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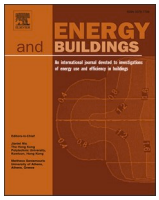
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What should be automated in offices? Occupants' preferences for automation levels from a large survey in Spain and the Netherlands

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ABSTRACT

Occupant-centered building control requires defining not only which building services should be automated but also the role occupants prefer to retain in the control loop. However, empirical evidence remains fragmented across single services, leaving a gap in understanding how preferred automation levels varies across building services and daily routines. This study establishes an evidence-based typology for occupant-centered building automation, mapping preferences across ten services and three workday phases through a large-scale questionnaire of 3504 office workers in the Netherlands and Spain. Using a consistent five-level automation scale, we map preferences across ten building services and three distinct workday phases (arrival, active work, and leaving). Results show that automation preferences are context-dependent, varying according to the specific building service and the current workday phase. HVAC systems, particularly mechanical ventilation, show the strongest acceptance of automated control, whereas directly reachable elements, such as openable windows and personal devices, are predominantly preferred under manual control. A primary finding of this study is the prevalence of 'mixed-control' profiles (61.5% of respondents), showing that occupants' desire for personal control is service-dependent. Furthermore, we provide empirical evidence of the interaction strategy gap, demonstrating that higher automation acceptance is statistically contingent upon digital, desk-reachable, and information-rich control interfaces. Prior experience with automated systems emerged as the most consistent predictor of acceptance of automation, suggesting that trust in the control loop is experience-based. These findings argue against one-size-fits-all automation and provide empirical basis for designing adaptive, service-specific control strategies that balance building energy goals with occupant agency.

1. Introduction

Reducing operational energy use while maintaining acceptable indoor environmental quality (IEQ) remains a challenge for the building sector and a key pathway for climate-change mitigation [1]. In office buildings, where thermal conditions, ventilation, lighting, solar control, acoustics, and view/privacy jointly shape comfort and productivity, performance depends not only on technical system capabilities but also on how building services are operated in everyday use [2–4]. Research has progressively shifted toward occupant-centered building design and operation, in which energy and comfort outcomes depend on alignment between building controls, indoor environmental requirements, and occupants' preferences [5,6]. Persistent discrepancies between predicted and measured building energy performance further reinforce the need to understand how occupants prefer building services to be controlled and what interaction conditions enable effective operation in practice [7,8]. Accordingly, evidence on occupants' control preferences is essential for strategies that deliver both energy efficiency and acceptable user experience [9].

Advanced building control strategies, such as occupancy-based control, predictive control, and adaptive algorithms, are studied and, in many cases, deployed in building automation systems, shaping when, how, and by whom control decisions are made [10–14]. These strategies do more than control building services, they define the occupant's role in the control loop. Human-factors research on levels of automation conceptualizes automation as a spectrum of human involvement across information acquisition, interpretation, decision-making, and action, and shows that outcomes depend not only on the type of automated control strategy but also on feedback and the ability to intervene or override when needed [15]. In buildings, this implies that the same system described as automated can be experienced differently depending on whether the system communicates status and intent (e.g., cues,

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explanations, recommendations), whether it requests confirmation, and whether override is accessible and reliable [6,16]. Consequently, developing a building control strategy requires clear specification of both the level of automation and the interaction mechanisms through which occupants remain informed and can influence outcomes, an issue central to occupant-centric design [5,8,9,15].

Empirical studies on occupants' preferences for building automated control indicate that acceptance depends on two conditions. Automation should preserve meaningful occupant agency (e.g., the ability to intervene) and provide sufficient transparency for occupants to understand system state and actions [16–18]. Occupants often report annoyance of extremes control strategies (fully manual or fully automated) and instead preferring intermediate arrangements in which the system provides support (e.g., recommendations or automated actions) while maintaining confirmation and/or override opportunities [16,18]. In office settings, studies of automated blinds and façades frequently report deactivation of fully automated modes and identify perceived loss of control as a recurring barrier to acceptance [19–21]. Experimental work further shows that clearer feedback about system state and actions can improve satisfaction and support energy efficient operation, underscoring the role of transparency in automated building services acceptance [16]. A recent review of occupant-centric controls similarly emphasizes that successful implementation depends on interaction mechanisms that support comprehension and accessible intervention when automation conflicts with occupant needs [22]. Therefore, automated building services are more likely to be accepted when occupants can interpret system status and intent, anticipate automated actions, and intervene via straightforward override or adjustment when automated decisions do not match their requirements [8,9,16,19].

A further implication of occupant-centered control is that preferred levels of automation are unlikely to be uniform across services or stable across time. Building services differ in how quickly they affect comfort, how noticeable their effects are, how reversible actions are perceived, and how disruptive automation may be during everyday work, which can influence whether occupants accept automation or prefer manual control [23]. Consistent with this, prior work shows that preferences for automated controls vary across occupants and across control contexts and systems, suggesting that a single automation level is unlikely to suit all situations [17,18]. In offices, perceived personal control is linked to satisfaction and comfort, but varies across buildings and user groups, indicating that personal control is not experienced consistently in practice [20,24,25]. At the service level, studies comparing manual and automated strategies for blinds and lighting report differences in discomfort and acceptability, illustrating that the same automation policy can be experienced differently depending on the system and context [16,19,21]. In addition, field studies show that interactions with controls can cluster around workday-phases, with some actions (e.g., manual window opening) occurring frequently at the start of the day, suggesting that control needs are shaped by routines as well as discomfort [26]. Office studies also report workday-phases use of heating-related personal controls (e.g., thermostat/TRV interactions and setpoint-related actions) and building control concepts often operationalize occupancy transitions through preheating and setback periods [10,11,27]. A systematic review of user-centered lighting controls also highlights that variability in working hours and occupant routines is often poorly represented by fixed schedules and default control logics [28]. However, this evidence remains fragmented across single services and heterogeneous constructs and rarely captures the stated preferences for automation levels across multiple services and workday phases using a consistent scale, limiting practical guidance for offices on what to automate, to what extent, and when occupants want to be involved [8,16–19].

Even when buildings provide manual control or override, these features may not enable effective interaction if controls are difficult to reach, unclear, or provide limited feedback about system state. A review of building control interfaces reports recurring usability problems across windows, blinds, thermostats, and lighting (poor labeling, inconvenient placement, ambiguous control–effect mapping, and weak system-state cues) often leading to under-use, misuse, and workarounds that can undermine comfort and energy performance [8]. Field monitoring and test in offices confirm that the interface through which occupants interact influences control behavior for lighting and shading [15,29]. Thermostat research similarly shows that interface complexity and poor information constrain understanding and contribute to ineffective use of control features [30,31], while work on operable windows highlights the value of direct, immediate agency for comfort regulation [32]. Large post-occupancy datasets further indicate that dissatisfaction frequently co-occurs with perceptions of limited personal control, suggesting that control can be experienced as absent even when options exist [20,24,33–35]. Interface design also conditions automation acceptance. Studies of automated blinds show higher acceptance when automation is intelligible and straightforward to intervene in, and when explicit feedback is provided about system state and actions [16,27]. Office lighting research likewise emphasizes that user-centered control concepts only succeed when implemented through interaction mechanisms that fit office routines and constraints [28,36,37]. These findings indicate that interface characteristics are central to whether automation and manual control policies are usable and acceptable in practice [8,15,16,28,37].

However, despite the growing emphasis on occupant-centered control, research still lacks a coherent, comparable evidence base on how office occupants prefer different building services to be automated and on the interaction requirements that make automation workable in everyday office routines. Existing studies provide valuable insights into specific systems and contexts, but they rarely compare explicit levels of automation across a broad set of building services using a consistent assessment scale, test whether preferred automation varies across workday phases, and jointly assess interface preferences that shape how easily occupants can understand and intervene in automated operation [8,16–20,22,24]. In practice, these gaps leave human–building interaction strategies under-specified. Control algorithms may be technically sophisticated yet misaligned with occupants' preferred role in control, while inadequate interface design can make feedback and override difficult to access and thereby undermine the mechanisms that support trust and acceptance [8,9,16,38].

This study addresses these gaps using a large-scale questionnaire of office occupants in the Netherlands and Spain. We map preferred levels of automation across three workday phases (arrival, while working, leaving) and ten building services using a five-point ordered response scale ranging from fully manual control to recommendation-based support and automated control with varying notification and override conditions. We also assess the preferred interface characteristics (device type, interface position, and information level) to identify interaction requirements that support acceptable automation and practical intervention. The aim is to provide evidence for office automated control strategies that reflect service- and workday phase-specific preferences and can be implemented through usable, informative, and accessible interfaces.

2. Methodology

2.1. Study design and recruitment

This study is based on responses to an online questionnaire distributed to office workers in the Netherlands and Spain. Participants were recruited through a Dutch online survey sampling provider (Panel Inzicht). Eligibility was restricted to adults who reported working in an office environment. Quality control procedures included minimum completion-time thresholds, attention-check items, and consistency checks using repeated questions at different points in the questionnaire. Only respondents who passed all checks were retained. In total, 3504 respondents provided valid responses and country information (NL =

1870; ES = 1634). The recruitment, eligibility screening, quality-control procedure, and composition of the final analytical sample are summarized in Fig. 1. A post-hoc power analysis was conducted to validate this sample size. For the proportional-odds ordinal logistic regression models used in this study, a minimum sample size of approximately 450 to 600 respondents per country was required to detect small effect sizes (OR = 1.3) with a power of 0.80 and . Our actual samples of 1870 (Netherlands) and 1634 (Spain) significantly exceed these requirements, ensuring high statistical sensitivity for the service-specific and phase-specific predictors analyzed. Participation was voluntary and respondents could withdraw at any point by closing the browser.

The study protocol, including the questionnaire and procedures, was reviewed and approved by the Human Research Ethics Committee of Delft U/niversity of Technology under ID 3515. Participants gave their informed consent by ticking an agreement box before accessing the first survey page.

2.2. Questionnaire structure and content

The questionnaire covered five domains: (i) Demographics, (ii) office context, (iii) environmental context, (iv) current building services, (v) automation preferences by workday-phase, (vi) automation preferences by building service, and (vii) interface characteristics preferences. Table 1 summarizes the main constructs and response formats. The distributed questionnaire is provided in Appendix A.

Participants were not provided with information regarding the estimated implementation costs or potential financial savings associated with automation. The questionnaire focused on occupants' preferred level of involvement in building control rather than on economic feasibility or willingness to pay.

2.3. Statistical analysis

2.3.1. Descriptive statistics

We first summarized automation preferences across workday phases, building services, and interface characteristics using absolute frequencies and row-normalized percentages (i.e., percentages summing to 100% within each category), complemented by data visualizations.

2.3.2. Workday-phase shifts in preferred automation

To test whether the same respondents expressed different automation preferences across workday phases (“arrival” vs. “while working”; “while working” vs. “leaving”), we treated responses as paired (within-respondent) categorical data. For each adjacent phase pair, we constructed a square contingency table that cross-tabulates automation levels at phase 1 (rows) against phase 2 (columns). These tables (i) provide a complete summary of transitions between categories (e.g., from “manual” to “automated-with-override”) and (ii) serve as the standard input for paired multi-category tests and agreement metrics [39]. To visualize these within-person transitions across the three-phase sequence, we plotted an alluvial diagram in which bar segments show marginal distributions at each workday-phase and flows represent respondents moving between automation levels from one phase to the next.

Table 1
Overview of questionnaire sections, main constructs, and response formats.

Section	Main constructs	Response format
Demographics	Age, Sex, Education, Country of Residency	Single-choice
Office context	Location, Work frequency (Days/Hours), Desk type (Fixed/Flex)	Multiple-choice & Numeric
Environmental Context	Floor level, Layout, Window proximity, Noise/View satisfaction	5-point Likert & Descriptive
Current Building Services	Availability of 10 services (HVAC, Lighting, etc.) and current automation level	Binary (Yes/No) & Multi-selection
Automation preferences by workday-phase	Desired control during: Arrival, While working, and Leaving	5-level Automation Scale (Manual to Full Auto)
Automation preferences by building service	Desired control level for 10 specific building services	5-level Automation Scale (Manual to Full Auto)
Interface preferences	Preferred Type (Analog/ Digital), Position, and Information Level	Single-choice

We quantified within-respondent stability using weighted Cohen's kappa (k), which measures agreement beyond chance while accounting for the ordinal nature of the five-level scale (disagreements of one step within the scale are treated as smaller than disagreements of several steps) [40]. To test whether changes show a systematic direction on the ordered scale, we recoded the five response options as ordinal scores from “fully manual” to “fully automated” and applied Wilcoxon signed-rank tests to paired phase responses. This non-parametric test is appropriate for ordinal outcomes and paired observations and evaluates whether responses tend to shift upward (toward more automation) or downward (toward more manual control) [41,42]. We report effect size as $r = Z/\sqrt{N}$ INCLUDEPICTURE "data:image/svg+xml;utf8,%3csvg%20xmlns=%22http://www.w3.org/2000/svg%22%20width=%22400em%22%20height=%221.08em%22%20viewBox=%220%20%20400000%201080%22%20preserveAspectRatio=%22xMinYMin%20slice%22%3e%3cpath%20d=%22M95,702c-2.7,0,-7.17,-2.7,-13.5,-8c-5.8,-5.3,-9.5,-10,-9.5,-14c0,-2,0.3,-3.3,1,-4c1.3,-2.7,23.83,-20.7,67.5,-54c44.2,-33.3,65.8,-50.3,66.5,-51c1.3,-1.3,3,-2,5,-2c4.7,0,8.7,3.3,12,10s173,378,173,378c0.7,0,35.3,-71,104,-213c68.7,-142,137.5,-285,206.5,-429c69,-144,104.5,-217.7,106.5,-221l0%20-0c5.3,-9.3,12,-14,20,-14H400000v40H845.2724s-225.272,467,-225.272,467s-235,486,-235,486c-2.7,4.7,-9,7,-19,7c-6,0,-10,-1,-12,-3s-194,-422,-194,-422s-65,47,-65,47zM834%2080h400000v40h-400000z%22%3e%3c/path%3e%3c/svg%3e" * MERGEFORMATINET, where Z

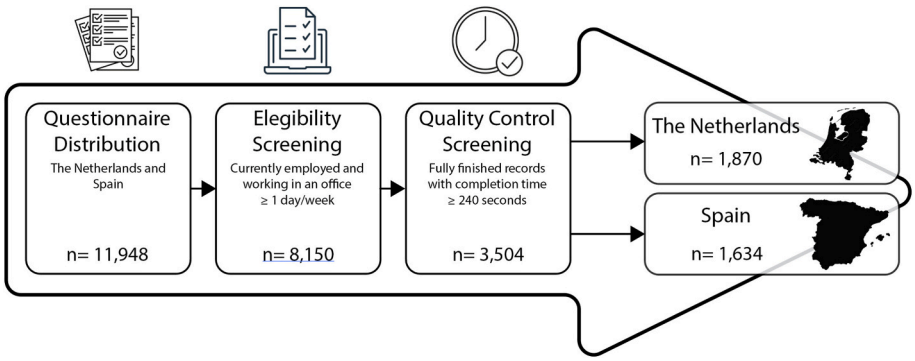


Fig. 1. Recruitment, eligibility screening, completion-time quality control, and composition of the final analytical sample.

is the standardized Wilcoxon statistic and N is the number of paired observations.

As complementary, distribution-based checks that do not require ordinal scoring, we applied (i) the Stuart–Maxwell test of marginal homogeneity to assess whether the overall distribution of automation levels differs between two phases for the same respondents [43], and (ii) Bowker's test of symmetry to assess whether transitions are directionally balanced (e.g., whether from "manual" to "automated" control transitions occur as often as the reverse) [44].

2.3.3. Service-specific preferences for automation

For each of the ten building services, we summarized the distribution of preferred automation levels. To test whether the same individuals expressed different preferences for conceptually related services (e.g., heating vs. air-conditioning; indoor vs. outdoor shading), we conducted within-respondent pairwise comparisons using the Stuart-Maxwell test applied to square contingency tables [43], adjusting *p-values* for multiple comparisons using Holm's method [45]. These paired tests isolate service effects from between-respondent differences in the sample.

To characterize cross-service heterogeneity, we derived respondent-level profiles based on each respondent's pattern across the ten services: *Manual* (only manual-type levels), *Automated* (only automated-type levels), and *Mixed control* (a combination of manual and automated levels). To interpret the Mixed control profile, we decomposed preferences within this subgroup by calculating, for each service, the percentage distribution across the five automation levels.

2.3.4. Predictors of preferring higher automation

To identify factors associated with preferring higher automation, we estimated proportional-odds ordinal logistic regression models [46]. The outcome is the five-level automation preference scale, ordered from "fully manual" to "fully automated." Separate models by phase and by service allow associations to differ depending on when (workday phase) and what (building service) is being automated.

Model results are reported as odds ratios (OR) with 95% confidence intervals (CI). In this study, ORs indicate whether a predictor is associated with a greater tendency to select *higher* automation categories (OR > 1) or *lower* (more manual) categories (OR < 1), holding other variables constant. We checked the proportional-odds assumption using standard diagnostics [47]; where minor deviations were observed, we interpret ORs as average effects across thresholds.

2.3.5. Associations among interface attributes and interface type

To examine whether interface attributes are chosen independently, we tested associations among preferred interface type ("digital" vs. "analog"), position ("close to entrance" / "on the desk" / "close to the system"), and information level (ordered cue options). We first quantified overall pairwise associations between attributes using tests of independence and report Cramér's V as effect size [39].

To identify which specific combinations drive these global associations, each attribute level was recoded as a binary indicator (selected vs. not selected), and we tested all level-by-level pairings across attributes using contingency tables, reporting the signed coefficient as effect size [39]. *P-values* for these multiple level-by-level tests were adjusted using a Bonferroni correction [45].

To quantify how information level and position jointly relate to choosing a "digital" interface, we estimated a binary logistic regression with interface type as the outcome ("digital" = 1; "analog" = 0), excluding "no preference" responses [40] Information level was entered as an ordered predictor and interface position as a categorical predictor (reference = "close to entrance"). Coefficients were exponentiated to ORs with 95% CIs. For interpretability, we also plotted the observed proportion choosing a digital interface across information levels, stratified by interface position.

Finally, to test whether respondents who prefer higher automation also tend to prefer different interface designs, we assessed associations between preferred automation level ("while working") and each interface characteristic (type, position, information level) using tests with Cramér's V effect sizes, excluding "no preference" responses [39].

3. Results

3.1. Respondent characteristics and workspace context

On average, respondents worked 3.5 days per week in the office and 7 h per day at the workplace. The sample was broadly balanced by sex assigned at birth (female $n = 1795$; male $n = 1680$; prefer not to say $n = 16$). As shown in Fig. 2, most of the respondents were middle-aged adults (predominantly 35–54 years); most had at least secondary education and nearly half reported a bachelor's degree. Satisfaction with the outdoor view was generally moderate to high, and most respondents sat relatively close to a window (76.4%), typically on the lower floors (ground floor = 37.7%; first floor = 31.6%). The workspace configurations were oriented toward fixed and shared settings: 72.3% reported working at the same desk (vs. 27.7% flexible desking), and 76.4% worked in enclosed shared offices or open-plan desk areas (vs. 23.6% private offices or cubicles).

Fig. 3 provides the baseline context for what respondents can actually control in practice. Heating, air-conditioning, and lighting were the most widely available services (reported as available by 76% for heating and 72% for air-conditioning and lighting). For heating and air-conditioning, current control was split across "manual," "semi-automated," and "fully automated" control modes, indicating that respondents are exposed to heterogeneous control strategies even for the same service. Lighting was more often "manual" (45%), although a large number reported "automated" lighting (21%). Mechanical ventilation was frequently not available or not perceived as an available system (76% "not available"). When present, mechanical ventilation was predominantly "automated." In contrast, openable windows were available to 56% of respondents and were almost exclusively "manual" (52%), suggesting that window opening remains the main occupant-driven means to affect fresh air and thermal conditions. Shading was comparatively scarce (indoor shades available to 29%; outdoor shades to 35%) and, when available, tended to be "manual." Personal devices were rare (task lights 19%, personal fans 12%, personal heaters 7%) and predominantly "manual." Overall, several occupants report limited access to shading and personal devices, implying fewer opportunities to fine-tune comfort beyond a small set of simple manual actions (e.g., switching lights, opening windows).

3.2. Preferred level of automation across workday phases and predictors

Fig. 4 summarizes (i) the distribution of preferred automation levels at "arrival", "while working", and "leaving", and (ii) within-respondent changes between workday phases. At "arrival", respondents were evenly split between "manual" and "automated" control options (50% vs. 50%). The share preferring some form of automation increased slightly "while working" (52%) and was highest at "leaving" (54%). This shift is concentrated within the automated response options: "automated-no override" increased from 10% at "arrival" to 20% at "leaving", while "fully manual" decreased from 44% to 41% and "manual with notifications" from 6% to 5%.

The transitions represented in Fig. 4 show that most respondents retained the same preference across workday phases on the five-point automation scale (ranging from fully manual to automated control with varying notification and override conditions), while a minority changed. However, Wilcoxon signed-rank tests indicate systematic within-respondent shifts toward higher automation from "arrival" to "while working" ($p = 2.34 \times 10^{-7}$, $r = 0.17$) and from "while working" to "leaving" ($p = 1.30 \times 10^{-10}$, $r = 0.27$). From arrival to while working, 15.1% moved at least one step toward higher level of automation and 10.9% moved toward lower automation (net +4.2%). From "while

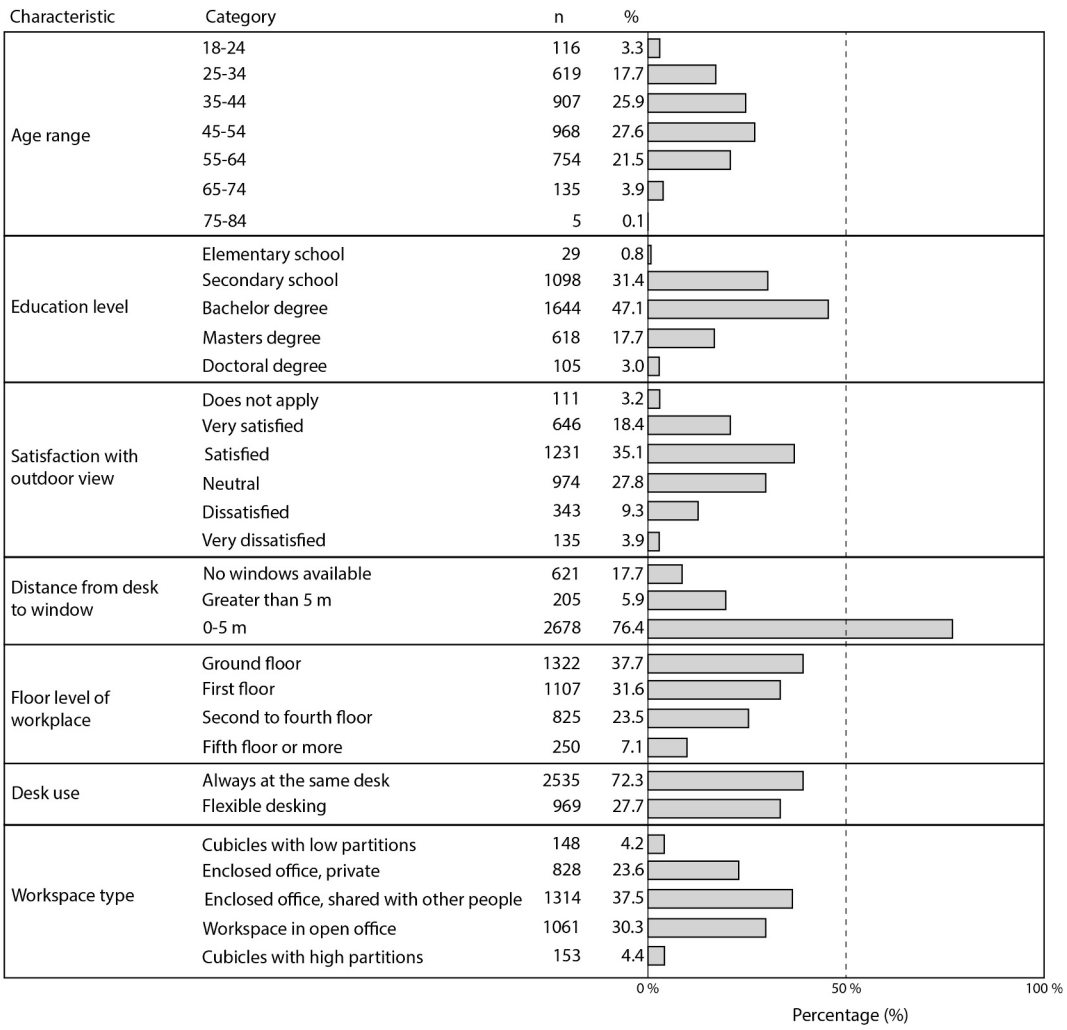


Fig. 2. Sample and workspace characteristics of the respondent population. Data is grouped by variable (age range, education level, satisfaction with the outdoor view, distance from desk to window, floor level of workplace, desk use, and workspace type), with categories listed within each group.

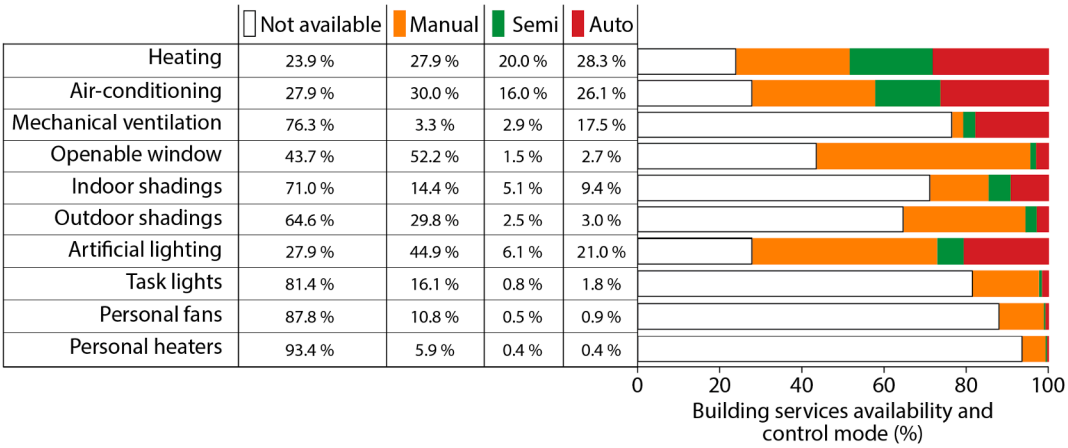


Fig. 3. Availability and current control mode of building services in respondents' workplaces. Rows list building services, and stacked bars show the share of respondents for whom each service is not available, manually controlled, semi-automated, or fully automated.

working to leaving", 19.2% moved toward higher level of automation and 10.4% moved toward lower automation (net +8.8%). Agreement between adjacent phases remained high (weighted k = 0.782 and 0.718), indicating that preferences are largely stable overall. Nonetheless, when respondents do change, shifts occur more often toward higher automation later in the workday.

Building on Fig. 4, Fig. 5 classifies respondents into workday-phase preference profiles: Manual (the same manual-type option at all three phases), Automated (the same automated-type option at all three phases), and Mixed control (any change across phases). Most respondents

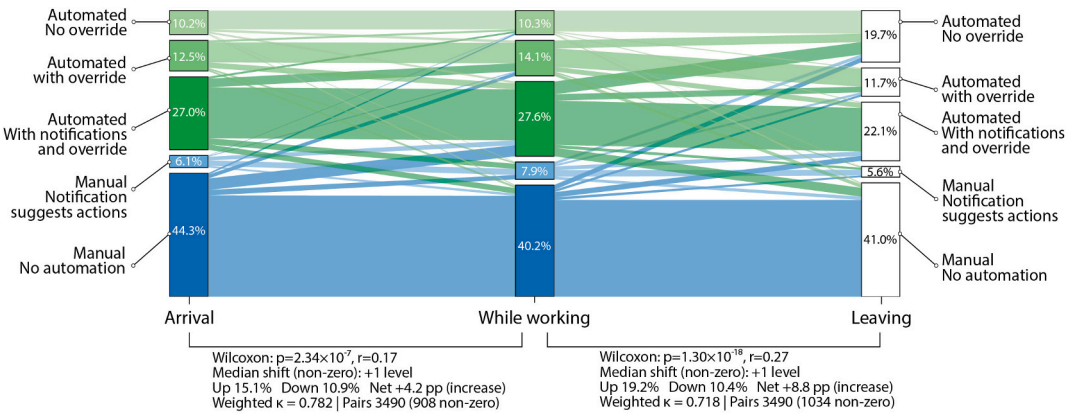


Fig. 4. Preferred automation levels at three workday phases (arrival, while working, and leaving). Bar segments show the share of respondents selecting each automation level, while the connecting streams represent individual transitions between stages (upward flows indicate moves toward more automation, downward flows toward more manual control). Summary statistics beneath each pair of stages report Wilcoxon signed-rank tests, effect sizes, proportions moving up or down the scale, and weighted agreement (k) between stages.

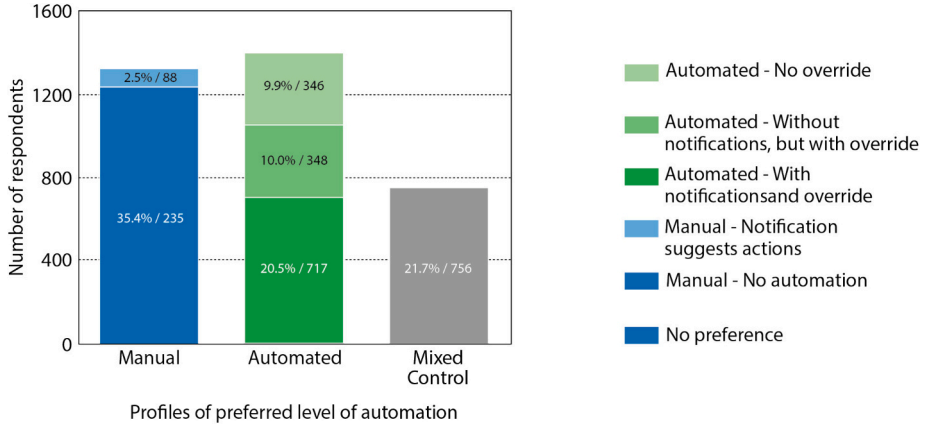


Fig. 5. Number of respondents per preference profile: (i) Manual (manual at all workday phases), (ii) Automated (automated at all stages), and (iii) Mixed (preferences vary across workday phases).

exhibited stable phase-to-phase preferences: 78.3% were classified as Manual (37.9%) or Automated (40.4%), while 21.7% were classified as Mixed control. In particular, 35.4% preferred "fully manual" control at every workday phase. Within the Automated profile, choices that preserved occupant agency (override and/or feedback) were most common, whereas "fully automated" control with no override represented the smallest automated subgroup (9.9%).

To examine which factors are associated with preferring higher automation at each phase, Fig. 6 reports odds ratios (ORs) from ordinal logistic regression models estimated separately for "arrival", "while working", and "leaving" (OR $>$ 1 indicates higher odds of selecting a more automated control option; OR $<$ 1 indicates higher odds of selecting a more manual control option). Across workday phases, prior experience with automated services is consistently associated with higher odds of preferring automation (ORs typically $>$1), whereas prior experience with manual control is associated with lower odds (ORs typically $<$1). Workspace characteristics show smaller but systematic associations: private offices tend to reduce automation preference, while shared offices and flexible desking tend to increase it, particularly during "while working" and "leaving". Demographic effects (e.g., country, gender) tend to fall near the "small-effect" band, indicating limited practical impact relative to experience- and workspace- related predictors. Overall, familiarity with automated controls emerges as the most consistent correlated parameter of preferring automation across the day.

3.3. *Preferred level of automation by building services and predictors*

Fig. 7 shows that preferred automation levels vary by building service, describing a clear gradient from HVAC to personalized environmental control systems. Personalized environmental control systems (task lights, personal fans, personal heaters, and openable windows) exhibit the strongest preference for "fully manual" control: 67% for task lights, 70% for personal fans, 69% for personal heaters, and 68% for openable windows. Shading and lighting occupy an intermediate position, with "fully manual" control still dominant but with substantial number of respondents preferring automation when override and/or notifications are available. In contrast, HVAC services show the preferred choice as "automated" control. For heating and air-conditioning, "fully manual" control accounts for 39% and 41%, respectively, and the most common automated choice is "automated with notification and override" (29% and 28%). Mechanical ventilation stands out as the building services preferred mostly automated, with the lowest "fully manual"share (35%) and the highest "fully automated" share (19%). Pairwise comparisons (horizontal brackets) confirm that these differences are not only visual. Most service pairs differ significantly in how preferences are distributed across the five control levels (p $<$ 0.05), with non-significant results mainly occurring between closely related services (e.g., heating vs. air-conditioning). Across services, "notification suggests manual actions" remains a small minority (approximately 5–7%).

Fig. 8(i) shows the profiles of respondents across building services:

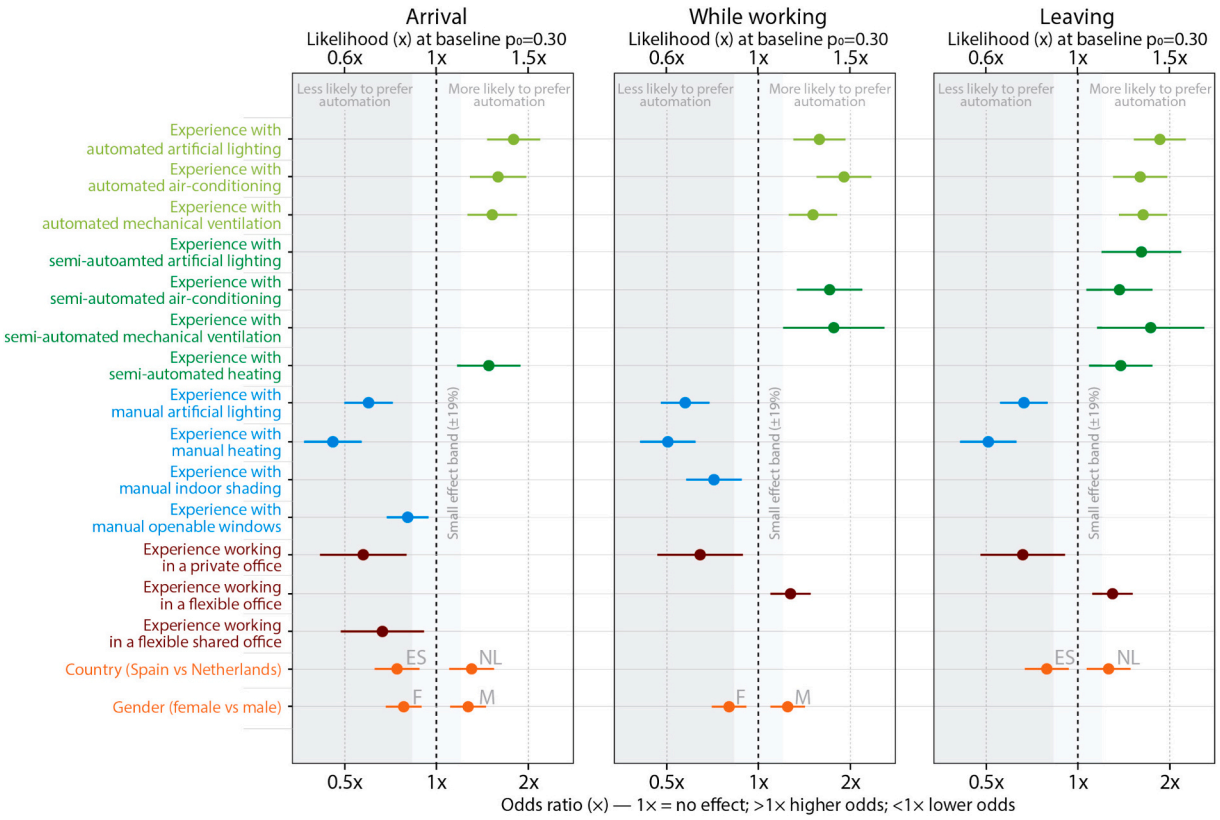


Fig. 6. Predictors of preferred automation across workday phases. Odds ratios (OR; points) with 95% confidence intervals (bars) from ordinal logistic regression models estimated separately for the Arrival, While working, and Leaving workday phases. OR values >1 indicate higher odds of selecting a higher automation level (i.e., preferring more automated options), whereas OR values <1 indicate lower odds (i.e., a shift toward more manual options), relative to the reference category while holding other predictors constant. The grey band denotes an approximate small-effect region around OR = 1 (about ±5 percentage points in the predicted probability at the baseline probability $p0 = 0.30$). Predictors are colour-grouped by domain: prior automated experience (green), prior manual experience (blue), workspace characteristics (dark red), and demographics (orange). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

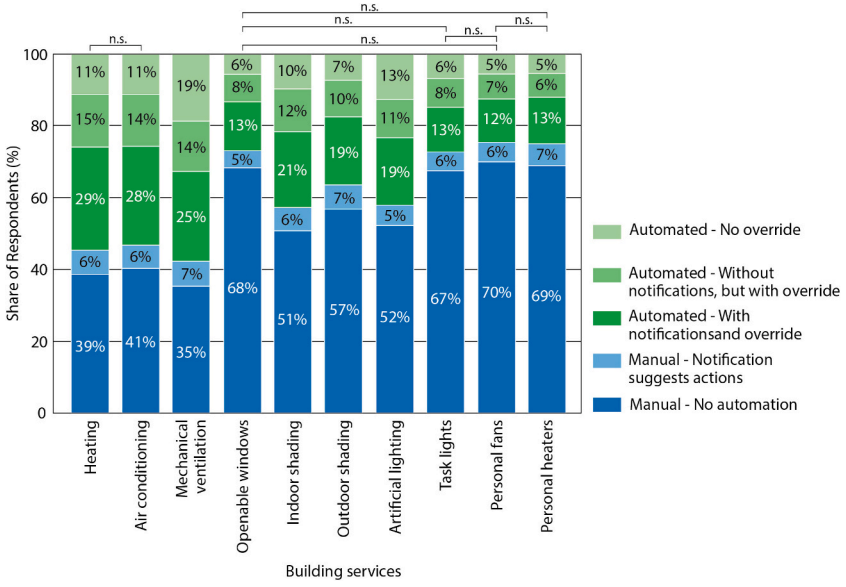


Fig. 7. Preferred level of automation by building service. Horizontal brackets indicate pairwise comparisons of the distributions across services; "n.s." denotes no statistical significant differences ($p \geq 0.05$), whereas no brackets indicate statistically significant differences ($p < 0.05$).

Manual (same manual option for all services), Automated (same automated option for all services), and Mixed control (preferences vary by service). The Mixed control profile is the largest group (61.5%, n = 2241), while consistent Manual profiles (27.3%, n = 994) are more common than consistent Automated profiles (11.2%, n = 410). Fig. 8(ii) decomposes the Mixed control profile by.

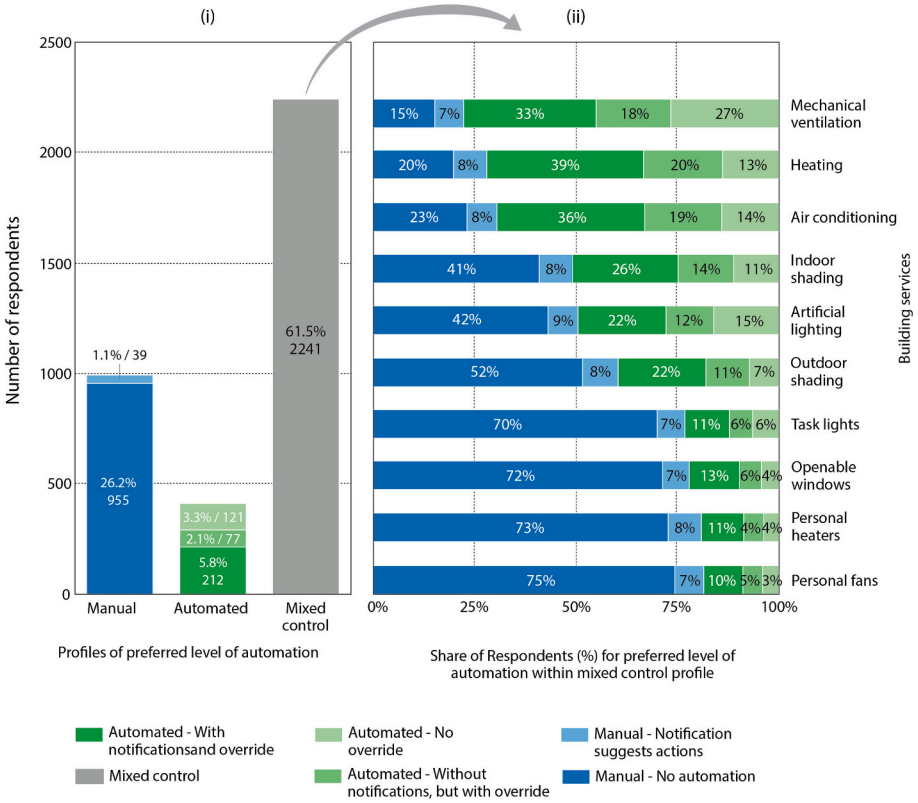


Fig. 8. Profiles of preferred automation and decomposition of mixed-control preferences by building service. (i) classifies respondents according to whether they choose the same automation level for all services ("Manual" or "Automated") or vary their choice across services (Mixed control). (ii) Decomposition of "Mixed" profile by building service.

building service. Even among respondents who vary their preferences across services, HVAC remains mainly preferred "automated" (mechanical ventilation: 78% selecting an automated control option; heating: 72%; air-conditioning: 69%). Shading and lighting sit in the middle (indoor shading: 49% "manual" vs. 51% "automated"; lighting: 51% "manual" vs. 49% "automated"), while outdoor shading remains predominantly "manual" (60% "manual"). Personal devices and operable elements remain strongly "manual" within this mixed group (task lights: 77% "manual"; openable windows: 79%; personal heaters: 81%; personal fans: 82%).

To examine why automation preferences differ by building service, we fitted separate ordinal logistic regression models for each service (Fig. 9). ORs summarize whether a factor is associated with a greater tendency to select higher automated control levels (OR $>$ 1) or more manual options (OR $<$ 1). Across building services, prior control experience shows the most consistent association. Predominantly prior manual control experience is linked to lower odds of preferring higher automated control, while prior semi−/automated experience is linked to higher odds, with the strongest effects for HVAC and clear patterns also for openable windows. Workspace characteristics show smaller associations (private offices generally lower automated control preference; flexible/shared desking higher), and desk distance to the window is most relevant for façade-proximate services (openable windows and shading), where greater distance corresponds to higher odds of preferring automation. Demographic effects are modest. Spain (vs. the Netherlands) typically shows ORs below 1 (often excluding 1), and when gender effects appear they indicate slightly lower automated control preference among women.

3.4. Preference for control interface characteristics

Fig. 10 summarizes respondents' preferred interface characteristics. For interface type, respondents leaned toward "digital devices" (43%), followed by "analog devices" (33%), with 25% reporting "no preference". For interface position, the most common preference was "next to the entrance" (37%), followed by "on the desk" (28%). Fewer respondents preferred controls "close to the system" (19%) or reported "no preference" (17%). For information level, preferences concentrated on providing some feedback. "Basic cues" (27%) and "system status" (24%) were most frequent, whereas richer information options were less common ("status+suggestions" = 14%; "status+suggestions+feedback" = 10%). "No cues" (13%) and "no preference" (12%) were least selected.

To test whether these interface attributes are chosen independently, we assessed pairwise associations among type, position, and information level using 2 tests with Cramér's V effect sizes ($N = 2322$). Interface type showed the strongest association with information level ($\chi 2(4) = 340.2$, $p < 0.001$, $V = 0.38$), followed by a moderate association with position ($\chi 2(2) = 99.3$, $p < 0.001$, $V = 0.21$). The association between position and information was weaker ($\chi 2(8) = 117.3$, $p < 0.001$, $V = 0.16$).

Fig. 11 decomposes the overall associations among interface type, position, and information level into level-by-level relationships using signed ϕ coefficients (cell-wise association strength and direction; stars indicate significance). The strongest and most coherent pattern links digital interfaces with desk-reachable and information-rich designs. "Digital" co-occurs with "on the desk" position ($\phi = +0.16$***) and with higher information levels, particularly "status+suggestion+feedback" ($\phi = +0.18$***). In contrast, analog interfaces show the complementary configuration, co-occurring with "next to entrance" position ($\phi = +0.20$***) and with minimal information (in particular "no cues", $\phi = +0.29$***). Position-information associations are generally smaller, but remain directionally consistent with these configurations (e.g., "no cues" with "next to entrance", $\phi = +0.18$***; "status+suggestion" with "close to the system", $\phi = +0.09$***). Overall, the heatmap indicates two coherent interface configurations: (i) digital-desk-information and

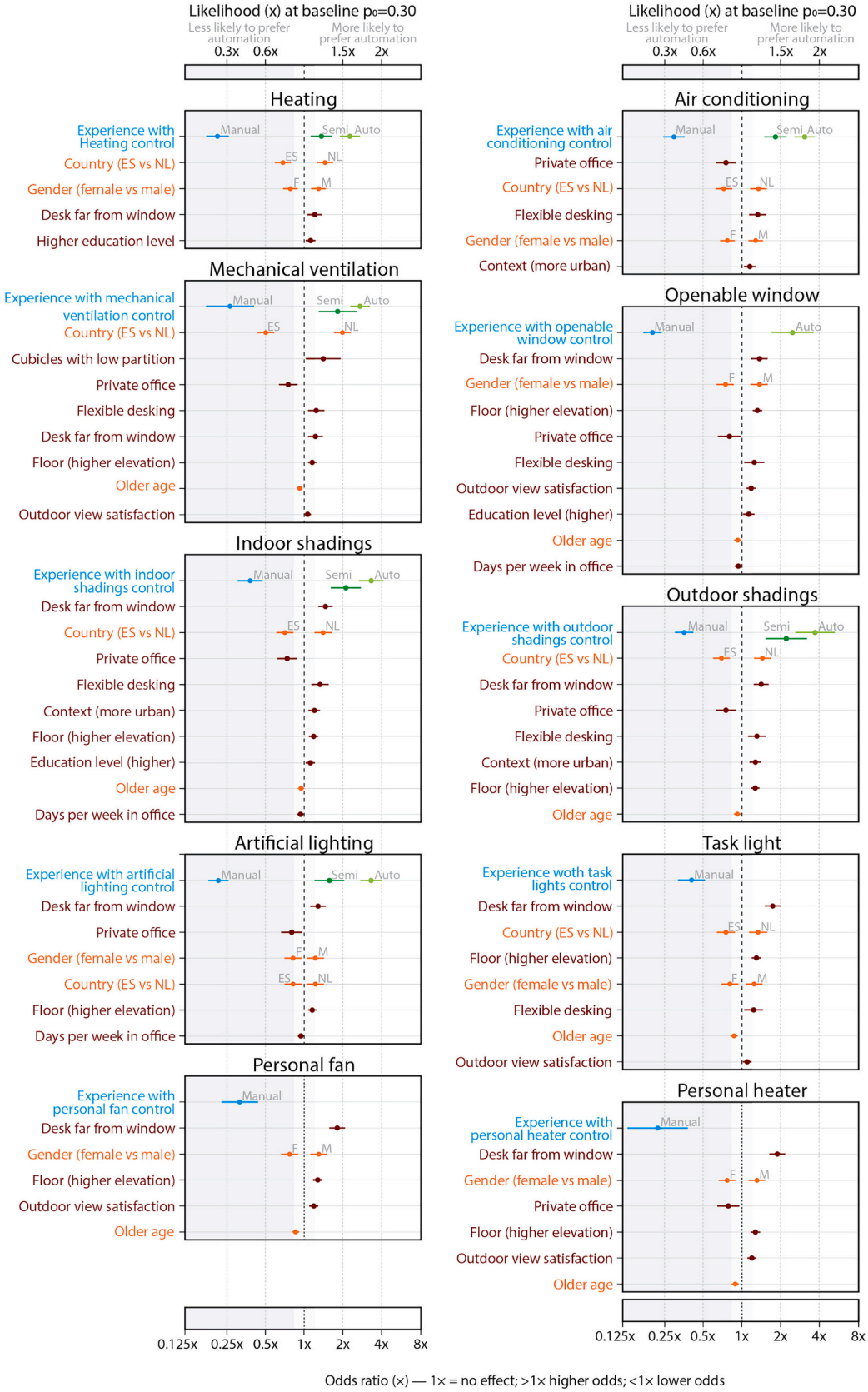


Fig. 9. Building service–specific predictors of preferring higher automation. Odds ratios (points; 95% confidence intervals, bars) from ordinal logistic models estimated separately for each service. The dashed vertical line marks no effect (OR = 1×). The top scale shows the corresponding change in likelihood at a baseline probability $p0 = 0.30$. Colors group predictors: prior experience with the same service (blue = manual, green = semi- or fully automated), workspace characteristics (dark red), and demographics (orange). Values to the right of 1× indicate higher odds of choosing a more automated option, and values to the left indicate lower odds. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

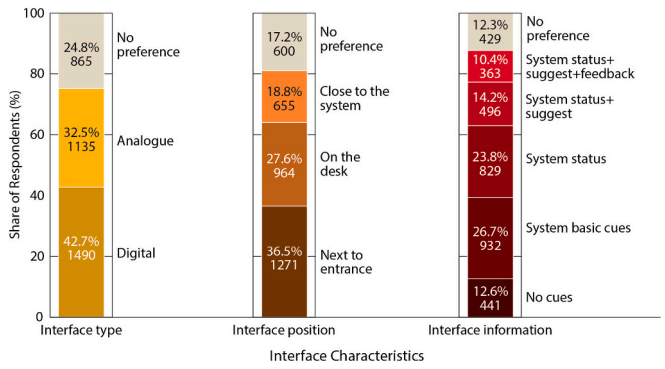


Fig. 10. Number of respondents' preferences for interface type ("digital", "analog", "no preference"), interface position ("next to the entrance", "on the desk", "close to the system", "no preference"), and interface information level ("no cues", "basic cues", "system status", "status + suggestions", "status + suggestions + feedback", "no preference").

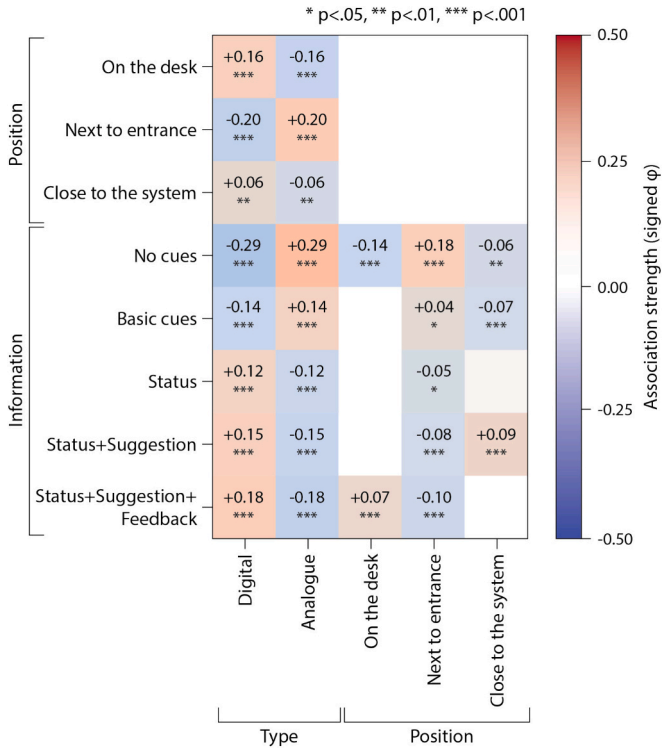


Fig. 11. Level-by-level associations between interface type, position, and information. Cells show signed ϕ coefficients from 2 × 2 contingency tables (N = 2322), with positive values (red) indicating that two levels co-occur more often than expected by chance and negative values (blue) indicating under-representation. Asterisks denote statistical significance (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(ii) analog-entrance-basic cues.

Fig. 12 examines predictors of choosing a "digital" (vs. "analog") interface, consistent with the patterns suggested by the association matrix. Fig. 12(i) reports odds ratios from a logistic regression model. Two effects stand out. First, higher level information is strongly associated with choosing "digital" interfaces (OR > 1), indicating that respondents tend to pair digital devices with interfaces that display system status, suggestions, and feedback. Second, interface position differentiates "digital" versus "analog" choices: desk-mounted controls are associated with higher odds of choosing "digital", whereas entrance-mounted controls are associated with lower odds (i.e., a shift toward analog).

Fig. 12(ii) shows the observed proportions and illustrates the joint pattern across positions. The share selecting a digital interface increases with higher level of information for all three positions, and remains highest for desk-mounted interfaces (33% for "no cues" increasing to 82% for "system status, suggestion, feedback"), followed by interfaces close to the controlled system (18% to 86%), and lowest for entrance-mounted interfaces (18% to 80%). Taken together, these results reinforce a coherent "digital-reachable-information" configuration, while analog choices associate withentrance-mounted and basic information options.

3.5. *Associations between preferred automation level and interface characteristics*

We examined whether interface preferences are associated with respondents' preferred automation level during the "while working" phase, which we use as the primary indicator of preference for automated control. Responses of "no preference" for interface characteristics were excluded. Fig. 13 presents three plots showing, for each automation level, the share of respondents selecting each option for (i) interface type, (ii) interface position, and (iii) information level; Cramér's V summarizes the strength of the $\chi 2$ association in each plot.

For interface type, Fig. 13(i) shows a clear shift toward "digital" interfaces as respondents prefer higher levels of automation. Among those preferring "fully manual" control, 38% prefer "digital" interfaces and 62% prefer "analog" devices, whereas among those preferring "fully automated" control, 74% prefer "digital" and 26% prefer "analog". This pattern corresponds to a moderate association between automation preference and interface type (Cramér's $V = 0.31$).

For interface position, Fig. 13(ii) shows smaller differences across automation levels. Among respondents preferring "manual" control, 54% prefer controls "next to the entrance", 30% "on the desk", and 16% "close to the system". For automation with override, preferences are more evenly distributed (38%, 41%, and 22%, respectively), and for "fully automated" control they are 46%, 23%, and 31%. Because entrance-mounted controls remain common across all automation levels and shifts across positions are modest, the association is weak (Cramér's $V = 0.13$).

For information level, Fig. 13 also indicates a weak association. "Manual" control preferences are more often paired with minimal feedback (23% "no cues"; 35% "basic cues"), whereas automation with override is more often paired with higher level information (36% "status+suggestions+feedback"). However, the distributions overlap substantially across automation levels, so the overall association, while statistically significant, remains weak (Cramér's $V = 0.13$).

4. Discussion

Overall, our findings challenge the idea that office occupants have a single, stable preference for automation. When preferences are considered jointly across workday phases and building services, most respondents fall into a "mixed-control" profile, indicating that an acceptable control strategy depends on what is being controlled and when control decisions take place. This aligns with occupant-centered automation research showing that preferences and acceptance are context- and task-dependent rather than fixed individual characteristics [48–51], and it provides quantitative support for control designs that differentiate across services and routines.

With respect to workday phases, most respondents selected the same automation level at "arrival", "while working", and "leaving", indicating substantial within-respondent stability. However, among the minority who changed their preference, shifts toward more automated options were more common than shifts toward more manual options from "arrival" to "leaving", yielding a tendency toward higher automation at

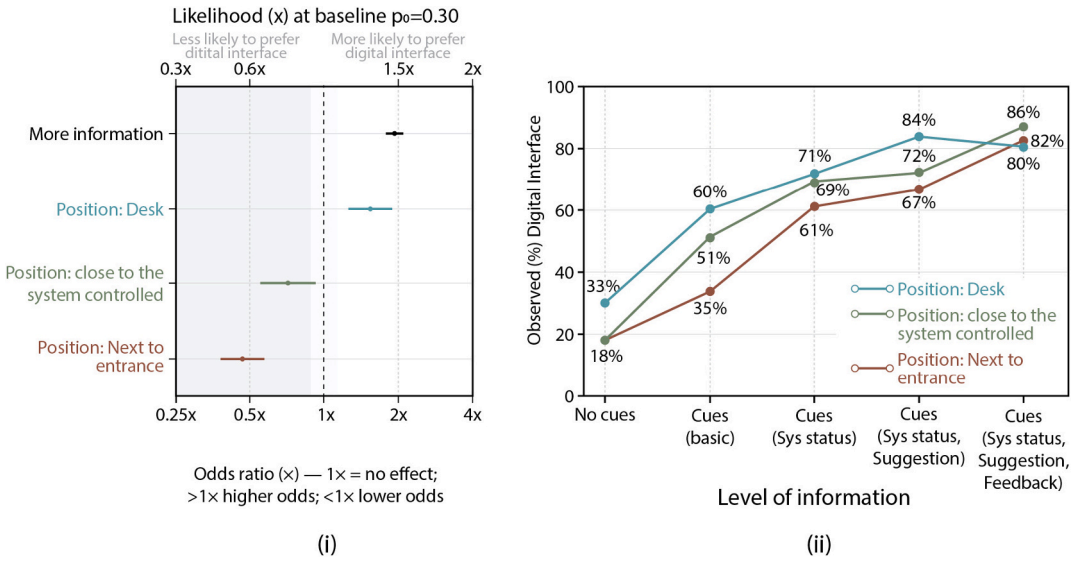


Fig. 12. Predictors of choosing a digital interface. Left: Odds ratios (points; 95% CIs) from a logistic model predicting digital vs analog as a function of information richness and interface position; the dashed line marks OR = 1× and the header notes the baseline probability $p0 = 0.30$. Right: Observed share choosing digital (%) by information level, stratified by position (Desk, Close to the system, Next to entrance). Digital preference increases with information and is highest for on-desk placement, intermediate near the system, and lowest at the entrance.

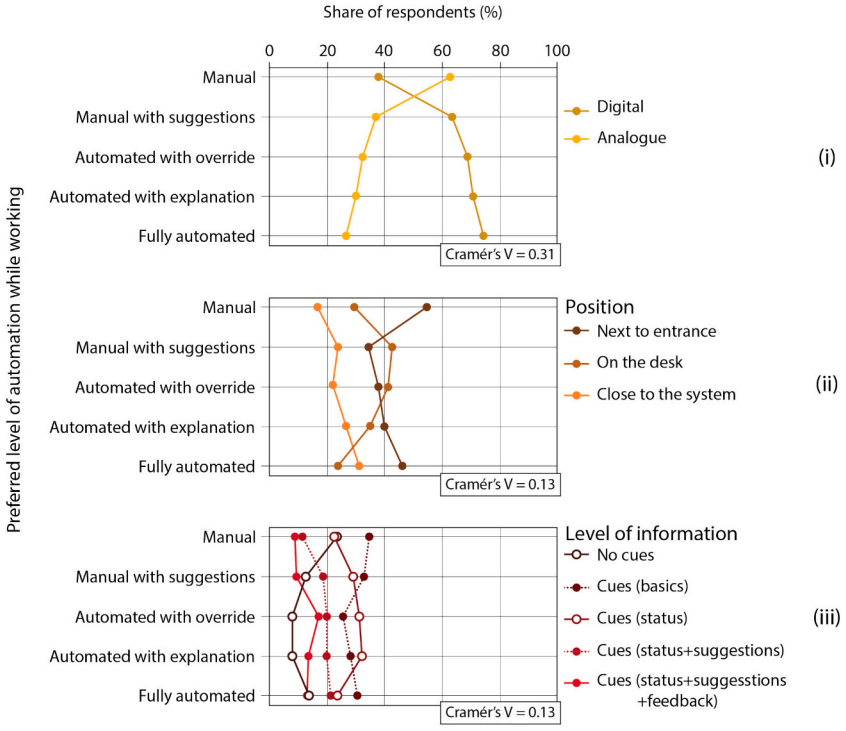


Fig. 13. Distribution of preferred interface options within each preferred automation level during the "while working" phase ("no preference" responses excluded). Points/lines represent observed shares of respondents selecting each interface option across automation levels. For each panel, Cramér's V summarizes the overall strength of association between automation preference and the corresponding interface characteristic (effect size from the $\chi 2$ test of independence; $V = 0$ indicates no association and larger values indicate stronger association).

the end of the workday. This should not be interpreted as a continuous increase in preference over time. Rather, it indicates that the distribution of preferred automation levels differs across workday phases. This phase dependence is consistent with previous evidence showing that occupant interactions with building services are structured by office routines and occupancy transitions, and it suggests that automated control strategies may need to account for workday phases (e.g., different support at arrival vs.\ active work vs.\ leaving) instead of relying on a single default interaction and control strategy [38,52–54].

Preferences also differ strongly by building service. HVAC-related services (especially mechanical ventilation, followed by heating and air-conditioning) show the highest number of respondents preferring automated control, whereas personal devices and directly operable elements (task lights, personal fans/heaters, and openable windows) are predominantly preferred as "fully manual". Shading and artificial lighting occupy an intermediate position: many respondents still prefer

manual control, but a substantial number accepts automation when it preserves agency through override and/or provides clear notification. Together, these results indicate that automated control strategy should be treated as a service-specific design decision rather than a single global "manual" versus "automated" policy, consistent with earlier evidence on service-dependent perceptions of responsibility and control [8,27,55]. These service-specific preferences are summarized in Table 2.

The preferred automation levels identified here do not prescribe specific control variables or algorithms. Depending on the service, automation may act through temperature setpoints, airflow, lighting levels, shading position, or other variables. Advanced approaches such as model-predictive or reinforcement-learning control are possible implementation strategies [10,56], but were not evaluated in this survey. The results instead define the preferred level of occupant involvement, including notification, feedback, and override, regardless of the underlying control strategy.

Automation also involves different costs and energy-saving opportunities across services. HVAC and mechanical ventilation may require sensors, actuators, control hardware, system integration, and commissioning, but can reduce energy use by matching operation to occupancy and demand. Lighting controls can save energy through occupancy sensing and daylight dimming, while automated shading can reduce cooling and lighting demand by controlling solar gains and daylight [12–14,57]. However, actual costs and savings depend strongly on the existing building, retrofit needs, climate, occupancy, and operation. Since this survey did not collect cost or energy-use data, the results should be seen as an occupant-preference input to a broader technical and economic assessment, rather than as a direct cost-benefit analysis.

Across services, prior control experience shows the most consistent association with preferring higher automation levels. Respondents who have previously experienced a service operating in a semi−/automated control mode are more likely to prefer automated control for that service, whereas those familiarized to manual control tend to prefer manual control strategies. This pattern is strongest for HVAC (heating, cooling, and ventilation) and is also evident for openable windows and lighting. This supports an interpretation of automation preference as partly experience-based: preferences for different levels of automation may reflect learned expectations about whether automation is reliable and useful for a particular service, and whether manual interaction is effective and worth retaining. This aligns with evidence from automation and smart-home research linking prior experience with automated systems to greater trust, acceptance, and willingness to use automation again [18,48,58].

Finally, results on preference for interface highlight that occupants do not perceive interface characteristics independently. Instead, respondents tend to select coherent interface configurations, in particular "digital + desk + information-rich" configuration and a complementary "analog + entrance + low-information" configuration. Moreover, interface preferences relate systematically to preferences for automation: respondents who prefer higher automation more often select digital and information-rich interfaces, whereas respondents that prefer manual control more often select analog and low-information configurations. This suggests that increasing automation without improving the interface may be counterproductive: as occupants rely more on system automated control logic, accessible controls and clear information become essential to support transparency and preserve personal environmental control. Conversely, for services that occupants prefer to keep manual, simple and robust interfaces may be sufficient. These findings reinforce that occupant-centric automation is not only about control logics, but also about providing interaction mechanisms (reachability, ease of use, and system cues) that make automation acceptable within everyday office routines [8,16,18,55].

Table 2
Preference-based ranking of office building services by occupants' desired level of automation.

Preference for automation	Building services
Highest	Mechanical ventilation
High	Heating, air-conditioning
Intermediate	Indoor shading, outdoor shading, artificial lighting
Lowest	Openable windows, task lights, personal fans, personal heaters

This study has limitations. It is based on stated preferences collected in a cross-sectional survey, and actual in-situ behavior (particularly overrides under real discomfort, glare, noise, or social constraints) may differ. While we distinguished workday phases, we did not track individuals longitudinally or link preferences to measured indoor conditions, control actions, or energy outcomes. The sample is limited to office workers in two European countries and may not represent other cultural or building contexts. In addition, participants were not provided with information on implementation costs or potential financial savings; therefore, the reported preferences should not be interpreted as willingness to pay for automation and may differ when economic trade-offs are explicitly considered. Finally, the reported relationships are associative rather than causal.

5. Conclusion

Using an online questionnaire with 3504 office workers in the Netherlands and Spain, this study quantified preferred automation levels for ten building services across three workday phases and examined how these preferences relate to interface type, interface location, and information provision. The results show that automation preferences in offices are not random, they are structured, context-dependent, and actionable for both design and building operation.

Three patterns stand out. First, preferences shift modestly over the workday phases, with highest preference for automation during the "leaving" phase, suggesting that predictable transitions are moments when occupants are most willing to delegate control. Second, preferences are strongly service-specific. Background services such as mechanical ventilation and heating are widely preferred as automated, especially when occupants can override. Directly reachable and highly personal systems, including openable windows, task lights, and personal heaters and fans, are strongly preferred manual. Third, most respondents display a "mixed" profile, varying their preferred automation by both phase and service rather than consistently choosing "manual" or "automated." This indicates that heterogeneity is a key signal to design for, not noise to average out.

Individual experience and workspace context further shape these preferences. Familiarity with automated control of a given service is consistently associated with a higher willingness to preferred automation again, while habitual manual operation aligns with a desire to keep that service manual. Workspace arrangements also matter. Private offices tend to be associated with lower preference for automation, whereas shared and flexible desk environments show greater tolerance for delegating control, pointing to social and organizational influences on comfort management. Interface preferences are similarly patterned. Respondents tend to select coherent configurations, in particular a "digital, desk-reachable, information-rich" combination, over an "analog, entrance-located, low-information" combination, and stronger automation preference is associated with choosing digital, information-rich, desk-reachable controls.

These findings argue against one-size-fits-all automation policies. In practice, occupant-centered control strategies should be phase-specific and service-specific, and they should explicitly accommodate mixed user profiles. A practical translation is to prioritize automated modes with transparent override for room-level services that occupants are willing to delegate (particularly ventilation and thermal conditioning) while keeping control of openable windows, personal heaters, personal fans, and task lighting in occupants' hands. Automation support can be increased during predictable transitions (e.g., preparing to leave) when

willingness to delegate is highest. Finally, control interfaces should be aligned with these interaction expectations. Placing information-rich digital interfaces within easy reach at the desk is consistent with automated operation that still preserves meaningful intervention through accessible override and clear system-state cues. For both new-build and retrofit projects, such differentiated strategies are more likely to support energy goals while reducing conflict and preserving perceived agency.

Future work should therefore move from stated preference to field validation and mechanism testing. Two directions are particularly promising. First, longitudinal field studies that log control actions and overrides, alongside indoor environmental conditions and energy use, can test how workday phase- and service-specific preferences translate into real behavior and performance. Second, the individual drivers identified here can be extended with psychological constructs (such as personality traits, perceived agency, trust in automation, and control beliefs) to explain why some occupants accept delegation while others resist it, and how interface cues and transparency moderate that relationship. Together, these steps would support the development of adaptive control strategies that learn from interaction, tailor automation by service and context, and deliver energy benefits without sacrificing comfort or occupant personal control.

CRediT authorship contribution statement

Pedro de la Barra: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pablo Martinez-Alcaraz:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Eleonora Brembilla:** Writing – review & editing, Validation, Supervision. **Alessandra Luna-Navarro:** Writing – original draft, Validation, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors 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. Questionnaire Structure

The following tables detail the questionnaire structure used to collect the data, organized by the thematic sections presented in the survey.

Table A1
Demographic questions.

Question	Type of answer	Answer
Please indicate your age range:	Single choice	1. Under 18 2. 18–24 3. 25–34 4. 35–44 5. 45–54 6. 55–64 7. 65–74 8. 75–84 9. 85 or older
What is your sex assigned at birth?	Single choice	1. Female 2. Male 3. Intersex 4. Prefer not to say 5. Other
Please indicate your level of education:	Single choice	1. Elementary school 2. Secondary school 3. Bachelor degree 4. Masters degree 5. Doctoral degree
In which country have you lived the longest?	Single choice	Country selection

Table A2
Office context questions.

Question	Type of answer	Answer
In which country is your office situated?	Single choice	Text - Country
On average, how many days a week do you spend in the office?	Single choice	Number - 1 to 5
On average, how many hours a day do you spend at your workplace?	Single choice	Number - 1 to 10
Are you usually working at the same desk:	Single choice	1. No, I do flexible desking 2. Always at the same desk
What is the outdoor context of your office building?	Single choice	1. Urban 2. Semi-urban 3. Rural
How satisfied are you with the outdoor noise from your window? (from traffic or people outside)	Single choice	5-point likert scale (Very dissatisfied to very satisfied)

(*continued on next page*)

Table A2 (*continued*)

Question	Type of answer	Answer
In which floor are you usually working in?	Single choice	1. Ground floor 2. First floor 3. Second to four floor 4. Fifth floor or more
Which of the following best describes your personal office environment?	Single choice	1. Enclosed office, private 2. Enclosed office, shared with other people 3. Cubicles with high partitions 4. Cubicles with low partitions 5. Workspace in open office (just desks)
How distant is your desk from the window?	Single choice	1. 0 to 5 m 2. Greater than 5 m 3. No windows available
How satisfied are you with the outdoor view from your window? (Consider aspects such as content, and visual interest.)	Single choice	5-point likert scale (Very dissatisfied to very satisfied)
Which of the following building services are present in your office space? (Check all that apply, these are systems that can affect your comfort and environment)	Multiple choice	1. Heating 2. Air-conditioning 3. Mechanical ventilation 4. Openable windows 5. Outdoor shadings 6. Indoor shadings 7. Artificial lighting 8. Task lights 9. Personal fans 10. Personal heaters 11. Other
How are the following building services controlled in your workspace? (For each system you selected, choose how it is controlled.)	Single choice	1. Manual 2. Semi-Automated 3. Automated

Table A3
Workday phase questions.

Question	Type of answer	Answer
For each situation, indicate how you'd prefer the building services (such as lighting, temperature, and window shading) to be controlled. 1. When you arrive at your desk. 2. While you are working. 3. When you are leaving the office at the end of the work day.	Single choice	1. Fully manual 2. Notification suggests manual actions 3. Automated WITH notification. I can override. 4. Automated WITHOUT notification. I can override. 5. Fully automated. No override.

Table A4
Building services questions.

Question	Type of answer	Answer
For each of the building services listed below, indicate how much personal control you'd like to have in your workspace. (Even if you do not have those building services) 1. Heating 2. Air-conditioning 3. Mechanical ventilation 4. Openable windows 5. Outdoor shadings 6. Indoor shadings 7. Artificial lighting 8. Task lights 9. Personal fans 10. Personal heaters	Single choice	1. Fully manual 2. Notification suggests manual actions 3. Automated WITH notification. I can override. 4. Automated WITHOUT notification. I can override. 5. Fully automated. No override.

Table A5
Interface questions.

Question	Type of answer	Answer
Which type of interface do you prefer for controlling building services?	Single choice	1. Analogue – switches, knobs, dials, or valves 2. Digital – Touchscreens or digital panels 3. No strong preference
Where would you prefer the control interface to be located?	Single choice	1. Next to the office entrance – Accessible when entering or exiting the room 2. On the desk – Easily accessible while working 3. Close to the controlled system – For example, next to the window or radiator 4. No strong preference
What level of information do you prefer to be displayed on the control interface?	Single choice	1. No information or cues – I prefer a simple interface 2. Basic cues – Basic information about functionality 3. System status – lights on/off, room temperature 4. System status + suggested manual actions – What's happening and what I could do 5. System status + suggestions + performance feedback – Includes info on comfort and energy impact 6. No strong preference

Data availability

Data will be made available on request.

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