ to a new application context.

During the experiment, we found a strong preference for control interfaces that provide clear system cues and are easily accessible, particularly those mounted on the desk. These interface characteristics achieved the highest satisfaction scores across all usability dimensions. Insights from the post-experiment interviews and questionnaires, however, suggest that while desk-mounted controls were preferred in the individual office lab setting, participants anticipated favoring wall-mounted configurations in shared offices. This reflects the influence of social norms, privacy considerations, and aversion to personal desk space. This context dependency, particularly regarding interface position, aligns with findings from previous studies that show spatial and social conditions shape interaction with building controls [25,27,40]. These results suggest that one-size-fits-all solutions may not be effective and highlight the need for adaptable or personalized control strategies. Although the information was not ranked as important as position (Fig. 10), both the experimental results (Fig. 7) and interview findings showed that information level supports a positive experience with the automation system when the information is relevant to the user's needs. However, users' perceived acceptance of automation did not appear to be influenced by the level of information provided. This finding should be verified through behavioral experiments that measure override behavior under varying levels of information, as there may be a discrepancy between *perceived* and *actual* acceptance. Other studies showed, for instance, that transparency and user understanding might mitigate the resistance often associated with automated building systems [27].

Regarding the *type of device*, participants showed a clear preference for the digital interface, primarily because it was the only option providing system-state information, as illustrated in Fig. 7(a). Notably, digital control interfaces that included such information were both preferred over analog interfaces without information and perceived as easier to use, particularly when equipped with explicit system-state cues. This finding reinforces previous research emphasizing the role of intuitive and informative interfaces in enhancing user satisfaction and facilitating behavior change [41,42]. However, the preference for digital over analog controls also presents an important challenge. While digital or touch-based interfaces can deliver richer feedback, they may introduce accessibility barriers for certain user groups [26]. Hybrid solutions, combining physical elements (e.g., buttons or tactile feedback) with digital components providing system information, have been shown to improve both usability and inclusivity across domains [32]. It is important to note that these findings are specific to the controlled office-lab setting and may not directly generalize to real-world environments.

Participants' initial expectations for analog interfaces appeared to evolve over the course of the experiment. Although simple analog controls were initially preferred, post-experiment feedback revealed a shift toward interfaces that provided clearer system feedback, often associated with digital configurations. This progression suggests that direct interaction with control interfaces can enhance understanding, perceived ease of use, and overall attitudes toward personal control and automation. Similar patterns have been reported in usability research on residential thermostats, where real-world interaction exposed limitations of seemingly simple interfaces and highlighted the value of feedback and clearer information for effective use [43]. These results highlight the value of usability testing not only as an evaluation tool but also as a means of fostering user learning and managing expectations.

The diversity in participants' ranking of interface characteristics, ranging from the importance of system feedback to a preference for simplicity, clearly indicates that participants' needs are not uniform. This finding aligns with prior research showing that while some users value detailed system feedback and advanced control features [42,43], others prefer simple, easy-to-use interfaces that minimize cognitive load [3]. These individual differences suggest that flexible or personalized control strategies may be necessary to accommodate varying user expectations and interaction styles.

This study has several limitations. First, it was conducted in a single controlled office lab with 20 relatively young participants with technical expertise, which constrains the generalizability of the findings to other building types, user groups, and cultures. Second, the experiment focused on lighting and shading in a specific set of interface configurations, so the results may not extend to other building services or interface designs. Finally, preferences and acceptance of automation were measured using self-reported questionnaires in both the office lab and hypothetical shared-office scenarios, without observing long-term use or override behavior in real shared spaces. Future research should therefore test similar interfaces in real multi-occupant offices, include more heterogeneous user groups, and combine usability ratings with behavioral measures of interaction and overrides over time.

5. Limitations

This study was conducted as a controlled, task-based usability experiment with a limited sample ($n = 20$) in a single office-lab environment with a specific layout and fixed interface placement constraints. Accordingly, the findings should be interpreted as evidence of relative differences in perceived usability between the tested interface configurations, rather than as population-level preference estimates. Although the within-participant design supports robust comparisons across scenarios, the sample size does not allow reliable assessment of demographic subgroup effects (e.g., age- or gender-related differences) or their interaction with interface characteristics.

The scenario set was designed as targeted contrasts rather than a fully factorial experiment to reduce the participant burden and enable controlled comparisons. As a result, not all combinations of device type, position, and cue level were tested. In particular, digital wall-mounted configurations were not included. Consequently, effects of *System Cues* should be interpreted as scenario-conditioned and are primarily evaluated within the desk-mounted digital condition. Future research should test a fully factorial set of configurations to disentangle the main effects and interactions more comprehensively.

Finally, the primary outcomes of this study were perceived usability (modified PSSUQ), stated acceptance, and qualitative feedback. Objective performance indicators (e.g., task completion time, repeated actions/incorrect attempts, or assistance requests) were not systematically recorded, constraining conclusions about interaction efficiency. Future work should replicate these findings in broader samples and across diverse office typologies and floor plans, and combine subjective outcomes with objective performance measures, ideally through field or longitudinal deployments.

6. Conclusion

In this study, we utilized the PSSUQ framework to investigate user experience with building control interfaces for lighting and shading, focusing on *Overall Satisfaction* related to “Type of Device”, “Position”, and “System Cues”. We first validated the PSSUQ’s suitability for this context, involving interaction strategies for lighting and shading in an office environment. This study represents a novel application of the PSSUQ, extending its use beyond traditional settings. Compared to other methods for evaluating building control strategies, our approach provided more detailed insights into participant requirements for *Ease of Use,Reachability*, and *Information*. The effectiveness of the methodology implemented in the office lab was due in part to its ability to encourage meaningful interaction with the interfaces during task-based scenarios. This resulted in more informed and consistent responses across participants. The alignment between quantitative findings and qualitative interview insights further strengthens the validity of the results and supports the robustness of the usability testing framework in this application.

The results showed higher preferences for desk-mounted, digital interfaces that provided clear system-state cues. These characteristics consistently received the highest usability scores across all dimensions and played a central role in participants’ acceptance of automated building systems. Preferences for control interfaces varied based on contextual factors, such as whether the setting was private or shared, and individual characteristics, such as attitudes toward automation and expectations of simplicity. These findings underscore the importance of context-aware control strategies rather than one-size-fits-all solutions. Additionally, participants’ expectations changed after interacting with the control interfaces during the experiment. Initial preferences for analog and simple solutions moved toward digital, information-rich systems. This shift highlights the role of empirical experience in influencing user preferences toward control interfaces.

Future work should further explore the influence of contextual variables (e.g., shared vs. individual space) and personal factors (e.g., familiarity, cognitive style) on user interface preferences. Moreover, research should investigate how different types and levels of system information impact user engagement with automation, comfort, and control in everyday use. These findings could inform the development of tailored HBI strategies that align with diverse user needs and support both indoor environmental quality and building performance.

CRediT authorship contribution statement

P. de la Barra: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **P. Martinez-Alcaraz:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis. **E. Brembilla:** Writing – original draft, Visualization, Validation, Supervision, Methodology. **G. Brager:** Writing – original draft, Validation, Methodology. **K. Exss:** Writing – original draft, Validation, Methodology. **A. Luna-Navarro:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Pedro de la Barra reports financial support was provided by Horizon Europe. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Summary of participants’ responses to single items per scenario

Table A.1 reports the mean and standard deviation (SD) of responses for each PSSUQ item across the six interface scenarios. These item-level results complement the category-level findings presented in the main text by providing a more detailed view of how participants rated specific aspects of usability (*Ease of Use*, *Information*, and *Reachability*) in each scenario.

Table A.1

Mean and standard deviation of PSSUQ item scores across the six interface scenarios (sc-1 to sc-6). Each cell shows the average usability score (higher values indicate more positive ratings) and the corresponding standard deviation (reflecting response variability) for each questionnaire item.

Item	Category	SC1 Mean ± SD	SC2 Mean ± SD	SC3 Mean ± SD	SC4 Mean ± SD	SC5 Mean ± SD	SC6 Mean ± SD
1	Ease of use	2.86 ± 0.99	3.42 ± 0.77	2.95 ± 1.18	3.90 ± 1.09	4.50 ± 0.61	4.58 ± 0.61
2	Ease of use	3.55 ± 0.91	4.00 ± 1.00	3.53 ± 0.90	3.90 ± 1.26	4.40 ± 0.60	4.63 ± 0.76
3	Ease of use	2.68 ± 1.04	3.68 ± 0.89	2.79 ± 1.18	3.67 ± 1.20	4.85 ± 0.37	4.63 ± 0.76
4	Ease of use	3.36 ± 1.00	3.53 ± 0.96	2.89 ± 1.10	3.71 ± 1.38	4.60 ± 0.60	4.42 ± 0.84
5	Ease of use	4.14 ± 0.64	4.11 ± 0.81	4.16 ± 0.96	4.19 ± 0.98	4.85 ± 0.37	4.63 ± 0.60
6	Ease of use	2.91 ± 1.27	3.32 ± 0.89	2.63 ± 1.07	3.19 ± 1.50	4.55 ± 0.76	4.53 ± 0.70
7	Ease of use	2.50 ± 1.10	3.21 ± 0.92	2.58 ± 0.90	3.19 ± 1.33	4.25 ± 0.85	4.47 ± 0.70
8	Ease of use	3.00 ± 0.87	3.32 ± 1.06	3.32 ± 1.16	3.29 ± 1.23	4.25 ± 0.85	4.37 ± 0.83
9	Information	2.50 ± 1.30	2.58 ± 1.17	2.53 ± 1.31	3.10 ± 1.37	4.70 ± 0.57	4.63 ± 0.68
10	Information	2.82 ± 1.18	2.95 ± 1.27	2.89 ± 1.24	3.52 ± 1.12	4.80 ± 0.41	4.58 ± 0.61
11	Information	2.14 ± 1.04	2.68 ± 1.34	2.42 ± 1.22	2.90 ± 1.26	4.70 ± 0.57	4.68 ± 0.48
12	Information	2.91 ± 0.81	3.11 ± 1.15	3.00 ± 1.15	3.67 ± 1.28	4.75 ± 0.44	4.53 ± 0.77
13	Reachability	2.68 ± 1.43	4.53 ± 0.84	2.42 ± 1.35	4.57 ± 0.93	4.85 ± 0.49	4.68 ± 0.58
14	Reachability	2.41 ± 1.14	4.53 ± 0.84	2.16 ± 1.17	4.48 ± 0.93	4.75 ± 0.55	4.89 ± 0.32
15	Reachability	2.68 ± 1.21	4.37 ± 0.90	2.63 ± 1.26	4.43 ± 1.08	4.75 ± 0.55	4.79 ± 0.42
16	Reachability	2.64 ± 1.22	4.21 ± 0.71	2.47 ± 1.12	4.38 ± 1.12	4.65 ± 0.75	4.74 ± 0.56

Data availability

Data will be made available on request.

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