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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.

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

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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 [14–16] 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 decision making 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