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Human-building interaction at work: Findings from an interdisciplinary cross-country survey in Italy

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Abstract

This study presents results from an interdisciplinary survey assessing contextual and behavioral factors driving occupants' interaction with building and systems in offices located across three different Mediterranean climates in Turin (Northern), Perugia (Central), and Rende (Southern) Italy. The survey instrument is grounded in an interdisciplinary framework that bridges the gap between building physics and social science environments on the energy- and comfort-related human-building interaction in the workspace. Outcomes of the survey questionnaire provide insights into four key learning objectives: (1) individual occupant's motivational drivers regarding interaction with shared building environmental controls (such as adjustable thermostats, operable windows, blinds and shades, and artificial lighting), (2) group dynamics such as perceived social norms, attitudes, and intention to share controls, (3) occupant perception of the ease of use and knowledge of how to operate control systems, and (4) occupant-perceived comfort, satisfaction, and productivity. This study attempts to identify climatic, cultural, and socio-demographic influencing factors, as well as to establish the validity of the survey instrument and robustness of outcomes for future studies. Also, the paper aims at illustrating why and how social science insights can bring innovative knowledge into the adoption of building technologies in shared contexts, thus enhancing perceived environmental satisfaction and effectiveness of personal indoor climate control in office settings and impacting office workers' productivity and reduced operational energy costs.

Keywords

Human-building interaction; occupant behavior; office buildings; questionnaire survey; interdisciplinary framework; indoor environmental comfort

1. Introduction

After decades of international research and state-of-the-art advances, the field of building occupant behavior is maturing, bringing insights from psychology and building science together. [1–4]. Beginning early in the 1990s, psychologists such as Stern discussed the human’s desire for control over environmental factors [5]. Similarly, in the energy research field, Humphrey first introduced the principle of human adaptation as the concept of homeostasis: *“if a change [of the indoor environmental conditions of a space] occurs such as producing discomfort, people react in a way to restore their comfort condition”* [6].

The link between occupants and building controls in office buildings is managed by performance optimization scenarios and controlled by building automation systems (BAS) and energy management and control systems (EMCS) [7]. This interaction also requires management decisions about building operation, which are regulated by energy codes and standards (e.g., ASHRAE Standards [8, 9]) and conform to the specific policies and needs of building owners and operators.

Traditional BAS and EMCS are used to delimit comfort conditions based on fixed values recommended by these codes and standards, based on norms [8, 10]. The concept of occupant comfort was introduced into office building design in the early 1970s, with Fanger’s theory of experimental and statistical measure of comfort levels (PMV and PPD) in mechanically ventilated buildings [11]. According to this theory, thermal comfort expectations were explained based on physics and heat transfer phenomena under experimental laboratory settings [11]. Since then, building technological solutions have been developed to ensure constant and neutral comfort conditions for all office contexts and the majority of occupants [12]. As an example, office space thermostat settings are generally regulated to ensure an 80% average in occupant satisfaction [13]. Nonetheless, the link between satisfaction and comfort has been demonstrated progressing beyond the physical parameters controlled by the BAS and EMCS. Several studies demonstrated that occupants perceiving higher control over their indoor environment were more satisfied (85% more) than the ones who have or perceive less control capability [21–26]. Also, to the extent that users perceive positive realization of control, their satisfaction over the indoor environment is guaranteed, if not augmented [20]. Prohibiting specific actions or too much persuasion can be perceived as constraints, resulting in a desire for what has been banned or restricted—or even a repulsion towards the persuading message [28]. On the contrary, behavioral selection can be perceived as stressful. This means the greater the number of behavioral options, the more difficult the task of selection. Following from this, people tend to be more dissatisfied with the choices they have made, provoking a vicious circle of demotivating effects [27]. Scholars demonstrated that choices of control options can be explained by behavioral and personality psychology [29]. Due to the non-mechanistic and dynamic characteristics of human behaviors, comfort preferences, requirements, and needs, the operation of heating, ventilation, and air conditioning (HVAC) and control systems may largely vary in office spaces. Simulation studies have confirmed that office workers who are proactive in using building controls with the purpose of saving energy (i.e., turning off lights and HVAC systems, plug loads, and equipment when not necessary) consume up to 50% less energy than their peers who are not able to implement control actions [14]. Similarly, through field studies, Masoso [15] described the "dark side" of building energy use, by analyzing the energy-intensive consumption patterns of monitored office building

energy-related occupants' behavior – i.e., working longer hours, or leaving computer screens and lights on when leaving the spaces.

Menassa, et al. [16] developed a comprehensive framework to quantify about 20% achievable behavioral-driven energy savings using an optimized link between occupant behavior and building controls [17]. In their study, building performance simulation programs were employed to reproduce the effect of improved occupants' control of energy and building systems (e.g., turning off lights when not needed, adjusting thermostats setpoints, relying on natural ventilation and daylighting) on diverse operating end uses. Ehrhardt-Martinez reported [17] an average of 7% energy savings from observed improvement in controls of the thermostat settings and usage of computer and office appliances. Greater energy savings, averaging between 8.5% and 14%, are recounted when including the role of building operators (e.g., management of lighting controls), and, on average, up to 15% when including user engagement campaigns at work [18]. What significantly emerges from these studies is that observed energy savings are typically smaller than the predicted potential, with two consequences.

First, as confirmed by recent studies [19], behavioral energy savings based on an optimized link between occupant behavior and building controls vary with building-related characteristics (e.g., building type, size, and vintage) and building-independent effects [20] (e.g., eco-feedback, network synergy, etc.). Office spaces entail the greatest energy-saving potential among commercial buildings, followed by educational buildings [17]. Regarding building size, operational energy saving opportunities emerge relatively larger in small offices (26%—27%) than big offices (10%—11%). This can be explained by the fact that small office buildings typically tend to be manually operated, and rely on occupant interactions with the building controls more, while, to a greater extent, large office buildings use centrally controlled HVAC and lighting systems, limiting occupants' interactions.

Secondly, optimized occupants' interaction with the building envelope and control systems emerge as a function of specific barriers, incentives, and contextual factors [21-23], which are often neglected or overlooked [24]. These contextual factors include, but are not limited to, the diversity of occupants' working profiles [14, 15, 16] from front desk workers to management positions; the behavioral and occupancy patterns [28, 29] varying from part-time to full-time employees; workers' gender, age [30, 31], and socio-demographic background [32]. These factors affect comfort needs, attitudes [33], habits, preferences, and, hence, the interaction with controls available in the office environment.

With the introduction of the neurophysiological hypothesis of adaptive comfort theories for naturally ventilated buildings introduced by de Dear and Brager in the 1990s [34, 35], contextual comfort stances started to drive enhancements and applications of codes and standards regulating energy performance in commercial buildings worldwide [8]. More recently, adaptive comfort theories have progressed to support building control technologies that influence the modern idea of personalized provisions of comfort for all [35-37]. Also, the possibility of personal adaptations to the indoor environment (i.e., modification of clothing levels [36–38]) has been theorized [1,13] and investigated as one of the energy- and comfort-related behaviors having an impact on building energy consumption [39]. Nonetheless, local variations of indoor environmental conditions, contextual factors, and diversity of occupants' preferences (e.g., gender, age,

culture) are rarely taken into consideration by personalized office buildings control systems to date [32]. Recently, the use of human-building interaction-related data, with machine learning techniques and artificial intelligence, in combination with social science insights, has been theorized as a promising interdisciplinary research field to increase energy efficiency and reduce energy consumption in the building sector [40]. This approach embraces disciplines such as sociology, social psychology, data science, and building physics to find behavioral patterns of energy consumption in residential [41] and commercial sectors [42]. Specifically, in the commercial sector, scholars [23] claimed that the uptake of behavior-based interventions among employees calls for an interdisciplinary approach, having an impact on the organization's energy, environmental, and economic performances.

This study attempts to identify climatic, cultural, and socio-demographic influencing factors, as well as to establish the validity of the survey instrument and robustness of outcomes for future studies. The final goal of this work is to illustrate *why and how* social science insights can bring innovative knowledge to building technologies—enhancing occupant satisfaction with indoor office environments, and having an impact on perceived comfort and productivity while reducing energy costs.

2. Methodology

In a previous correlated study, as introduced by D'Oca, et al. [42], the authors developed a research framework synthesizing building physics with social science for studying human-building interaction in office settings [43]. The interdisciplinary nature of the framework is based on the adoption of building physics and social theories explaining the environmental and cognitive processes underpinning the comfort-related human-building interaction in shared office settings. The Drivers–Needs–Actions–Systems (DNAS) framework [44] is chosen for rationalizing comfort-related adaptive behaviors in buildings. The Social Cognitive Theory (SCT) from Bandura [45] is selected as a general theory explaining the environmental, cognitive, and behavioral factors influencing the human decisionmaking process in social contexts. Following these schemes, the research framework attempts to provide insights into four key learning objectives:

- (1) Improve the understanding of occupants' environmental, cognitive, and behavioral motivational drivers leading humans to interact with the control systems (such as opening/closing windows, operating blinds and shades, adjusting thermostats and artificial lights) in socially dynamic environments such as office settings
- (2) Investigate how subjective norms, attitudes, as well as
- (3) Group negotiation and workspace dynamics influence the group interaction with control systems and how adaptive control behavior is influenced by the perceived ease of usage and knowledge of building technology
- (4) Occupants' perceived comfort, satisfaction, and productivity (Figure 1).

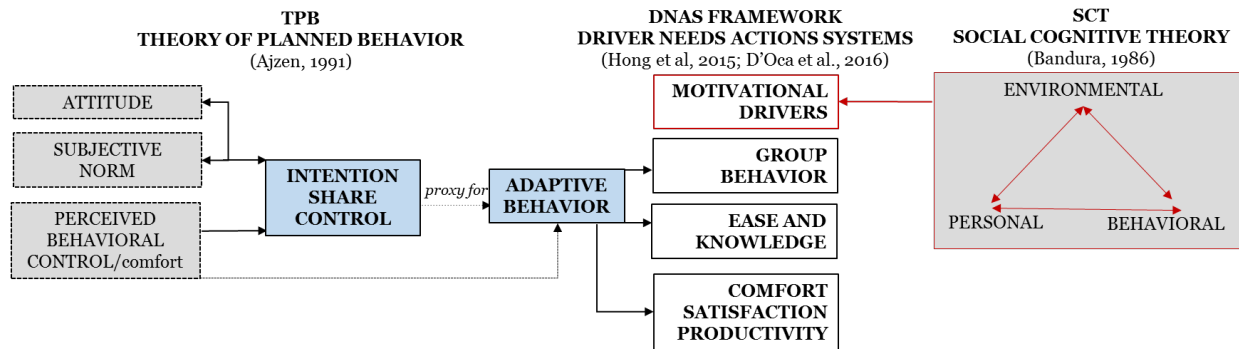


Figure 1. The adopted interdisciplinary research framework synthesizing the TPB, SCT, and the DNAS framework to address four key learning objectives: motivational drivers, group behavior, ease and knowledge, satisfaction and productivity [43]

2.1. The survey questionnaire

Based on the proposed research framework, a survey questionnaire has been designed consisting of 37 questions (Table 1). Measures of the variables are made either through Likert-type scales (i.e., Fanger’s 7-point comforts scale or 5-point scale where 1 typically indicates strong disagreement and 5 strong agreement) or control questions. Every survey question in the questionnaire is implemented within the Qualtrics Software [46] environment and represents one or more independent variables, correlated with a variable ID, to articulate the measures of the investigation. Each survey response is recorded through the Qualtrics software together with the date of compilation and geographical coordinates of the University Institution. To meet data-privacy requirements, the survey remains anonymous, and no personal identification or sensitive data are collected.

Table 1. Summary of the 37 survey questions, correlated with the variable ID

| | Variable | Var ID | Measure | Survey Question (English original version) |
|----|--------------------------|--------|---------------|---|
| 1 | Comfort | Q1.1 | Comfort Scale | Please tell us how you currently feel in your workspace. |
| 2 | Satisfaction | Q1.2 | Likert Scale | To what extent are you satisfied or not satisfied with the following current conditions? |
| 3 | Productivity | Q1.3 | Likert Scale | How would the following conditions influence your current productivity at work? |
| 4 | Thermal Discomfort | Q2.1 | Control | How would you best describe the sources of your thermal discomfort at work, if there are any? |
| 5 | Visual Discomfort | Q2.2 | Control | How would you best describe the sources of your visual discomfort at work, if there are any? |
| 6 | Acoustic Discomfort | Q2.3 | Control | How would you best describe the sources of your acoustic discomfort at work, if there are any? |
| 7 | IAQ Discomfort | Q2.4 | Control | How would you best describe the sources of your air quality discomfort at work? |
| 8 | Clothing level | Q8.3 | Control | How would you best describe how you are currently dressed? |
| 9 | Intention | Q4.1 | Likert Scale | Statements regarding opinions on intention to share control devices in the workspace. |
| 10 | Behavioral Beliefs | Q4.3 | Likert Scale | Statements regarding coworkers sharing control of devices in the workspace. |
| 11 | Normative Beliefs | Q4.4 | Likert Scale | Statements regarding coworker’ expectations on sharing control of devices in the workspace. |
| 12 | Knowledge | Q.45 | Likert Scale | Statements regarding knowledge of control devices in the workspace. |
| 13 | Ease of Control | Q4.2 | Likert Scale | If I want to, I can easily share the control of... |
| 14 | Role | Q8.1 | Control | How would you best describe your work position? |
| 15 | Occupancy | Q8.2 | Control | In a typical week, how many hours do you spend in your personal workspace? |
| 16 | Age | Q8.4 | Control | What’s your age range? |
| 17 | Gender | Q8.5 | Control | What’s your gender? |
| 18 | Culture | Q8.6 | Control | Which is your ethnic background? |
| 19 | Geography | Q8.7 | Control | In which country have you spent the majority of your life? |
| 20 | Education | Q8.8 | Control | The highest level of education you have completed or are in the process of completing. |
| 21 | Window | Q3.1 | Control | Do you have control to open or close the windows in your workspace? |
| 22 | Blinds/shades | Q3.4 | Control | Do you have control to open or close the window blinds or shades in your workspace? |
| 23 | Thermostat | Q3.7 | Control | Do you have control to adjust the thermostat (heating/cooling) in your workspace? |
| 24 | Lights | Q3.9 | Control | Do you have control to turn on or off the light switch(es) in your workspace? |
| 25 | Windows opening | Q3.2 | Control | Please tell us why you normally open the window(s) at work during different seasons? |
| 26 | Windows closing | Q3.3 | Control | Next, please tell us why you normally close the window(s) at work during different seasons? |
| 27 | Blinds/shades opening | Q3.5 | Control | Why do you open the blinds or shades in your workspace during different seasons? |
| 28 | Blinds/shades closing | Q3.6 | Control | Why do you close the blinds or shades in your workspace during different seasons? |
| 29 | Thermostat adjustment | Q3.8 | Control | Why do you adjust the thermostat in your workspace during different seasons? |
| 30 | Lights on/off | Q3.10 | Control | What are the possible reasons why you normally switch the lighting (on or off) in your workspace? |
| 31 | Adaptive behavior (hot) | Q6.1 | Control | If you feel hot at work, over a typical workweek of this season, what is your first - second action? |
| 32 | Adaptive behavior (cold) | Q6.2 | Control | If you feel cold at work, over a typical workweek of this season, what is your first - second action? |
| 33 | Density | Q5.1 | Control | How many people in your workspace share control of the following devices? |
| 34 | Group Negotiation | Q5.2 | Control | How often do you negotiate with your coworkers about sharing control of the following devices? |
| 35 | Group Norms | Q5.3 | Control | How is the decision made to adjust your office environment z)? |
| 36 | Building type | Q7.1 | Control | In what year the building your workspace is located in was built? |

2.2. Translation guidelines

The survey instrument, originally developed in English for the future worldwide implementation process, was translated into an Italian questionnaire. Semantic and conceptual equivalence of survey questions was guaranteed by retranslating the same survey questions back into English again, before finalizing translated versions, following a double translation process (DTP) [47]. The two English versions were compared for inconsistencies, mistranslations, meaning, cultural gaps, and lost words or phrases. If any differences were found, translators were consulted to find out why this had occurred and how the instrument could be revised. A few iterations of this comparative step occurred to ensure proper translation before the final translated version was approved. The Italian version of the survey was added into the online Qualtrics Software. Individual links to the questionnaires were created and sent to the target groups at the institutional mail address of the three Italian universities.

2.3. Cross-country validation

The survey questionnaire was validated in three university institutions across Italy located in Turin (Polito), Perugia (UniPg), and Rende (UniCal).

Italy is characterized by a typical hot-summer Mediterranean climate (Csa) as defined by the Köppen Climate Classification System, the most widely used for categorizing the world's climates [48]. The three institutions are characterized by different micro-climates, with diverse heating (HDD) and cooling (CDD) degree days. Estimates of the HDD are Celsius-based, two-year average (2015 to 2016) for a base temperature of 15.5 C (Figure 2).

Turin (hereafter “North”) is one of the biggest metropolitan cities in Italy located in the northern humid subtropical climate zone (HDD = 1684; CDD = 961), and has a population of around 890000 inhabitants.

Winters are moderately cold but dry; summers are mild in the hills and quite hot in the plains.

Perugia (hereafter “Center”) is an Italian city located in the central part of Italy, and has a population of around 167000 inhabitants. The city experiences a humid subtropical climate (HDD = 1397; CDD = 1137).

The climate in this area has mild differences between highs and lows, and there is adequate rainfall year round. Rende is a small city in Italy that has a population of around 35600 inhabitants. The climate in Rende (hereafter “South”) is warm and temperate, typical of the southern Mediterranean climate on the coast of Italy (HDD = 864; CDD = 1461). The rain in Rende falls mostly in the winter, with relatively little rain in the summer.

Figure 2. Celsius-based two-year-average (2015 to 2016) HDD and CDD estimations for a base temperature of 15.5C for Turin, Perugia, and Rende, Italy. Estimates were made from www.degreedays.net, using temperature data from www.wunderground.com

3. Results

The targets for the proposed survey were administrative staff, faculty members, and students that regularly occupy their working space. The Qualtrics survey link was sent to the sample through the institutional e-mailing list of the three Universities (Polito, UniPg, UniCal) over a period of four weeks during the spring season (from April 5th to May 8th, 2017). Three reminders were sent to the participants at the end of each week. A total number of 1160 valid responses were collected from the online questionnaire (Table 2). Despite incentives (see Section 4.2), the response rate was low (between 11% and 16%).

Table 2. Response rate of the survey questionnaires in the three university institutions

| | PoliTo - Turin | UniPg - Perugia | UniCal - Rende |
|----------------------|----------------|-----------------|----------------|
| Total Valid | 502 | 405 | 253 |
| Total Sent | 4424 | 2991 | 1598 |
| Response Rate | 11% | 14% | 16% |

Survey compilation time (time respondents spent answering the whole survey) was around 20 minutes for the majority (80%) of the collected responses, and no predominant variation in compilation time was found among the three institutions.

Gender of respondents was almost equally distributed (50% male and 48% female). Respondents are most frequently full-time employees (with 31-40 hours workspace occupancy), who typically occupy shared or private offices (33%), or shared open offices (30%). The remaining respondents did not specify their office configuration (this question was not mandatory). Cubicle spaces are seldom used in the sample (2%). Significantly, single private offices emerge typically occupied by men (61%) in the range 40-61 years old, and less frequently by women (37%) or younger people in the range 18-28 years old (1%). The majority of the sample population holds a PhD or master's degree (41%), or a master's or an equivalent five-year degree (36%).

3.1. Perceived Thermal Comfort

To measure perceived thermal comfort, respondents were asked how they felt in their workspace at the moment the survey was compiled. Thermal sensation rates were coded on a Likert Scale, where 1 indicates hot discomfort (1= Hot) and 7 indicates cold discomfort (7 = Cold).

A Chi-square goodness-of-fit test was performed to determine the correlation of the comfort measure with the other numerical attributes weighted on a 5-point Likert scale, to which a normalization procedure was applied. Also, only those attributes, whose weights met the minimum criterion of 0.8, were selected through factor loading. All the measures were included in the Chi-square test. Specifically, a correlation having statistical relevance was found between perceived thermal comfort and satisfaction with the indoor temperature ($X^2 = 241$; $P < 0.001$) and indoor air quality ($X^2 = 88$; $P < 0.001$). The influence of indoor temperature ($X^2 = 151$; $P < 0.001$) and indoor air quality ($X^2 = 88$; $P < 0.001$) on perceived productivity, as well as gender ($X^2 = 48$; $P < 0.001$), also emerged as factors that correlate to the reported perceived thermal comfort (Figure 3). Statistical significance of these correlation is tested and confirmed, with all the tests of variables having P-values less than 0.001.

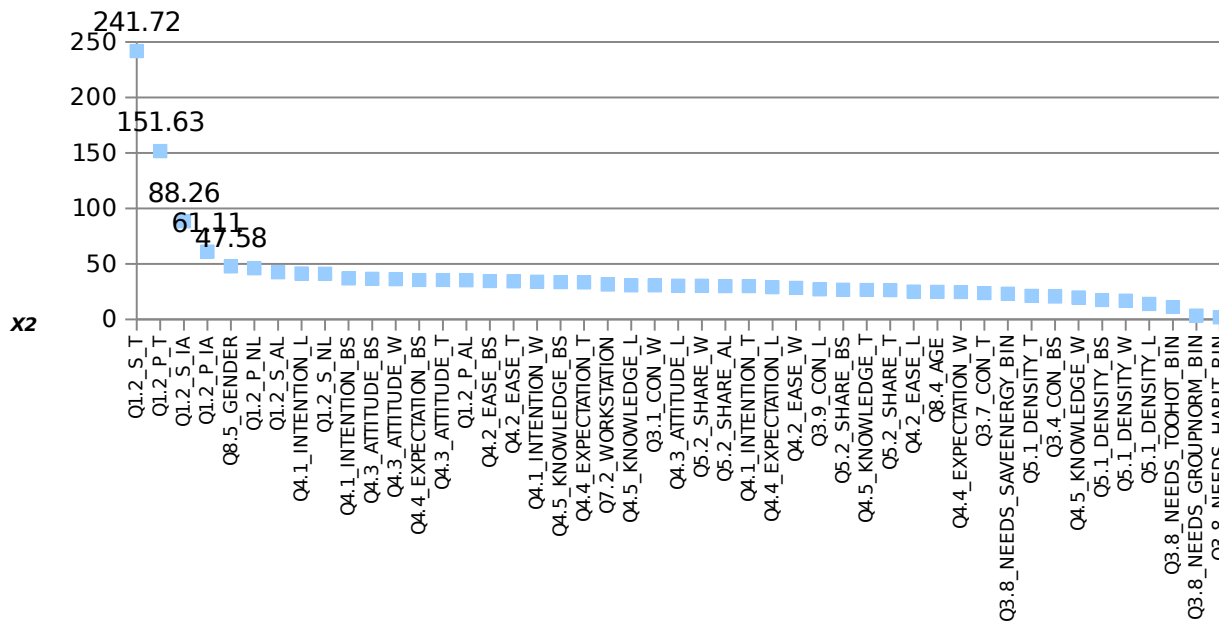


Figure 3. Chi-square goodness-of-fit test statistics, used to determine correlation of comfort measure to other numerical attributes (after normalization)

Following the main results of the Chi-square and statistical significance tests, we further ran a variable importance analysis, as described in [49, 50], to test whether and how indoor temperature, indoor air quality, and gender influence perceived thermal comfort. In Table 3, results of the order logistic regression of these selected attributes on thermal comfort are presented, including the standard error, z-values, 95% CIs and P-values.

Table 3. Results of the order logistic regression, performed with Stata [59], on the selected attributes influencing perceived thermal comfort

| Variable ID | Std. Err. | z-value | P value | 95% CIs | |
|-------------|-----------|---------|---------|-----------|-----------|
| Q12_S_T | 0.0473916 | -2.79 | 0.005 | 0.7687582 | 0.9548938 |
| Q12_S_IA | 0.0529416 | -0.65 | 0.514 | 0.8664517 | 1.074379 |
| Q12_P_T | 0.0452732 | -2.26 | 0.024 | 0.8069608 | 0.9847218 |

| | | | | | |
|-------------|-----------|-------|-------|-----------|----------|
| Q12_P_IA | 0.0541435 | -0.56 | 0.577 | 0.8688089 | 1.081472 |
| Q8.5_GENDER | 0.1430915 | 1.91 | 0.056 | 0.9941956 | 1.559857 |

Satisfaction with the indoor temperature, influence of temperature on productivity and gender emerge as variables influencing the perceived thermal comfort, having statistical significance.

Motivational Drivers

Figure 4 illustrates a comparative analysis of the key self-reported motivational drivers of exercised control of building technologies gathered in the office environments located in Northern, Central, and Mediterranean climatic zones in Italy. Behavioral choices include occupants' interaction with window opening, window closing, blinds and shade opening, blinds and shade closing, thermostat adjustment, and light switching. Office workers mainly open windows to have fresh air (by natural ventilation), while they typically close windows because the indoor temperature is perceived as too cold or too warm. Window blinds and shades are more frequently pulled up or opened to let more daylight in the office space, while they are drawn mainly to reduce glare on the computer screens or workspace. Thermostat set points and lighting systems are generally regulated to restore comfort conditions in the workspace (because the temperature is perceived as too hot or too cold or to adjust lighting levels in the room) and less frequently as a consequence of an energy conservation behavior.

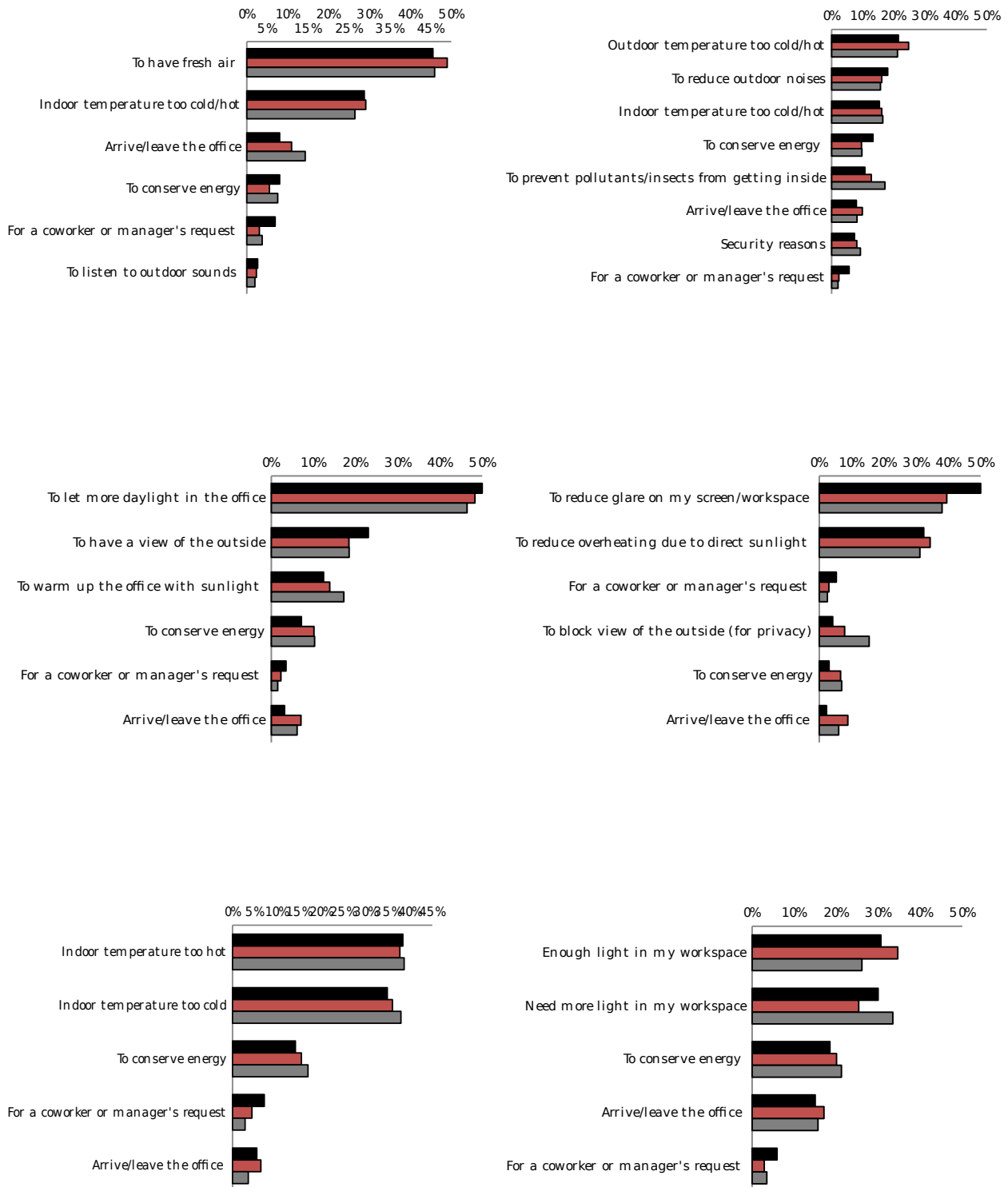


Figure 4. Motivational drivers of behavior (self-reported exercised behavioral control) in Northern-continental (black), Central-mild (red) and Southern-Mediterranean (gray) climatic zones in Italy. From the upper left to the right side: Window Opening, Window Closing, Blinds and Shade Opening, Blinds and Shade Dawning, Thermostat Adjustments, Light Switching.

3.2. Group Behavior

3.2.1. Intention to share control

The intention to share controls in office environments was measured by asking respondents about their willingness to accept different control settings based on the majority of their coworkers' opinions. Response

rates were coded on a Likert Scale, where 1 indicates low likelihood to accept (1= very unlikely) and 5 for high willingness (5 = very likely). As a general comment, the “somewhat likely” response dominates, no obvious differences between four controls (thermostat, windows, lighting, shades) was found among the three climatic regions. In the specific cases, occupants in the Mediterranean region emerge as less willing to share the control of thermostat settings, operable windows, and lighting systems. Occupants in the Northern region appear generally more willing to share control of the indoor environment with their coworkers (Figure 5). Additionally, occupants in the South presented a more disperse response rate with just a few answers presented by less than 10% in all the cases.

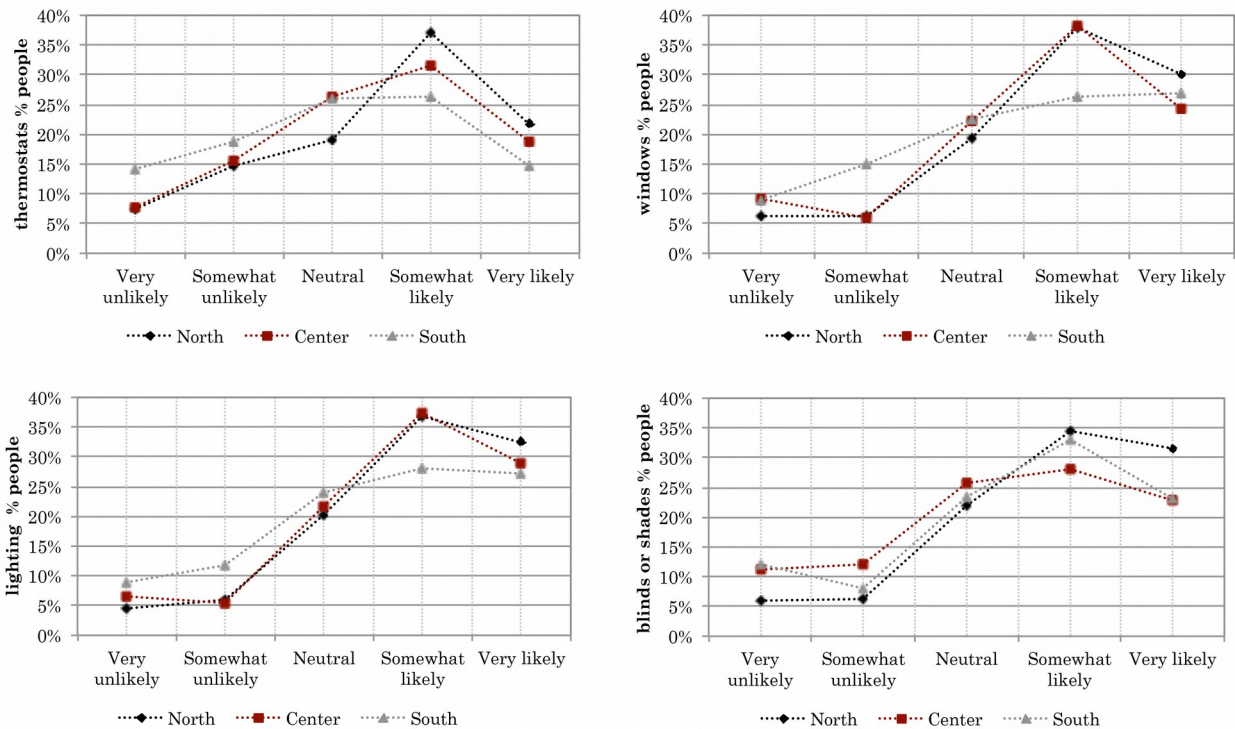


Figure 5. Intention to share controls with the coworkers, across the three climatic zones

Although the respondents occupy different types of office spaces, shared or private offices (33%), shared open offices (30%), cubicle spaces (2%) and unspecified (35%), no statistically significant correlation was observed between office layouts and occupants' subjective evaluations or perceived control.

3.2.2. Attitude

To measure attitudes, respondents were asked to express their opinion on the following statements:

“Coworkers sharing control of the temperature settings, opening and closing window, blinds and shades and switching on/off the lights at the shared office is...”. Responses were coded on a 5-point Likert scale ranging from 1= Very Bad to 5= Very Good. The shared control of the indoor environment in the office space is generally perceived a fair or good thing across all the climate zones (Figure 6, with no paramount variation between four controls (thermostat, windows, lighting, and shades) among the three climatic regions.

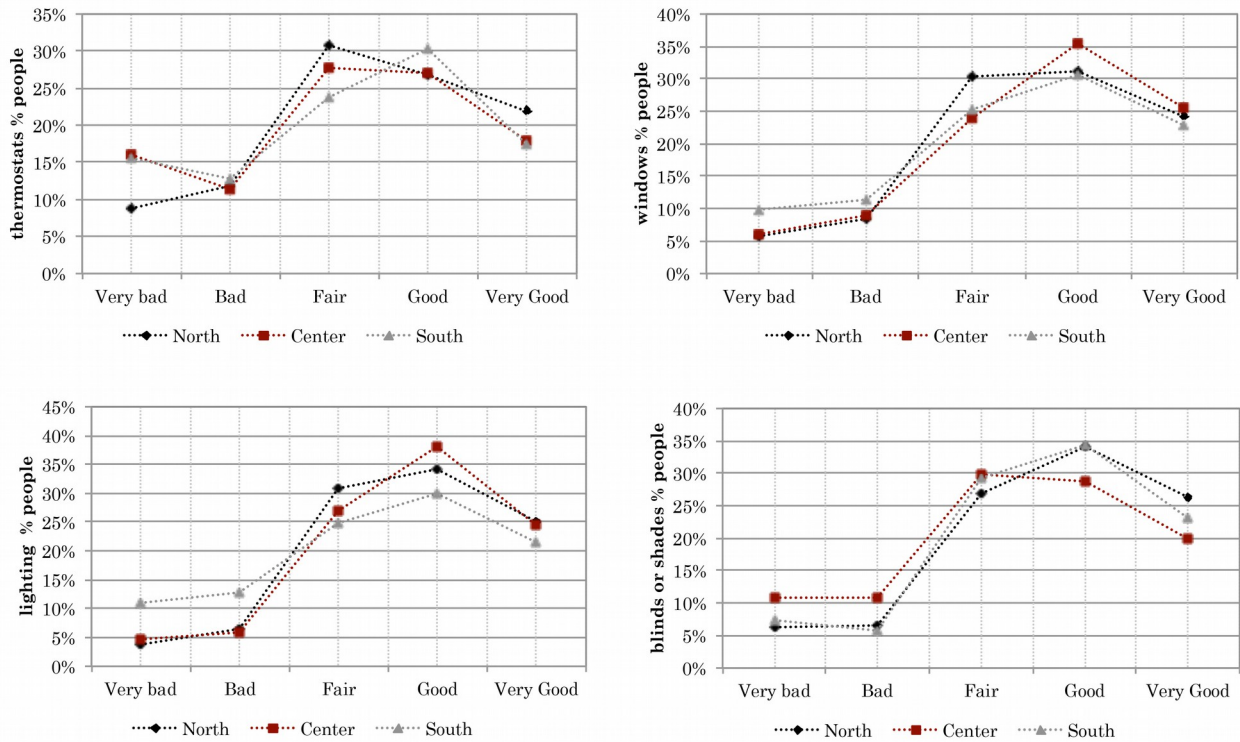


Figure 6. Attitudes toward sharing controls with coworkers, across three Italian climate zones

3.2.3. Subjective Norm

To measure subjective norms, respondents were asked to what extent they agree or disagree with a statement on coworkers' expectations of sharing control devices in the workspace: *“The majority of my coworkers expect me to share control over the adjustment of the thermostat settings, opening and closing of windows, blinds and shades and lighting systems.”* Responses were coded on a Likert scale ranging from 1 (strong disagreement) to 5 (strong agreement).

Occupants in the Northern region tend to report a stronger subjective norm on the co-workers' expectation to share the control over the indoor environmental quality. Respondents in the Southern region tend to report weaker co-workers' expectations of sharing thermostat, window, and lighting systems controls. Occupants in the Central region seem to disagree on shared control over blinds and shades. (Figure 7).

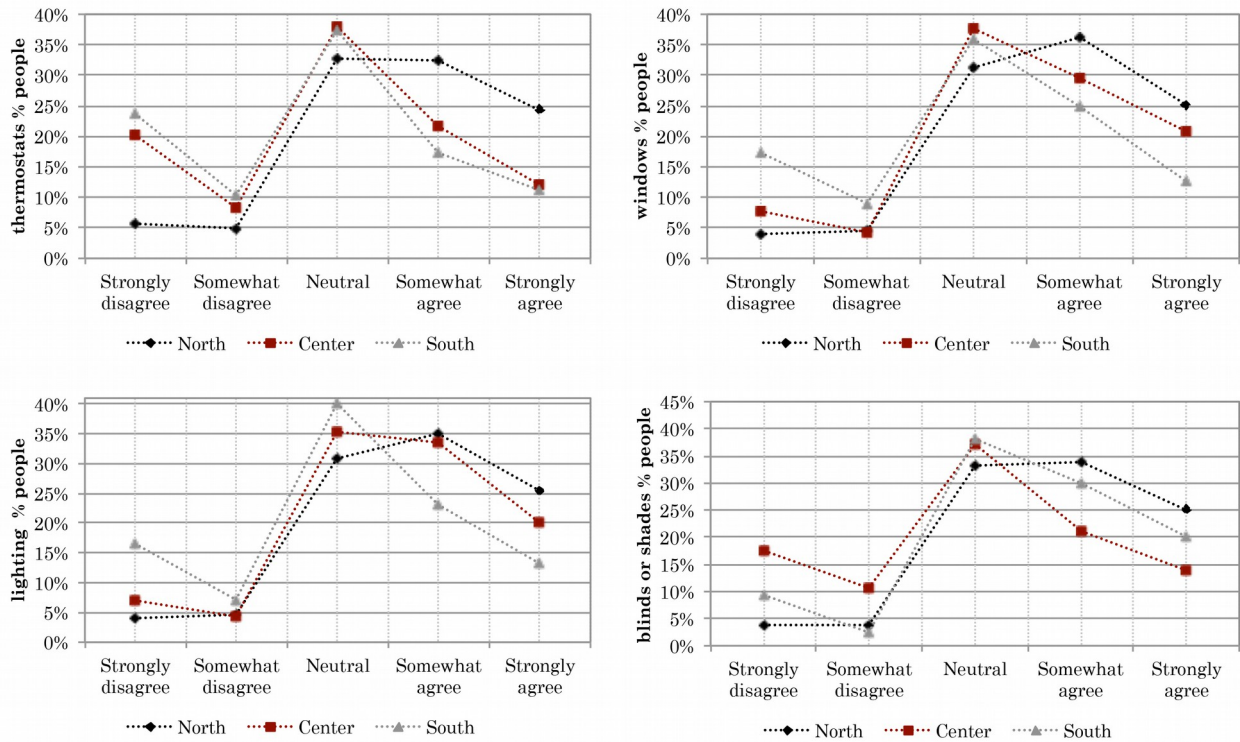


Figure 7. Subjective norms towards sharing controls with coworkers, across three Italian climate zones

3.2.4. Workspace density and frequency of negotiation

To measure workspace density, we asked respondents how many people in their workspace share control of the thermostat setting, operable windows, shades and blinds, and lighting systems. If known, respondents could select an option from only “me,” “1 other co-worker,” or “2 or more co-workers.”

To measure the frequency of interaction, respondents were asked how often they negotiate with their coworkers about sharing control of the control devices during a typical working week in the current season. If allowed to negotiate the conditions, respondents were asked to select an option from “less than once a week,” “once a week,” “once a day,” or “more than once a day.” Figure 9 illustrates the frequency of negotiation across the three Italian climate zones, based on workspace density. The figure shows people sharing control of: temperature settings with one person (T_1) or with two or more people (T_2+), window position with one person (W_1) or with two or more people (W_2+), blinds and shade position with one person (B_1) or with two or more people (B_2+), as well as artificial lighting with one person (L_1) with two or more people (L_2+). People sharing control of natural ventilation with two or more people (w_2+) reported to negotiate more frequently the decision to operate the operable windows (see Figure 8).

Figure 8. The frequency of negotiation across the three Italian climate zones based on workspace density. The graph illustrates people sharing control of: temperature settings with one person (T_1) or with two or more people (T_2+), window position with one person (W_1) or with two or more people (W_2+), blinds and shade position with one person (B_1) or with two or more people (B_2+), as well as artificial lighting with one person (L_1) with two or more people (L_2+).

3.2.5. Group norms

To measure group norms, respondents were asked how the decision is made to adjust office indoor environmental quality, by operating the thermostats, managing windows, blinds and shades, and lighting systems. Typically, the first person that speaks out a state of discomfort freely decides to interact with the control systems. As a second option, coworkers accept to meet the needs of those who express discomfort, (i.e., through group discussion). Less frequently, workers operate the devices without talking to others or having a required group discussion. Very infrequently, occupants have to accept the conditions preset by the energy manager or the person with the highest rank in the office. No significant variation among climate zones was found (Figure 9).

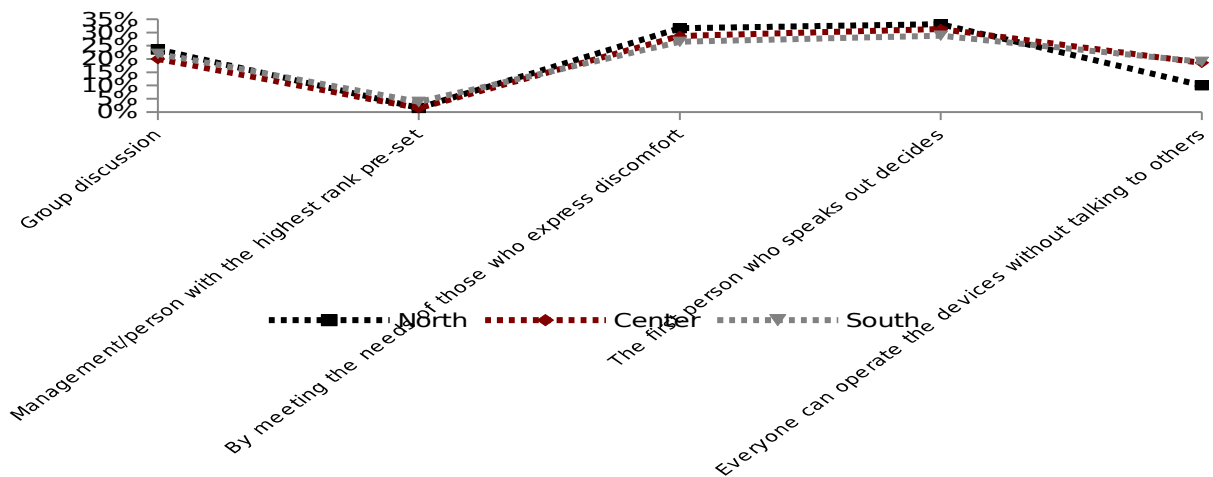


Figure 9. Workspace group norms across the three climatic zones

3.3. Ease of sharing and knowledge of controls

To measure ease of sharing control of building technology in shared office settings, respondents were asked how easy it is for them to share control of thermostat settings, operable windows, blinds and shades, and artificial lighting in their workspace. Response rates were coded on a Likert Scale, where 1 indicates strong

disagreement and 5 strong agreement on the ease of sharing controls. People seem to be able to easily share the control of operable windows, lighting systems, and blinds and shades more than the thermostat settings (Figure 10).

To measure knowledge on operating control devices in shared office settings, respondents were asked to measure their comprehension on how to adjust thermostat settings, opening and closing windows, turning on and off artificial lighting, and operating blinds and shades in their workspace. Response rates were coded on a Likert Scale, where 1 indicates a low degree of knowledge, while 5 indicates a high degree of knowledge. Respondents appeared to be more acquainted with the usage of windows, blinds and shades, and artificial lighting than the regulation of thermostats in their workspace (Figure 10).

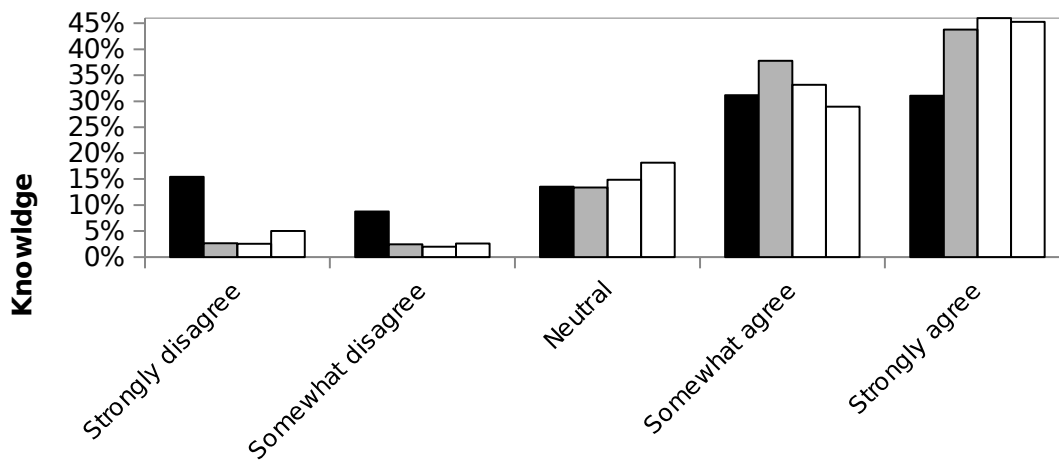


Figure 10. The frequency of perceived ease of sharing and knowledge of control averaged across the three Italian climate zones

3.4. Satisfaction and Productivity

To measure satisfaction, respondents were asked to what extent they are satisfied with the quality of the indoor temperature, indoor air quality, natural lighting, and artificial lighting. Satisfaction rates were coded on a Likert Scale, where 1 indicates a negative correlation of each variable towards satisfaction (1= very unsatisfied) and 5 indicates positive correlation (5 = very satisfied).

To measure productivity, respondents were asked to what extent the quality of the indoor temperature, indoor air quality, natural lighting, and artificial lighting influence their productivity at work. These variables'

influence on perceived productivity was coded on a Likert Scale, where 1 indicates negative correlation (very unsatisfied) and 5 indicates positive correlation (very satisfied). Occupants tend to appear more satisfied with the quality of natural and artificial lighting than the indoor temperature and indoor air quality. Natural and artificial lighting seems to predominantly influence productivity, while variables such as indoor temperature and quality of indoor air are more frequently perceived as responsible factors for loss in productivity, as perceived by the office workers (Figure 11).

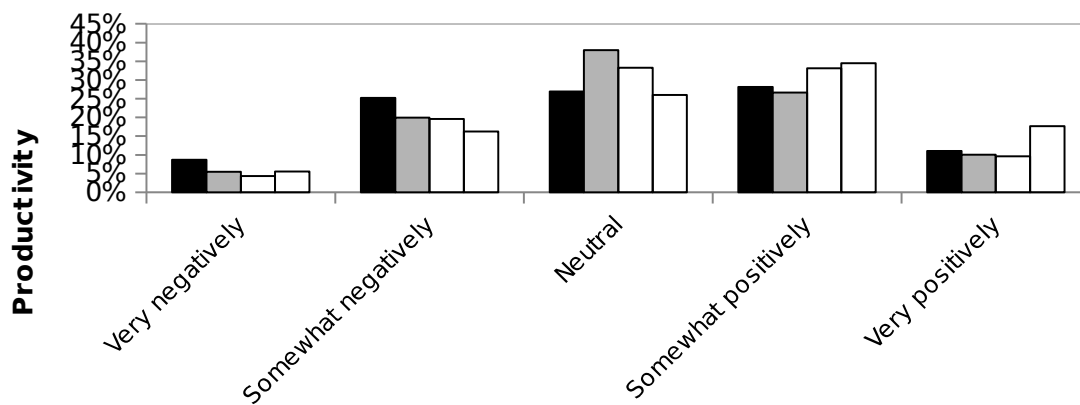


Figure 11. The frequency of self-reported satisfaction and productivity averaged across the three Italian climate zones. Composite statistics were further created to observe the deviation of the surveyed behavioral measures, where all the surveyed numerical variables coded on a 5-point Likert Scale were considered. Table 4 presents the max, min, mean, and standard deviation of all major investigation (e.g., comfort, productivity, intention to share control, etc.) measures.

Table 4. Mean and standard deviation of major measures

| | | Measure | Max | Min | Mean | St. Deviation |
|--------------------------------|---------|---------|-------|-------|-------|---------------|
| Perceived Comfort Satisfaction | Comfort | Q1.1_TC | 3.882 | 3.862 | 3.872 | 0.010 |
| | T | Q1.2_T | 4.056 | 1.928 | 2.992 | 1.064 |
| | IA | Q1.2_IA | 4.042 | 1.938 | 2.990 | 1.052 |
| | NL | Q1.2_NL | 4.664 | 2.218 | 3.441 | 1.223 |
| | AL | Q1.2_AL | 4.342 | 2.286 | 3.314 | 1.028 |
| Productivity | T | Q1.3_T | 4.225 | 1.927 | 3.076 | 1.149 |

| | | | | | | |
|----------------------------|-----|---------|-------|-------|-------|-------|
| | IA | Q1.3_IA | 4.188 | 2.128 | 3.158 | 1.030 |
| | NL | Q1.3_NL | 4.547 | 2.305 | 3.426 | 1.121 |
| | AL | Q1.3_AL | 4.255 | 2.227 | 3.241 | 1.014 |
| Intention to share control | T | Q4.1_T | 4.822 | 2.388 | 3.605 | 1.217 |
| | IA | Q4.1_W | 4.854 | 2.490 | 3.672 | 1.182 |
| | NL | Q4.1_BS | 4.900 | 2.624 | 3.762 | 1.138 |
| Ease of control | AL | Q4.1_AL | 4.592 | 2.166 | 3.379 | 1.213 |
| | T | Q4.2_T | 4.665 | 2.123 | 3.394 | 1.271 |
| | W | Q4.2_W | 4.840 | 2.552 | 3.696 | 1.144 |
| Attitude | B&S | Q4.2_BS | 4.795 | 2.569 | 3.682 | 1.113 |
| | AL | Q4.2_AL | 4.827 | 2.637 | 3.732 | 1.095 |
| | T | Q4.3_T | 4.413 | 1.883 | 3.148 | 1.265 |
| Subjective Norm | W | Q4.3_W | 4.616 | 2.310 | 3.463 | 1.153 |
| | B&S | Q4.3_BS | 4.659 | 2.313 | 3.486 | 1.173 |
| | AL | Q4.3_AL | 4.642 | 2.432 | 3.537 | 1.105 |
| Knowledge control | T | Q4.4_T | 4.622 | 2.360 | 3.491 | 1.131 |
| | W | Q4.4_W | 4.681 | 2.559 | 3.620 | 1.061 |
| | B&S | Q4.4_BS | 4.655 | 2.491 | 3.573 | 1.082 |
| Knowledge control | AL | Q4.4_AL | 4.688 | 2.552 | 3.620 | 1.068 |
| | T | Q4.5_T | 4.924 | 2.168 | 3.546 | 1.378 |
| | W | Q4.5_W | 5.000 | 3.258 | 4.129 | 0.871 |
| Knowledge control | B&S | Q4.5_BS | 4.967 | 3.169 | 4.068 | 0.899 |
| | AL | Q4.5_AL | 4.951 | 3.267 | 4.109 | 0.842 |

Figure 12 plots the max, min, mean, and standard deviation of the measures, across the 5-point Likert scale. Among the available control options regarding the indoor environment, respondents emerge less satisfied with the temperature setting, also reporting that this discomfort has a negative influence on their productivity. Respondents reported a weaker intention to share the control of the thermostat settings with their coworkers, corresponding to a reduced ease in sharing the control of the thermostats, and an inferior knowledge on how to use the technology, when compared to the control of operable windows, blinds and shades, and lighting systems. Similarly, the respondents report negative attitudes towards sharing the control of the temperature settings. These results imply that the majority of the surveyed employees perceive that coworkers having to share control of the temperature settings is a bad circumstance, where social norms on negotiating controls emerged not having any positive effect on perceived comfort, satisfaction, and, hence, productivity.

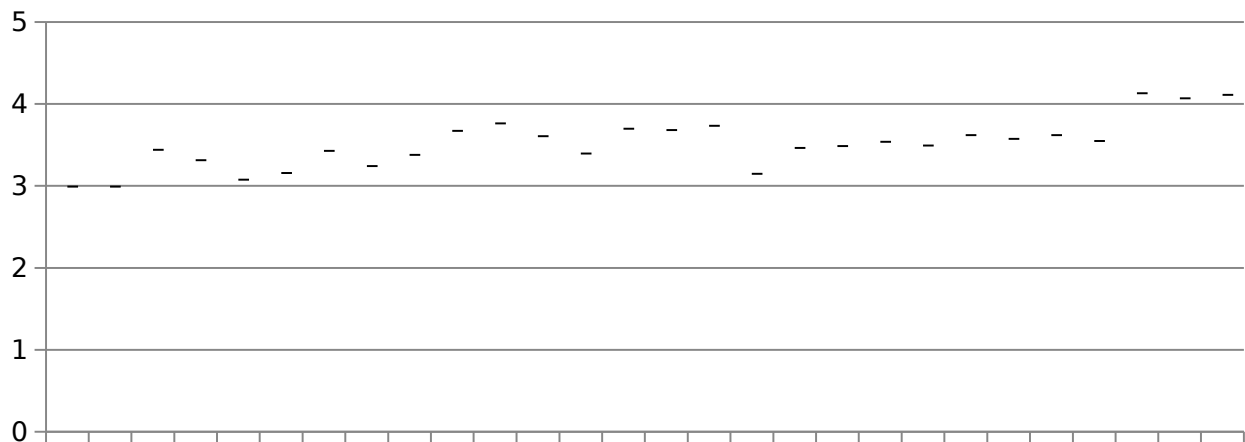


Figure 12. Deviation of measures

Figure 13 confirms the general dissatisfaction over the shared control of the thermostat settings in office spaces. Respondents recounted that, in most cases, control of the thermostat setting is not accessible, or else

it is controlled by others. This circumstance explains why the majority of respondents reported a strong disagreement on the ease of sharing the settings of thermostats, and them having consequences of satisfaction with indoor temperature. Thermal comfort (temperature) is identified as one of the key sources of discomfort in office spaces.

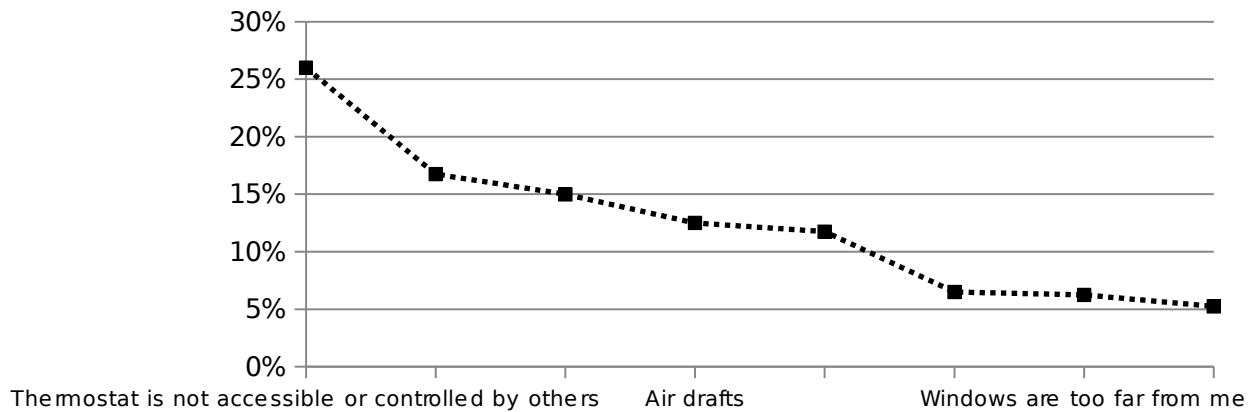


Figure 13. Key sources of discomfort in the workspace

4. Discussing limitation of the study

Performing an interdisciplinary survey study remains a challenging task. Key limitations of the current work are discussed in the following sections, for which mitigation strategies are proposed.

4.1. Sample target

The survey instrument was designed to collect responses from administrative staff, faculties (professor and lecturer), researchers, visiting scholars, and Ph.D. or graduate students. Occupancy rates of these targeted samples may not largely differ from the ones of typical commercial office buildings (9 am–6 pm working schedule), and several occupancy patterns may vary similarly depending on the organizational role. It is assumed that occupancy patterns of faculty members leaving their offices to teach classes or to supervise students are comparable to the ones of managerial positions attending meetings elsewhere, while the occupancy rates of students and researchers might be similar to the ones of regular employees, etc. A different aspect to consider is the perception of group dynamics and social norms, where the academic research environment may have a different impact on the employee’s perception on how to behave in certain situations (organizational roles, hierarchy, perceived pressure, etc.). These aspects are worthy of further research using the designed survey instrument.

4.2. Sample size

Sample size is a critical issue to consider in questionnaire design to avoid biased results [51]. Response rates can be kept high by providing respondents with incentives to motivate them to fill in the questionnaire, such as monetary awards or gift certificates. To encourage participation, institutions provided respondents with incentives consisting of five USB pens for each institution, assigned at the conclusion of the survey to randomly selected participants who voluntarily included their email address into a separate database for the

prize draw. Although incentive was provided to maximize the participation, the participation rate is low (11% to 16%). However, it is still acceptable in terms of statistical significance. In future studies, there is a need of education or awareness campaigns or triggers.

4.3. Self-reported data

Self-reported questionnaires have often been criticized for providing circumstantial results [50, 51]. Occupants may report, for example, what they *think* they will do rather than what they *actually* do in practice. Moreover, survey responses related to perceived comfort, satisfaction and productivity could be biased from factors such as weather, indoor environmental quality, and stress levels, which vary day by day [52-54]. One strategy typically adopted to isolate variation in behaviors due to climatic fluctuation is the reproduction of the survey study over different periods of the year. For this reason, the same survey instrument will be submitted during the winter and summer seasons. Data comparison will be performed to highlight climatic factors affecting perceived comfort, satisfaction, and productivity, as well as self-reported perceptions and behavioral beliefs. Another common practice aims to converge self-reported data with actual energy-savings data, or measured environmental parameters, in order to reveal important underlying drivers for behavior [24, 51, 55-58]. For the analysis of these questions, a similar mitigation strategy will be adopted for this research. As an example, survey responses on self-reported perception over the indoor environmental parameters (e.g., indoor temperature, air quality, illuminance level) will be paired with meteorological data (e.g., outdoor temperature, relative humidity, solar radiation on the horizontal level) to determine the possible influence of external climate conditions on comfort, satisfaction, and productivity. Meteorological data were accessed from external weather stations in the closest proximity of the geographical coordinates associated with each survey institution.

5. Conclusions

This work presents results from a cross-country questionnaire survey assessing the contextual and behavioral factors in adopting building technologies in university offices across distinctive Mediterranean climates: Turin (North), Perugia (Central) and Rende (South), Italy. Compared to state-of-the-art literature in the field, this work brings innovation in interdisciplinary survey methods and cross-country knowledge on human-building interactions in the workspace. The innovative research method used in this survey questionnaire is grounded in an interdisciplinary framework [43] merging building physics and social science insights on the energy- and comfort-related human-building interaction in the workspace. By adopting this socio-technical framework in a cross-country context, analyses of more than 1000 collected responses on self-reported behavioral intention, attitudes, social norms, as well as perceived behavioral control, comfort, satisfaction, and productivity illustrated *why and how* social science insights, in tandem with building physics theories, can bring innovative knowledge into the understanding of office workers' interactions with building technologies to control their indoor environment.

Results of the survey questionnaire provided insights into four key learning objectives, as follows:

- I. Regarding individual's motivational drivers in interacting with shared building environmental controls: office workers open windows primarily to introduce fresh air into space; they typically close windows because the indoor temperature is perceived as too cold or too warm. Window blinds and shades are more frequently pulled up or opened to let more daylight in the office space, while they are drawn mainly to reduce glare on the computer screens or workspace. Thermostat set points and lighting systems are generally regulated to restore comfort conditions in the workspace (because the temperature is perceived as too hot or too cold or to adjust lighting levels in the room) and less frequently as a consequence of an energy conservation behavior.
- II. Regarding group dynamics: the intention to share controls does not emerge correlated to perceived comfort, satisfaction, productivity, and knowledge on how to use technology, but rather as a behavioral trait of the occupant. Shared control of the indoor environment in the office space is generally perceived as a fair or good thing across all the climate zones, highlighting a common positive attitude of office workers towards sharing control devices. Occupants in the Northern region (Turin) tend to report a stronger subjective norm on the co-workers' expectation to share the control over the indoor environmental quality.
- III. Regarding perceived behavioral control of building technologies (ease of usage and knowledge): office workers tend to perceive greater ease of sharing control of operable windows, lighting systems, and blinds and shades than thermostat settings. Similarly, respondents appear to be more acquainted with the use of windows, blinds, shades, and artificial lighting than the regulation of thermostats in their workspace. Consequently, a general dissatisfaction over the shared control of the thermostat settings in office spaces emerges.
- IV. Focusing on perceived comfort, satisfaction, and productivity, office workers tend to appear more satisfied with the quality of natural and artificial lighting than indoor temperature and indoor air quality. Natural and artificial lighting seem to predominantly influence productivity, while variables such as indoor temperature and indoor air quality are more frequently perceived as responsible for the loss of productivity. Gender plays a statistically significant role in influencing perceived thermal comfort. Perceived comfort also emerged to be correlated with satisfaction and productivity, and less correlated with the ease of use and knowledge of control, as well as attitudes and subjective norms.

Further research will focus on leveraging the interdisciplinary collaborations to enhance data-driven knowledge on perceived satisfaction and effectiveness over the personal control of indoor climate in office settings across diverse climatic zones worldwide. The same survey instrument is currently being deployed in university institutions in China, USA, Australia, Poland, and Hungary. A comparative cross-country data analysis will be performed and presented.

Another current project is the inclusion of significant contextual and behavioral influencing variables in predictive models of the human-building interaction in office spaces. Such interdisciplinary enhancement is a promising future development in this field of study. This further research may increase the accuracy of predictive models of energy use behaviors, enhancing occupant comfort and ease of the use of building

technologies, as well as supporting optimized building design, operation, and human-centered energy policies in the commercial building sector.

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