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Intersecting Heuristic Adaptative Strategies, Building Design and Energy Saving Intentions When Facing Discomfort Environment: A Cross-country Analysis

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Intersecting Heuristic Adaptive Strategies, Building Design and Energy Saving Intentions When Facing Discomfort Environment

Abstract

Occupants' adaptive strategies play an important role in office buildings' energy consumption. Previous research has mostly focused on the adaptive strategies triggered by occupants' indoor discomfort; however, it is crucial to understand if specific adaptive strategies are linked to occupants' energy-saving intentions. This study explores the relationships among employees' heuristic decision-making in their first choice of adaptive strategies (technological solutions or personal adjustments) when facing extreme discomfort conditions, and their energy-saving intentions, then links these patterns with building design, workplace contextual factors and demographics. A cross-sectional survey was collected among university employees from China, Brazil, Italy, Poland, Switzerland, and the US. Our results demonstrated that the accessibility to indoor environmental controls (IECs) and office type were significant factors for adaptive strategies. There was a positive relationship between the number of IEC features and percentage of employees choosing a technological solution. When feeling too hot, occupants in private offices are more likely to adopt a technological solution, whereas occupants in cubicles are more likely to choose a personal adjustment. Occupants with energy-saving intentions are less likely to choose thermostat adjustments or use portable devices as adaptive strategies than their counterparts. Finally, the cluster analysis suggests females were more likely to use adaptive strategies for energy-saving purposes than males. The majority of occupants would turn on/off lighting to save energy. The study provides contributions in the connection between heuristic decision-making process, and energy-saving intentions and recommendations on design strategies for building architects, engineers, and managers.

Keywords: Occupant behavior, adaptive strategies, energy saving, indoor environmental controls, office types

1 Introduction

Decarbonizing the buildings and construction sector is critical to achieving the Paris Agreement commitment and the United Nations Sustainable Developments Goals [1], [2]. Buildings are responsible for approximately 40% of energy- and process-related emissions in the United States (US), and reducing carbon emissions in buildings is one of the most cost-effective measures to mitigate climate change [3]. Despite the encouraging efforts being taken globally on stringent building energy codes and standards for new and existing buildings, the 2019 Global Status Report on buildings and construction shows that the sector fails to catch up with the level of climate action needed [4]. While existing or new buildings have adopted new technologies, a significant number of commercial buildings have not achieved expected energy efficiency targets, resulting in an energy performance gap between the design and actual energy performance of buildings [5]–[7]. Occupants' adaptive strategies are among many factors contributing to such an increase in energy use, for example, heating and cooling practices, which play a significant role in commercial buildings' energy consumption [8], [9]. There might be a tradeoff between maintaining a comfortable indoor environment and reducing energy consumption, as an ideal indoor environment changes as occupants vary their thermal preferences and demand [10]; therefore, it is challenging, if not impossible, to create an indoor environment that could satisfy all occupants in the office setting. In this regard, taking behavioral strategies to deal with extreme discomforts (e.g., too hot or too old) becomes essential in helping reduce personal dissatisfaction and influence energy consumption.

Occupants' first choice of strategies to deal with personal discomforts through adopting and adjusting the indoor environment is considered an individual's intuition- a specific type of heuristics in decision-making, which can significantly affect energy use and indoor environmental quality (IEQ) [11], [12]. These heuristic decision-making strategies are defined as the actions that occupants would take to restore a comfortable indoor environment, including thermal, acoustic, and visual comforts, as well as indoor air quality through technological solutions or personal adjustment [13]. For example, when occupants feel hot in the summer, they may take the following adaptive actions: (1) pull-down blinds to block the sun, which can reduce solar heat and cooling demand [14], (2) lower the thermostat setpoint, which could increase cooling demand [15], or (3) turn off lights, which can reduce lighting energy use as well as internal heat, thus reduce cooling demand. These actions have different impacts on building operation, which in turn influence energy consumption in varying ways; therefore, this study focuses on occupants' heuristic decision-making in their adaptive strategies and energy-saving intention in office buildings by considering building design, workplace contextual factors, and demographics. Occupants' first choice of strategies generally rely on technological solutions or personal adjustments. Specifically, technological solutions are defined as occupants using devices, equipment, and/or energy systems to adjust the indoor environment and restore thermal comfort conditions, such as adjusting thermostat settings to control heating, air-conditioning (HVAC), or mechanical ventilation; operating windows and blinds; switching lights; using a personal fan and heater, and so on. On the other hand, individual adjustments are non-technological solutions, including adjusting clothing layers, walking to a cooler/hotter space, or having a hot or cold drink.

2 Literature review

2.1 Energy saving potential from adaptive strategies

Studies have found different energy saving potentials could be either using technological solutions or personal adjustment strategies [16]. For example, adjusting daily thermostat setpoints in multi-use office buildings according to the climate can reduce building load by 74.6% and energy consumption by 59.7% [17]. One study suggest that using a dynamic set temperature (DST) correlated to occupants' clothing adjustment has the potential to save energy up to 65.5% compared to a fixed temperature set-point [18]. Approximately 30%-40% of energy use can be reduced by controlling operable windows, electric fans, and air-conditioners compared to conventional strategies of maintaining a static setpoint of 26 degrees Celsius for air conditioning [19]. Another study also suggests that adaptive temperature setpoints are capable of achieving 34.3% energy savings compared to conventional fixed temperature setpoint control [20]. Furthermore, different levels of adaptive strategies will lead to different energy savings [21]; for example, a study reports that Predicted Mean Vote (PMV)-based HVAC control, representing a flexible, comfortable indoor temperature, can save 1.6% of energy usage per day compared to fixed setpoint temperature control [22], and relaxing PMV-based thermal comfort requirements can lead to more energy saving potentials.

While technological adaptive actions can impact building energy use, other adaptive actions, such as personal adjustments can impact building performance indirectly [23]. While fewer studies have focused on the actions aimed at occupants' personal adjustments, some research has highlighted that occupants have greater controls over their thermal environment in mixed-mode buildings than in buildings with automated controls [24]. Clothing is an important factor to compensate for individual differences in the preferred indoor temperature, especially in naturally ventilated buildings [25]. Active conditioning through thermostats becomes unnecessary if the indoor temperature falls within the range that occupants can maintain comfort through clothing adjustments. A field study conducted in classrooms and offices estimated the potential energy saving due to personal adaptations and found that 9.6% energy for centralized heating can be saved according to clothing strategies to keep thermal comfort [26].

2.2 Building design, adaptive strategies and energy saving

Building design can significantly influence employees' IEQ, work productivity, and energy-saving intention [9], [13], [27]. Here, building design refers to the designs of office layout and indoor environment controls (IECs). Recently, there is an increasing trend of designing open-plan offices with fewer partition walls, doors, and other spatial boundaries to improve employees' interaction and to save energy, money, and space [28]. Office layout design, such as open-plan, shared, and enclosed offices, is one of the leading factors influencing indoor environment, which also influences occupants' perceptions, thermal comfort, IEQ satisfaction, productivity, and organizational well-being [29], [30]. Removing partitions or creating "unbounded" offices can stimulate social interaction and collaboration; however, the lack of spatial boundaries can decrease collective intelligence due to potential cognitive overload, distraction, bias, and other symptoms [31], [32].

The design of offices influences occupants' different adaptive strategies; occupants in shared offices operate blinds less often and are more tolerant of intensive daylight than occupants in private offices [33]. A study concludes that the number of adaptive strategies decreases significantly in shared spaces compared to in private offices, indicating that people might be afraid of adjusting workplace conditions that may annoy co-workers [34]. Another study later confirmed that the fear of bothering others is very pronounced among office employees. Many employees believe that personalized control systems (e.g., task lighting, desk fans) have great potential to empower occupants to improve their comfort in energy-efficient ways [35]. That is, group dynamics and social norms in different office settings can influence employees' motivation to save energy. Different types of social norms (i.e., descriptive and injunctive norms) in open-plan and shared offices can also impact employees' energy-saving intention [36], [37]. Descriptive norms, which is the perceived prevalence of others' behaviors, are likely to be more salient and influential in shared and open-plan offices [38]. In single-person offices, occupants may have to rely on and internalize injunctive norms, which are an individual's perceived expectations from others to act in a certain way, to gauge their energy-saving intention and behaviors. Additionally, the number of occupants sharing an office influences the ways in which occupants restore thermal comfort [39] and save energy [40]. For example, occurrences of opening/closing windows and putting on/taking off clothes increase with the number of occupants in shared offices while turning on ceiling fans occurs most often in single-person offices [41].

One of the key barriers preventing occupants from taking certain adaptive strategies or energy saving actions lies in the design of human-building interfaces; that is, whether the building design allows occupants to interact with, control, or adjust indoor environment devices (e.g., personal devices, lighting, or HVAC system). Accessibility to IECs typically measures one's degree of control over indoor environment devices, such as whether thermostat is adjustable or windows and electric lighting systems are operable, and can influence IEQ, energy saving, and thermal comfort due to its physical and psychological impacts [9], [42], [43]. Once occupants are offered the opportunity to manage IECs, energy consumption could be reduced as people take certain adaptive strategies [44]. For example, occupants with control over windows reported a higher neutral temperature (i.e., allowing a higher cooling temperature setpoint) in summer, used less air conditioning, and, accordingly, saved more energy than their counterparts [45]. People with high levels of access to IECs would be more tolerant of environmental discomfort, thus consuming less energy to combat discomfort [46]. Due to office layout or energy-saving reasons, however, the majority of occupants have no or low levels of IECs [29], [47].

One study tried to automate the occupant-building interaction via smart zoning of thermal loads and optimally regulating the setpoints of zones in a large building, which might achieve 15% energy reduction and 25% increased thermal comfort [48]. An occupant in a single or private office generally has more controls over the thermostat, ventilation, lighting, and noise than occupants in open-plan layouts [9], [49]. Lighting control is often impossible in open-plan offices, while it is usually possible in the offices with fewer occupants or desks [50]. One recent study suggested that access to light switches was positively related to occupants' IEQ-productivity belief [13]. Additionally, an air-conditioning system based on occupant preference recognition control is more applicable in a personal office space [51]. The impacts of office layout and IECs on occupants' IEQ, productivity, or adaptive strategies is well-estimated; however, little research is focused on the interconnected factors of office layout, accessibility of IECs (i.e., whether they have access to an IEC or not, and if how many), and level of accessibility (i.e., whether occupants share the IECs) on both environmental discomfort adaptive strategies and energy-saving intention, which is one of the main focuses of this paper.

2.3 The influence of workplace contextual factors and demographics

Office-contextual factors can potentially influence occupants' adaptive strategies, such as work position and occupancy hours (hours spent at work), which are related to specific office tasks and activities and have been shown to influence occupants' IEQ [42], [52]. For example, managers tend to have higher levels of perceived comfort than non-managers due to the hierarchical nature of workplaces [53]. Additionally, occupants who are not in a leadership position and work in an office surrounding with footsteps, machine noise, or conversation areas have lower IEQ satisfaction. Therefore, occupants in leadership positions are significantly more satisfied with indoor comfort-related parameters than their counterparts, indicating the link between higher work positions and apparent advantages regarding office type, size and quality of workspaces, IECs, and so on [89]. A recent study, on the other hand, suggests that neither job position nor occupancy hours appear to have an impact on occupants' IEQ-productivity belief [13].

The link between work position, occupancy hours, adaptive strategies, and energy saving requires deeper investigation. Demographic factors are other critical variables that could lead to different adaptive strategies. People from different demographic backgrounds, such as different climate zones or economic backgrounds, have different IEQ expectations and tolerances. Therefore, demographics take different adaptive strategies to address discomfort or have different energy-saving intentions [54].

2.4 Theoretical framework

This study's theoretical framework is based on the concepts of bounded rationality in behavioral economics and heuristic decision-making [55], [56]. As opposed to perfect rationality, bounded rationality is the concept that human rationality is bounded by limitations in human's thinking capacity, available information, and time [56]. Bounded rationality is related to descriptive, normative, and prescriptive accounts of behaviors and is associated with heuristics of thinking process [57], [58]. A heuristic is defined by Gigerenzer and Gaissmaier [59] as a "strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods”. Heuristics are rules of thumb developed through experience that have become intuitive processes [59]. Because using heuristics saves mental effort, they may imply greater errors or biases than “rational” decisions; however, simple heuristics can solve problems that logic and probability cannot, especially when an occupant has limited resources and information in an office setting.

Pro-environmental or energy-saving behaviors can be influenced by heuristics or intuition. For instance, people tend to be more worried about climate change during hot, dry summers than other seasons, showing reliance on the availability heuristic, but also using attribute substitution, which is when people use less relevant but more accessible information (e.g., today’s temperature), in place of more salient but less accessible information, such as global climate change patterns, in creating their environmental beliefs [60], [61]. Additionally, certain experiences, character traits, and motivations shape people’s behavior and intuitions [60], [62]–[64]. People who have direct experience with the effects of climate change will likely have more “accessible frameworks of thought” to inform their energy-saving decision. Personality traits, such as extraversion, impulsivity, and openness to experience, can also impact intuitions about pro-environmental decision-making [63], [65], as can differences in motivations types (e.g., altruistic or egoistic motives) [66].

Energy-saving decision-making models, however, often fail to account for bounded rationality of human thoughts, which are constrained by time, informational, computational, and cognitive resources and capacity [67]. These constraints, especially in situations of uncertainty, tend to lead people to rely on heuristics, as it lessens the cognitive burden required by complex thought and decision-making processes [67], [68], which may be a common situation in the office setting. Thus, this study addresses the link between heuristics in relation to occupants’ first choice of adaptive strategies when the built environment is not ideal (i.e., too hot or too cold).

2.5 The present study

This study investigates employees' heuristic decision-making in adopting indoor environmental adaptive strategies and energy-saving intention in office settings when facing extreme thermal discomfort (i.e., too hot or too cold). Heuristics are measured by occupants' first choice of adaptive strategies in dealing with heating and cooling practices by considering either *technological solutions* or *personal adjustments*, which also serve as the indicator of potential energy saving.

Given the existing literature on adaptive strategies, two gaps appear that deserve more research efforts. First, the majority of studies mainly focus on the adaptive strategies that are triggered by occupants' indoor discomfort; however, is it possible that adaptive strategies are linked to occupants' energy-saving intentions? For example, would people choose to adjust the thermostat because they want to save energy or restore thermal comfort? Second, the relationship between the first choice of adaptive strategies, building design, accessibility to IECs, and occupants' workplace contextual factors, as well as demographics remain underexplored all together in one study, including*: how and in what ways do occupants share IECs and adopt the first action to adjust the indoor environment, which indirectly influence their energy saving intentions?* Specifically, we address the following research questions:

- Which heuristic decision-making, that is, the first choice of adaptive strategies (whether technological solutions or personal adjustments), do occupants make in extreme discomfort conditions, such as when feeling too cold or too hot?
- How do building design, such as office types and the level of accessibility to IECs, connect to occupants' first choice of adaptive strategies?
- How do workplace contextual factors, such as work position, occupancy hours, and demographics connect with occupants' first choice of adaptive strategies?
- How do occupants' energy-saving intentions relate to adaptive strategies?

- Do occupants' energy-saving intentions have a certain pattern and does this pattern vary across different genders and countries?

This study makes several contributions by examining (1) the connection between heuristic decision-making processes and energy-saving intention in adapting the indoor environment for thermal comfort; (2) demographic differences, such as in gender and country of residence; (3) the interconnected factors of office type, IECs, and workplace contextual factors; (4) a deeper analysis on the accessibility of IECs (i.e., whether occupants have any and how many) and level of accessibility (i.e., whether occupants share the IECs with other co-workers); and (5) cluster patterns between the first choice of adaptive strategies, energy-saving intentions, and demographic differences. Fig. ***1*** describes the research framework. The rest of the paper is organized as follows: Section 3 describes the survey design, data collection, and methodology used to analyze the relationship between independent and dependent variables, as well as clustering of occupants' energy saving behaviors by demographics. Section 4 shows the results, Section 5 presents discussion, and Section 6 offers conclusions.

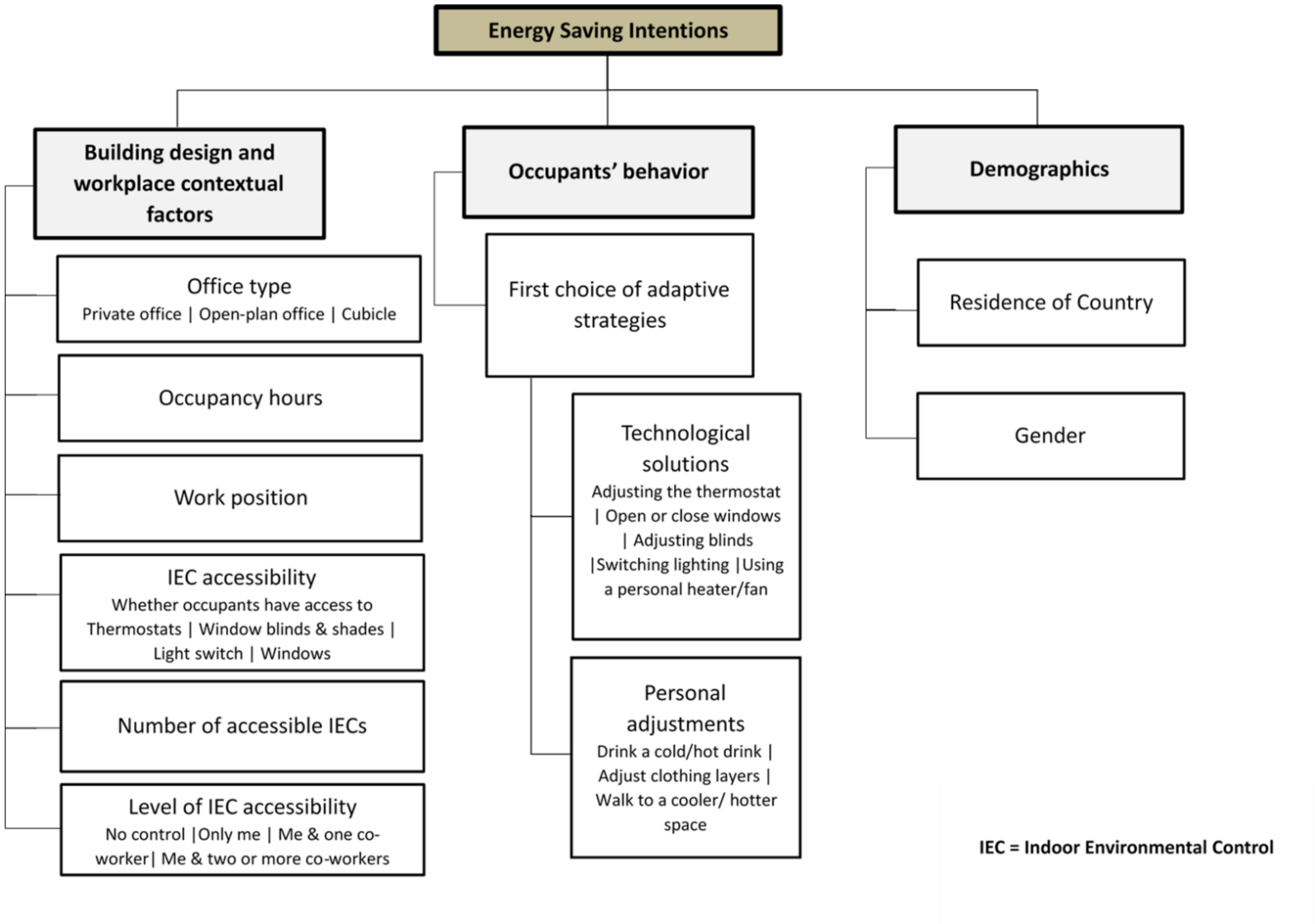

Fig. 1. Overall framework of first choice adaptive strategies and energy-saving intention

3 Method

This study collected an online survey data using Qualtrics survey platform and distributed through Qualtrics Paid Panel Service. Ethics protocols and data privacy protection for handling human subject data had been approved in all participating institutions. The participants, age 18 or older, were recruited from several email listservs consisting of university staff, faculty, researchers, and graduate students regularly occupying office buildings in six universities across the following countries: Brazil, China, Italy, Poland, Switzerland, and the US. In this study, the differences in countries indicate possible differences in climate. The total sample size was 2,466 (Brazil = 252, China = 209, Italy = 399, Poland = 371, Switzerland = 191, and the US = 1,044). The data was collected across four seasons of 2017 (e.g., Brazil, Italy, Poland, China, and the US) and in the fall and winter of 2018 (e.g., Switzerland). Note that Brazilian (southern hemisphere) data was collected during their spring to early summer. To avoid the seasonal and climate differences across countries, we adopted two approaches: first, participants reported their opinions on certain questions across four seasons, such as situations relating to IECs, and second, we measured adaptive actions as occupants' response to the situations when occupants typically feel too hot or too cold at work, which is a subjective view regardless of the current temperatures or thermal situations outdoor. Importantly, our demographic variables and contextual factors (e.g., accessibility to IECs, occupancy hours, and office type) would not generally change due to the seasons or outdoor temperatures.

3.1 Survey instrument

Before designing this study's survey, a critical review was performed on the questionnaire surveys in occupant behavioral literature, e.g., [69] as well as other standards including ASHRAE 55 [70] and Smart Control and Thermal Comfort (SCAT) project [71] to define the measures related to adaptive strategies and thermal comforts. The original questionnaire was developed in English and translated into several languages including Chinese, French, German, Italian, Polish, and Portuguese. A translation guideline protocol was developed and followed to ensure equivalence and coherence across languages. Semantic, conceptual, and normative equivalence of survey questions were guaranteed by re-translating and verifying survey questions back into English before finalizing translated versions, as outlined in the double translation process (DTP), one of the most adopted translation processes for survey questionnaires [9]. The structured questionnaire consisted of five main parts: (1) thermal comfort perception, IEQ satisfaction, and perceived productivity; (2) reasons for IEQ discomfort; (3) group conformity intention and associated social-psychological variables (e.g., attitudes, perceived ease of control, group norms for sharing controls (published in [9]); (4) first and second adaptive actions taken when the participant feels too cold or hot at the workplace; and (5) building design (e.g., office type, accessibility to and level of accessibility of IECs), workplace contextual factors (e.g., occupancy hours and work position) and demographic information (e.g., gender and country of residence). This paper mainly focuses on analyzing occupants' first choice of adaptive strategies when feeling discomfort (heuristic decisions) by taking demographics, building design, IECs, and work contextual factors into account.

3.2 Measures

All measures, except for building design and workplace contextual factors and demographics, were obtained from participants' responses to the survey questions based on a 5-point Likert-type scale.

3.2.1 Dependent variables:

The choice of adaptive actions to thermal discomfort was one of the dependent variables, and the questions asked: "If you feel too hot at work, over a typical work week of this season, what is your first and second action?" The same question was asked for the "feel too cold" situation. The actions were divided into two types: (1) technological solutions, including adjusting thermostats, open or close windows, adjusting blinds, switching lighting, and using a personal heater/fan, and (2) personal adjustments, including having a cold/hot drink, adjusting clothing layers, and walking to a cooler/ hotter space. The analysis focused only on the first adaptive action to indicate occupants' intuitive responses.

Energy saving intentions, the other dependent variable, were encoded based on participants' answers to "why do you normally operate … (a certain IEC feature) in different seasons?" The IECs include windows, blinds, adjusting thermostat settings, and lights. We have created four binary variables, WindowSaveBi, BlindSaveBi, ThermSaveBi, and LightSaveBi, to represent occupants' energy-saving intentions for each IEC feature. When a participant chose "to conserve energy" as a reason for operating a particular control feature, they were scored as "1" on that corresponding binary variable; otherwise, "0" was recorded. Further, a summary variable (ReasonSaveBi) was created to indicate overall energy-saving intentions, meaning whether participants had considered energy saving as a reason for operating any of four IEC features. ReasonSaveBi was also a binary variable coded as

"1" as long as one of the aforementioned four binary variables scored "1". Otherwise, it was coded as "0".

3.2.2 *Independent variables*

The independent variables were grouped into three categories: building design, workplace contextual factors, and demographics.

3.2.2.1 *Building design and workplace contextual factors*

Building design includes office type, IEC accessibility (yes or no), number of accessible IECs, and level of accessibility, while workplace contextual factors include office occupancy and work position.

Office type was measured by the type of private offices, open-plan offices, or cubicles. Private offices include private, enclosed offices. Open-plan offices include shared enclosed and open offices with no internal walls dividing into smaller areas, whereas cubicles include small partitioned-off office spaces.

IEC accessibility was measured by whether occupants can or cannot operate the IECs and was collected by the following four questions including: "Do you have control to…" (a) "….open or close the windows…" (b) "…open or close window blinds or shades" (c) "…adjust the (heating/cooling) thermostat settings…" (d) "….turn on or off the light switch(es)…" "at your workspace?" Participants answered "yes=1" or "no=0" to these questions. *The number of accessible IECs* would be the sum of the above four answers.

Level of accessibility to IECs was measured by the number of occupants sharing each of the IEC controls (i.e., windows, thermostats, light switches, and window blinds or shades); the greater the number of employees who share control over the same feature, the lower the level of accessibility. The four levels of accessibility include: (1) no access to control, (2) only me (can control), (3) sharing controls with one other co-worker, and (4) sharing controls with two or more co-workers.

Office occupancy was measured by the number of hours that occupants stay in the office in a typical week. Participants choose one of the brackets from “1-10 hours” to “more than 50 hours”, with 10-hour intervals.

Work position was measured by each occupants’ employment type, such as faculty (professor and lecturer), administrators (IT, office workers, business managers, accountants, communication specialists, etc.), graduate students, and researchers.

3.2.2.2 Demographics

Demographic factors include gender and country of residence. Gender was dummy coded as 0 (female) and 1 (male). Country difference was measured by occupants’ current country of residence, including Brazil, China, Italy, Poland, Switzerland, and the US.

3.3 Analytic strategy

Table 1 presents an overview of the performed analyses and their corresponding purpose. First, a summary of *descriptive analyses* was presented for the selected variables to explore workplace contextual factors in each country. Second, χ^2 *tests of independence* were performed to determine whether there were statistically significant differences in first choice of adaptive strategies across countries and within different workplace contextual factors. Third, χ^2 *tests of independence* were conducted to explore the relationship between first choice of adaptive strategies and energy-saving intentions. These analyses were conducted using IBM SPSS 25.0. Finally, *k-means clustering* was performed to explore whether occupants’ energy-saving intentions have certain patterns varied across demographics. Cluster analysis was conducted using Python and the scikit-learn library [72].

Table 1 Overview of the analysis

Analysis performed	Purpose
Descriptive analyses	Explore and summarize building design and workplace contextual factors
χ^2 tests of independence	Investigate whether adaptive strategies adopted by occupants differ across countries and with workplace contextual factors

	Explore the relationship between adaptive strategies and energy-saving intentions
k-means clustering	Explore whether the patterns of energy-saving intentions vary across demographics

4 Results

This result section presents the results of (1) the distributions of building design and workplace contextual factors; (2) the significant differences in adaptive strategies across countries and within different workplace contextual factors; (3) the relationships between adaptive strategies and energy-saving intentions; and (4) the patterns of energy-saving intentions across demographic differences.

4.1 Distributions of building design and workplace contextual factors

Our descriptive analyses summarize the distributions of office type, IEC accessibility, occupancy hours, and work position. Among the three office types (private offices, open-plan offices, and cubicles), the open-plan office was the most common type in all countries (more than 60%), except for in the US, where private offices and open-offices were equally common (40%). In general, cubicles were the least common type, with the highest percentages found in the US (21.1%) and China (14.7%). A graphical representation of distribution of office types by country is presented in the appendix (Fig. 11).

On average, most occupants shared IECs with more than one co-worker, especially in Brazil and China (Fig. 2). Approximately 86.0% of the Chinese and 91.3% of Brazilian employees had access to operable windows; on the other hand, most US employees (76.0%) could not operate windows, followed by the employees in Switzerland (31.1%). In Italy, 30.1% of the employees operated windows without sharing with any co-workers. Regarding the level of accessibility to blinds, 48.4% of the US employees had no access. Similarly, 33.5% of the Italian employees had no access to blinds, and 24.5% did not share with any co-workers. Thermostat accessibility (i.e., whether someone could control thermostats) was not available for the majority of employees in the US (73.2%), Italy (61.5%), and Switzerland (53.3%). In comparison, sharing thermostats was dominant in China (76%) and Brazil (68.8%). Lighting accessibility was frequent in all countries and generally shared with more than one co-worker. Surprisingly, about 18% of the US occupants had no access to artificial lighting controls. Regarding occupancy, the most common ranges of weekly occupancy hours were from 31 to 40 and 41 to 50 hours in all countries. Notably, about 50% of the Italian employees spent from 31 to 40 hours in the office per week, while 19% of the Chinese employees spent more than 50 hours in the office. The majority of occupants belonged to administrative staff (59.8%) and faculty (19.8%), while 11.5% and 8.9% of participants were researchers and graduate students, respectively. Regarding gender distribution, 39.9% of occupants were male and 60.1% were female.

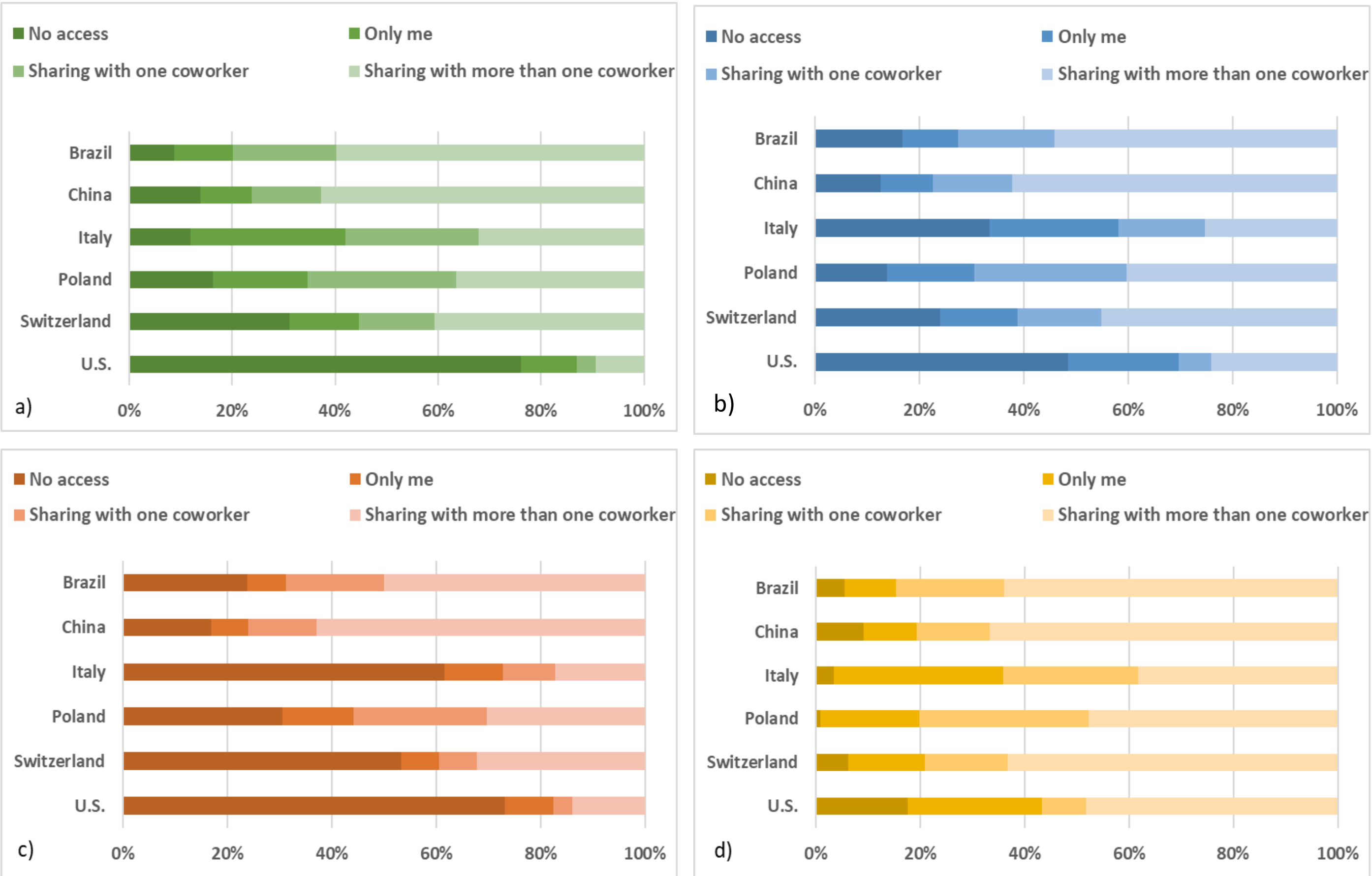

Fig. 2. Level of accessibility to each IEC: a) windows, b) blinds, c) thermostats, d) lighting.

4.2 The first choice of adaptive strategies across demographics and workplace contexts

The χ^2 tests of independence were performed to explore whether there was any significant relationship between demographics, building design, workplace contextual factors, and occupants' adaptive strategies. The result suggests that all the independent variables were significantly related to adaptive strategies, except for occupancy hours (see Table 2 and Table 3). The following sections detail the comparisons across different independent variables.

4.2.1 Country differences in adaptive strategies

The χ^2 test of independence results showed that there was a significant relationship between the first choice of adaptive strategies and country of residence. Statistical significance was found for both when occupants were feeling too hot, χ^2 (5, N=2,262) = 76.24, $p < .001$, and when feeling too cold, χ^2 (5, N=2,281) = 383.13, $p < .001$. As Fig. ***3*** shows, Brazilian (58.1%), Italian (61.4%), and Polish (68.1%) employees preferred a technological solution when feeling too hot; however, personal adjustments were preferred in Switzerland, the US, and China, but with a small margin. On the contrary, when feeling too cold, most participants, especially in the US (81.3%), preferred personal adjustment strategies, except for Poland, where technological solutions still dominated (75.1%).

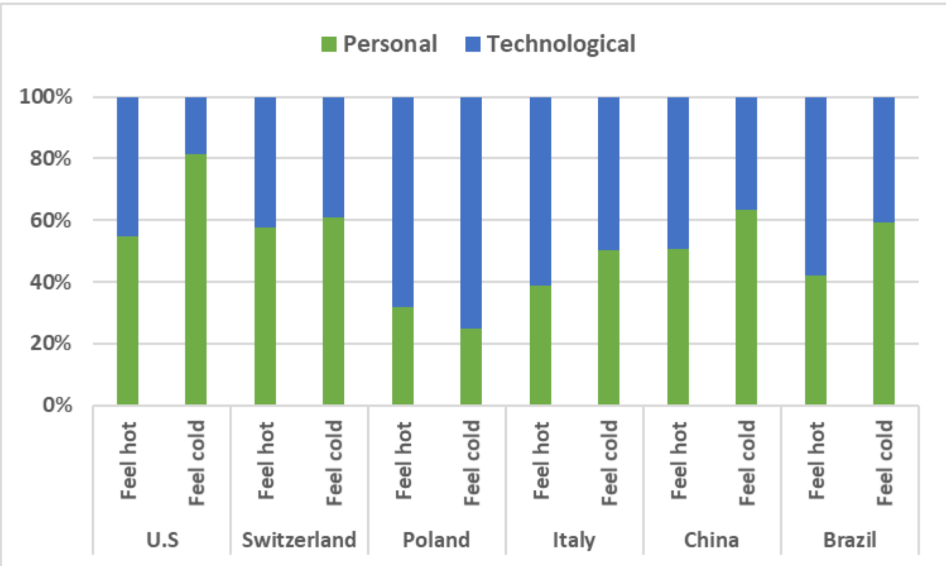

Fig. 3. Personal and technological adaptive strategies by country

4.2.2 Adaptive strategies and accessibility to indoor environmental control (IEC)

The χ^2 tests of independence was conducted to determine the relationship between IEC accessibility and first choice of adaptive strategies. Across all the countries, there was a significant relationship between IECs and adaptive strategies (see Table 2), indicating that occupants who had access to the IECs were more likely to adopt a technological solution to adjust the indoor discomfort conditions.

Table 2. Results of the χ2 test of independence between IEC accessibility and adaptive strategies

		Feeling hot			Feeling cold		
IECs	Having control	Personal (%)	Technological (%)	χ2	Personal (%)	Technological (%)	χ2
Thermostat	yes	39.7	60.3	43.64***	50.4	49.6	120.11***
	no	54.0	46.0		73.4	26.6	
Blind	yes	42.7	57.3	33.20***	56.3	43.7	67.46***
	no	56.0	44.0		74.7	25.3	
Window	yes	40.4	59.6	58.116***	50.5	49.5	189.30***
	no	57.0	43.0		79.4	20.6	
Lighting	yes	45.9	54.1	11.93***	60.1	39.9	36.23***
	no	58.5	41.5		81.3	18.7	

* $p< 0.05$, ** $p <0.01$, ***$p<0.01$

To further explore the country differences, a separate χ^2 tests of independence was used to explore the relationship between each IEC and adaptive strategies for each country (see Appendix 2). Note that occupants who had thermostat control were more likely to adopt a technological solution in Italy and Poland. Blinds and windows controls were significant variables of technological solutions in the US. IEC accessibility was also a significant variable in Switzerland when occupants felt too hot, whereas window control was significant in the condition of feeling too cold. More importantly, the number of IEC features an occupant had access to was a significant variable related to adaptive strategies, χ^2 (4, N=2261) = 86.52, $p < .001$, when feeling too hot, and χ^2 (4, N=2,280) = 221.86, $p < .001$, when feeling too cold. Noticeably, there was a positive relationship between the number of IEC features and percentage of employees choosing a technological solution (Fig. 4). This implies that a greater access to IECs can determine a higher level of using technological adaptive strategies that directly influences building energy demand.

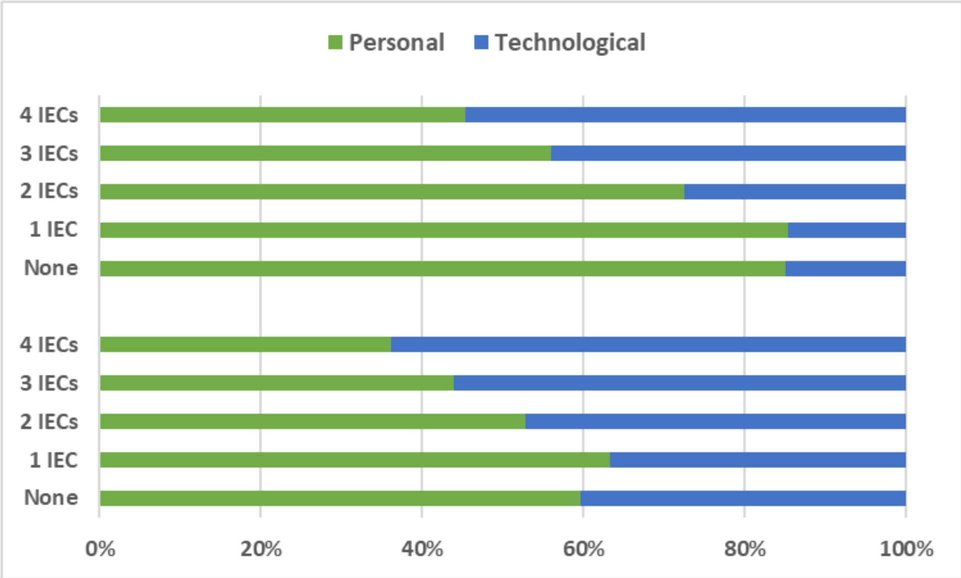

Fig. 4. Number of IEC features (from 0 to 4) and adaptive strategies when occupants were feeling cold (top) and hot (bottom)

4.2.3 Adaptive strategy differences across office type, work position, and level of accessibility to IECs

The results of the χ^2 test of independence were significant between office type and first choice of adaptive strategies when occupants felt too hot, χ^2 (2, N=2,228) = 30.46, p < .01. Specifically, occupants in a private office were more likely to adopt a technological solution (61.3%), whereas occupants in cubicles were more likely to choose a personal adjustment (Fig. 5). Similarly, this relationship was also significant in the case of occupants feeling too cold, χ^2 (2, N=2250) = 67.37, p < .01. In fact, about 85% of occupants in cubicles chose personal adjustment approaches, probably due to the low percentages of them having any control over IECs. Furthermore, results of χ^2 tests of independence between work position and adaptive strategies were significant when occupants felt too hot, χ^2 (3, N=2142) = 47.86, p < .01, and too cold, χ^2 (3, N=2,168) = 111.86, p < .01. Faculty staff were more likely to adopt a technological solution when feeling too hot (66.9%) and too cold (60.9%), whereas about 60% of graduate students were more likely to choose a personal adjustment (Fig. 6).

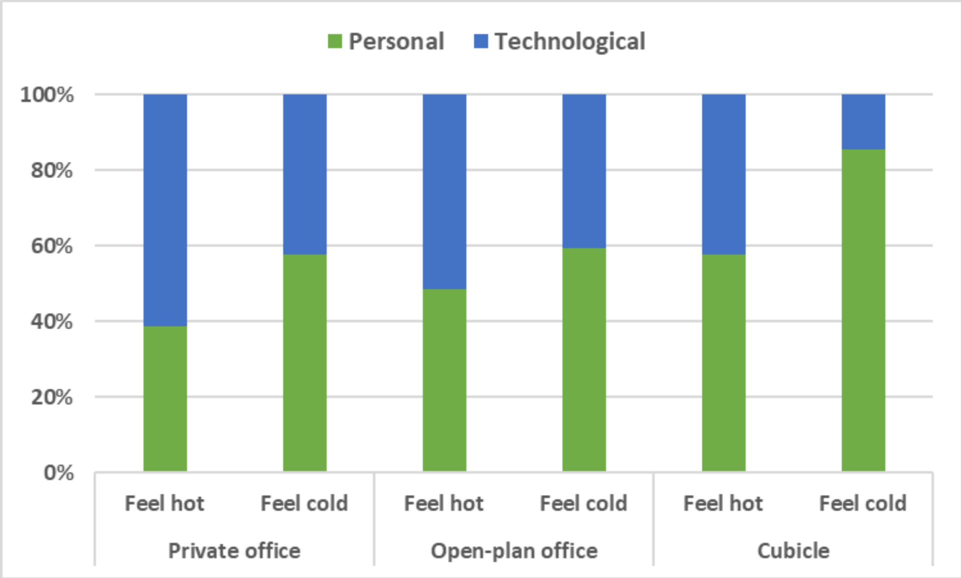

Fig. 5. Adaptive strategies across office types when occupants were feeling hot and cold

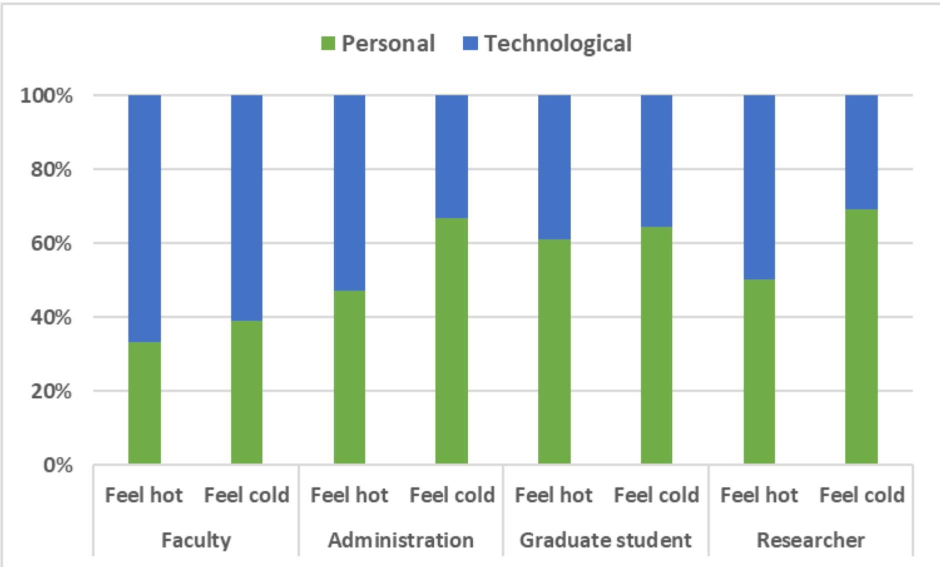

Fig. 6. Adaptive strategies across work positions when occupants were feeling hot and cold

This study further tested the relationship between the level of IEC accessibility and adaptive strategies. Table 3 indicates that the level of sharing IECs with co-workers was significantly related to technological solutions and personal adjustments in both discomfort conditions. As an example, occupants who had sole access (sharing 'only me') to windows or shared with one co-worker were more likely to choose a technological solution. A similar result was observed in the case of blinds, thermostat, and lighting sharing. In contrast, those who shared window operation with more than one co-workers, were more likely to use a personal adaptation, especially when feeling cold (80%). This result suggests that social norms of not disturbing others could play a key role in performing adaptive strategies in shared spaces. Surprisingly, occupancy hours and adaptive strategies were not significantly related.

Table 3. Results of $\chi 2$ test of independence between level of accessibility to IECs and adaptive strategies

		Feeling hot			Feeling cold		
IECs	**Accessibility Level**	**Personal (%)**	**Technological (%)**	χ^2	**Personal (%)**	**Technological (%)**	χ^2
Thermostats	No access	54.0	46.0	85.18***	72.8	27.2	147.31***
	Only me	31.1	68.9		41.6	58.4	
	Sharing with one co-worker	26.8	73.2		41.1	58.9	
	Sharing with more than one co-workers	47.2	52.8		57.8	42.2	
Blinds	No access	56.5	43.5	69.20***	74.6	25.4	83.97***
	Only me	36.1	63.9		52.2	47.8	
	Sharing with one co-worker	33.5	66.5		50.3	49.7	
	Sharing with more than one co-workers	49.1	50.9		59.9	40.1	
Windows	No access	57.0	43.0	105.64***	79.4	20.6	207.46***
	Only me	29.9	70.1		44.2	55.8	
	Sharing with one co-worker	31.7	68.3		45.7	54.3	
	Sharing with more than one co-workers	48.9	51.1		55.3	44.7	
Lighting	No access	58.5	41.5	73.79***	81.3	18.7	91.70***
	Only me	35.7	64.3		54.0	46	
	Sharing with one co-worker	34.8	65.2		49.2	50.8	
	Sharing with more than one co-workers	53.0	47.0		65.6	34.4	

* $p< .05$, ** $p <.01$, *** $p<.001$

4.3 Energy saving intentions and adaptive strategies

To better understand energy-saving intentions and adaptive strategies, this study further conducted descriptive analyses on the reasons for performing adaptive strategies, and found substantial percentages of occupants, 60.2% of all participants and 47.2% of those with some accessibility to IECs, reported that they operated IECs to save energy. For example, occupants reported that they closed windows to save energy and get warmer, instead of raising thermostat temperatures settings in winter. Therefore, we further conducted a χ^2 test of independence to explore the connection between preferred adaptive strategies and energy-saving intention, that is, whether energy saving was mentioned as an important reason for operating any of the IECs. Note that adjusting lighting was not provided as one of the main adaptive strategies because it is less directly linked to thermal discomforts.

Table 4 shows that adaptive strategies differed significantly between occupants who reported energy-saving intentions and those who did not, in both conditions of feeling too hot, χ^2 (2, N=2158) = 35.79, p < .01, and feeling too cold, χ^2(2, N=2172) = 21.01, p < .01. Occupants who reported energy-saving intentions as a reason for operating IECs had a higher portion of choosing closing/opening windows/shades as their adaptive strategies when feeling too hot (29.2%) and when feeling too cold (22.4%) than those who reported no energy-saving intentions (20.4% too hot and 14.49% too cold). On the other hand, occupants who reported energy-saving intentions for technological solutions had a lower portion of choosing thermostat adjustments or adding a portable appliance (23.8% for too hot and 18.6% for too cold) as adaptive strategies than those who reported no energy-saving intentions (33.7% for too hot and 22.3% for too cold). These results indicate that occupants' energy-saving intention could change through interactions with IECs.

Table 4. Results of adaptive strategies with and without energy-saving intentions

		Adaptive strategies			
		Personal adjustment	Technological solution		
Indoor Condition	Energy-saving intentions	Have a drink, adjust clothing, walk to another space	Windows/Blinds	Thermostats/ Portable appliances	Total
Too hot	Without	45.9%	20.4%	33.7%	100%
	With	48.0%	29.2%	23.8%	100%
Too cold	Without	62.8%	14.9%	22.3%	100%
	With	59.1%	22.3%	18.6%	100%

On further analysis of different types of IECs, we found that occupants who reported energy-saving intentions significantly differed from their counterparts in the first choice of adaptive strategies when feeling too cold or too hot, except for thermostat adjustments in dealing with the hot condition (Table 5). In general, people who reported energy-saving intentions, no matter which IECs they had, were more likely to restore thermal comfort through operating windows or blinds, and less likely to adjust thermostats or bring in portable devices, than their counterparts, meaning that occupants with energy-saving intentions perceived technological solutions (e.g., thermostats or portable devices) as not energy-saving friendly equipment.

Table 5. Results of independence test between energy-saving intentions through specific IEC and adaptive strategies

IEC	Feeling hot χ^2	Feeling cold χ^2
Thermostats	2.66	11.94**
Blinds	32.87***	25.30***
Windows	66.94***	52.43***
Lighting	16.14***	10.51**

* p< .05, ** p <.01, ***p<.001

4.4 Clustering analysis

We conducted a cluster analysis to determine if occupants' energy-saving intentions, when adopting adaptive strategies, have certain patterns, and whether these patterns vary across demographics.

4.4.1 Clustering method

Four variables were used for the cluster analysis: WindowSaveBi stands for whether occupants would open or close the windows to save energy; similarly, the variables of BlindSaveBi, ThermSaveBi, and LightSaveBi were coded to indicate whether occupants would open/close the blinds, adjust thermostats, and turn on/off the lights for energy-saving purposes. The clustering variables were referred to as clustering features. A widely used clustering technique, k-means clustering, was used in this study. For a typical working flow of k-means clustering, the first step is to determine the optimal number of clusters, which is an important hyper-parameter for the clustering. There are a couple of semi-empirical criteria that could assist the selection of the number of clusters, including Average Silhouette Score, Within-cluster Sum of Squared Distances (WSSD), and Dendrogram. This study applied the second approach, which is based on comparing WSSD of different numbers of clusters. WSSD measures the sum of the distances between the samples and their cluster centroid. WSSD was defined by the following equation:

$$\mathrm{WSSD(k)} = \sum_{k=1}^{K} \sum_{i \in C_k} \sum_{j=1}^{p} (x_{ij} - \mu_i)^2 \quad (1)$$

where *K* is the number of clusters, C_k is the set of the *k*-th cluster, x_{ij} is the coordinate of *j*-th instance of cluster *i*, and μ_i is the coordinate of cluster centroid of cluster *i*. A smaller WSSD indicates the cluster member is closer to their cluster centroid, signaling a better clustering. As increasing numbers of clusters would naturally result in a smaller WSSD, our goal is to select a small number of clusters that still have a low WSSD, because too many clusters could lead to over-fitting [73]. To achieve this goal, we attempted to identify the "elbow region" to select the optimal number of clusters. The elbow region usually represents diminishing returns with the further increasing of clusters; as shown in Fig. 7, the elbow region was centered around six. Therefore, we selected six as the optimal number of clusters in this study.

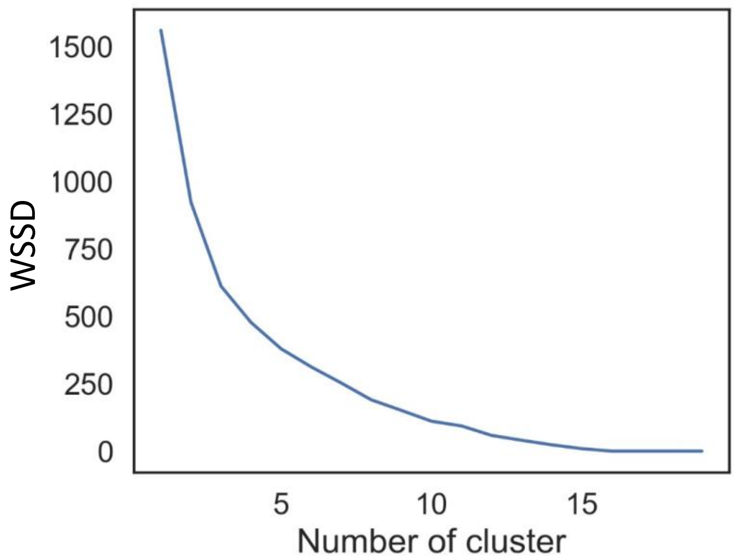

Fig. 7. Within-cluster Sum of Squared Distances (WSSD) of different numbers of clusters

4.4.2 Clustering results on adaptive strategies for energy saving intentions

This study named the six distinct clusters related to energy saving as such: i) no adaptive strategy - do not operate any IEC; ii) lighting – only turn on/off lighting; iii) windows – only open/close windows; iv) blinds & lighting – operate both blinds and lighting; v) windows & lighting – operate both windows and lighting; vi) all – operate all the IECs, for energy-saving purposes. Results show that operating lighting was the most popular strategy for energy-saving purposes (Fig.8; Table 6). Four of the six identified groups would turn on/off lighting to save energy (41.7%). On the contrary, very few occupants would adjust the thermostat for energy-saving purposes (5.9%). It is possible that more than half of the participants did not operate any IEC for energy-saving purposes, or they do not have access to IECs, as indicated in Table 6.

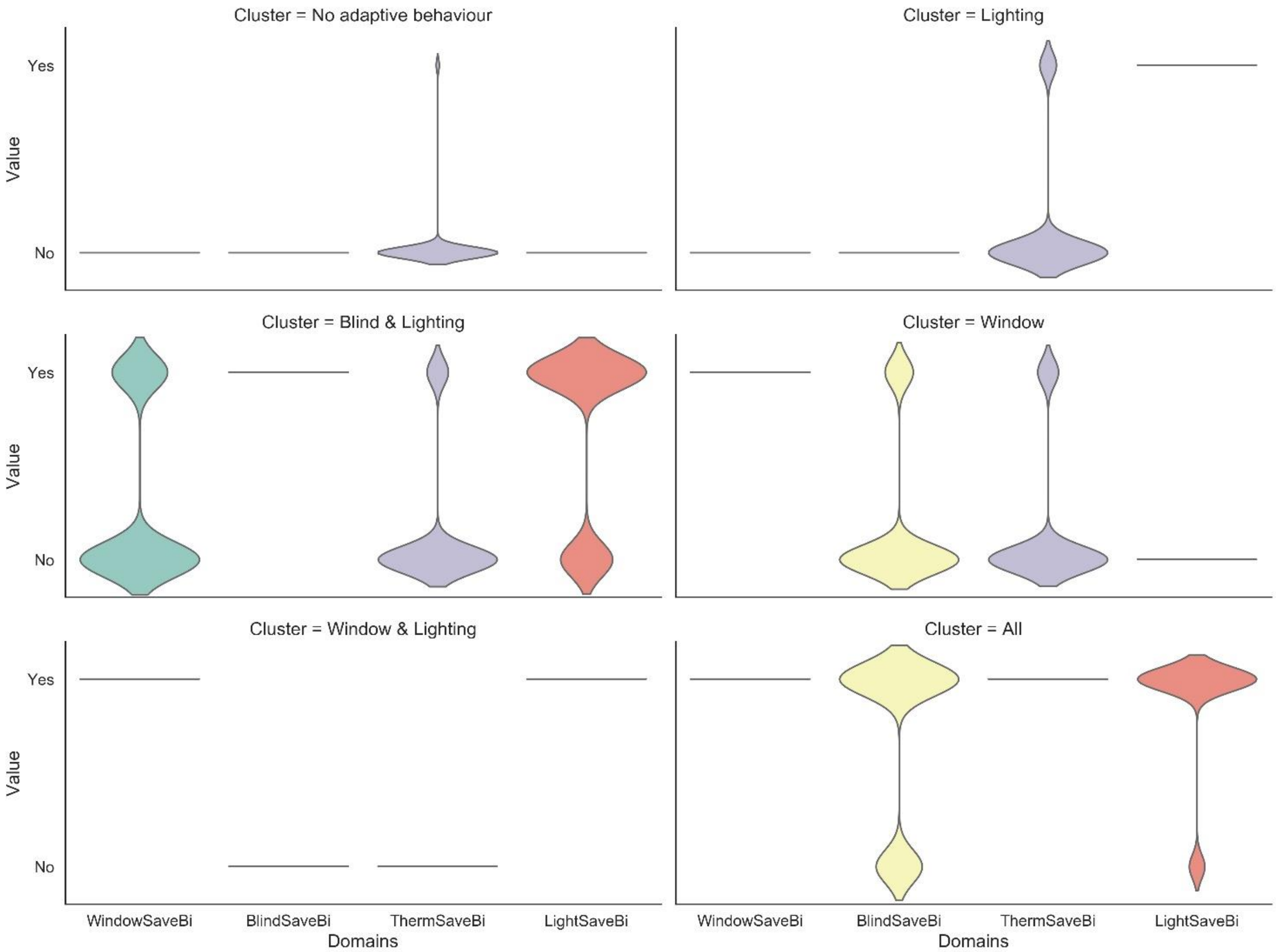

Fig. 8 Result of cluster analysis on preferred adaptive strategies (i.e., operating any of the IECs) for energy-saving purposes

Table 6. Results of cluster analysis on energy-saving intentions and adaptive strategies

Cluster	Characteristics	Percentage (%)
No adaptive strategy	No adaptive strategy for energy saving	50.6
Lighting	Only operate lighting for energy saving (turn off lighting)	23.1
Blinds & Lighting	Operate blinds and lighting for energy saving	8.8
Windows	Only operate windows for energy saving (open or close windows)	7.6
Windows & Lighting	Operate windows and lighting for energy saving	3.9
All adaptive strategies	Operate all IECs for energy saving	5.9

4.4.3 Influence of demographic factors on energy-saving intentions

This section explores how energy-saving intentions may have been influenced by two important demographic factors: country of residence and gender (Fig. 9). In the US, more than 63% of occupants reported they did not operate any IECs for energy saving, which was higher than the other five countries investigated. Importantly, whether occupants would operate the IECs for energy saving was not only determined by occupants' willingness, but also by their access to IECs; for instance, our results show that 27.8% of Brazilian and 17.2% of Chinese employees would open or close the windows to save energy, but only 2.0% of US employees would do so. One possible reason is that window controls in the US are more likely to be automated than in other countries, such as China and Brazil [74]; therefore, the US occupants might not be able to close or open windows whether they want to or not.

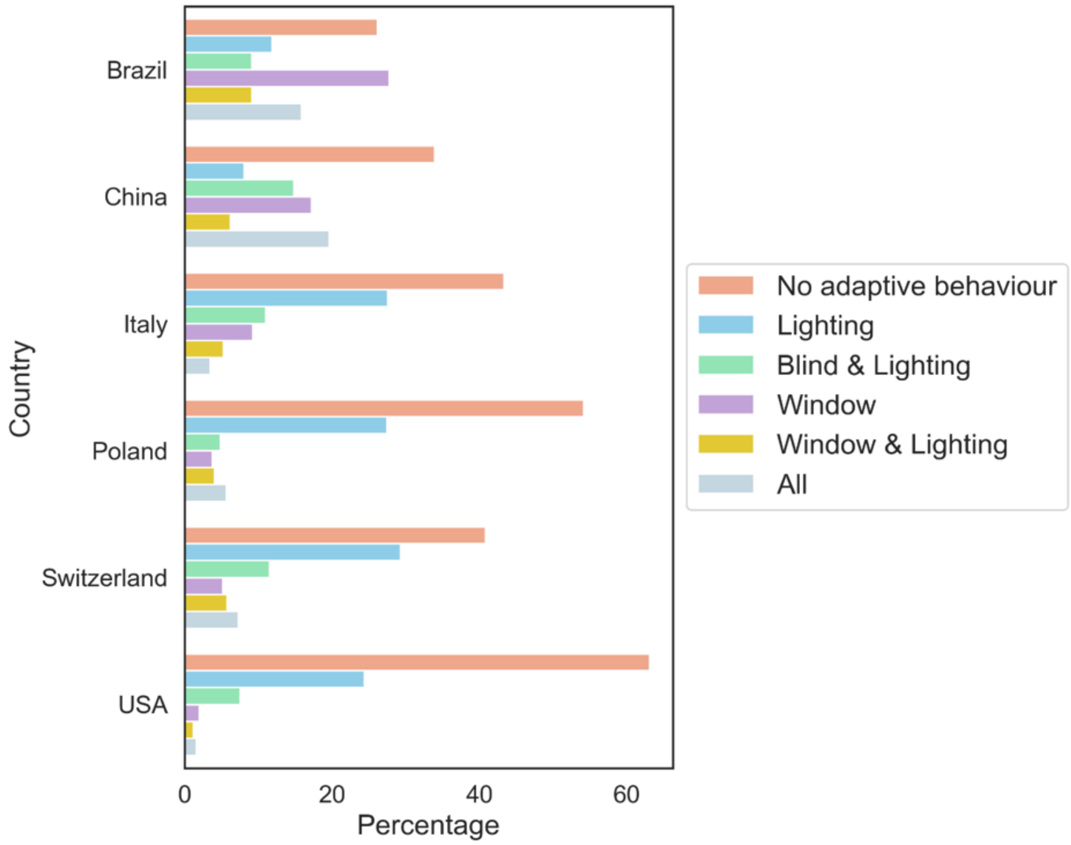

Fig. 9. Results of clustering of adaptive strategies for energy-saving purposes by countries

Among all the countries, 61% of females were slightly more likely to report using the adaptive strategies for energy-saving purposes, compared to 55% of males who reported doing so (Fig. 10). The biggest difference between females and males was in their lighting behaviors: 24% of females were willing to operate lighting to save energy, while only 20% of males were likely to do so. The other four clusters were similar in terms of the percentage of males and females.

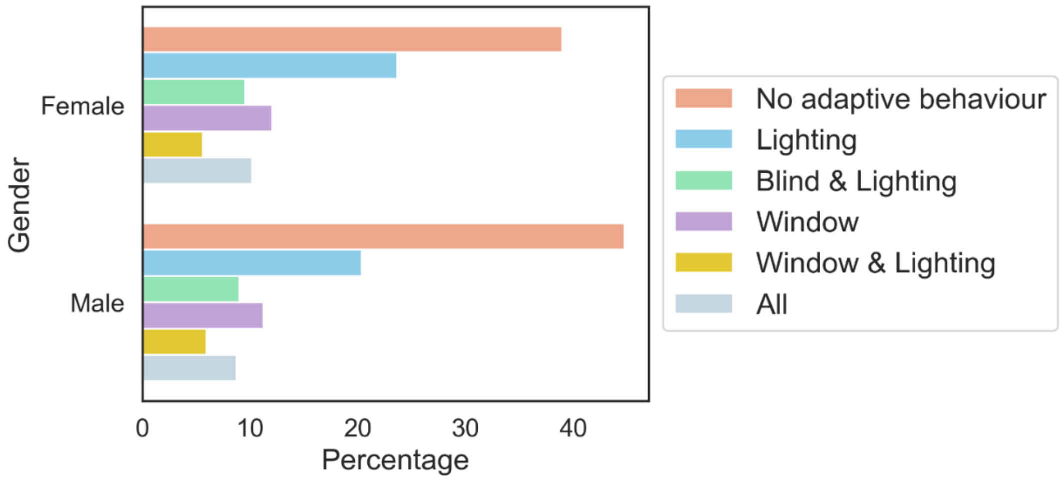

Figure 10 Clustering by different genders

5 Discussion

5.1 Summary of results

This paper investigated the first choice of adaptive strategies to thermal discomfort, a heuristic decision, and energy-saving intentions, as well as analyzed the influence of demographics, building designs, and workplace contextual factors on adaptive strategies. The main findings and implications can be summarized as follows:

(1) Building design influences occupants' adaptive strategies**.** Specifically, we found that occupants who had access to an IEC were more likely to adopt a technological solution to restore thermal comfort than their counterparts. However, occupants preferred to use a personal adjustment through clothing or drinks when they had to share the IECs with more than one co-worker, especially when the indoor environment is too cold. Although little research has carried out specific comparison on 'technological solution versus personal adjustment,' many studies confirm whether and how occupants restore their comforts is influenced by the accessibility of the control features [34], [75], [76]. Similarly, occupants in a private office were more likely to adopt a technological solution, whereas occupants in cubicles preferred a personal adjustment. These findings suggest that occupants prefer to choose quick solutions by using available technologies, and they are more likely to change personal behaviors when they are sharing the space or air-conditioning with co-workers.

(2) Hierarchical workplace positions affect what adaptive strategies an individual take. Faculty members were significantly more likely to adopt a technological solution when feeling hot and cold; however, graduate students were more likely to choose personal strategies, which might be due to the fact that graduate students generally do not have their own office and tend to share IECs with others. Our finding is aligned with previous studies emphasizing that people prefer more personal adjustments when they are sharing IECs with colleagues due to the influence of group norms [9].

(3) Office employees in different countries have different first choice adaptive strategies to deal with thermal discomforts. Our study found that Brazilian, Italian, and Polish employees preferred a technological solution, whereas Chinese, Swiss, and US employees preferred personal solutions when feeling too hot. When feeling too cold, on the other hand, the differences were minor, and only Polish employees preferred technological solutions. These differences could be a result of cultural or climate influences; future research would benefit from investigating these factors further. These findings were in line with the work of Wang et al [54], which also found that country and climate zone are one of the most important factors influencing thermal behavior worldwide.

(4) Employee's preferred adaptive strategies against thermal discomfort are influenced by energy-saving intentions. Occupants who showed some level of energy-saving intentions are more likely to operate windows and shades as their first choice adaptive strategy, whereas occupants that reported no energy-saving intentions had a higher chance of selecting thermostat adjustments or adding a portable appliance. This tendency is consistent across all IECs for occupants with energy-saving intentions. This finding suggests that occupants with no energy-saving intentions tend to use technological solutions when dealing with thermal discomforts.

(5) Based on cluster analysis, the majority of occupants would turn on/off lighting to save energy. On the contrary, very few occupants would adjust the thermostat for energy saving purposes. More than half of the participants did not take any strategies for energy saving purposes. The USoccupants are more likely not to take any actions for energy saving purposes than occupants from

other countries. This result could be attributed to the fact that the limited accessibility to the IECs (e.g., windows were not operable) for occupants in the US. Regarding gender, females were slightly more likely to use adaptive strategies for energy saving purposes, especially in regards to lighting operation.

5.2 Recommendations

This research provides several insights and recommendations. In particular, occupants' adaptive strategies can be addressed to promote energy efficient strategies of dealing with thermal discomfort. We have provided several recommendations:

First, office layout and number of occupants in shared spaces constitute significant design parameters that influence occupants' choice of a personal adjustment or a technological solution to thermal discomfort. Building designers should recognize that personal adjustment of adaptive strategies was used more often than technological solutions in shared spaces with more occupants, especially when many occupants shared control over IECs. Further, the number of IECs and the number of employees who chose technological solutions are positively related. Therefore, office design should consider office types, number of occupants, access to IECs, and geographical differences when implementing thermal comfort adaptive strategies. This result suggests that communication among employees a key factor in organizing common strategies for thermal discomfort adaption and energy-saving behavior.

Second, it is important for building designers or policymakers to identify if occupants' preferred first choice of adaptive strategies is based on personal thermal needs, energy conservation needs, or both. These motivations could be tailored into energy saving guidelines to make them more feasible and personalized because personalized energy-saving methods and campaigns can increase energy-saving behaviors [77], [78]. Additionally, workplaces should promote awareness of energy-saving behaviors at work through information campaigns, discussion boards, and/or trainings to align employee thermal discomfort adaptive behaviors with energy-saving intentions.

Third, the design of IECs needs to consider occupants' energy-saving intentions. We found that energy-saving intentions were mainly impacted by limited accessibility to the IECs due to automated building design (e.g., motorized and uncontrolled windows and blinds). As a result, access to IECs, both in terms of available controls and number of people sharing controls, influences occupants' first choice, heuristic decision to deal with thermal discomforts when a technological solution is not possible. This situation especially holds in a shared office where social norms can further restrict access to IECs. Therefore, decision-makers should consider a good balance between restricted operation modes of building interfaces and systems that facilitate energy previsions and management, and accessible control features that allow greater adaptability of the indoor environment to the occupants' comfort preferences and needs, and enable energy-saving intentions. Specifically, energy-saving intentions can be promoted by using operable windows and shades to adjust personal comforts, instead of using thermostats. Finally, accessible lighting switching is important to consider as a control feature that occupants are more likely to use for energy-saving purposes.

Fourth, building design needs to recognize the drawbacks of using individualized control solutions that might increase energy consumption. There are two approaches to the solutions: social and technological. For the social aspect, the use of eco-feedback, including the amount of energy used and its environmental impact and normative information (e.g., what temperature settings other occupants are using, or recommended temperature settings) could be effective for occupants [79]. Eco-feedback with normative information has been proven effective in influencing occupants to use less energy in multiple studies. At the same time, organizational support or a norm of energy saving allows employees to feel at ease in communicating with co-workers about energy saving [80], [81]. Second, on the technological side, using occupancy sensors can help reduce energy waste; for example, turning off personal fans, heaters, monitors or other devices if occupants are absent. Additionally, the control system needs to process the input of different area zones to learn individual preferences, and tune temperature settings in a way that improves occupant comfort while striving to save energy.

5.3 Limitations

Several limitations of this research need to be addressed. *First*, even though the sample size is large and diverse, it is not representative of the office population of each country, and our results might not be generalizable to other commercial office spaces. Future researchers could try to tackle this challenging issue by developing a survey sampling strategy that can represent the population of office buildings in different countries. *Second*, this study adopts a cross-sectional survey design focusing on self-reported occupant behaviors without insights from non-self-report measures (including actual building features, architecture, and design information). Self-reports on subjective perceptions and attitudes, however, have been repeatedly proven as valid and important measures, and can help to correlate normative values with other group behaviors at work [37], [82]. Future researchers could investigate the impacts of building physical factors in a more controlled environment, such as experimental studies. *Third*, the majority of our data were collected across different seasons and climates. As mentioned in the Methods Section, we adopted the approaches to ask participants the reasons for operating IECs across four seasons. Further, we measured adaptive thermal actions as a response to situations when occupants *typically* feel too hot or too cold at work, rather than to the current thermal situations, regardless of outdoor temperatures or seasons**.** Our regression model also considered the country of residence as control variables so that the climate was controlled for. Yet, future studies should gather more samples from a wider location across countries with similar or different climates to validate our results and compare the effects of climates, seasons, and other relevant aspects. In sum, future studies can expand the survey to cover more populations, building types, and climate zones, as well as conduct measurements of indoor environment and occupants' interactions with building components, devices, and systems to compare the survey results and to understand their consistency and differences.

6 Conclusion

This study investigates occupants preferred adaptive strategies, including technological solutions and personal adjustments, to deal with thermal discomfort in office spaces. This study is novel in identifying the link between the first choice of adaptive strategies, which indicates heuristic decision-making, and occupants' energy-saving intentions. Without processing information too much, occupants' first choice of adaptive strategies can significantly influence building energy consumption. Our findings highlight new insights that can inform building designers in planning a more user- and energy-friendly indoor environment for office occupants in various physical building environments and workplace contexts. While more new or retrofitted buildings have implemented centralized and automatic technological solutions, our study encourages researchers to continue to explore the interconnected factors between physical building factors, including accessibility to indoor environmental controls, level of accessibility, office type, social factors such as group norms (social rewards or punishment), and demographics factors. Providing a flexible building design that motivates and enables users to choose energy-saving adaptive strategies to mitigate thermal discomfort issues remains an essential research topic. A flexible design refers to the flexibility in the building design that facilitates diverse types of occupant behaviors to ensure their comfort, and satisfactions while considering energy consumption. Individualized thermal comfort devices is an example of flexible design. Existing studies found certain individualized thermal devices can enhance occupant comfort and relax the comfort temperature range, which might help reduce energy consumption. Further studies, however, are needed to evaluate various approaches to motivating occupants to save energy, including providing informative feedback, peer competition, rewards or recognition, and behavioral education or training [83] in order to reduce energy usage. As mentioned earlier, allowing the control system to learn from the temperature settings provided by individual preferences, develop better algorithms, and improve automatic or default settings, so that occupants do not need to tweak those settings each time, and therefore lower the possibility of using more energy. In sum, this research highlights the important relationship between adaptive strategies and energy-saving intentions related to building design, workplace contextual factors, and demographics, and gives recommendations to building designers, engineers, and managers to develop potential adaptive strategies that integrate energy-saving behaviors.

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Annexes

7.1 Appendix 1

A representation of the distribution of office types is presented in Fig. ***11***.

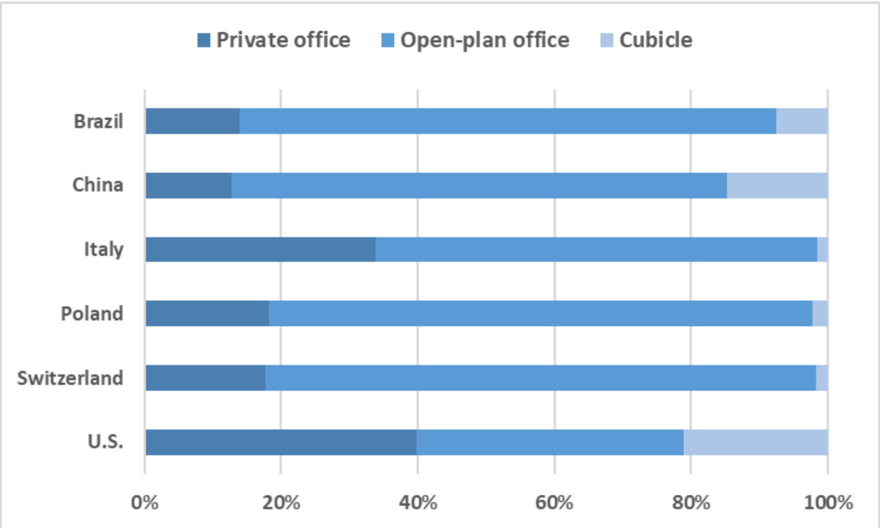

Fig. 11. Percentages of office types by country

7.2 Appendix 2

Table 7 shows the results of the chi-square tests of independence between IECs and adaptive strategies in each country.

Table 7. Results of chi-square tests of independence between IECs control and adaptive strategies in each country. * p< 0.05, ** p <0.01, ***p<0.01

		Brazil					
		feeling hot			**feeling cold**		
IEC	Having control	Personal (%)	Technological (%)	χ^2	Personal (%)	Technological (%)	χ^2
Thermostats	yes	41.5	58.5	0.84	59.0	41.0	0.09
	no	50.0	50.0		61.8	38.2	
Blinds	yes	40.3	59.7	0.44	60.7	39.3	0.59
	no	46.7	53.3		53.3	46.7	
Windows	yes	42.3	57.7	0.08	58.2	41.8	1.35
	no	38.9	61.1		72.2	27.8	
Lighting	yes	40.5	59.5	2.23	58.1	41.9	3.58
	no	61.5	38.5		84.6	15.4	
		China					
		feeling hot			**feeling cold**		
IEC	Having control	Personal (%)	Technological (%)	χ^2	Personal (%)	Technological (%)	χ^2
Thermostats	yes	49.7	50.3	0.29	61.7	38.3	0.15
	no	55.2	44.8		65.5	34.5	
Blinds	yes	44.7	55.3	*8.14***	61.7	38.3	0.52
	no	77.3	22.7		69.6	30.4	
Windows	yes	46.2	53.8	*4.39**	60.0	40.0	1.99
	no	69.6	30.4		75.0	25.0	
Lighting	yes	50.9	49.1	0.30	64.6	35.4	3.61
	no	43.8	56.3		41.2	58.8	
		Italy					
		feeling hot			**feeling cold**		
IEC	Having control	Personal (%)	Technological (%)	χ^2	Personal (%)	Technological (%)	χ^2
Thermostats	yes	30.7	69.3	*5.90**	41.3	58.7	*6.77***
	no	43.5	56.5		55.4	44.6	
Blinds	yes	36.9	63.1	0.61	47.1	52.9	1.61
	no	41.2	58.8		54.2	45.8	
Windows	yes	36.2	63.8	*8.50***	47.7	52.3	*5.59**
	no	60.0	40.0		67.5	32.5	
Lighting	yes	37.9	62.1	2.97	50.1	49.9	0.07
	no	61.5	38.5		53.8	46.2	

		Poland					
		feeling hot			**feeling cold**		
IEC	Having control	Personal (%)	Technological (%)	χ^2	Personal (%)	Technological (%)	χ^2
Thermostats	yes	29.0	71.0	3.17	19.4	80.6	*11.52***
	no	39.7	60.3		37.8	62.2	
Blinds	yes	30.6	69.4	1.16	23.5	76.5	2.06
	no	38.6	61.4		33.3	66.7	
Windows	yes	29.3	70.7	*6.04**	22.9	77.1	2.56
	no	46.3	53.7		32.8	67.2	
Lighting	yes	31.8	68.2	1.66	24.40	75.60	*9.08***
	no	66.7	33.3		100.00	0.00	
		Switzerland					
		feeling hot			**feeling cold**		
IEC	Having control	Personal (%)	Technological (%)	χ^2	Personal (%)	Technological (%)	χ^2
Thermostats	yes	44.0	56.0	*10.14***	59.1	40.9	0.47
	no	69.4	30.6		64.4	35.6	
Blinds	yes	53.4	46.6	*5.43**	57.2	42.8	3.78
	no	75.0	25.0		75.0	25.0	
Windows	yes	52.9	47.1	*4.25**	55.6	44.4	*7.65***
	no	70.0	30.0		78.0	22.0	
Lighting	yes	54.9	45.1	*7.10***	60.7	39.3	0.34
	no	100.0	0.0		70.0	30.0	
		US					
		feeling hot			**feeling cold**		
IEC	Having control	Personal (%)	Technological (%)	χ^2	Personal (%)	Technological (%)	χ^2
Thermostats	yes	45.9	54.1	*11.21***	68.5	31.5	*40.14****
	no	57.9	42.1		86.4	13.6	
Blinds	yes	50.0	50.0	*9.16***	76.8	23.2	*14.48****
	no	60.0	40.0		86.6	13.4	
Windows	yes	47.9	52.1	*5.53**	72.4	27.6	*17.17****
	no	56.7	43.3		84.5	15.5	
Lighting	yes	54.3	45.7	0.35	80.10	19.90	5.67
	no	57.0	43.0		88.20	11.80	