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Abstract

This study investigates human-building interaction in office spaces across multiple countries including Brazil, Italy, Poland, Switzerland, the United States, and Taiwan. We analyze social-psychological, contextual, and demographic factors to explain cross-country differences in adaptive thermal actions (i.e. cooling and heating behaviors) and conformity to the norms of sharing indoor environmental control features, an indicator of energy consumption. Specifically, personal adjustments such as putting on extra clothes are generally preferred over technological solutions such as adjusting thermostats in reaction to thermal discomfort. Social-psychological factors including attitudes, perceived behavioral control, injunctive norms, and perceived impact of indoor environmental quality on work productivity influence occupants' intention to conform to the norms of sharing environmental control features. Lastly, accessibility to environmental control features, office type, gender, and age are also important factors. These findings demonstrate the roles of social-psychological and certain contextual factors in occupants' interactions with building design as well as their behavior of sharing environmental control features, both of which significantly influence building energy consumption, and thus, broader decarbonization.

1. Introduction

Buildings are responsible for 36% of global primary energy use and nearly 40% of energy-related carbon dioxide emissions (CO_2) due to heating, ventilation, air-conditioning (HVAC), water heating, lighting, and plug-in equipment [1,2]. While energy use in the building sector continues to grow, building envelopes and energy efficiency policies are not improving quickly enough; for example, two-thirds of countries still do not have building energy codes [2]. Occupant behavior is one out of six driving factors that affects building energy use [3,4], impacting building retrofit, thermal comfort, indoor environmental quality (IEQ), productivity, and energy waste. Occupant behavior also creates uncertainty in predicting energy consumption, leading to a significant mismatch between forecasted and actual energy use [5–8].

The daily interaction between environmental control features and occupants, influences a large portion of a building's total energy use [9]. In addition, occupants' expectations of comfort and satisfaction within their indoor environment have physiological and psychological impacts on the occupants themselves, as well as economic impacts such as productivity [10–12]. These expectations and perceptions can also affect the actions that occupants would take to satisfy their physiological and psychological needs. These adaptive actions might affect a building's indoor environment (e.g., indoor temperature, humidity level, lighting, CO_2, etc.) and energy consumption. However, the interactions between occupants and building technologies remain underexplored including: how and in what ways occupants share environmental control features (ECFs) and adapt thermal actions including cooling and heating behaviors in relation to social-psychological and contextual factors. These areas are especially overlooked from the multifaceted perspectives of technology, culture, and norms.

About 70% of American office workers now work in shared spaces [13]. Sharing ECFs serves as an important mediator between energy efficiency, occupants' comfort and IEQ satisfaction. Regarding indoor ECFs, studies note that the interaction between occupants and control systems has direct impacts on energy consumption and individual comfort satisfaction [14–16]. Reduced building controls generally leads to increased occupants' discomfort. Notably, even the illusion of control could be related to thermal comfort, leading to the research that distinguish between available (technological aspects) and perceived (social-psychological or affective states) controls [17]. In addition, the feeling of lacking control could lead to a vicious cycle of "self-fulfilling prophecy" as termed in psychology [18], where occupants become less likely to change their comfort conditions [17]. Noting this, there is still no consensus on the impact of perceived control versus available controls [8,19].

Regarding energy use, perceived level of control over the thermal environment could reduce energy consumption by 9% without sacrificing occupants' thermal comfort [20]. One study concluded that office occupants tend to operate the easiest use of ECFs first; however, multiple adaptive actions may be taken depending on contextual constraints [21]. This result also suggests that the ease to access and the knowledge of using ECFs need to be carefully examined with contextual factors in order to better understand occupant behaviors.

Expanding the area of ECFs, there is a growing recognition of the influence of contextual factors and environmental variables on occupant behavior. The example of contextual factors in building related research could include the accessibility of personal controls, transparency of automation systems, presence of mechanical/electrical systems, interior design, seating layout, visibility of energy use and so on [8]. Our study defines contextual factors as the stimuli and phenomena that surround in the environment external to the individual and that affect the

meaning of organizational behavior [22], such as the accessibility of ECFs, office type and occupancy hours.

Occupant behavior in terms of adapting to the indoor environment has become more complex as the design of new buildings becomes more sophisticated with diverse office layouts, advanced sensor technologies, and centralized automation systems and these factors provide occupants with more options to adjust their indoor environment to meet their needs [23]. The negotiation process among occupants for sharing ECFs (such as adjusting the thermostat); however, should be recognized particularly with individuals in shared offices. For example, studies show that group dynamics and norms significantly affect employees' motivation to interact with building control systems and to save energy [24–26]. Occupants may choose to rely on technological solutions (e.g., thermostat settings), personal adjustment (e.g., adding or removing clothes or having hot/cold drinks) [8,27], negotiation with others, or refrain to psychological coping strategies to obtain thermal comfort [14]. Each of these strategies has different levels of concern in regards to causing discomfort to others. Therefore, understanding adaptive actions and their relationship to ECF sharing in a group setting is essential in building decarbonization, as the type and frequency of adaptive actions affect office energy consumption.

1.1. The Present Study

Instead of directly measuring energy use behavior or the impacts of ECF accessibility, this study takes a fundamental approach to analyze the factors influencing occupants' conformity intention to share ECFs, and understand the reasons for taking the initial adaptive thermal actions when feeling uncomfortable at work. In doing so, the study investigates six distinct national contexts, including Brazil, Italy, Poland, Switzerland, the United States, and Taiwan, using an

original dataset that includes survey responses from a total of 3,472 office occupants.

Group conformity intention, a social-psychological concept, is defined here as the level of occupants' intention to share ECFs in buildings, based on the group norms that most co-workers agree upon. This paper focuses on these types of norms, considering that office occupants are typically not responsible for utility costs. While appliances and facilities are often shared among co-workers, which makes tracking individual-level energy use difficult, the sense of individual responsibility for energy conservation decreases [25]. More importantly, occupants' behaviors are easily observed, and there is often a high degree of social interaction or conflicts in workplaces. ECFs in this study are considered as the mechanical and electrical features and equipment, as well as the building envelope features that control and monitor buildings' lighting, temperature, and IEQ. In particular, this research focuses on occupants' interactions with operable windows, blinds, thermostats, and lights at their workplace.

This research provides a unique opportunity to examine the following research topics in the context of different countries. First, occupants' willingness to share ECFs based on group norms and adaptive thermal actions when someone is feeling too hot or too cold. Second, whether these can be explained by: (a) contextual factors (e.g., occupancy hours, office type, and ECF accessibility) and/or; (b) demographics (e.g., gender, age and location) and/or; (c) social-psychological factors (e.g., attitudes, norms, perceived behavioral control, IEQ satisfaction) based on an integrated theoretical framework.

1.2. Theoretical Framework

This study uses an integrated theoretical framework, previously developed by D'Oca and colleagues [5], to better explore the influence of occupant behavior on building energy

performance and the socio-technical factors influencing occupants' intention to share controls. This framework is a synthesis of several theories from building physics and social psychology including the drivers-needs-actions-systems (DNAS), the theory of planned behavior (TPB) [28], and social cognitive theory (SCT) [29]. The DNAS considers one's need to control building energy technologies as a direct consequence of personal needs. The DNAS states that occupant behaviors are influenced by the consequence of stimuli (drivers of a behavior) from the social and physical environment (i.e., norms, environmental factors) to accomplish personal cognitive and biological needs (i.e., privacy, physical comfort). However, the DNAS mainly addresses the impacts of building physical components such as building design and technologies on occupants, which limits the degree to which motivations, attitudes, norms, or other group dynamics can be covered. Instead, the TPB provides the explicit attitudinal and behavioral components to complement the DNAS, that is, how one's need to perform a behavior in the workplace is affected by attitudes, perceived behavioral control (PBC), and subjective norms (mostly injunctive norms). Injunctive norms are defined as perceived social pressure from co-workers and employers on how one should behave [6]. The TPB has been widely adopted by researchers to explain pro-environmental and energy saving behavioral intention and behaviors [30–33]. Finally, the SCT connects with the DNAS framework and the TPB by emphasizing the interconnected components of environmental (social and physical), personal cognitive, and behavioral factors. The SCT suggests that the influence of one's experiences, the actions of others, and physical environmental factors can influence behavior [29]. The behavioral change can be achieved through changed self-efficacy, behavioral capability, expectations, self-control and observational learning.

Taken together, the DNAS is adopted to provide a framework describing the human-

building interaction phenomena and motivation to adopt a solution when feeling thermal discomfort. Based on the SCT, this study attempts to investigate how employee's perceptions of their physical (e.g., access to ECFs) and social environment (group norms, organizational culture), as well as personal factors (e.g., knowledge, demographics), affect the norms of sharing ECFs and adaptive thermal actions when one is uncomfortable at work. The extended TPB identifies how one's intention to share ECFs and specific adaptive thermal action is potentially affected by beliefs (e.g., belief in the impact of IEQ on productivity), injunctive norms (e.g., perceived approvals from co-workers on how one should behave), attitudes and PBC, contextual factors (e.g., access to building ECFs), and demographics (e.g., age, gender, and country of residence).

2. Method

An internet-based questionnaire was designed with Qualtrics survey software and administered through Qualtrics Paid Panel Service, a popular online data collection platform used by researchers. The participants, age 18 and older, were recruited from the university staff, faculty, researchers, and graduate students regularly occupying office buildings from nine universities and research centers across six countries/regions including Brazil, Italy, Poland, Switzerland, the United States, and Taiwan. Table 1 lists the data collection time and season in each participating location. In this study, the differences in countries and regions encompass all possible differences in climate, culture, and everything else. The final sample size was 3472 (Brazil=252, Italy=728, Poland=715, Switzerland=191, USA=1306, Taiwan =280). Ethics protocols and privacy issues for handling human subject data had been approved in all participating institutions.

Table 1
Data collection time and seasons

Country	Data collection time	Season
Bazil	10/19 - 12/15/2017	Spring - Early Summer
Italy	3/20 - 5/9/2017	Spring
Poland	4/4 - 6/29/2017 7/31/17 - 1/20/2018	Spring Fall - Winter
Switzerland	10/11/17-1/10/2018	Fall - Winter
Taiwan	7/29-8/23/2017	Summer
U.S.A.	4/28-11/7/2017	Spring - Fall

2.1. 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. These steps are outlined in the double translation process (DTP) [34], one of the most adopted translation processes for survey questionnaires. University listservs 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, belief in the impact of IEQ on work productivity, and reasons for thermal discomfort. The second part asked about indoor ECF options and the behaviors utilized to exercise control. The third part of the survey measured individual conformity intention and the social-psychological variables that potentially predict the

conformity intention (dependent variable). The fourth part of the survey included two questions regarding the first and second actions taken when participants feel too cold or hot in the office. The final part of the survey contained questions about contextual factors and demographic information. Multiple response methods, such as checking a box or clicking and dragging a statement were used to ease participant choices and reduce boredom.

2.2. Measures

All measures except for building contextual and demographic variables were estimated by participants' responses to the items with a 5-point Likert-type scale.

2.2.1. Dependent variables

2.2.1.1. Conformity intention. Intention to conform to the group norms of sharing ECFs was measured by four separate items based on five-point scales with the following options: 1 = very unlikely, 2 = somewhat unlikely, 3 = neutral, 4 = somewhat likely, 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 $\alpha = 0.89$).

2.2.1.2. First choice of adaptive thermal actions. We asked the participants, "If you feel hot at work, over a typical work week of this season, what is your first and second action?". The same question was asked in the "feel cold" situation. We divided the actions into two types: HVAC technological solutions (including adjusting thermostat and using a personal heater/fan; coded as 1) and personal adjustments (e.g., drink a cold/hot drink, adjust clothing layers, walk to a cooler/hotter space, or open or close a window; coded as 0).

2.2.2. Independent variables

2.2.2.1. Contextual factors. The contextual factors include office type (shared or single-occupant office), office occupancy (i.e. hours in the office per week) and accessibility to ECFs. The ECF accessibility was measured by four questions: "Do you have control to …" (a) "… adjust thermostat setting", (b) "… turn on/off light switches", (c) "…open/close window", and (d) "… adjust window blinds or shades" "… in your workplace?". Participants scored 1 whenever the answer was "yes" and scored 0 when the answer was "no" or "not sure". The final score was the sum across four items.

2.2.2.2. Social-psychological factors. Social-psychological factors include six variables: attitudes toward sharing ECFs, injunctive norms, PBC, knowledge about control features, and indoor environmental quality (IEQ satisfaction and belief in the influence of IEQ on productivity). Specifically, attitudes, referring to an individual's favorable or unfavorable evaluation of sharing ECFs, were measured by four statements: "Co-workers sharing control of the ..." (a) "… temperature setting", (b) "… windows", (c) "… artificial lighting", and (d) "… blinds or shades" "… is very good/bad" (Cronbach's $\alpha = 0.94$). Injunctive norms, considered as perceived expectations from group members to act in a given situation, 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 and closing windows", (c) "…artificial lighting", and (d) "… blinds and shades" "… with them" (Cronbach's $\alpha = 0.95$). PBC, referring to the extent to which subjects felt ease or difficulty in sharing ECFs, 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) "… artificial lighting", and (d) "… blinds or shades" (Cronbach's $\alpha = 0.87$). Knowledge was measured by the level of perceived knowledge of operating ECFs in the workplace, including adjusting the thermostat, opening/closing windows, turning on/off shades

and blinds, and switching on/off the lights (Cronbach's $\alpha = 0.75$). IEQ satisfaction was measured by the extent to which participants perceived the overall satisfaction with five components: indoor temperature, quality of indoor air, natural lighting, artificial lighting, and acoustics in the workplace (Cronbach's $\alpha = 0.73$). The belief in the impact of IEQ on productivity was measured by the extent to which participants rated the influence of IEQ on their work productivity (Cronbach's $\alpha = 0.85$).

2.2.2.3. Demographics. Demographics including gender, age, and the country of residence were collected. 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. The country affiliation was also dummy coded. Table 2 presents the mean and standard deviation (*SD*) of each social-psychological measure as well as the factor loading based on exploratory factor analysis.

Table 2
Means and standard deviations of social-psychological variable measures.

Variable		*Loading*	*Mean*	*SD*
Intention – I am willing to … based on the majority of my coworkers' opinions				
1	accept indoor temperature settings	0.83	3.81	1.13
2	open and close windows	0.89	3.83	1.10
3	switch on/off the lights	0.86	3.90	1.10
4	open/close shades and blinds	0.90	3.86	1.09
Attitude – Coworkers sharing control of … in a shared office is very bad (1) – very good (5)				
1	the temperature settings	0.87	3.44	1.16
2	the windows	0.95	3.59	1.09
3	the artificial lighting	0.92	3.67	1.16
4	the shades and blinds	0.94	3.64	1.10
Injunctive Norms – The majority of my coworkers expect me to share… with them				
1	control over the adjustment of the thermostat settings	0.89	3.50	1.15
2	opening and closing of windows	0.95	3.51	1.14
3	Lighting	0.94	3.55	1.13

4	blinds and shades	0.94	3.51	1.13
PBC – If I want to, I can easily share control of …				
1	thermostat settings	0.79	3.29	1.45
2	opening and closing the windows	0.89	3.52	1.39
3	artificial lighting	0.84	3.76	1.25
4	blinds and shades	0.87	3.68	1.31
Knowledge – I know how to …				
1	adjust the thermostat	0.69	3.72	1.52
2	open and close windows	0.82	4.13	1.31
3	turn on/off shades and blinds	0.82	4.33	1.13
4	switch on/off the lights	0.74	4.60	0.84
IEQ Satisfaction – I am satisfied with…				
1	indoor temperature	0.65	3.05	1.17
2	quality of indoor air	0.76	3.11	1.17
3	quality of natural lighting	0.69	3.30	1.36
4	quality of artificial lighting	0.73	3.34	1.17
5	quality of acoustics	0.65	3.01	1.19
IEQ Productivity – I think … influences my productivity at work				
1	indoor temperature	0.80	3.15	1.21
2	quality of indoor air	0.84	3.20	1.10
3	quality of natural lighting	0.77	3.51	1.15
4	quality of artificial lighting	0.81	3.32	1.07
5	quality of acoustics	0.77	3.11	1.17

3. Results

3.1. Analytic strategy

We first conduct exploratory and confirmatory factor analyses to examine the uni-dimensionality of all social-psychological measures. An average score, as a composite measure, was obtained for each construct if the results indicated a one-factor solution. Pearson correlation tests were conducted between each pair of the variables (including demographics and contextual factors) that could serve as predictors in the regression models to determine the strength of their linear relationships. Then, descriptive analyses were conducted to explore the social-psychological factors (e.g., attitude, norms, perceived behavioral control), contextual factors, and

ECF access in each country. Third, descriptive analysis was conducted to produce an overview of the reasons for operating ECFs. Binary logistic regression analysis was further performed to uncover the factors influencing the choice of adaptive thermal actions (a technological solution versus a personal adjustment), when facing thermal discomfort in the office. Finally, the analysis of variance (ANOVA) was conducted to compare the levels of conformity intention across countries, and then linear regression analysis was conducted to determine the relationship between conformity intention and the proposed predictors, with all countries modeled together and then separately. Based on the common practice in social science and the relative large sample size of this study, an α level of 0.05 was used to determine statistical significance [35]; results that have *p* values between 0.5 and 0.10 were also mentioned; the entire array of *p* values were presented in the tables of inferential statistical results. All analyses were performed using IBM SPSS 24.0.

3.2. Handling missing data

Our sample has 3.5-10.7% missing data on the independent variables on which intention to conform were regressed. Little's MACR test determined that the missingness pattern was not Missing Completely at Random (MCAR), $\chi^2(5509) = 5841.53$, $p < 0.01$. When the missing data is not MCAR, using listwise deletion will likely introduce bias; therefore, multiple imputations were applied in this study. Multiple imputation is a preferred imputation technique for its ability to maintain the underlying distribution of the data [36] and keep all the cases for the analysis [37–39]. Five rounds of imputations were conducted with SPSS 24.0. After the missing data imputations, one regression model was fit on each set of the imputed data and the estimates were pooled together by Rubin's Rules [40]. For example, assuming Q is the parameter of interest of a

single population, the multiple imputation point estimate is the average of the m estimates of Q from the imputed datasets, $\underline{Q} = \frac{1}{m}\sum_{i=1}^{m} \quad \widehat{Q}_i$ [41]. We applied multiple imputations in particular to the social-psychological predictors, because those variables have the highest missing rate (up to 10.74%) and there should not be any "not applicable" situations in theory. Social-psychological variables typically measure participants' perception; therefore, even when there is not a concrete existence (such as a stated or published organizational rule on energy saving), occupants still hold some perception (e.g., how much the co-workers are approval or dis-approval of saving energy). This study did not use multiple imputations in predicting the choice of adaptive thermal actions because the model did not include social-psychological predictors and the missing rates on all variables were low (up to 4.58%).

3.3. Regression diagnostics

We conducted regression diagnostics to ensure the accuracy and the generalizability of the regression models by examining the outliers, influential cases, and the assumptions including linear relationships between the dependent and independent variables, multicollinearity, homoscedasticity, and error normality [42]. First, outliers and influential cases were identified according to the standardized residual and *Cook's D*. Any case that had a standardized residual whose absolute value was larger than 3 or a *Cook's D* that exceeded 4/n were inspected [43]. Across the five imputed data sets, 33-36 cases were removed from the original 3385 cases. Second, the variance inflation factor (VIF) scores were inspected. All variables' VIF ranged from 1.04 to 2.46, within the acceptable limits, indicating multicollinearity was not a problem [44]. Third, the residual versus fitted values plot was inspected. The plot shows that residuals had a fairly even spread across different levels of the predicted value, indicating homoscedasticity.

Finally, the *P-P* and *Q-Q* plots of the residuals were analyzed, and the results indicated no extreme deviations from the expected cumulative distribution, suggesting that the residuals were nearly normally distributed. These steps were also followed through when the regression analysis for each individual country was conducted.

3.4. Descriptive statistics

Among social-psychological variable, knowledge scored the highest (*Mean* = 4.20, *SD* = 0.93), followed by intention to comfort the norms of sharing ECFs (Mean = 3.85, *SD* = 0.96), attitude (Mean = 3.58, *SD* = 1.01), PBC (*Mean* = 3.57, *SD* = 1.14), and injunctive norms (*Mean* = 3.52, *SD* = 1.06). The IEQ satisfaction scored the lowest (*Mean* = 3.16, *SD* = 0.85), and the belief in the impact of IEQ on productivity scored at average (*Mean* = 3.26, *SD* = 0.99). It is worth mentioning that the responses regarding different ECFs diverged to some extent. For example, the PBC on thermostats scored 3.29 on average (*SD* = 1.45), while the PBC on artificial lighting scored 3.76 (*SD* = 1.25). All these statistics can be found in Table 2. In the test of the correlations between the independent variables, we found the most correlations were statistically significant ($p < 0.01$), but not as high as indicating any problems of collinearity. The highest Pearson correlation coefficient existed between IEQ satisfaction and perceived IEQ-productivity connection ($r = 0.53$). The three elements of the TPB – attitude, injunctive norms, and PBC – also had moderate correlations with each other ($r = \sim 0.50$). It is worth noting that office type and overall accessibility to ECFs only correlated at 0.08, indicating that occupants in single-person offices did not have a significantly higher control level on ECFs. Approximately, a third (33.0%) of the participants reported themselves as spending 31-40 hours per week in their office, while another third (31.8%) reported as spending 41-50 hours per week in their office. The rest of the

participants fell into the brackets of 1-10 hours, 11-20 hours, 21-30 hours, and over 50 hours.

3.5. Comparison of social-psychological and contextual variables among countries

Assessment of IEQ satisfaction and belief in the impact of IEQ on productivity are similarly distributed across all countries (Figure 1). Among the TPB variables, Brazil, Poland, and Switzerland provided more strongly positive answers, but answers within each of these countries were also diverse. For example, the answers from Italy and Taiwan mainly lie between neutral and slightly positive and U.S. had the lowest reported PBC and injunctive norms. These patterns seem to be consistent with the finding that U.S. participants rated themselves as the least knowledgeable in operating ECFs, while Brazilian and Polish participants rated themselves as the most knowledgeable.

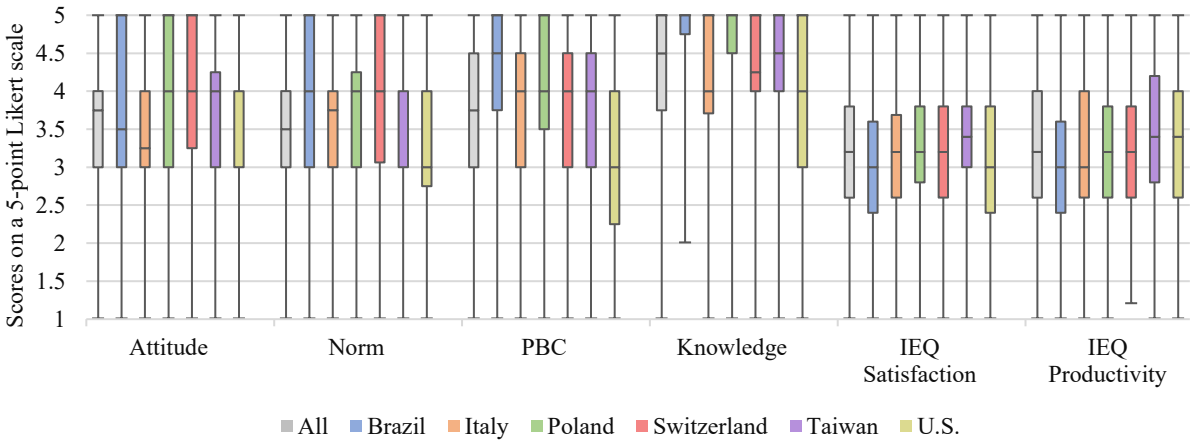


Figure 1. Boxplots for the social-psychological variables.

Figure 2 indicates that Taiwan and Brazil had the highest percentages of participants working in shared offices (93.2% and 86.9%), followed by Switzerland and Poland (83.3% and 81.1%), with Italy and the U.S. having the lowest percentages (68.7% and 62.5%). Regarding ECFs, the majority of occupants (81.5-98.2% across countries) had access to lighting control,

whereas access to thermostat controls was lowest among ECFs in most countries, except for the U.S., where occupants had the lowest access rate to window control. Interestingly, the access rate varied the most in window control, from 24.9% in the U.S. to 90.1% in Brazil. Overall, Brazil has the highest ECF accessibility, whereas the U.S. had the lowest; arguably, this highlights the differences in building design strategy. While the U.S. had the highest number of single-occupant offices, these spaces generally did not allow ECF access, as compared to other countries in our sample. These building contextual factors, discussed in later sections, affected the choice of adaptive thermal actions and conformity intention in regard to the norms of sharing ECFs.

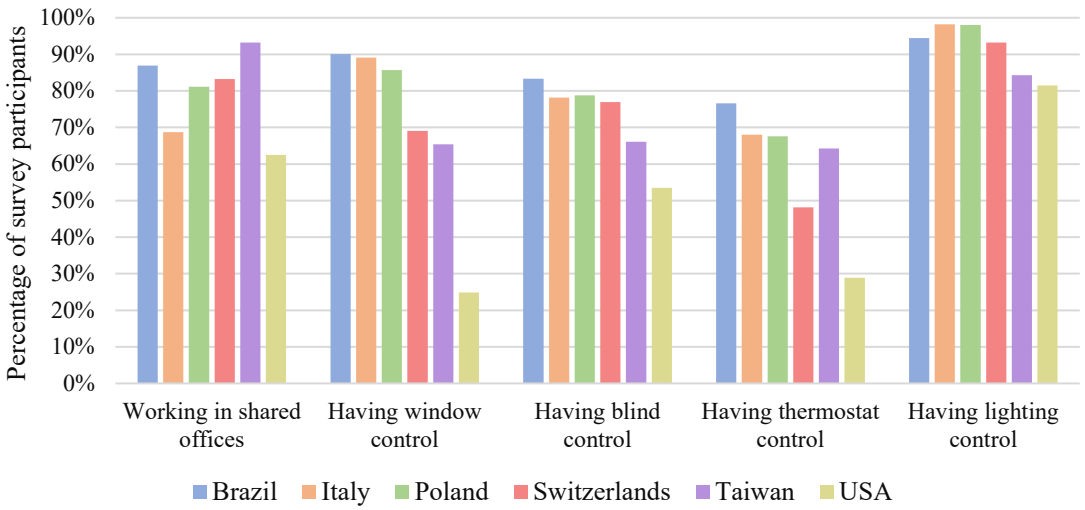


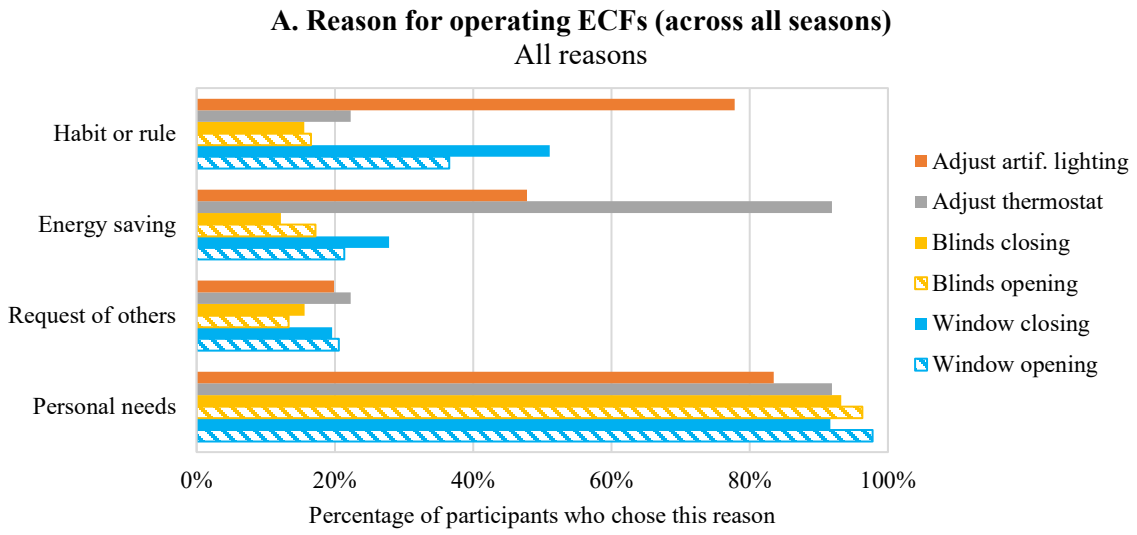
Figure 2. Contextual features across countries.

3.6. Adaptive thermal actions: Technological solutions vs. personal adjustments

The occupants' choice of adaptive thermal actions to restore personal comfort significantly affects building energy use and indoor environmental conditions. We consider the first adaptive action an important indicator of potential energy savings because certain actions directly involve *technological solutions*, such as adjusting thermostats or using a personal fan

and heater, which increases energy consumption. Other adaptive actions, *personal adjustments* (e.g., putting on extra clothing, or opening/closing windows and blinds), do not involve any electric equipment or appliances, but directly influence personal thermal sensation. Participants were specifically asked about the first action taken when they felt too hot or too cold across four seasons.

Results of our analysis suggest that while about 20% of the ECF operation is sourced from colleagues' requests and 20-50% (depending on the specific type of ECFs) from arriving at/leaving office and safety/security rules, most occupants operate ECFs in our study for personal adjustments. The facts that windows are mostly operated to obtain thermal comfort apart from ensuring good air quality and that thermostats are solely operated for thermal comfort highlight the importance of adaptive actions (see Figure 3A).



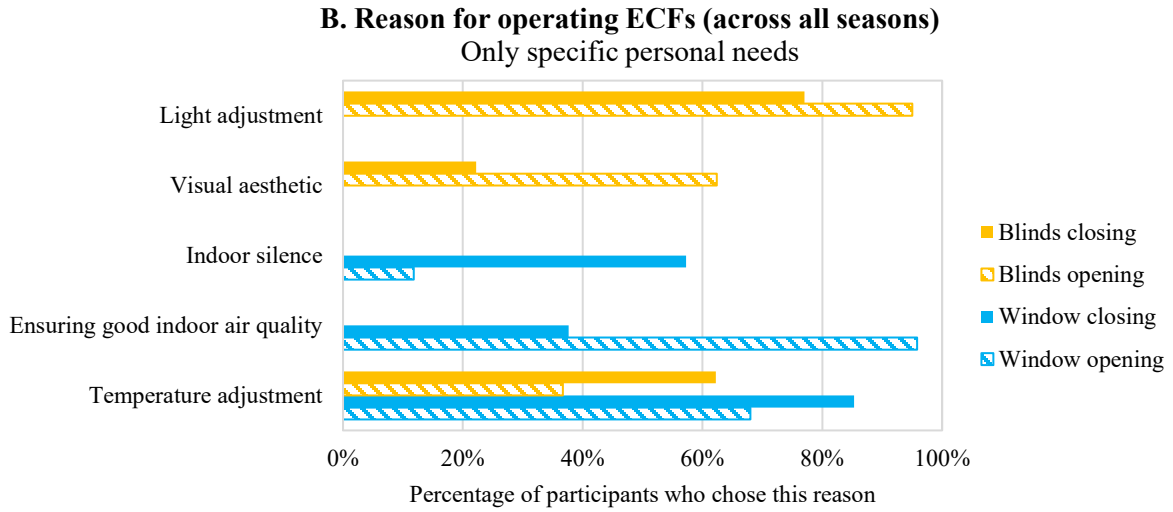


Figure 3. Reasons for operating environmental control features (ECFs**). A)** presents the main reasons for operating ECFs. Note: "Habit or rule" includes leaving, arrival, and safety/security rules. Different colors indicate different behavior of operating a particular ECF. **B)** presents a break-down of the personal needs as shown in the bottom cluster in **A**. Lighting and thermostats are not included in **B** because there is only one personal need associated with each of the two ECFs: to add more light for lighting and to combat thermal discomfort for thermostats. IAQ - indoor air quality.

Overall, participants preferred personal adjustments over technological solutions both when feeling too hot (69.6% vs. 30.4%), $\chi^2(1) = 493.9$, $p < 0.001$, and feeling too cold (78.6% vs. 21.4%), $\chi^2(1) = 1056.01$, $p < 0.001$, without considering other factors. Interestingly, there was a stronger preference for personal adjustments when feeling cold than feeling hot, $t(3169) = 9.33$, $p < 0.001$. Occupants' preference for personal adjustments was also reflected by the fact that "temperature adjustment" was the second most mentioned reason for operating windows in offices after "ensuring good air quality" (Figure 3B).

We further explored the factors affecting the first adaptive thermal action with two separate binary logistic regression analyses with demographics and contextual factors as the predictors. Countries were dummy coded with the U.S. as the reference group and entered as control variables. As Table 3 suggests, thermostat control accessibility was the strongest predictor of choosing a technological solution when occupants felt either too hot or too cold. As

expected, occupants with thermostat control accessibility were nearly twice as likely as those without control to choose a technological solution when feeling too hot or cold. Window control is another significant predictor of adaptive actions, but only when feeling too hot: occupants who could operate windows were nearly one fourth less likely to adopt a technological solution (e.g., air-conditioning) than those who cannot. Blind control did not have any effect on either situation.

Table 3
Results of binary logistic regression analyses on the first choice of adaptive action towards thermal discomfort.

	When too hot				When too cold			
Variable	*B*	*SE*	*Odds ratio*	*Sig.*	*B*	*SE*	*Odds ratio*	*Sig.*
Contextual Variables								
Office type	0.19	0.10	1.21	0.07	0.45	0.12	1.57	0.00
Occupancy hours	0.04	0.04	1.04	0.26	0.02	0.04	1.02	0.61
Environmental Control Features								
Window	-0.28	0.12	0.76	0.02	-0.14	0.14	0.87	0.29
Blind	0.03	0.11	1.03	0.82	0.06	0.12	1.06	0.61
Thermostat	0.55	0.10	1.73	0.00	0.65	0.11	1.91	0.00
Demographics								
Age	0.20	0.04	1.23	0.00	0.08	0.05	1.08	0.10
Gender	-0.34	0.09	0.71	0.00	-0.22	0.10	0.80	0.03
Brazil	-0.71	0.21	0.49	0.00	-1.42	0.34	0.24	0.00
Italy	-0.49	0.15	0.62	0.00	0.27	0.16	1.30	0.10
Poland	-0.27	0.14	0.76	0.06	0.68	0.16	1.97	0.00
Switzerland	-0.67	0.23	0.51	0.00	-0.10	0.26	0.91	0.70
Taiwan	0.52	0.17	1.67	0.00	0.76	0.19	2.14	0.00
(Constant)	-1.03	0.26	0.36	0.00	-1.95	0.29	0.14	0.00

Note: This table lists the standardized regression coefficients (Bs), standardized errors (SEs), and odds ratios of the binary logistic regressions that predict the choice of a technology solution (as opposed to a personal adjustment) as the first response to thermal discomfort. Choice of a technological solution was coded as 1 and the choice of a personal adjustment was coded as 0. For office type, single-occupant office was coded as 1 and shared office as 0; for gender, female was coded as 1 and male as 0. The U.S. was used as the reference group in dummy coding and is therefore not in the table.

Office type was an important predictor of adaptive actions when feeling too cold. Occupants in single-occupant offices were about half more likely to choose a technological solution than those in shared offices when feeling too cold. When feeling too hot, occupants in single-occupant offices were also more likely to choose a technological solution, but the pattern was marginally significant. These results are consistent with the previous finding that occupants in shared offices rely more on individual or psychological coping mechanisms (e.g., adding a layer of clothes) rather than challenging the current ECF settings, which may cause discomfort to others [14,15].

Regarding demographics, we found that women are less likely to choose a technological solution than men when feeling both too hot and cold. Several previous studies found that women are more likely to make personal adjustments than men, rather than standing up to adjust a control system, even though women are more critical of their thermal environment [45,46]. We also found older occupants preferred to use technological solutions when it was too hot, and the pattern was marginally significant in the situation of feeling too cold.

After controlling for demographic and contextual factors, we found office occupants in Brazil, Switzerland, and Italy had the strongest preference for personal adjustments when feeling too hot, while those in Taiwan had the least. That might be attributed to the differences in climate and building features. Taiwan's average peak temperature in summer (i.e., 38.0°C in Taipei for the past 5 years) was typically higher than that of Brazil (i.e., 31°C in Florianópolis in the past 5 years) in the cities where the survey was conducted [47,48]. Additionally, reducing the indoor temperature below 23 °C through air conditioning is inferred to make occupants feel comfortable due to high humidity in Taiwan [49,50]. These factors make personal adjustments less effective in restoring thermal comfort in Taiwan than in Brazil. When feeling too cold,

Brazilians still had the strongest preference for personal adjustments, while Taiwanese and Polish occupants had the least. The result with Polish participants is not surprising. The low temperature in the winter of Poland usually drops below 0°C; therefore, office occupants are accustomed to rely on technological solutions. The contrast between Brazil (Florianópolis) and Taiwan (Taipei) may be due to the fact that Taipei is somewhat colder than Florianópolis (average lowest temperature 8°C vs. 15°C), although both cities have mild winters [51]. It is more often for Taipei occupants to use a small portable heater while the buildings in Taipei and Florianópolis are typically not equipped with central heating systems [52,53].

Figure 4A and 4B reflect the percentage of occupants who prefer technological solutions in each country and how it relates to the prevalence of sharing office space and access to thermostat controls. Interestingly, the U.S. occupants' preference for technological solutions is stronger when feeling too hot than feeling too cold, while the differences in other countries are not so salient. It is worth noting that the preference for technological solutions does not necessarily increase with the increase in the portion of occupants who have thermostat controls, suggesting that the impact of thermostat control on preferred adaptive actions differs across countries. Similarly, office type does not have a unified impact across the countries.

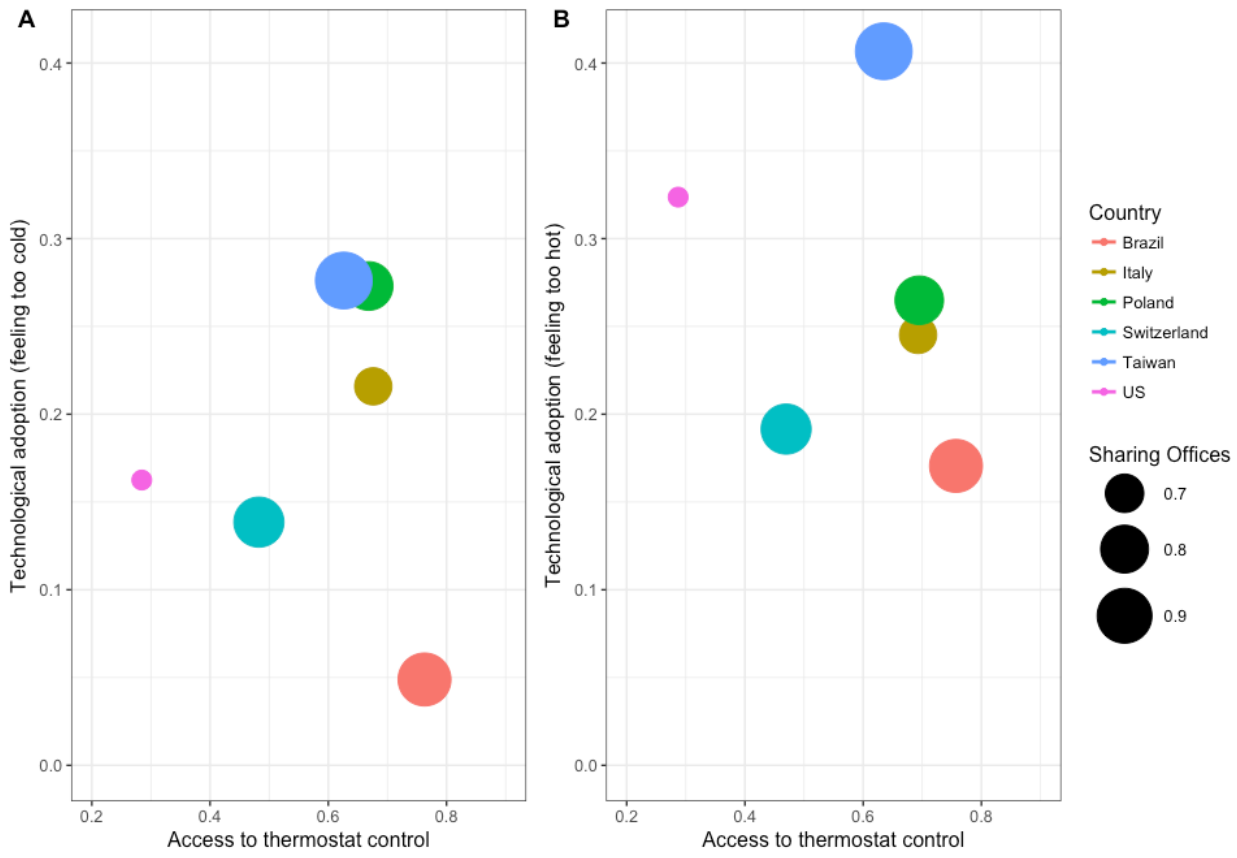


Figure 4. Country stance on office sharing, thermostat control, and preference for technological solutions. **A)** illustrates the percentage of participants that chose a technological solution when feeling too cold as the first adaptive action on the y-axis, while **B**) refers to choosing a technological solution when feeling too hot as the first adaptive action. On both figures, the size of the circles depicts the portion of participants that share offices, and the x-axis illustrates the percentage of participants that have access to thermostat control. Each color represents a country.

3.7. Factors that influence conformity intention across countries

Results of the ANOVA show that all countries have positive intentions to conform to the group norms of sharing ECFs, while the levels of positivity differ across countries, F (5,3379) = 14.67, $p < 0.001$. To identify the factors that influence conformity intention while controlling for the country of residence, an ordinary least squares (OLS) regression analysis was conducted (Table 4). Our analysis suggests that several social-psychological variables are positive predictors of conformity intention. Consistent with the TPB [54], positive attitudes, higher PBC,

and stronger injunctive norms all positively predicted conformity intention in our study. Interestingly, while the impact of IEQ satisfaction was only marginally significant, occupants who had a stronger belief in the positive influence of IEQ on their productivity were significantly more likely to conform. This suggests that the perceived impact of IEQ on productivity was a more important predictor than the measure of IEQ itself, and that occupants may be willing to accept a group decision on ECFs to obtain higher IEQ and productivity for co-workers. Knowledge about ECFs, however, was not a significant predictor.

Table 4
Results of regression analysis on group conformity intention of sharing ECFs

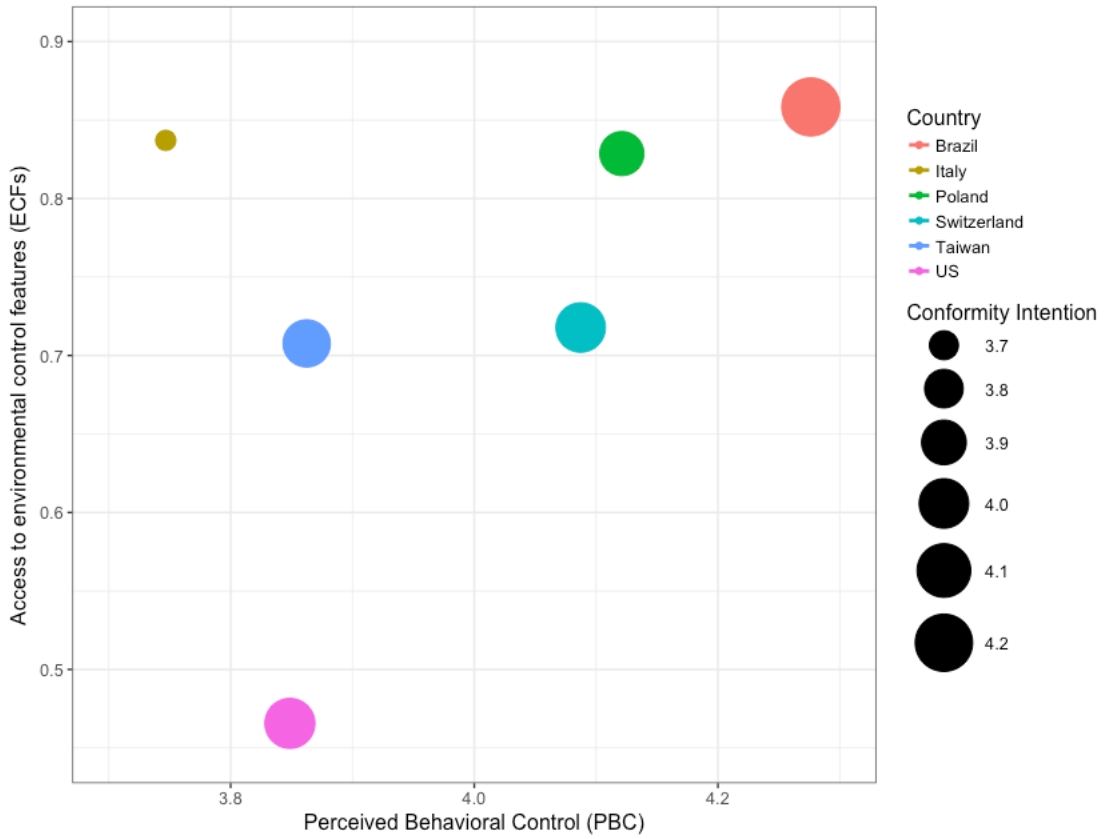
Variable	*B*	*SE*	*t*	*Sig.*
Social-Psych Variables				
Attitude	0.26	0.02	15.22	0.00
Injunctive norms	0.13	0.02	8.40	0.00
PBC	0.23	0.02	14.43	0.00
Knowledge	-0.00	0.02	-0.04	0.97
IEQ satisfaction	0.03	0.02	1.63	0.10
IEQ productivity	0.04	0.02	2.49	0.01
Contextual Variables				
Office type	-0.18	0.03	-5.32	0.00
ECF accessibility	-0.09	0.01	-6.10	0.00
Occupancy hours	0.01	0.01	0.71	0.48
Demographics				
Age	-0.03	0.01	-2.27	0.02
Gender	0.09	0.03	3.30	0.00
Brazil	-0.01	0.06	-0.13	0.89
Italy	-0.31	0.04	-7.30	0.00
Poland	-0.30	0.04	-7.03	0.00
Switzerland	-0.25	0.06	-3.95	0.00
Taiwan	-0.29	0.06	-5.30	0.00
(Constant)	1.81	0.12	15.55	0.00

This table lists the unstandardized regression coefficients (Bs), standard errors (SEs), and *t* values of the regression model on intention to conform for all respondents. For office type, single-occupant office was coded as 1 and shared office as 0;

for gender, female was coded as 1 and male as 0. The U.S. was used as the reference group in dummy coding and is therefore not in the table.

Among contextual factors, the length of occupancy hours was not a significant predictor. Occupants with higher ECF accessibility and in single-occupant offices were less likely to conform, suggesting that occupying a single space and the convenience of accessing ECFs may direct occupants to not consider others' opinions or make occupants less willing to give up controls because of a loss aversion effect [15].

Comparing across countries, occupants from Brazil and the U.S. had higher group conformity intention than those from Italy, Poland, Switzerland, and Taiwan after accounting for social-psychological, contextual, and demographic factors. Figure 5 serves as an example, illustrating how certain social-psychological and contextual factors interacted and affected conformity intention across countries. We found PBC increases with ECF accessibility, in general, except in Italy, where the PBC level was low despite relatively high ECF accessibility. The level of conformity intention, however, did not always correspond to the level of PBC or ECF accessibility, highlighting the need to further analyze the factors that affect the conformity intention to share ECFs in each country.


Access to environmental control features (ECFs)
0.9
0.8
0.7
0.6
0.5
3.8
4.0
4.2
Perceived Behavioral Control (PBC)
Country
Brazil
Italy
Poland
Switzerland
Taiwan
US
Conformity Intention
3.7
3.8
3.9
4.0
4.1
4.2

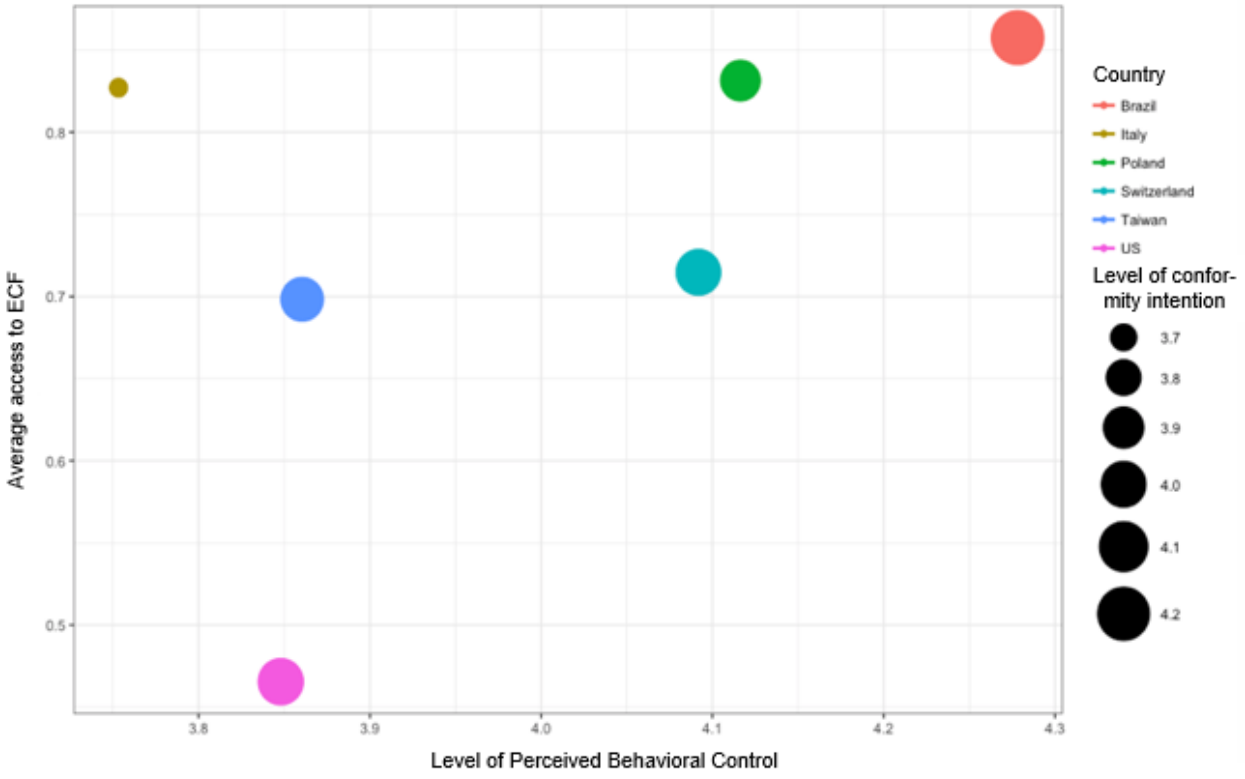

Average access to ECF
0.8
0.7
0.6
0.5
3.8
3.9
4.0
4.1
4.2
4.3
Level of Perceived Behavioral Control
Country
Brazil
Italy
Poland
Switzerland
Taiwan
US
Level of confor-
mity intention
3.7
3.8
3.9
4.0
4.1
4.2

Figure 5. Country stance on ECF accessibility, PBC, and conformity intention. The size of the circles depicts the level of conformity intention (without controlling for other factors); the y-axis illustrates the average level of ECF accessibility; the x-axis illustrates the level of PBC. Each color represents a country.

Brazil and the U.S., for example, were the two countries with the highest conformity intention; but the influencing factors differed to some degree. The regression models for these two respective countries (Table 5) showed that attitude was the strongest predictor of conformity intention for U.S. occupants, whereas PBC was the strongest predictor for the Brazilians. For both countries, higher ECF accessibility was associated with lower conformity intention. Interestingly, office type was a significant predictor for the U.S. occupants but not for the Brazilians. We suspect that occupying a single-occupant office lead to lower conformity intention, in particular, for occupants from more individualistic cultures. Another possible reason is that the level of ECF accessibility was generally high in our Brazilian sample, not differing between shared and single-occupant offices (M_{shared}=3.58, M_{single}=3.60); whereas the level of ECF accessibility in the U.S. was significantly higher in single-occupant offices (M_{shared}=2.43) than in shared offices (M_{single}=1.66), $t = 12.12$, $p < 0.001$.

Table 5
Results of regression analysis on the factors influencing the level of the conformity intention in Brazil and USA.

	Brazil				USA			
Variables	*B*	*SE*	*t*	*Sig.*	*B*	*SE*	*t*	*Sig.*
Social-Psych Variables								
Attitude	0.15	0.06	2.65	0.01	0.28	0.03	10.74	0.00
Injunctive Norms	0.22	0.06	3.68	0.00	0.10	0.02	4.46	0.00
PBC	0.46	0.06	8.06	0.00	0.10	0.02	4.73	0.00
Knowledge	-0.10	0.10	-1.00	0.32	0.04	0.02	1.70	0.09
IEQ satisfaction	0.04	0.07	0.58	0.56	0.05	0.03	2.02	0.04
IEQ-Productivity	0.06	0.07	0.79	0.43	0.08	0.02	3.33	0.00
Contextual Variables								
Office type	-0.03	0.15	-0.21	0.83	-0.05	0.02	-2.27	0.00
ECF accessibility	-0.12	0.05	-2.38	0.02	-0.27	0.05	-6.01	0.02

Occupancy hours	-0.01	0.04	-0.35	0.73	0.01	0.02	0.40	0.69
Demographics								
Age	-0.05	0.05	-1.03	0.30	-0.04	0.02	-2.26	0.02
Gender	0.09	0.12	0.76	0.45	0.04	0.04	0.89	0.37
(Constant)	1.48	0.55	2.70	0.01	1.99	0.19	10.68	0.00
Adjusted R^2			0.58				0.29	

This table lists the unstandardized regression coefficients (Bs) and t values of the regression models on intention to conform for office occupants in Brazil and the US. For office type, single-occupant office was coded as 1 and shared office as 0; for gender, female was coded as 1 and male as 0.

The social-psychological factors of attitudes, PBC, and injunctive norms were highly important for both cultural groups. In comparison with American occupants, injunctive norms (perceived approval from co-workers) was a stronger predictor for the Brazilian occupants. Partly, it might be that Brazilians are more collectivist than Americans and tend to avoid conflicts with ingroup members [55], which may have resulted in Brazilians preferring sharing public facilities based on norms more than American occupants. Interestingly, both IEQ satisfaction and the belief of IEQ influencing productivity were important for the U.S. occupants, but not so relevant to the Brazilians. The U.S. occupants may have a higher IEQ expectation at work in comparison to Brazilians for three reasons: 1) higher IEQ at home in the U.S. as a result of a higher purchasing power of home appliances: 90% of the American households have air conditioning whereas only 16% of Brazilian households has it [56] and U.S. ranked higher worldwide in the spending on electric home appliances [57]; 2) the stricter building standards in the U.S., including a larger ventilation rate than in Brazil: Brazilian building coding scheme is still voluntary [58,59], and it is expected to have regular revisions to overcome limitations [60], and 3) the notion that Brazilians preferred to avoid conflicts in public; therefore, any thermal discomfort had more bearing on the U.S. occupants. Lastly, knowledge was marginally significant for the U.S. occupants: higher level of perceived knowledge was associated higher conformity intention.

4. Discussion and implications

There are four main findings in this research: (1) Being in a single-occupant office and having higher ECF accessibility are negatively correlated with the intention to conform and share ECFs. Further, time spent in offices hardly matters after accounting for other factors. Future research could extend our work to examine whether the close physical proximity in shared office setting, occupancy hours and other social demographic factors creates a synergistic atmosphere for conserving energy; (2) The social-psychological variables including PBC, attitudes, and injunctive norms are the key components when predicting the norms of sharing ECFs with other factors considered. Therefore, it is important to create positive group norms and attitudes toward sharing ECFs and boosting individuals' level of PBC while providing building control technology; (3) Personal adjustments are preferred over technological solutions in reaction to thermal discomfort, which informs a new approach for building design and promoting energy savings. One possible reason for preferring personal adjustments may relate to the finding that occupants in shared offices perceive greater ease in sharing window control than thermostat control [61]; and (4) Gender differences continue to emerge in group ECFs operations. Men might have the desire to act independently from others' opinions; whereas women have a stronger desire to preserve group harmony, and thus tend to agree with the majority. Additionally, some cultures expect women to be more submissive, and this gender stereotype may motivate women's tendencies to conform [46].

This work highlights the following key suggestions which could be of interest to building architects, engineers and managers:

First, providing occupants with a certain level of control over ECFs. In some situations, too much automation may be ineffective in meeting comfort needs, which leads to unhappy or

unproductive occupants. It is important to find the right balance between automation and comfort.

Second, the design of shared office space should encourage the norms of sharing ECFs. Additionally, the design enabling sub-space level controls in shared spaces can possibly create a level of control for occupants while encouraging energy-friendly behaviors. For example, an occupant leaving his/her space can turn off his/her own lights without influencing others.

Third, new buildings design can benefit from enabling explicit and physical control features such as operable windows, moveable blinds, adjustable lights, adjustable thermostats. If such features are automatically controlled, allowing occupants understand how they work through training, can avoid issues of occupants purposely de-activate the features. Hence, enabling occupants to correctly overwrite controls can help address issues of disabling control features.

Fourth, creating an office environment that encourages occupants to utilize non-technological solutions to meet comfort needs while considering energy savings. We observed a strong tendency to obtain thermal comfort through operating windows instead of adjusting thermostats or bringing in personal equipment due to the consideration of saving energy. This tendency highlights the need for building managers to better educate office occupants about the optimal methods of personal adjustments including operating windows. For example, energy saving potential from opening/closing windows depends on outdoor temperatures and indoor airflow direction and velocity, and therefore operating windows does not necessarily save energy. This type of manual adaptive action also contributes to the discrepancy between predicted and actual building energy consumption [4,14,62]. Finally, occupants' perceived impact of IEQ on productivity affects the intention to share ECFs, and therefore has the potential

to mediate energy consumption. This finding suggests a new direction for building policymakers to consider and adjust employees' work expectations along with the design criteria of IEQ [63].

Several limitations to this research need to be addressed, which also highlights potential challenges for future research. *First*, our study sample is large and diverse; yet, it is not representative of the office population of each country. However, a bootstrapping procedure (a widely used resampling method to deal with potential bias in the original sample, [64]) conducted with our data produced a model with all the significant and non-significant variables remaining the same, suggesting that our results can be generalized to the population from which our sample was drawn. Future researchers could try tackling this challenging issue by developing a survey sampling strategy to represent the population of office buildings in different counties. Additionally, our study focuses only on the university office buildings, so our results cannot be generalized to other commercial office spaces. Future researchers should validate our research in different office settings.

Second, this study is a cross-sectional survey design focusing on occupants' self-reports without insights from non-self-report measures (including actual building features, architecture, and design information). Future researchers could investigate the impacts of these building physical factors in a more controlled environment. Self-reports on perceptions and attitudes, however, have been commonly and repeatedly proven as valid measures and to correlate strongly with normative and other group behaviors [6,25].

Third, the majority of our data were collected across different seasons and climates. For example, the data from Italy, Taiwan, Brazil and some universities in Poland were collected across spring and summer periods, while the data from Switzerland and the U.S. were collected across four seasons, which is not an ideal situation. Note that our Brazilian data were collected

during their spring to early summer, which was similar to the season of some countries. To avoid the seasonal and climate differences across countries, we adopted two approaches: first, we asked participants to report the reasons of operating ECFs across four seasons (see Fig. 3A and 3B), and second, we measured adaptive thermal actions as the response to the situation when occupants *typically* feel too hot or too cold at work rather than to the current thermal situation, regardless of outdoor temperatures or seasons**.** Importantly, our social-psychological variables (e.g., norms of sharing ECFs, attitudes, etc.) and contextual factors (e.g., accessibility to ECFs, occupancy hours and office type) would not typically change due to the seasons or outdoor temperatures. Another limitation concerns the diverse climates, especially in countries with great climate diversification such as Brazil and other countries. In order to address this limitation, our regression models were obtained with the country of residence as control variables so that the climate was also controlled for. Yet, future studies should gather more representative samples from a wider territory across countries with similar or different climate in order to compare the effects from climates, seasons, and other relevant aspects.

5. Conclusion

This study bridges a gap in occupant behavior literature by examining human-building interaction and its relationship with group dynamics within the context of building ECFs operations. Understanding how occupants share ECFs is the prerequisite for estimating occupants' energy use in helping design more functional and effective technical solutions (HVAC & and their control) for indoor environment comfort.

The importance of interdisciplinary research in the field of energy and occupant behavior is well documented [25,65], and Stern [66,67] asserts the importance of merging human behavior with energy research. A shift from assessing individual behaviors to evaluating how group

dynamics and social influences affect human-building interaction is needed to better understand energy consumption and carbon reduction and its possible trends in office settings. Thus, we aim to overcome these barriers with our interdisciplinary approach, which can further improve policy-making process and the design and operation of buildings [5]. Specifically, this study explores human-building interaction through the lens of social psychological and organizational and building physics research, adding a unique perspective to the literature. It also provides rich information for building related research to understand the well-cited mismatch between forecasted and actual building energy use. In practice, it offers insights for developing tailored and effective programs and policies to help buildings and their organizations operate at peak performance. In fact, researchers have outlined the need for energy policies to utilize socio-technical approaches to analyze building energy use [68]. Therefore, interdisciplinary studies help researchers develop a more holistic understanding of energy use, while they also develop more holistic solutions to avoiding excessive energy use.

This study suggests that there are no one-size-fits-all solutions across culture or gender to enable effective human-building interactions for occupants' comfort and energy savings. Considering cultural and building specific characteristics, researchers and policymakers should conduct in-depth research regularly to better understand their occupant behaviors and inform effective retrofits of buildings or improvement of operations. An ideal building design is to enable and use both sensing and qualitative feedback to automatically and periodically learn occupants' habits, motivations and needs. More importantly, while reducing carbon emissions is a global mission, no universal policies could succeed without understanding how building technologies and social-psychological factors affect energy consumption in different countries or regions. Our research provides insights for building designers and policymakers to develop

potential energy-saving strategies which integrate technological and behavioral considerations for a well-built work environment.

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