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ABSTRACT

Indoor environmental quality (IEQ) plays a key role in determining occupants' productivity at work; however, the analyses in the interconnected factors among building physical, attitudinal, social and demographic components in one study are lacking. To link this research gap, this study investigates these interconnected factors' influence on occupants' IEQ-productivity belief, defined as personal subjective evaluation on the linkage between the impacts of five IEQ aspects (the qualities of indoor temperature, air, natural and electric lighting and acoustics) and productivity.

A cross-sectional survey data is collected in university offices from six countries (Brazil, Italy, Poland, Switzerland, Taiwan and the U.S.). Results of multiple linear regression model indicate that IEQ satisfaction is the strongest positive predictor of the IEQ-productivity belief; this relationship is stronger in private offices. Country of residence is the second primary predictor. Several attitudinal-behavioral factors, including thermal comfort, perceived ease of controlling indoor environmental features, attitudes toward sharing controls, and are all positively associated with IEQ-productivity belief. Interestingly, the level of control accessibility to light switches has the strongest impact on as opposed to other controls. On the other hand, group norms and conformity intention were not significant predictors. Regarding demographics, men are more likely to perceive the IEQs has positive impacts on their productivity than women without considering other variables in the regression model; on the contrary, women are more likely to consider all IEQs as having positive impacts on productivity than men, after considering other variables. Our findings provide suggestions in helping prioritize wellness in workplaces.
Keywords: indoor environment quality (IEQ); social-psychological factors; work productivity; building characteristics; office type; building controls

1 Introduction

The majority of people spend more than 85% of their time indoors [1]. The indoor environmental quality (IEQ) of a workplace influences occupants' work productivity, learning performance, and well-being. Inadequate IEQ levels are associated with headaches and difficulty in concentration [2], negative moods [3], decreased work motivation [4], reduced cognitive capacity and poor work performance [3,5–7], perceived discomfort [8], indoor environmental dissatisfaction [5], job dissatisfaction [9], and so on. Typical IEQ measures include aspects of indoor air quality and ventilation, thermal comfort, electric and natural lighting, and noise and acoustics. An indoor environment is considered comfortable when 80% of its occupants are satisfied with environmental settings [10]. The effects of IEQ on work productivity and other aspects of well-being are widely documented; however, very few studies focus on these comprehensive IEQ factors with physical, social-psychological, and cultural perspectives in one study.

Scholars have identified four main interconnected aspects that affect work productivity: personal, social, organizational, and environmental factors [11]. Specific to the factors influencing IEQ, researchers have distinguished three components including physiological, psychological, and physical environmental conditions [12]. Among multiple physical factors, thermal comfort, indoor air quality and ventilation, lighting, noise and acoustics, office layout were the key factors affecting occupants' productivity [11]. Some researchers even consider thermal quality to be one of the most critical factors for occupant satisfaction among all IEQ aspects [6,13–17]. A growing number of researchers, however, have focused on the quality of lighting and acoustics (e.g. [5,18–21]) or combined IEQ aspects on productivity (e.g. [22–27]). The IEQ has become an interconnected, multidisciplinary, and complicated issue as the design of new buildings becomes more sophisticated with multiple office layouts, advanced sensing technologies, and with both centralized and decentralized automation systems. These factors provide occupants individually and collectively with co-workers to adjust indoor environment, however, satisfaction toward these adjustments requires further investigation.

Many aspects of IEQ perception or satisfaction are indeed an outcome of personal health, mood, and environmental factors [28]. One aspect of IEQs may affect the way occupants respond to other aspects [14]. Satisfaction with one physical parameter of IEQ is strongly dependent on satisfaction with all other IEQ indicators; therefore, it is important to consider all IEQ factors holistically [29]. For example, noise annoyance, poor lighting, and thermal discomfort, individually and in combination significantly reduce occupants' mood [30,31]. More importantly, the cause-effect relationship could be intertwined. While the IEQ is generally assumed to directly influence occupants' productivity and occupants' motivation, expectation or attitude could influence IEQ satisfaction, thus indirectly influencing occupants' productivity. The term "behavioral environment" has been proposed by some researchers who emphasize both behavioral and social factors (e.g., privacy, collaboration, distractions) in analyses of occupant comfort and other IEQ aspects [32–36]. Yet, the majority of research has focused on the individual effects of a single or limited aspect of IEQ. Therefore, deeper analyses are needed to examine the synergistic effects of interconnected IEQs on work productivity [37]. More importantly, the factors of demographic difference, social influence, or group dynamics are critical but they are often underestimated or ignored in the IEQ evaluation. Scholars have emphasized that there is a gap in the evidence explaining the connections among occupant factors, IEQ perceptions, and building design [29].

The purpose of this study, therefore, is to fill this gap by investigating the interconnected factors influencing occupants' belief of IEQ on work productivity, considering both physical components of the built environment and occupants' psychological, social and demographic factors. This paper therefore first addresses two fundamental groups of factors influencing occupant' IEQ belief – office layout and indoor environmental controls (IECs, the accessibility to the controls of lighting, thermostat, window, and blind), then we propose a multi-dimensional framework including (1) building and workplace characteristics, (2) attitudinal and behavioral factors, and (3) social or institutional factors, to study the link between IEQ-productivity belief from occupants' perspectives. By "IEQ-productivity belief," we mean occupants' subjective attitudes and evolutions on the direct impacts of the qualities of indoor temperature, indoor air, electric and natural lighting, and acoustics on occupants' work productivity. To the best of the authors' knowledge, this work brings innovation by proposing the aforementioned multi-dimensional framework based on theories, which was also grounded on empirical findings. Aside from evaluating individual lenses, this piece recognizes the importance of considering social or group-level factors to achieve productive offices, without excluding the influence of physical factors as building characteristics on this role.

2 Literature review

2.1 Impacts of office layout on IEQ

There is an increasing trend of designing open-plan offices worldwide with fewer walls, doors, and other spatial boundaries to improve employees' collaboration and interaction and to save energy, money, and space [11,38]. Satisfaction with office layout has played the largest effect on occupants' comfort satisfaction after accounting for other IEQ and personal control factors [8]. As for the leading factors influencing the indoor environment, are office layout design, such as open-plan or enclosed offices, influences occupants' perceptions, thermal comfort, IEQ satisfaction, productivity, and organizational well-being [11,22,39,40]. One school of thought argues that removing or creating "unbounded" offices can stimulate social interaction and collaboration [41]. On the other hand, another school of thought insists that a lack of spatial boundaries can decrease social interaction and collective intelligence due to potential overload, distraction, bias, and other symptoms [42,43]. One recent study found the volume of face-to-face interaction indeed decreased significantly (approx. 70%) in open offices, with an associated increase in electronic interaction [44].

Scholars have emphasized that there are disadvantages to open-plan offices when office design is inadequate, including increased cognitive workload [45], distraction [5,46], concentration problems and fatigue [47,48], decreased job satisfaction [49], window proximity [11], and so on. Other factors, such as improper thermal conditions and poor air quality, have been reported to influence discomfort in open-plan offices [48,50]. The literature supports that occupants' thermal comfort is higher in office spaces with fewer desks than in open spaces or environments with multiple desks [51].

One of the most commonly mentioned causes for these dissatisfactions is poor acoustic conditions, that is, the disturbance caused by noise and the lack of speech privacy [5,47,52]. The level of dissatisfaction with noise and lack of privacy increases with the size of the open-plan offices [11] and type of work activities [47]. Additionally, satisfaction with privacy in open-plan offices directly influences occupants' satisfaction with other IEQ factors, such as ventilation and lighting [49]. Overall, open-plan office occupants who are more satisfied with their environments are also more satisfied with their jobs, suggesting the importance of the physical environment in organizational well-being and effectiveness [49]. Therefore, improvement of the indoor environment can significantly increase environmental satisfaction in open-plan offices [53]. Table 1 lists the studies indicating the reasons for IEQ dissatisfaction in open-plan offices.

Table 1.
Studies addressing reasons of IEQ dissatisfaction in different offices

Reasons	Context	Authors & References
General distraction and overload	Office type and health/productivity	de Croon et al., 2005 [45], Brill & Weidemann, 2001 [46]
	Open-plan office, IEQ/productivity	Varjo et al., 2015 [5]; Kang, Ou & Mak, 2017 [47]
	Open-plan office, acoustic and productivity	Haapakangas et al., 2014 [48]
Air quality	Indoor air and health, performance, behaviour	Wyon, 2004 [2]
	Open-plan office and overall IEQ	Varjo et al., 2015 [5]
	Open-plan office and IEQ/privacy	Veitch et al., 2007 [49]

	Open-plan office and IEQ/health/psychosocial environment	Pejtersen et al., 2006 [50]
Temperature	Open-plan office and IEQ	Varjo et al., 2015 [5]
	Office environment comfort and non-physical parameters	Castaldo et al., 2018 [54]
	Open-plan office and IEQ/ productivity	Varjo et al., 2015 [5]; Kang, Ou & Mak, 2017 [47]
	IEQ and office subjective assessment and occupant satisfaction	Frontczak et al., 2011 [52]
Lighting	Open-plan office and IEQ/privacy	Veitch et al., 2007 [49]
Window proximity	IEQ and productivity	Al Horr et al., 2016 [11]
Lack of privacy	IEQ and productivity	Al Horr et al., 2016 [11]
	Open-plan office and IEQ/privacy	Veitch et al., 2007 [49]
IECs accessibility	IEQ and comfort/health	Sakellaris et al., 2019 [22]
	Office environment comfort and non-physical parameters	Castaldo et al., 2018 [54]
Inflexible use of space	Office type, job satisfaction and group cohesiveness	Lee and Brand, 2005[55],

2.2 Indoor environmental controls

One of the important factors influencing IEQ and productivity in different office types is the accessibility to the IECs. Accessibility to IECs typically measures one's degree of actual control over building systems – for example, whether the thermostat is adjustable or windows and electric lighting systems are operable. The level of accessibility to control is one of the most influential factors for user satisfaction, energy-saving and personal comfort due to its physical and psychological impacts [8,39,56]. Multiple studies report that control accessibility is positively associated with overall IEQ satisfaction [51,57,58], work performance or productivity [22,59–62], perceived comfort [8], and fewer building-related symptoms [22]. Specifically, the presence of operable windows is linked to occupants' perception of control over temperature, ventilation, light, and noise [22]. Additionally, improper lighting conditions can lead to sleep distortions, (winter) depression and loss of concentration [63]. Additionally, combined controlling parameters are strongly related to overall comfort, as well as with perception towards privacy, office layout, and decoration satisfaction [22]. Even the illusion of control could increase occupants' thermal comfort [64]. In contrast, absent or reduced levels of control can lead to discomfort, frustration and decreased job performance [11]. Occupants' awareness of their lack of control could even lead to a "self-fulfilling prophecy" [65], where occupants become less likely to change their comfort conditions [64].

Due to office layout or energy-saving reasons, the majority of occupants have no or low level of IECs [22]. An occupant in a single and private office, however, has more control of the temperature, ventilation, lighting, and noise than occupants in open-plan layouts [53]. Occupants in open workspaces have lower acceptability and tolerability of work environment than occupants in single offices [51]. Lighting control is often impossible in open-plan offices, while it is usually possible to control the illuminance level in the offices with fewer desks [51]. The impacts of natural and electric lighting on occupants' IEQ and their productivity, however, require more research. For example, despite its positive evidence, control accessibility can be also perceived as a negative effect. It may be viewed as an element that disturbs the surrounding environment [66–68], as an extra burden, or as having unwanted performance effects after examining a specific aspect of IEQ [69]. Some of these inconclusive results may be due to limited sample size, study design and measures of IEQs. Therefore, deeper investigation should comprehensively include physical IEQ aspects, building characteristics, and related social environmental factors in one study. Table 2 lists relevant studies indicating the factors influencing IECs.

Table 2.
Studies on the impacts of the level of accessibility to IECs

Outcomes	Context	Authors & References
IEQ satisfaction and comfort	Comfort in office type	Bluyssen, Aries & van Dommelen, 2011 [8]
	IEC and performance	Al Horr et al., 2016 [11]
	lighting control and visual comfort	Sadeghi et al., 2016 [70]
	IEC control and comfort/health	Sakellaris et al., 2019 [22]; Boerstra et al., 2013 [57]

	Office environment comfort and non-physical parameters	Castaldo et al., 2018 [54]
	IEC and occupant satisfaction	Kim & de Dear, 2012 [58]
Work performance or productivity	IEC and performance	Al Horr et al., 2016 [11]
	Lighting control and comfort	Sadeghi et al., 2016 [70]
	IEC control and comfort/health	Sakellaris et al., 2019 [22]
	IEC control and work performance	Boerstra et al., 2014 [59]; Clausen & Wyon, 2008 [60]; Lee & Brand, 2010 [61]
	lighting control and productivity	McCunn, Kim & Feracor, 2018 [62]
Job satisfaction and group cohesiveness	Workspace and performance/comfort	Lee & Brand, 2005 [55]
Building-related symptoms	IEC control and comfort/health	Sakellaris et al., 2019 [22]
Privacy	IEC control and comfort/health	Sakellaris et al., 2019 [22]
Perceived control, adaptive behaviour, group conformity intention	IEC control and cultural differences	Chen et al., 2020 [39]

2.3 The influence of cultural differences on IEQs

Cultural differences, such as differences in habits, attitudes, thermal preferences, motivations, and adaptive behaviors, can influence occupants' perceived IEQ. For example, thermal comfort tolerance is largely climate based, but can also be due to cultural differences, such as clothing type [71], degree of outspokenness or demureness [72,73], and ease of access to thermal controls [74]. The acoustic comfort was also affected by occupants' country of origin [75]. Scholars have reported that European and North American cities had higher indoor temperature while the temperature of Chinese cities was the lowest [71]. The Chinese participants had a higher acceptable percentage in terms of comfort, which was likely due to the habit of clothes worn by the Chinese participants and found to have the highest and widest range. Another study found that Slovenian occupants appeared to be more outspoken for the control of electric lighting, shades, and thermostatic values than the Italian occupants [72]. Daily cultural and environmental attitudes also impact certain aspects of IEQ despite similar thermal conditions [73,76]. While considering thermal comfort indices, researchers should take into account the psychological and socio-cultural processes involved in environmental assessment [73]. Along these lines, a study of eight European countries highlighted that perceived IEQ and occupants' comfort depend on socio-cultural aspects, as well as personal motivations and building characteristics [77]. Therefore, this study includes country difference under the dimension of demographics to study occupant IEQ-productivity belief.

2.4 Purpose of the present study

This study proposes an integrated framework to estimate the influence of building design and workplace contextual factors, attitudinal-behavioral and social influence factors and demographics on occupants' IEQ-productivity belief across six countries. Distinguishing from other studies, this study focuses on the following approaches of: (1) analyzing five aspects of IEQ instead of investigating only a certain aspect of IEQ; (2) focusing on occupant subjective evaluations or judgement on the linkage between the impacts of IEQ and work productivity simultaneously, instead of separating the measure of IEQ from that of work productivity; (3) emphasizing beliefs play a critical role in the production of behavior [78]; and (4) considering social and group factors as well as the interaction between physical building characteristics (e.g., office design, control) and attitudinal-behavioral factors (i.e., measures relating to overall evaluation of an object and behavioral intention) [79,80].

This study asserts that focusing on only one or two aspects of IEQ or separate measures of productivity from the IEQ-belief misses the opportunity to consider occupants' subjective judgment on the positive and negative impacts of the IEQ. Therefore, this study focuses on the IEQ-productivity linkage, rather than using a separate measure of productivity. More importantly, this study emphasizes that IEQ related concepts should be treated as a social or group-level factor rather than an only individual-level factor. For example, an occupant may be satisfied with the indoor environment not because of their persuasions but because of the attitude of other occupants or interaction of co-workers. The effect of country differences on IEQ-productivity belief is also considered because scholars have identified the important link between cultural differences and sharing building IECs and IEQ perceptions (e.g. [39]). In the following section, we first address the theoretical framework that supports our proposed dimensions, followed by the discussion regarding the variables associated with each dimension.

3 Theoretical Framework

Researchers have recently realized that a full understanding of occupant behaviors and the potential for building energy efficiency is only made possible by integrating both the physical and social sciences [80–85]. Increased attention to social-psychological factors related to occupant behavior beyond technological factors could offer valuable insights into IEQ (e.g., [51]). Existing theories, especially Ajzen's theory of planned behavior [86] and Stern and his colleagues' attitude-behavior-context model [87,88], have succeeded in predicting behaviors in specific domains. All models, however, generally show certain limitations in explaining behaviors in disparate domains or conditions. Therefore, combining existing theories is a promising approach to better explain the interconnected relationships between occupant behaviors and IEQ. Before outlining our proposed four dimensions, we first introduce two theories that provide its basis.

3.1 The theory of planned behavior (TPB) and the attitude-behavior-context (ABC) model

The first theory is the TPB, which we use to build the influence of social-psychological factors on occupants' behavior at the workplace. The TPB, a rational decision-making framework, is one of the most robustly developed theories in social psychology that explains how social-psychological factors influence behavioral intention and actual behavior [86]. The TPB argues that an intention is formed by weighing attitudes, subjective norms, and perceived behavioral control (PBC) [86]. An individual will execute a behavior when his or her behavioral intention is strong enough to follow up with a consequent action.

The second theory is the ABC model. The ABC model is used to explore how the factors at both individual/internal and organizational/external levels, as well as their interactions, relate to office occupants' IEQ-productivity belief. The ABC model argues that the relationship between attitude (A) (i.e., internal factors) and behavior (B) depends on the context (C), also known as the external condition. When a behavior is difficult or inconvenient, then an individual's attitude will not necessarily lead to the behavior [88]. In most applications of the ABC model, the C factor is generally a single variable that indicates the difficulty of the behavior to be put in place. Contextual factors can include various influences, such as monetary incentives and costs, physical capabilities and constraints, institutional and legal factors, interpersonal influences (e.g., social norms), and broader dimensions of the social context in some cases [87]. This paper suggests that the ABC model is particularly appropriate for studying occupant IEQ interaction, where influences from both the co-workers and organization are active.

3.2 The proposed four dimensions

Based on existing empirical studies and the TPB and ABC models, we propose four dimensions of understanding the influence of IEQ-belief on productivity (see Fig. 1). The first dimension is called *building characteristics and work-contextual* factors and the variables include office types (open-plan, private, and cubical), level of IECs accessibility: number of people sharing IECs, occupancy hours (hours spent at work), and work position. This paper includes occupancy hours and work position because the type of office task and activity have shown to influence occupants' IEQ [8,47,89–91]. For example, the hierarchical position of employees which is linked to influence, authority and power become critical in estimating IEQ and productivity [89]. Typically, occupants who are not in a leadership position and working in an office surrounding with footsteps, machine noise, or conversation areas have lower IEQ satisfaction.

The second dimension is named *attitudinal-behavioral* factors defined as a set of positive and negative evaluations toward a particular object and action, including IEQ satisfaction, attitudes toward sharing IECs, and perceived ease of control on IECs. The third dimension is *social influence or organizational* factors, including two interactive factors. One factor is the norms of sharing IECs as the indicator of social interactive factors (i.e., others' expectations and approval on individuals' behavior) constraining personal actions. The other factor is occupants' intention to conform to the group norms of sharing IECs. Scholars have demonstrated that group norms are positively related to occupants' conformity to the norms of sharing environmental control features in buildings [39]; here we include both group norms and conformity intention in the studied independent variables. Finally, this paper considers the influence of demographics such as country difference and gender as the fourth dimension. Additionally, designing a multi-dimensional framework can assist decision-makers and building planners in considering all relevant aspects when designing and operating a better-built environment. Based on the literature and theoretical framework, we hypothesize that:

- (H_1) Occupants in the private office are more likely to believe IEQ has positive impacts on their work productivity, than those in other office types.
- (H_2) Higher rank of work position (e.g., faculty) are more likely to believe IEQ has positive impacts on their work productivity, than lower rank of work position (e.g., students).
- (H_3) Occupancy hours are associated with IEQ-productivity belief.
- (H_4) Occupants who have accessibility to the IEQ controls (e.g., thermostats, blinds & shades, light switch, operating windows) are more likely to believe IEQ has positive impacts on their work productivity, than their counterparts.
- (H_5) Occupants who have higher IEQ satisfaction level are more likely to believe IEQ has positive impacts on their work productivity, than those with a lower IEQ satisfaction level.
- (H_6) Occupants who have higher thermal comfort level (i.e., neither hot nor cold) are more likely to believe IEQ has positive impacts on their work productivity, than those with a lower thermal comfort level (i.e. too hot or too cold).
- (H_7) Perceived ease of use IECs are positively related to IEQ-productivity belief.
- (H_8) Attitude towards sharing IECs is positively related to IEQ-productivity belief.
- (H_9) Positive levels of social influence (social norms and conformity intention) are positively related to IEQ-productivity belief.
- (H_{10}) Demographics factors including gender, age and country difference are associated with IEQ-productivity belief.

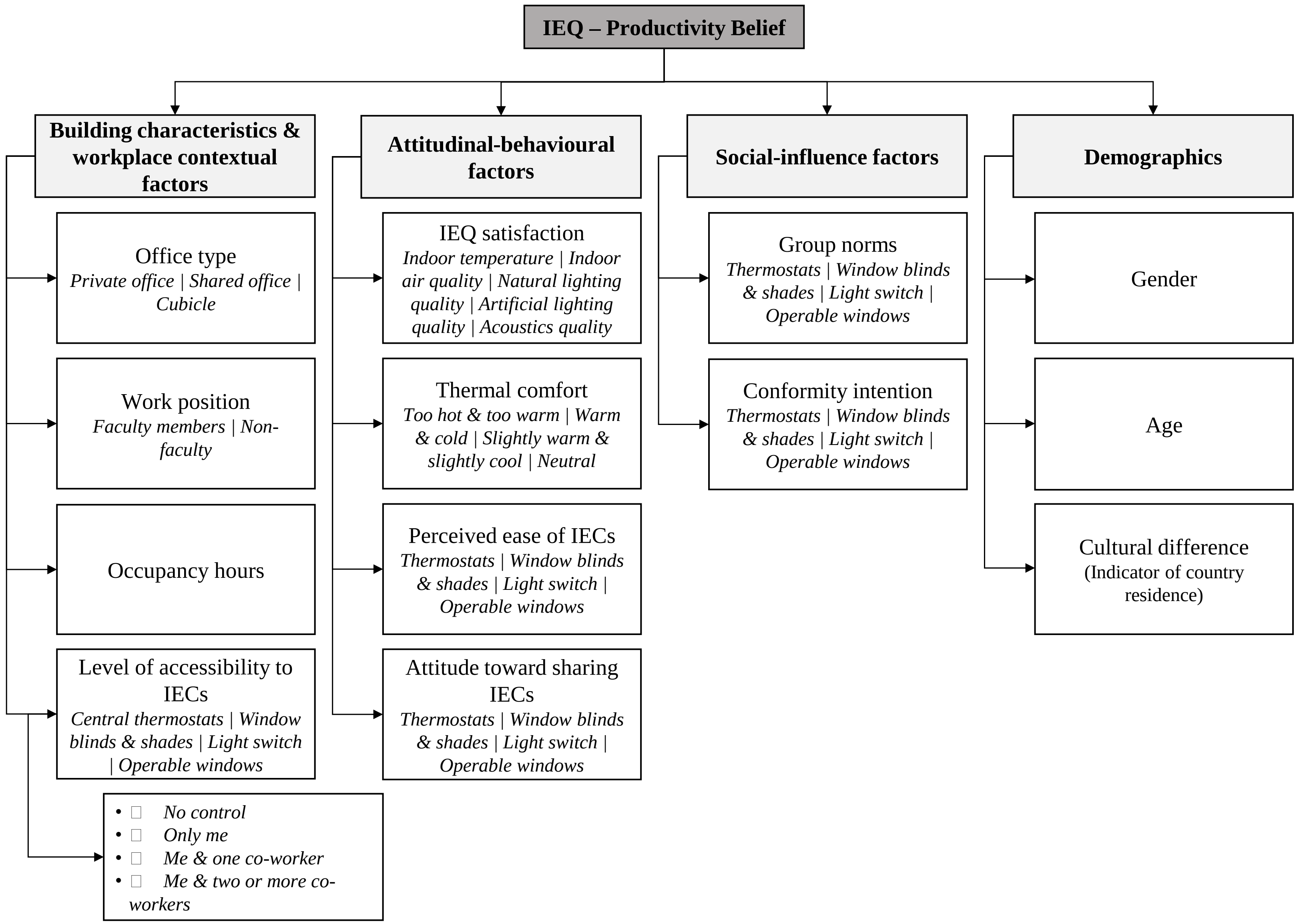


Fig. 1. Illustration of the proposed theoretical framework with four dimensions to study IEQ-productivity beliefs.

4 Method

An internet-based questionnaire was designed with Qualtrics survey software and administered through Qualtrics Paid Panel Service. The participants, age 18 and older, were recruited from the e-mail lists of university staff, faculty, researchers, and graduate students regularly occupying office buildings from six universities and research centers across six countries including Brazil, Italy, Poland, Switzerland, the United States (U.S.), and Taiwan. In this study, the differences in countries and regions encompass all possible differences in climate, culture, and everything else. The final sample size was 2,537 (Brazil = 252, Italy = 399, Poland = 371, Switzerland = 191, the U.S. = 1,044, Taiwan = 280) with 39.4% of males and 61.6% of females. The participants' age ranging from the highest to lowest percentages are: 29-39 years (28.6%); 51-61 years (23.9%), 40-50 years (23.7%), 18-28 years (15.7%), and 62 years old or older (8.2%). The work positions of our sample include: 58.4% of administrators, 17.7% of faculty, 11.8% of researcher, 10.8% of graduate students, and 0.2% of visiting scholars. Ethics protocols and data privacy protection for handling human subject data had been approved in all participating institutions.

4.1 Survey instrument

The survey instrument, originally developed in English, was then 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 was 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 [39]. University mailing lists were used to distribute the survey. An individual survey link for each university was thus created and sent to participants. The survey was anonymous, and no personal identifiers were collected. The structured questionnaire consisted of five parts. The first part asked about thermal comfort, IEQ satisfaction, IEQ-productivity belief, and reasons for IEQ discomfort. The second part asked about indoor environmental control features and the behaviors utilized to exercise these controls in the context of group rooms. The third part of the survey consisted of the measure of conformity intention and social-psychological variables (e.g., attitudes, and group norms) that potentially predict the IEQ-productivity belief. The fourth part of the survey included two questions regarding the first and second actions taken when the participant feels too cold or hot at the workplace (analyzed in another paper, [39]). The final part of the survey contained questions about building characteristics and work contextual factors (e.g., office type, number of people access to IECs: level of IEC accessibility, occupancy hours, work position) and demographic information (e.g., gender, age and country of residence). Fig. 1 shows the variables associated with the proposed four dimensions.

4.2 Measures

All measures except for workplace contextual and demographic variables were estimated by participants' responses to the survey items on a 5-point Likert-type scale. Table 3 presents the descriptive statistics of mean and standard deviation (*SD*) of all major variables.

4.2.1 Dependent variable: IEQ-productivity belief

Occupants' IEQ-productivity belief was measured by the extent to which participants rated the influence of five IEQ aspects on their work productivity positively or negatively. The aspects of IEQ-productivity belief included: (i) indoor temperature, (ii) quality of indoor air, (iii) natural lighting, (iv) electric lighting, and (v) acoustics. (Cronbach's $\alpha = 0.85$).

4.2.2 Independent variables

This section describes the measure for each independent variable based on the proposed four dimensions in the theoretical framework.

4.2.2.1 Building design and workplace contextual factors

This dimension includes building characteristics (e.g., office type and level of accessibility to IECs) and workplace contextual factors (e.g., office occupancy and work position).

Office type was measured by the type of private offices, open-plan offices, and 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.

Level of accessibility to IECs was measured by the number of people sharing each of the controls (i.e., windows, thermostats, light switches, and window blinds or shades). Each feature was estimated with (a) no access to control, (b) only me, (c) sharing control with one other co-worker, and (d) two or more co-workers.

Office occupancy was measured by the hours that occupants stay in the office per week and having participants choose one of the brackets from “1-10 hours” to “more than 50 hours” per week with the 10-hour intervals.

Work position was measured by the status of graduate students, faculty, staff, or researchers. Faculty members including professors and lecturers were dummy coded as 1, whereas non-faculty members including administrators, graduate students, researchers, and visiting scholars were dummy coded as 0. The reason for this grouping between faculty and non-faculty is because the majority of faculty have a private office, whereas non-faculty generally share offices.

4.2.2.2 Attitudinal and behavioral factors

This dimension includes the variables of IEQ satisfaction, thermal comfort, perceived ease of control on IECs, and attitudes toward sharing IECs.

IEQ satisfaction was measured by the extent to which participants perceived the overall satisfaction with five aspects: indoor temperature, quality of indoor air, natural and electric lightings, and acoustics. The five aspects were averaged to become a composite score of IEQ satisfaction (Cronbach's $\alpha = 0.73$).

Thermal comfort: Based on ASHRAE's thermal comfort scale [10], respondents indicated their level of thermal comfort based on a 7-point scale (1 =‘cold’, 2 =‘cool’, 3 = ‘slightly cool’, 4 = ‘neutral’, 5 = ‘slightly warm’, 6 = ‘warm’, 7 = ‘hot’). This study recategorized this variable to a continuous measure indicating the level of comfort from ‘not comfortable at all’ to ‘neutral’, where 1 = ‘too hot and too cold’, 2 = ‘warm and cool’, 3 = ‘slightly cool and warm’, and 4 = ‘neither hot nor cold’.

Perceived ease of control refers to the extent to which participants felt easy or difficult to share IECs and was measured by four statements: “If I want to, I can easily share the control of …” (a) “… thermostat settings”, (b) “… opening/closing the windows”, (c) “…switching electric lighting”, and (d) “… opening/closing blinds or shades” (Cronbach's $\alpha = 0.87$).

Attitude toward sharing IECs: refers to an individual's favorable or unfavorable evaluation of sharing IECs. They were measured by four statements: “Co-workers sharing control of the ...” (a) “… temperature setting”, (b) “… windows opening/closing”, (c) “… electric lighting switching”, and (d) “… blinds or shades opening/closing” “… is very good/bad” (Cronbach's $\alpha = 0.94$).

4.2.2.3 Social influence factors

This dimension includes group norms of sharing IECs and conformity intention to share IECs.

Group norms were considered as perceived expectations from group members to act in a given situation. They were measured by four statements: "The majority of my co-workers expect me to share control over …" (a) "… adjustment of the thermostat setting", (b) "… opening/ closing windows", (c) "…switching electric lighting", and (d) "… opening/closing blinds and shades" "… with them" (Cronbach's $\alpha = 0.95$).

Conformity intention was measured by four separate items based on 5-point scales with the following options: 1 = 'very unlikely', 2 = 'somewhat unlikely', 3 = 'neutral', 4 = 'somewhat likely', and 5 = 'very likely'. The four items were "I am willing to…" (a) "… accept indoor temperature settings", (b) "… open and close windows", (c) "… switch on/off the lights", and (d) "…open/close shades and blinds" "based on the majority of my co-workers' opinions" (Cronbach's $\alpha = 0.89$).

4.2.2.4 Demographics

Gender was dummy coded as 0 (female) and 1 (male). *Age* was measured by having participants choose one of the brackets from "18-28 years" to "62 years old and above" with 11-year intervals. *Country difference* is measured by occupants' country of residence, including Brazil, Italy, Poland, Switzerland, Taiwan, and the U.S. Furthermore, Brazil, Italy, Poland, Switzerland, and Taiwan were dummy coded to compare with the U.S. (the reference group).

5 Results

The following results first present the summary of descriptive statistics of selected variables. Second, a series of analyses of variance (ANOVA) was then conducted to compare the levels of

IEQ-productivity belief across building characteristics, workplace contextual, and demographic factors. Analysis of variance (ANOVA) is a statistical technique that is widely used to compare more than two groups on possible differences in the average (mean) of a quantitative (interval or ratio, continuous) measure [39,92,93]. The result of the ANOVA formula, the F statistic (i.e., *F*-ratio), allows for the analysis of multiple groups of data to determine the variability between samples and within samples. Finally, Ordinary Least Square (OLS) multiple linear regression analysis was conducted to estimate the effect of all the independent variables on IEQ-productivity belief simultaneously. Each predictor's coefficient is interpreted with all other predictors held constant [94–97]. The multiple linear regression model is the commonly used technique to analyze latent variables (such as the variables in our survey) in occupant related survey data [98]. An alpha (α) level of 0.05 was used to determine statistically significant. All analyses were performed using IBM SPSS 25.0.

5.1 Descriptive statistics

This section first presents a summary of descriptive statistics for major variables. Initially, the means and standard deviations of each aspect evaluated are presented according to the appropriate scale. In the next subsections, the responses are presented in a detailed manner, considering specific aspects of the dimensions proposed on this study (e.g. Fig. 4 and Fig. 5 in Section 5.2). As Table 3 indicates, the quality of natural lighting was considered as having the highest positive influence on productivity among the five aspects of IEQ. The number of people sharing the control of light switches was the highest among all the IECs. The majority of participants were more satisfied with the natural lighting in comparison with other aspects of IEQ. Regarding thermal comfort, the majority of participants feel neither too hot nor too cold.

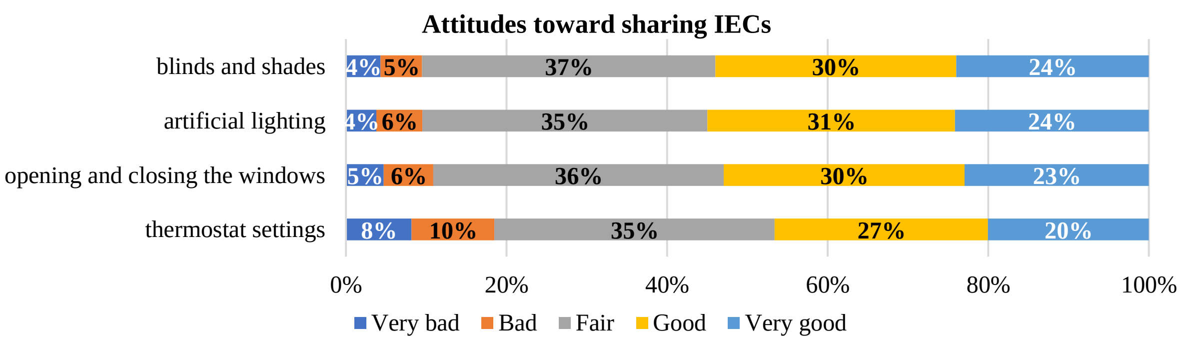
Table 3

Means and standard deviations (SD) of continuously measured variables

Variable name		**Mean**	**SD**
Dependent variable			
IEQ-Productivity belief – I think … influences my productivity at work negatively or positively			
1	indoor temperature	3.08	1.19
2	quality of indoor air	3.20	1.09
3	quality of natural lighting	3.51	1.13
4	quality of electric lighting	3.32	1.05
5	quality of acoustics	3.11	1.14
Independent variables			
Level of control – Number of people sharing the control of			
1	thermostat	1.36	1.29
2	window shades and blinds	1.57	1.26
3	windows	1.21	1.30
4	light switch	2.04	1.10
IEQ Satisfaction – I am satisfied with…			
1	indoor temperature	3.09	1.16
2	quality of indoor air	3.15	1.17
3	quality of natural lighting	3.29	1.36
4	quality of electric lighting	3.37	1.15
5	quality of acoustics	3.00	1.19
Thermal comfort - tell us how you currently feel in your workplace*		3.18	0.84
Perceived ease of control (Ease) – If I want to, I can easily share the control of …			
1	thermostat settings	3.24	1.46
2	opening and closing the windows	3.50	1.39
3	electric lighting	3.76	1.24
4	blinds and shades	3.68	1.30
Attitudes toward sharing IECs – Co-workers sharing control of … in a shared office is very bad – very good			
1	thermostat settings	3.40	1.16
2	opening and closing the windows	3.60	1.05
3	electric lighting	3.66	1.02
4	blinds and shades	3.64	1.04
Conformity intention – I am willing to … based on the majority of my co-workers' opinions			
1	accept indoor temperature settings	3.88	1.11
2	open and close windows	3.85	1.11
3	switch on/off the lights	3.92	1.08
4	open/close shades and blinds	3.85	1.11
Group norms – The majority of my coworkers expect me to share control over the … with them			
1	adjustment of the thermostat settings	3.51	1.16
2	opening and closing of windows	3.51	1.15
3	lighting	3.57	1.13
4	blinds and shades	3.52	1.13

*Note**: All the items except for thermal comfort (4-point Likert scale) were measured based on 5-point Likert-like scales.

Fig. 2 illustrates the percentages of perceived ease of control and attitudes towards sharing IECs. Considering attitudes, at least half of the respondents indicated a positive attitude towards each IEC (30 to 31% good, and 23 to 24% very good), except for thermostat settings (27% good, and 20% very good). Regarding perceived ease of control, at least half of the respondents indicated positive agreement on each IEC (25 to 31% agree, and 25 to 34% strongly agree). As Fig. 3 indicates, approximately half of the respondents indicated a positive agreement for each item of group norms (about 27% agree, and 23 to 25% strongly agree). Considering the conformity intention, two thirds of the respondents stated their willingness to conform to each IECs (34 to 36% somewhat likely, and 33 to 36% very likely).



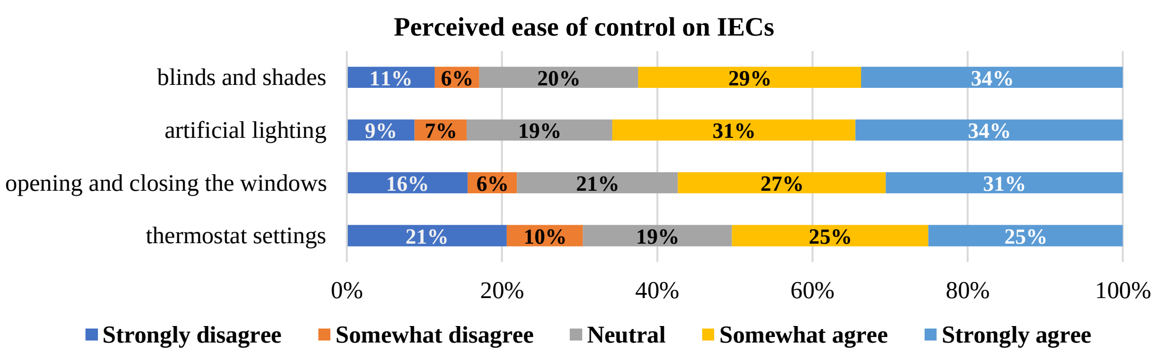


Fig. 2. Percentages of perceived ease of control and attitudes for different IECs.

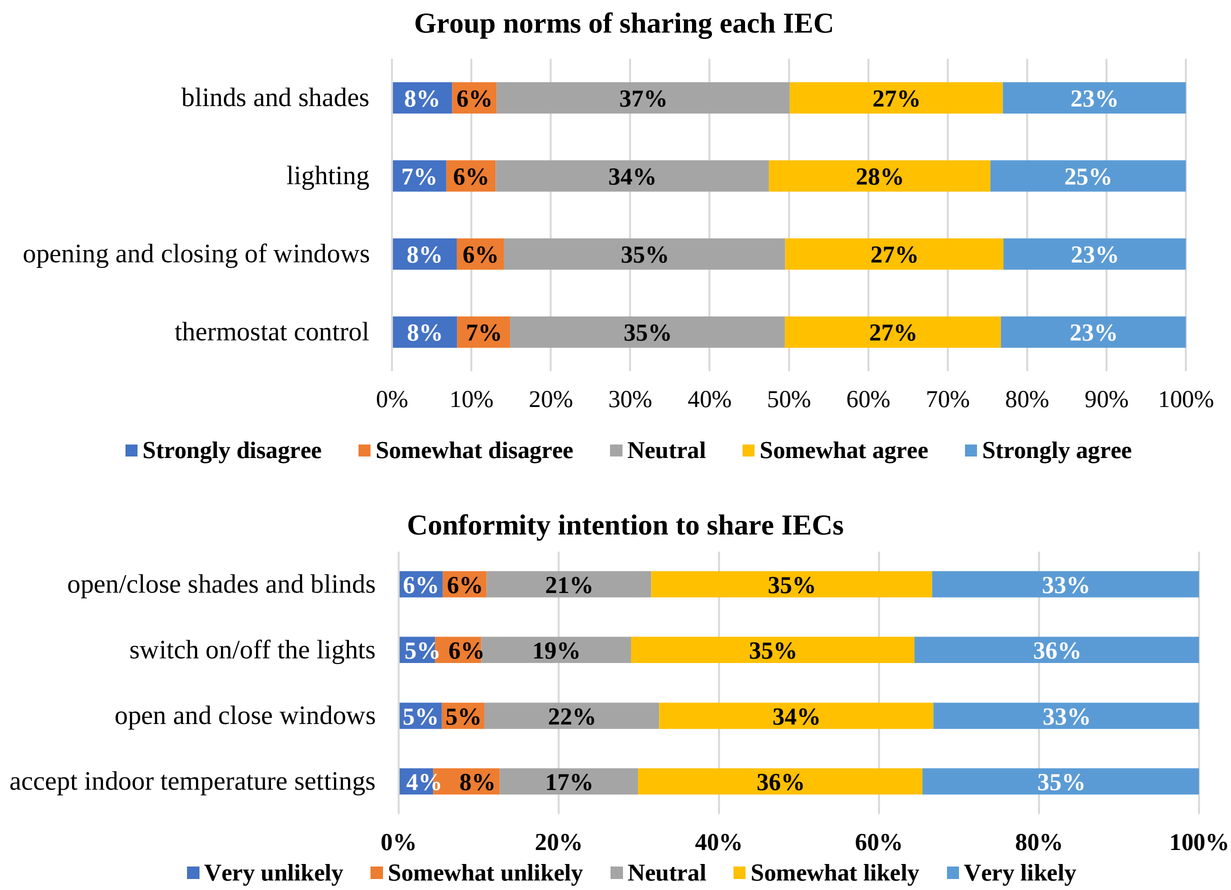


Fig. 3. Percentages of group norms and conformity intention for different IECs.

5.2 Results of analysis of variance (ANOVA)

To test the statistical difference in IEQ-productivity belief across various groups of building characteristics, workplace contextual, and demographic variables, a series of one-way ANOVA tests were further conducted (Table 4). The null hypothesis for ANOVA is that the mean (average value of the IEQ-productivity belief (dependent variable) is the same for all groups (categorical independent variables), while the research hypothesis is that the average is not the same for all groups [92,99]. Whenever the *F* value was significant, indicating that there was at least one group differing from one of the others, Tukey's HSD post-hoc tests were further performed to identify the statistical difference on each pair of group comparison.

Before we run the ANOVA, we ran the Levene's test to test the null hypothesis that the variance is equal across groups (assumption of variance of homogeneity). Results of the Levene's test is provided in Table 8 in Appendix 1. In Table 4, we presented the F statistics of ANOVA if it does not violate assumption of variance of homogeneity, (i.e. $p > 0.05$). If it violates the assumption of variance of homogeneity, (i.e. $p<0.05$), we performed Welch's ANOVA and compared its results with the asymptotic F distribution to determine significance [100].

Table 4 Results of ANOVA analysis on each aspect of IEQ-productivity belief across demographics, building characteristics, and contextual factors.

Each IEQ aspect	**Demographics**			**Office type and workplace contextual factors**		
	Gender	Age	Country difference	Office type	Occupancy hours	Work position
	F	*F*	*F*	*F*	*F*	*F*
Indoor temperature	(1,2368)= 22.354***	(1,2421)= 2.056	1,2521)= 5.994***	(1,2402)= 5.288***	(1,2420)= 1.514	(1,2306)= 2.070
Indoor air quality	(1,2367)= 13.753***	(1,2420)= 2.300**	(1,2520)= 4.115***	(1,2401)= 8.727***	(1,2419)= 1.779	(1,2305)= 0.861
Natural lighting	(1,2367)= 3.080*	(1,2420)= 1.294	(1,2521)= 2.312**	(1,2401)= 9.943***	(1,2419)= 1.021	(1,2306)= 1.191
Electric lighting	(1,2366)= 12.383***	(1,2419)= 3.056***	(1,2521)= 6.993***	(1,2400)= 1.251	(1,2418)= 0.257	(1,2305)= 2.646**
Acoustics	(1,2363)= 8.631***	(1,2416)= 1.828	(1,2517)= 20.109***	(1,2398)= 3.772**	(1,2415)= 1.204	(1,2303)= 4.460***
	Level of control accessibility					
	Thermostat	Window shades/blinds	Light switch	Operable windows		
	F	*F*	*F*	*F*		
Indoor temperature	(1,2411)= 1.406	(1,2338)= 1.184	(1,2303)= 8.930***	(1,2371)= 0.679		
Indoor air quality	(1,2410)= 2.733**	(1,2337)= 4.417***	(1,2303)= 2.983**	(1,2370)= 2.697**		
Natural lighting	(1,2411)= 14.193***	(1,2333)= 23.296***	(1,2301)= 5.936***	(1,2369)= 3.810***		
Electric lighting	(1,2410)= 1.459	(1,2336)= 1.158	(1,2302)= 3.587**	(1,2369)= 0.643		
Acoustics						

	(1,2406)= 1.829	(1,2333)= 0.474	(1,2297)= 2.405	(1,2367)= 0.568

Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5.2.1 Demographic difference in IEQ-productivity belief

The results of the ANOVA test show that there was a significant difference between gender on occupants' belief in the influence of five IEQ aspects on productivity (Table 4). Overall, IEQ-productivity belief was more positive for men than for women (see Fig. 4). Further, the post-hoc tests indicated men were likely to view indoor temperature had a more positive impact on their productivity than women. Similarly, men perceived that qualities of indoor air, natural and electric lightings, and acoustics influenced their productivity more positively than women (Fig. 4). Age, on the other hand, had a significant effect on only air quality and electric lighting. Occupants who were 62 years or older stated that indoor air quality influenced their productivity more positively in comparison with other age groups.

In terms of other demographics, country of residence had a significant difference in the influence of all IEQ aspects on productivity. The post-hoc tests show that occupants from Taiwan stated the highest positive belief in the impact of natural and electric lighting qualities on their productivity. The U.S. occupants stated the highest positive belief in the influence of natural lighting quality and acoustics quality on their productivity. However, the belief in acoustic quality impacting on productivity in Brazil was the lowest compared to other countries. These country differences in IEQ-productivity belief might be due to their building characteristics and workplace contextual factors. Therefore, we further examined the differences in the IEQ-productivity belief across these factors.

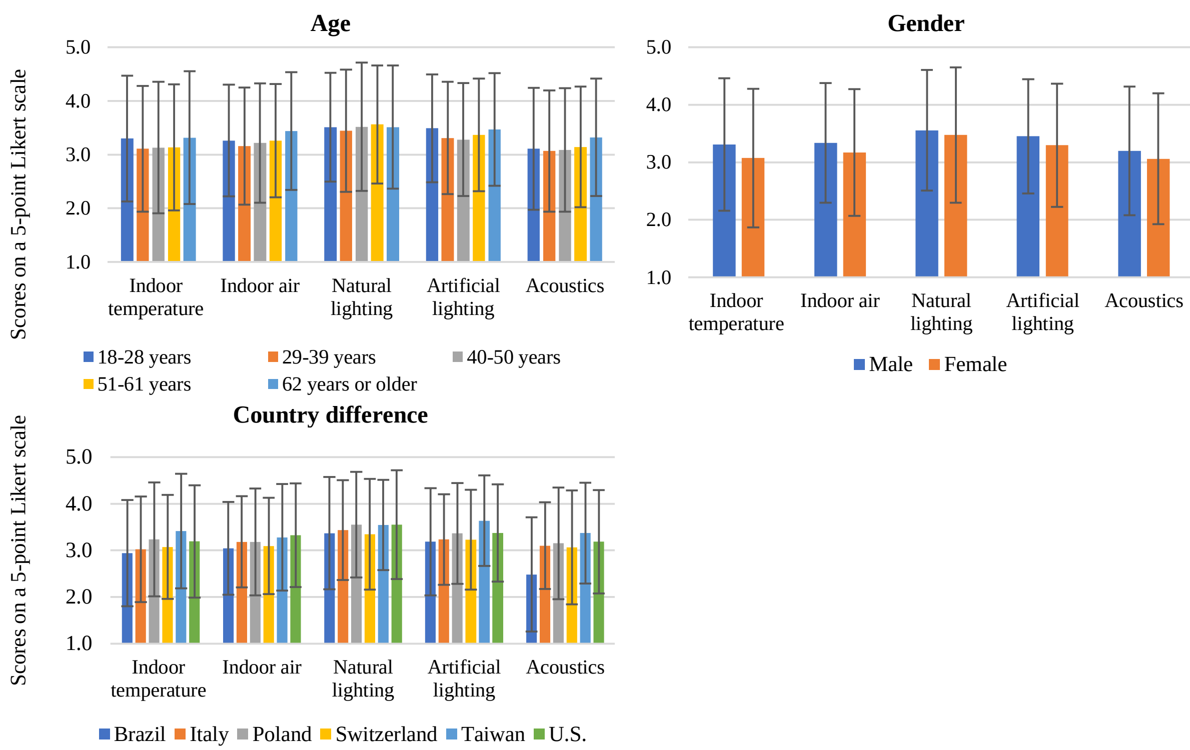


Fig. 4. Means and standard deviations of age, gender, and cultural difference on IEQ-productivity belief.

5.2.2 Differences of building characteristics and workplace contextual factors in IEQ-productivity belief

Results of the ANOVA test suggested that there were significant differences between office types on the beliefs of indoor air quality and natural lighting quality in influencing productivity (Table 4). Fig. 5 shows the levels of IEQ-productivity belief across building characteristics and workplace contextual factors. Specifically, occupants in private offices were more likely to perceive indoor air quality as having a positive impact on their productivity than occupants in shared offices and cubicles. Similarly, occupants in private offices perceived natural lighting quality having a stronger impact on their productivity than occupants in shared offices and cubicles. Office types, however, did not affect the influence of electric lighting quality on productivity. Finally, office occupancy did not significantly affect occupants' belief of how IEQ influenced productivity. We also found that there were significant differences across work positions on electric lighting quality and acoustics quality. Specifically, graduate students stated the highest positive influence of natural lighting quality on their productivity than faculty and staff, as Fig. 5 indicates. Visiting scholars however, had lower averages on the qualities of acoustics, lighting, indoor air, and temperature in comparison with other groups.

In terms of the level of control accessibility, Table 4 shows that the number of people sharing the control of IECs had significant differences on occupants' belief in how the qualities of air temperature, indoor air, and natural and electric lightings influenced productivity, except for the quality of acoustics. Specifically, the ANOVA test reported that thermostat control affected occupants' belief in how indoor air quality affected productivity. Further, those who had thermostat control only to themselves expressed that the indoor temperature affected their productivity more positively than those who did not have thermostat control or share with others; suggesting the importance of thermostat controls (see Fig. 5). Similarly, the number of people having the window shade and blind controls affected occupants' belief in how indoor air quality and natural lighting influenced their productivity. The post-hoc tests indicated that those who had controls to shades and blinds perceived a stronger and positive impact of the indoor air quality and natural lighting on their productivity more than the other two groups (i.e., those who did not have these controls and share these controls with one and more colleagues). In terms of window accessibility, our analysis suggested that it affected how indoor air quality and natural lighting productivity. Further, the post-hoc tests revealed that those who had the control of operating windows only by themselves perceived a higher and positive level of indoor air quality and natural lighting influenced their productivity more than those who did not have the window control and shared the window control with one and more colleagues. Lastly, this study found that having access to lighting controls affected how perceived indoor temperature, air quality, natural and electric lightings affected productivity. The post-hoc tests further revealed that those who had control of light switch only to themselves stated that the impact of indoor temperature affected their productivity positively the most.

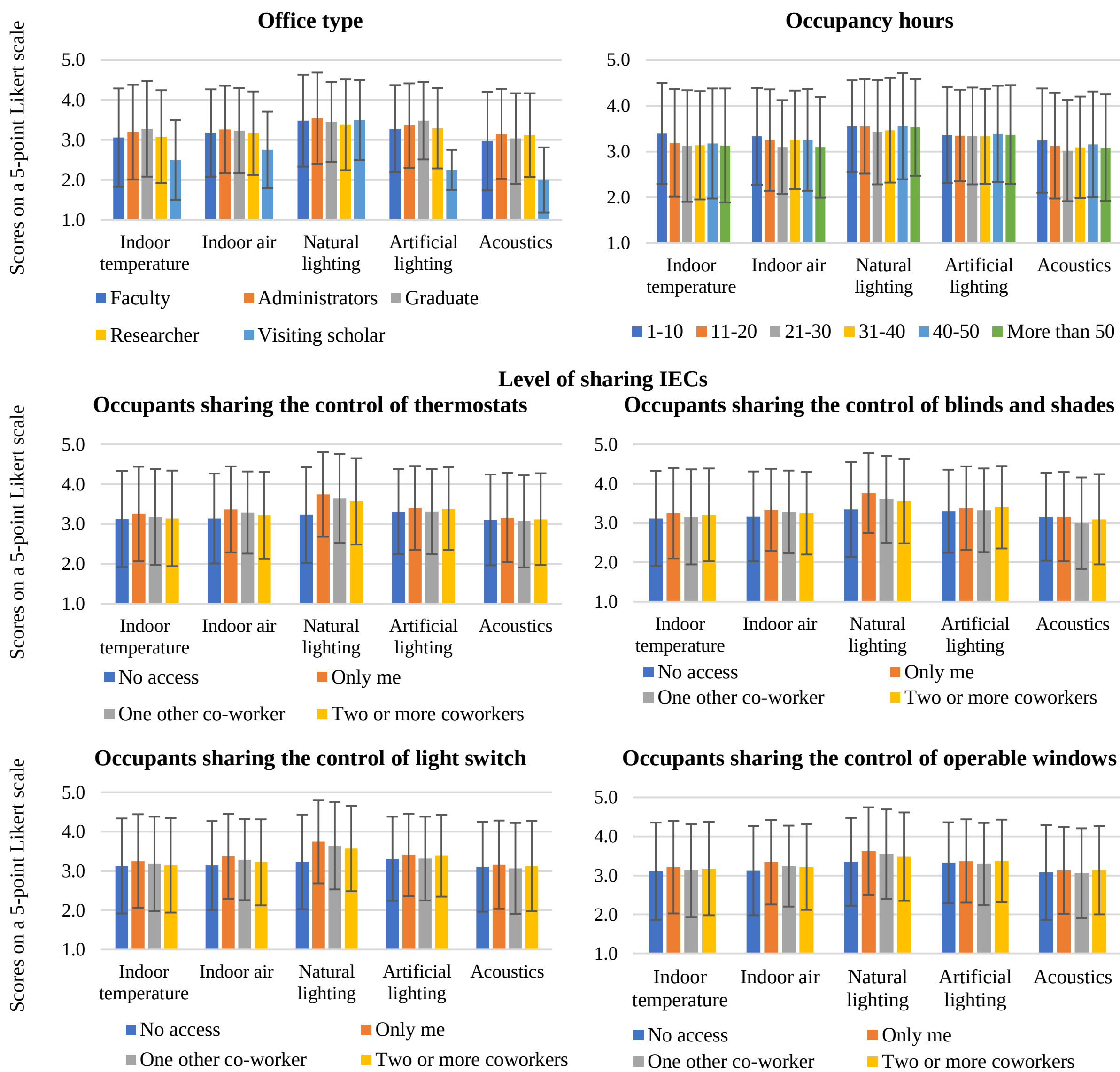


Fig. 5. Means and standard deviations of building characteristics and workplace contextual factors on IEQ-productivity belief.

5.3 Results of multiple linear regression model

To identify how building characteristics and workplace contextual (Dimension 1), attitudinal-behavioral (Dimension 2), social influence (Dimension 3) and demographic (Dimension 4) factors affect the IEQ-productivity belief altogether, an OLS multiple regression analysis was conducted (see Table 5) [96]. First, a preliminary analysis of the multicollinearity of the variables was performed to assess if there was a strong correlation between two or more variables in the regression model based on the test of variance-inflation factors (VIF). The VIF of the predictor shown in the regression table were all less than 2.5, and the conservative value of 2.5 was used for the cut-off point [101,102]. Overall, the model fit was good, F (21, 1897) = 37.318, p = 0.000, R^2 = 0.295, effect size = Cohen's d = 0.418. The following results report the significant factors based on each Dimension. Results of the regression model indicate that office type was the strongest positive predictor in Dimension 1: Occupants in the private offices were more likely to have a positive IEQ-productivity belief than those in shared offices and cubicles. Surprisingly, the number of people that can access to light switch was another positive significant predictor in Dimension 1, as well as the only significant predictor in the level of control accessibility, indicating that the more people who can access to the light switch, the more likely they will have a positive IEQ-productivity belief.

Regarding Dimension 2, all the attitudinal and behavioral factors including perceived ease of controls, attitude, thermal comfort, and IEQ satisfaction were positive and significant predictors. Most notably, satisfaction with the IEQ was the strongest predictor in Dimension 2 and in all the dimensions: occupants who had a higher and positive level of IEQ satisfaction were likely to believe IEQ as having a positive impact on productivity. Similarly, occupants who expressed a higher level of thermal comfort, a higher level of perceived ease of controls, and a positive attitude towards sharing IECs were more likely to have a positive IEQ-productivity belief. Contrary to our expectations, the social-influence factors in Dimension 3 were not statistically significant.

Among Dimension 4, women appeared to consider five IEQ aspects as having a greater impact on productivity than men; however, age was not a significant predictor. The difference in country of residence indicating the potential culture was the strongest predictor among all demographics and other predictors except for IEQ satisfaction. Specifically, U.S. occupants were more likely to perceive IEQ as having a positive impact on productivity than other countries' occupants except for those from Taiwan. That is, there were no significant differences between the U.S. and Taiwan. After considering all other factors affecting IEQ-productivity belief, occupants living in Brazil had the lowest level of IEQ-productivity level in comparison with occupants from other countries and the U.S. We suspect this could be associated with the fact that the majority of our U.S. occupants were in private offices than in shared offices and cubicles.

Table 5
Results of OLS multiple regression analysis on the factors affecting IEQ-productivity belief.

Variables [i]	***Beta***	***SE***	***t***	***Sig.***
Constant	1.080	0.142	7.585	0.000
Dimension 1: Building characteristics and workplace contextual factors				
Office type:				
Private	0.142	0.062	2.279	0.023
Shared	0.088	0.057	1.564	0.118
Work position	-0.067	0.057	-1.186	0.236
Occupancy hours	0.007	0.014	0.468	0.640
Level of control accessibility:				
Central thermostats	0.023	0.019	1.171	0.242
Windows blinds & shades	-0.030	0.018	-1.740	0.082
Light switch	0.031	0.016	1.963	0.050
Operable windows	0.003	0.019	0.170	0.865
Dimension 2: Attitudinal-behavioral factors				
IEQ satisfaction	0.492	0.022	22.208	0.000
Thermal comfort	0.040	0.020	2.016	0.044
Perceived ease of IECs	0.046	0.021	2.202	0.028
Attitude toward sharing IECs	0.075	0.023	3.229	0.001
Dimension 3: Social-influence factors				
Group norms	-0.007	0.021	-0.360	0.719
Conformity intention	0.013	0.022	0.572	0.567
Dimension 4: Demographics				
Gender	0.103	0.039	2.637	0.003

Age	0.001	0.002	0.754	0.662
Country of residence:				
Brazil	-0.390	0.071	-5.481	0.000
Italy	-0.307	0.078	-3.919	0.000
Poland	-0.226	0.067	-3.385	0.001
Switzerland	-0.251	0.074	-3.379	0.001
Taiwan	-0.085	0.070	-1.214	0.225

i: Female was coded as 1 and male as 0. Faculty position = 1, non-faculty= 0; office type was dummy coded with "cubicle" as the reference group and the six countries are dummy coded with the U.S as the reference group.: Thermal comfort is recoded as (too hot and too cold = 1, warm and cool =2, slightly cool and warm = 3, neither too cold nor too hot = 4). R^2 = 0.295.

5.4 Causes of having IEQ discomfort

In order to discover the causes of leading occupants' IEQ discomfort in each country, we conducted a qualitative analysis on the reasons for thermal, visual, acoustic, and air quality discomfort. Table 6 shows the causes of IEQ discomfort expressed in percentage for each country and the entire sample. For each type of discomfort, occupants could select more than one reason and the percentages were calculated dividing the collected answers by the number of respondents of each country. The majority of occupants (28.4%) declared thermal discomfort was mainly caused by the differences in temperature between the workspace and surrounding areas (i.e., hotter or colder). In particular, this discomfort reason was mostly observed among the occupants from the U.S. (32.0%), Switzerland (24.5%), and Brazil (23.3%). Also, thermostat inaccessibility was a frequently mentioned cause of thermal discomfort in the U.S. (26.0%) and in Italy (21.3%). The cause of air drafts from windows and/or air conditioning systems was the most mentioned discomfort causes in Poland (18.6%), although about 22% of occupants in Poland did not have this type of thermal discomfort. Regarding visual discomfort, inadequate natural lighting was the most identified cause, which was about 21.9% in total. Comparing with other countries, the U.S. occupants (about 25%) and Swiss occupants (about 25%) had the highest percentage of reporting inadequate natural lighting. The U.S. (about 22%) and Switzerland (20.7%) also reported the highest percentage of lacking poor view to outside or windows being too small or obstructed. On the other hand, 20.6% of Brazilian occupants reported the cause of window glare on their visual discomfort. Regarding acoustic discomfort, the majority of our participants declared the cause of the noise from inside across the countries (35.1%). The noise from outside was also mostly observed in Brazil (34.7%) and Taiwan (31.6%). Stuffy and stale air (22.8%), and insufficient natural ventilation (21.7%) caused occupants' discomfort in air quality in the entire sample. Taiwan had the highest percentages of these discomfort causes. An overview of the causes of IEQ discomfort across countries is also presented in Appendix 1.

Table 6.
Percentage of indicating the causes of IEQ discomfort across countries.

	Brazil (%)	Italy (%)	Poland (%)	Switzerland (%)	Taiwan (%)	U.S. (%)	Total (%)
Thermal discomfort							
My workspace is hotter/colder than other areas	23.3	15.7	14.5	24.5	21.3	32.0	24.8
Thermostat is not accessible or is controlled by others	8.1	21.3	15.5	17.5	20.3	26.0	21.0
Air drafts (from windows and/or air conditioning systems)	16.4	16.3	18.6	12.4	17.2	9.8	13.5
Windows are too close/far from me	14.5	7.0	8.2	9.8	12.5	9.8	9.9
Surfaces (walls, floors) around me are too hot/cold	7.6	11.9	5.6	6.8	11.2	2.4	6.0
I don't feel this type of discomfort	18.6	18.0	22.4	18.7	14.0	10.4	14.8
Other	11.6	9.8	15.1	10.2	3.5	9.6	9.9
Visual discomfort							
Not enough natural lighting	19.1	17.7	18.2	25.2	18.0	25.6	21.9
Lack of/poor view to outside (windows too small or obstructed)	11.2	10.7	14.7	20.7	12.7	22.3	17.3
Glare from windows (reflections on my computer screen/desk)	20.6	19.2	18.0	11.0	16.7	6.7	12.9
Too much artificial lighting	5.8	3.6	13.0	11.6	0.0	16.0	10.8
Not enough artificial lighting	18.8	10.1	5.6	7.4	16.0	4.6	8.4
Too much natural lighting	5.3	4.9	2.1	1.6	10.2	0.6	3.0
I don't feel this type of discomfort	16.3	31.0	25.8	18.1	24.5	21.7	23.0
Other	2.8	2.9	2.6	4.5	2.0	2.5	2.7
Acoustic discomfort							
Noise from inside (chatting, poor insulation from other spaces)	35.4	25.9	35.0	39.1	29.3	39.3	35.1
Background noise from inside (from equipment, mechanical systems)	17.6	15.9	16.6	17.7	24.1	23.2	20.2
Noise from outside	34.7	18.6	21.0	22.2	31.6	11.3	19.7
I don't feel this type of discomfort	11.3	38.8	27.2	17.3	14.4	24.1	23.4
Other	1.0	0.7	0.2	3.7	0.5	2.2	1.5

Air quality discomfort							
Stuffy/stale air	21.4	19.9	20.8	19.9	29.7	23.3	22.8
Poor natural ventilation	24.1	19.7	24.1	26.3	28.5	18.1	21.7
Poor mechanical ventilation system	9.3	9.8	17.6	17.5	12.2	14.5	13.8
Bad/strong odors and scents	14.2	13.3	13.7	13.5	15.2	12.9	13.5
I don't feel this type of discomfort	29.1	34.6	21.8	21.9	13.2	27.4	25.5
Other	1.9	2.7	2.0	1.0	1.1	3.9	2.7

6 Discussion

6.1. Summary of main findings

This study proposes a multi-dimensional framework to investigate the key factors influencing office occupants' IEQ-productivity belief, including (1) building characteristics and workplace contextual factors, (2) attitudinal and behavioral factors, (3) social influence factors, and (4) demographics factors. Such an approach is aligned with recent review studies [102, 39] and experimental studies that emphasize the influence of multi-domain aspects on occupants' indoor environmental perception [104]. Five of our 10 hypotheses (H_1, H_5, H_6, H_7, H_8) were fully supported and two of them are partially supported (H_4, only light switch is significant; H_{10}, only gender and countries are significant), and three were not supported (H_2, H_3, H_9) based on the results of regression model. The main findings and implications can be summarized as follows:

Regression analysis demonstrates that occupants working in a private office are more likely to have a positive IEQ-productivity belief. In supporting previous studies (e.g., Kim and de Dear (2013) demonstrating that occupants in private-office spaces are more satisfied with many aspects of IEQ and therefore our findings expand that understanding to productivity belief. In fact, they are more inclined to perceive indoor air quality, natural light, and acoustics as having positive impacts on their productivity than occupants in shared offices and cubicles. Office type, however, does not affect perceived lighting quality. Neither job position nor occupancy hours appear to change occupants' IEQ productivity belief in the regression results. The level of control accessibility to light switches has a significant impact on the IEQ-productivity belief as opposed to other IECs (i.e., thermostats, blinds and shades, and operable windows) after considering all the predictors. Similarly, Collins et al. [105] and Kim et al. [106] found that occupants who were provided with task lights to personally control reported higher levels of perceived lighting comfort. Examining closely, having access to certain IECs affects occupants' IEQ-work productivity belief. Mainly, those who have personalized control of the light switches, thermostats, windows, and shades and blinds only to themselves are more likely to believe the positive impacts of IEQ on their productivity than those who do not have IECs or share with one and more colleagues.

Attitudinal-behavioral variables, including IEQ satisfaction, thermal comfort, perceived ease to control IECs, and attitude toward sharing IECs, are the key factors affecting the IEQ-productivity belief with other considered factors. IEQ satisfaction appears to be the strongest predictor among all the independent variables. Surprisingly, the social influence factors, including group norms and conformity intention, are not significant predictors. There are some interesting demographic findings. For example, men are more likely to report that the IEQs have positive impacts on their productivity than women, without considering other factors (i.e., the ANOVA results). On the contrary, women are more likely to consider all IEQs as having positive impacts on productivity than men, after considering other factors (i.e., the regression results). In this view, our findings add to the growing body of knowledge which investigates the impact played by demographics on assessment of IEQ. Li and Yik [107] found differences in ranking of perceived importance of IEQ by gender. Bae et al [108] found that men have higher satisfaction towards IEQ compared to women. More importantly, country difference is the second strongest predictor of IEQ-productivity belief, followed by IEQ satisfaction indicating the potential impacts of cultural difference [Add our ERSS paper]. Especially, the U.S. occupants are more likely to perceive IEQ as having a positive impact on productivity than other countries' occupants, except for the Taiwanese occupants.

Finally, Table 7 summarizes the main findings of this study to explain whether the tested hypotheses were fully, partially, or not supported by the results.

Table 7.
Summary of main findings explaining the level that the tested hypotheses were supported.

Hypotheses			
Fully supported	**Partially supported**	**Not supported**	**Explanation**
H_1			Regression analysis demonstrates that occupants working in a private office are more likely to have a positive IEQ-productivity belief.
		H_2 H_3	Neither job position nor occupancy hours appear to change IEQ productivity belief in the regression results.
	H_4		Accessibility to light switches has a significant impact on the IEQ-productivity belief; however, other IECs do not appear to influence this role.
H_5 H_6 H_7 H_8			Attitudinal-behavioral variables, including IEQ satisfaction, thermal comfort, perceived ease to control IECs, and attitude toward sharing IECs, are the key factors affecting the IEQ-productivity belief with other considered factors.
		H_9	Findings indicate that social influence factors, including group norms and conformity intention, are not significant predictors for IEQ-productivity belief.
	H_{10}		Considering demographic factors, only gender and countries are significant regarding IEQ-belief.

6.2. Building design implications

This paper's empirical data and findings provide several insights, including prioritizing design strategies to support goal-driven decision making, justifying building wellness investments, and highlighting the importance of working across multiple disciplines and context to enrich our understanding regarding IEQ and productivity. While it would be ideal to provide a full spectrum of building solutions to improve the overall IEQ, our study helps to enhance the design process by uncovering the multi-dimensional factors that are most important. The strongest predictor of IEQ satisfaction demonstrates occupants' strong belief about the effect of IEQ on productivity, which can justify for decision-makers to improve IEQ belief through a multi-dimensional approach.

Quality of natural lighting demonstrates the strongest positive effect on productivity among the five aspects of IEQ in this study. We also found that occupants who work in private offices and those that have access to light switch are more likely to have a positive IEQ-productivity belief. Therefore, from the workplace utilization perspective, a balance between a private office and open cubicle spaces represents a key early stage design decision. In fact, our findings can help make a compelling case for more private office spaces. If enclosed private office spaces are impractical, cubicles with adjustable partitions may be considered. The use of modern furniture that provides modularity and height-adjustable privacy panels (with remote controls) can further add flexibility to dynamically changing needs and, at the same time, they may improve the IEQ belief. It is also possible to divide the lighting system in an open office into multiple subsystems: office-level lighting, block-level lighting, and personal-level lighting through the same adjustable partitions for instance. This multi-level design of the lighting system can grant energy saving but also allow employees the flexibility to control light. Similar findings are discussed in McCunn et al. [62], where a combination of office-level lighting provides uniformity across space, human-centric and biodynamic desk lamps allow greater controllability for light levels in the surrounding environment. The multi-level lighting system has demonstrated to be responsible for positive effects on the worker's perceived productivity levels.

This study also found that perceived ease of IECs and positive attitudes of sharing IECs increase the IEQ-productivity belief. In particular, having control of a thermostat only for individuals may increase IEQ-belief in productivity, which might not be possible in many buildings. The proper utilization of individualized temperature controls will require interdisciplinary coordination to incorporate a human-in-the-loop approach. Designing a functional control system, end-users' feedback with validations and technological innovations are necessary for experts from social sciences and natural and applied sciences [109–111].

Finally, designers and engineers should consider the cultural and climatic context of the region during design. Including subjective, qualitative aspects as proposed in this study is a great way to have a broader understanding on occupants' perceptions, which may also tailor policies to local needs [112]. For example, studies found that productivity is often affected by multiple IEQs, and occupant perceptions are mainly affected by demographics (e.g., gender and birthplace) and job activity [47]. Similarly, a large European study [8] assessed the impact of physical and social factors on workers' perceived comfort. It highlighted that while buildings' physical property could mostly explain perceived comfort, country-related factors were not so obvious. That relationship could have been obscured due to lack of clarity and proper wording of the survey questions and possibly for not taking into account underlying habits, moods, and personality traits.

6.3. Limitations of this study

Several limitations to this research exist, which also highlights potential challenges for future research. First, our study sample is large and diverse; yet, it is not representative of each country's office population. The uneven sample size across the countries could be a potential weakness, however, our study used the approach of OLS linear regression model to control for the effect of each predictor and country difference; therefore, each predictor's and country's coefficient is interpreted with all other predictors held constant [94,97]. Future researchers could try tackling this obstacle by developing a survey methodology strategy to include the diverse population of office buildings in one country. Second, our study focuses only on university office buildings. Therefore, our results cannot be generalized to other commercial office spaces. Future researchers should validate our measurements in different office settings. Third, social influence factors (group norms and sharing control conformity) in this study were found to be not significant. This finding might be because these measures were more closely related to IEC controls, indirectly influencing IEQs. Further investigation of social influence and group dynamic factors could focus on the direct measures of the IEQs. Finally, this study only examines the direct effects of our proposed independent variables (e.g., IEQ satisfaction) on IEQ-productivity belief based on theories; future researchers could investigate the opposite relationship to examine if productivity affects IEQ satisfaction or whether productive or happier occupants were more forgiving of the deficiencies in their indoor environment.

7 Conclusion

This work presented an effort to evaluate the effects of multi-dimensional factors on occupants' IEQ-productivity belief. One of the main findings here suggests that private offices with personal lighting control represent a better context for triggering a positive IEQ-productivity belief. This finding highlights the vexing problem researchers and designers face due to the limitation of real estate in providing private offices in many buildings. Undoubtedly, the level of sharing IEC controls impacts a building's energy use. By identifying which level of IEC controls increase IEQ-productivity believe, the findings from this study aid in selecting effective building control solutions. More importantly, our results demonstrate the importance of cultural difference and add to the growing body of IEQ knowledge. Regulatory agencies and standard developers could consider regional solutions to the factors identified here to allow for user-centric buildings. Cultural and building specific characteristics can also inform more targeted and effective building retrofit decisions and improve building operations.

Additionally, this study can bridge the gap between building technology and occupant-centered policies by using different methods, such as qualitative methodology, to deeper assess the occupant perceptions of building performance. The qualitative evaluations based on local cultural perspective can improve the process of designing tailored policies. Our findings in attitudinal-behavioral and demographic factors also suggest that integrating stakeholders of the building sector with social scientists' views are likewise necessary to understand better how building technologies and social-psychological factors affect IEQ in different countries or regions. In sum, this research provides insights for building designers and policymakers to develop potential IEQ strategies that integrate technological and attitudinal behavioral considerations for a well-built work environment.

8 Appendix 1

8.1 Test of homogeneity of variances

Results of the test the of homogeneity of variances based on mean are presented in Table 8.

Table 8. Test of homogeneity of variances

		Gender		
	Levene's Statistic	**df1**	**df2**	**Sig.**
Indoor temperature	2.135	1	2368	.144
Indoor air quality	1.250	1	2367	.264
Natural lighting	31.559	1	2367	.000
Artificial lighting	7.576	1	2366	.006
Acoustics	.512	1	2363	.474
		Age		
Indoor temperature	1.510	5	2421	.183

	Levene's Statistic	df1	df2	Sig.
Level of control accessibility of light switch				
Indoor temperature	0.134	3	2303	.940
Indoor air quality	1.288	3	2303	.277
Natural lighting	3.208	3	2301	.022
Artificial lighting	1.175	3	2302	.318
Acoustics	1.475	3	2297	.219
Level of control accessibility of operable windows				
Indoor temperature	.391	3	2371	.759
Indoor air quality	1.388	3	2370	.245
Natural lighting	.128	3	2369	.943
Artificial lighting	.230	3	2369	.875
Acoustics	1.376	3	2367	.248
Indoor air quality	.908	5	2420	.475
Natural lighting	4.700	5	2420	.000
Artificial lighting	.273	5	2419	.928
Acoustics	.235	5	2416	.947
Country of residence				
Indoor temperature	5.629	5	2521	.000
Indoor air quality	9.366	5	2520	.000
Natural lighting	7.140	5	2521	.000
Artificial lighting	4.060	5	2520	.001
Acoustics	15.578	5	2517	.000
Office type				
Indoor temperature	1.298	2	2402	.273
Indoor air quality	1.375	2	2401	.253
Natural lighting	.603	2	2401	.547
Artificial lighting	5.295	2	2400	.005
Acoustics	.228	2	2398	.796
Occupancy hours				
Indoor temperature	.833	5	2420	.526
Indoor air quality	2.448	5	2419	.032
Natural lighting	3.340	5	2419	.005
Artificial lighting	.287	5	2418	.920
Acoustics	.274	5	2418	.928
Work position				
Indoor temperature	1.029	4	2306	.391
Indoor air quality	1.074	4	2306	.368
Natural lighting	1.464	4	2305	.210
Artificial lighting	2.420	4	2306	.046
Acoustics	3.493	4	2303	.007
Level of control accessibility of thermostat				
Indoor temperature	.566	3	2411	.637
Indoor air quality	1.658	3	2410	.174
Natural lighting	13.398	3	2411	.000
Artificial lighting	.095	3	2410	.963
Acoustics	.361	3	2406	.781
Level of control accessibility of windows and shades				
Indoor temperature	.012	3	2338	.998
Indoor air quality	.932	3	2337	.425
Natural lighting	6.778	3	2337	.000
Artificial lighting	.178	3	2336	.911
Acoustics	.228	3	2332	.877

Table 8 continued

8.2 Causes of IEQ discomfort across countries

Fig. 6 to 9 shows the causes of thermal, visual, acoustic, and air quality discomfort across each country, respectively.

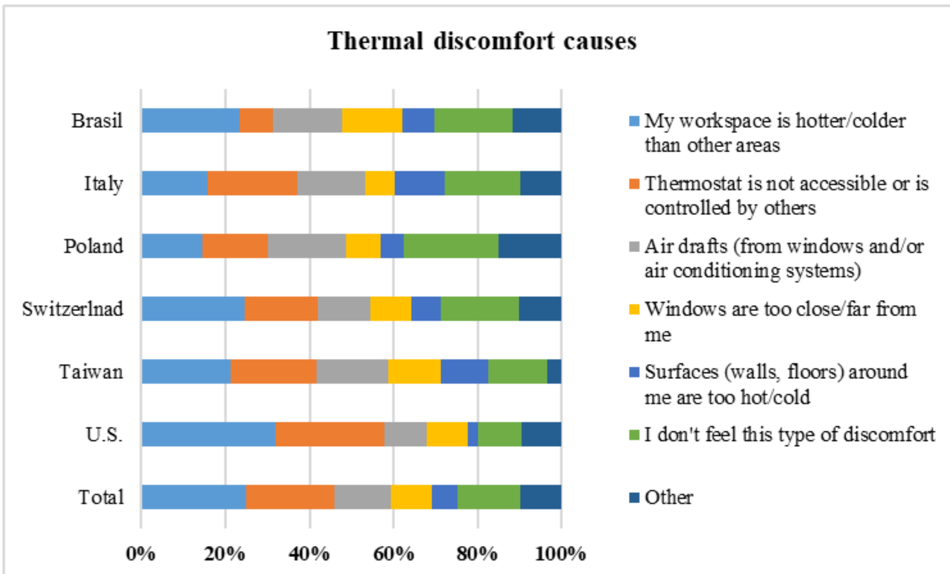


Fig. 6 Causes of thermal discomfort across countries

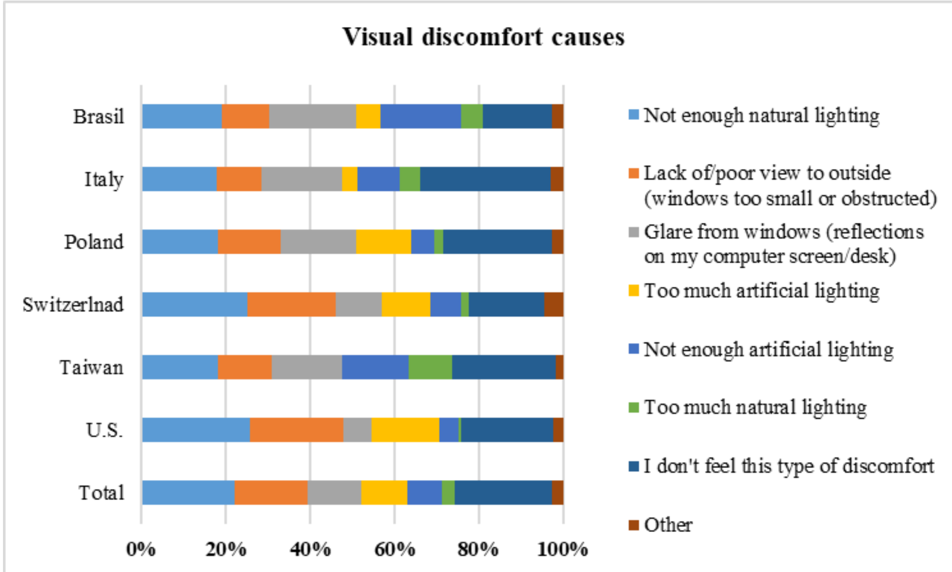


Fig. 7 Causes of visual discomfort across countries

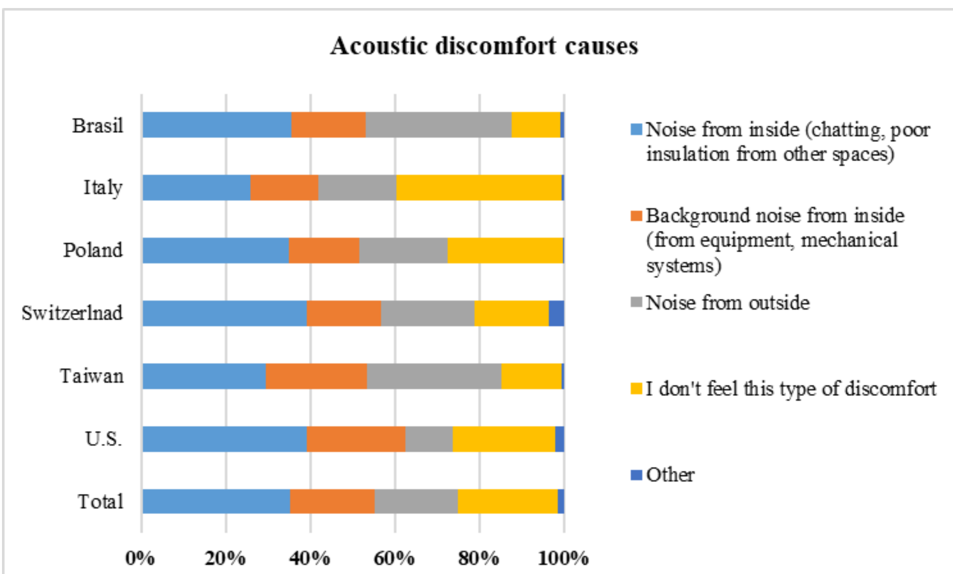


Fig. 8 Causes of acoustic discomfort across countries

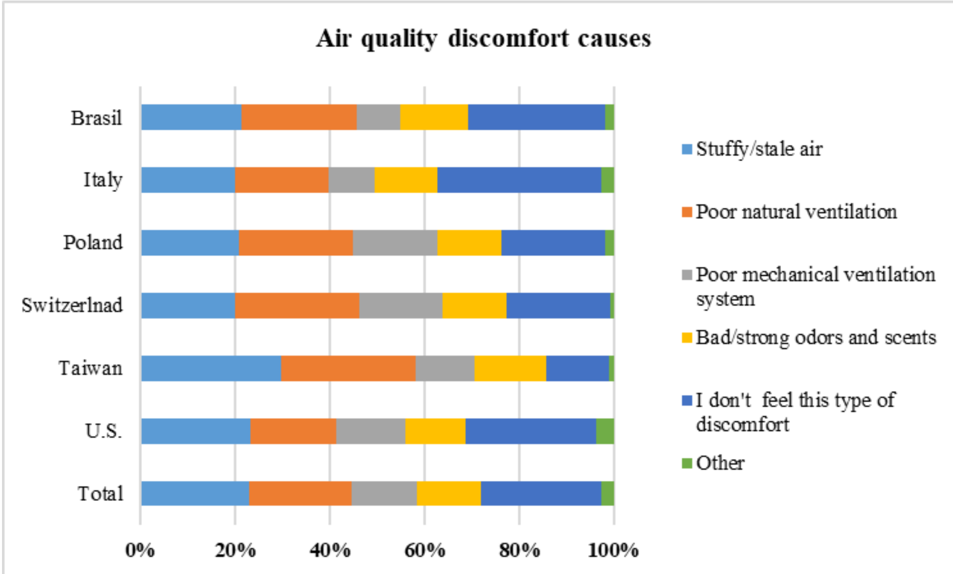


Fig. 9 Causes of air quality discomfort across countries

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