Communication Breakdown: Energy Efficiency Recommendations to Address the Disconnect between Building Operators and Occupants

Shelby N. Ruiz, Julia K. Day, Krissy Govertsen, Michael Kane

1. Introduction

There is a significant need for organized energy management in buildings to reach climate, and efficiency goals across the planet, a task industry experts are increasingly undertaking [1]. Buildings account for over one-third of total energy consumption and are a significant source of greenhouse gasses like carbon dioxide (CO_2) [2, 3]. As a result, the building sector is implementing progressively aggressive building codes, operation regulations, equipment incentives, and other strategies to meet energy efficiency and greenhouse gas reduction goals [4-7].

Throughout this paper, industry experts referred to as building operators are employed to leverage building systems to meet these performance goals. As these goals are achieved, building occupant behavior plays a more significant role in building performance [8-10]. This is supported by investigations within the completed International Energy Agency (IEA), Energy in Buildings and Communities Programme (EBC) Annex 66 “Definition and Simulation of Occupant Behavior in Buildings” [11] and the ongoing Annex 79 “Occupant-Centric Building Design and Operation” [12]. Occupant-centric design and operation goes beyond building performance metrics to value occupant health, comfort, and productivity [13, 14]. Therefore, the role of building operators has been expanded to incorporate occupant needs to reduce the negative impact occupant behavior has on building performance when their needs are not met. The relationship operators have with their building’s occupants, and that relationship’s impact on an operators’ ability to successfully fulfill their role is the focus of this research.

Building operators are uniquely positioned to improve the building performance occupant experience simultaneously [15]. In part, this is because when occupants can communicate comfort and environmental needs to their building operators, they are far more likely to be satisfied with their building conditions [16]. Furthermore, when occupants are more pleased with their environment energy savings tend to follow [17, 18]. Since communication is a pillar of successful relations, we can infer that satisfied occupants are a result of an effective occupant and operator relationship, which also benefits building performance [19, 20]. This paper presents findings of a large-scale international study of 72 building operator interviews across seven countries and five climate zones to understand building operators' perspectives better. This research aims to understand operators’ role in the buildings they manage and how communication with occupants affects their building operation. Many researchers do not recognize these human sociological and psychological aspects of building use and design. Education and trust are paramount in the occupant and operator relationship.

Findings point to a disconnection between operators and occupants and suggest how these relationships can be improved through better communication channels, better feedback, and the education of both operator and occupant. The value of this research is in its qualitative approach [21], which is used to understand the complicated relationship between operators and occupants more holistically.

2. Background

2.1 Occupants and Operators in Buildings

Occupants are individuals who experience indoor environments at varying degrees of frequency. Some occupants are in a building to work, live full time, or intermittently visit and typically do not hold a stake in the management or performance of a building (aside from their own home). Thus, the average occupant may not have the best understanding of how their comfort affects a building system [22], what to do when they are uncomfortable [20, 23, 24], or why an issue is happening [25, 26]. Occupants typically have a limited understanding of building systems, how they work, and how they deliver comfort services to the spaces they work or live in, especially without occupant training or education [25]. Additionally, occupants are often removed from interacting with building controls, decreasing their tolerance for discomfort and increasing their frustrations with lack of control [27].

Operators manage the balance between occupant comfort and the performance of the building, including, but not limited to, the safety, performance, optimization, and maintenance of the building's equipment. What operators are expected (or not) to do varies by title, training, and building sector [28]. The notion that operators formerly acted as stewards of their building and actively responded to the needs of their occupants has become antiquated, as energy efficiency and performance measures have taken over [29]. The nature of work for an operator has become a business-focused occupation, where budgets, systems, schedules, and efficiency may be prioritized over occupant needs [30]. The disconnect between occupant needs or expectations and an operator's requirement of meeting stringent performance standards leads to occupant discomfort, users asking for setpoints out of range, or creating their own interventions into a system. Occupant overrides or "hacks" like blocking vents or tricking their thermostat are typically only temporary fixes that lead to other issues in the system and frustration from an operational team [27, 31, 32].

Occupant-centric metrics are crucial to informing building design and operations [33]. Occupant metrics such as feedback can offer depth and richness of description, become helpful for operators when identifying problems in buildings, and even offer new solutions to problems [19]. The most common feedback method is occupant surveys, but they may also provide feedback in other ways such as a work order, occupant portal, or app [34-36]. Studies show that when occupants actively communicate with operators about their expectations and experiences, they are more likely to be satisfied with the built environment [16]. Unfortunately, most occupant feedback is negative and unsolicited, resulting in highly unstructured data sets [37]. Highly detailed and effectively managed occupant feedback can help operators learn from previous experience and decisions and improve occupant comfort and building energy performance.

2.2 Occupant Comfort

The indoor environment should be a place of comfort for building occupants, who report valuing thermal comfort over visual, acoustic, and environmental comfort measures [38]. However, in 2006, only 11% of the office buildings surveyed in the U.S. provided thermal environments that met generally accepted goals of occupant satisfaction. Thermal comfort is the subjective state of mind that building occupants express when they experience thermal satisfaction or dissatisfaction within an environment [39]. Thermal comfort depends on many variables, including external or environmental factors like air temperature, radiant temperature, humidity, air velocity, and personal factors such as clothing levels and metabolism.

The latter personal factors can further depend on more variables such as activity levels and environmental conditions or expectations. Since thermal comfort is a subjective measure of a person's satisfaction with an environment, it is a divisive concept for building professionals as they try to make as many people comfortable in a space as possible. Occupant behaviors play a significant role in building design, operation, and overall performance of a building system [40, 41]. Many factors affect an occupant's perception of thermal comfort, including social, cultural, psychological, and physiological variables. These and the nature in which occupants spend time in their buildings, interact with other occupants and building professionals, as well as the criteria that define the building's indoor environment, are all at play with occupant satisfaction.

An occupant's thermal comfort can affect their overall health and productivity [22, 42, 43]. It has been argued in the literature how much of an influence gender [44-47], age [48-50], and health parameters [51, 52] have on an occupant's level of comfort in buildings. Due to the variability in individual thermal comfort, there may be bias in thermal comfort standards that only consider gendered and age-specific variables that exclude other regular building occupants [22, 53, 54]. An increasing amount of literature calls for more diverse and inclusive thermal margins for persons outside of the male, working-age, and able-bodied demographic [46, 47, 55, 56].

Many factors determine when, how, and to what extent an occupant will interact with their building. Occupants will find ways to make themselves more comfortable in situations that do not meet their desired comfort levels, often resulting in building alterations, tricking their building sensors, or more neutrally, adapting through clothing or location [27, 31]. Technology or automation of building systems alone is not enough to predict energy use in buildings, as occupant comfort and behaviors are largely difficult to quantify [57, 58]. Although troublesome for building operators, these occupant interventions are evidence of building users adapting to their environments due to discomfort. The human dimension of building operation may be difficult to understand fully but integrating human factors into energy modeling may lead to higher energy efficiency, fewer conflicts surrounding occupant comfort, and smoother operation [59, 60].

Another factor that impacts an occupant's perception of comfort is the building typology they occupy. In residential settings, building occupants have greater spatial familiarity, more control over their spaces, and can improve thermal comfort as needed. Thus, in residential buildings, occupants show higher levels of acceptance with thermal variations [61], awareness of how their behaviors affect energy costs [62, 63], and how much energy is used for comfort [64]. Additionally, in residential settings, occupants are more familiar with or pay the electricity/utility bills themselves, impacting energy-related behaviors within their residence [65]. Comparatively, occupants in commercial settings may not hold the same awareness of resource consumption, hold the same expectations of comfort, or understand the cost of their behaviors [63, 66-68].

2.3 Thermal Comfort vs. Building Standards

Requirements for thermal comfort are set by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE: 55) standard, European Performance of Buildings Directive (EPBD - EN 16798) or the International Organization for Standardization's (ISO 7730) methods of determining and predicting thermal comfort inside of buildings [39, 69, 70]. These standards rely on established models to better understand indoor thermal comfort, such as Predicted Mean Vote (PMV), Percentage of People Dissatisfied (PPD), and Adaptive Comfort Model (referred to most commonly as the adaptive model). These models aim to improve estimates of how occupants perceive comfort using skin temperatures, balance occupant dissatisfaction levels, or overall adaptability to a given temperature [71].

These standards are often referenced in government building codes as the minimum requirements for thermal comfort in buildings. However, buildings are increasingly adhering to higher standards. For example, the WELL Building Standard (WELL) recognizes that thermal comfort preferences are highly individual, making it nearly impossible to find a temperature that will satisfy all occupants in the same space at the same time [72]. Therefore, WELL encourages designers to provide different thermal gradients and individual thermal comfort devices so building occupants can choose areas that best fit their thermal preferences.

2.4 Tenant Engagement and Education

Another way to increase occupants' overall satisfaction with their environmental conditions is to ensure they have the proper knowledge and education of the building interfaces and controls in their building [25, 73-75]. Studies have found that occupants who better understand how to operate their building controls (i.e., blinds, thermostats, lighting) are more likely to be satisfied with their space [26]. There are many different forms of education or tenant engagement, such as gamification, feedback, traditional training, and so on [26, 75]. Each strategy has different strengths and weaknesses and may be selected based on the individual circumstances, building type, occupants' existing knowledge levels, and controls available [76-78]. A combination of methods and repeated education measures can be more successful, especially in easing the tension between operators and occupants.

In the following section, the methodology and data analysis procedures are explained.

3. Methodology

3.1 Context and Background

Research in occupant behavior mostly relies on buildings' technical aspects and quantifiable measures. Still, the depth of information is lost when not collecting personal perceptions or approaching socio-economic issues [21, 59, 79]. Focusing solely on quantitative studies, other researchers seek formulas, simulations, and models to predict occupant behavior impacts in buildings. Still, they are challenged by sample size, reliability, and arguments of which model and approach are best to use in practice [45, 80-84]. Mixed methods studies, including qualitative and quantitative data, tend to paint a broader perspective of participants' realities but may be overpowered by factual numbers to draw meaningful conclusions, losing the benefits of additional insights into human feelings and perceptions [27, 85-90]. Qualitative studies are not meant to be generalizable or representative of entire populations, however, when considering interpersonal interactions and gaps in communication, quotes, observations, and human perceptions, qualitative studies can help reveal issues not found in quantitative-based research [91-93].

This study was founded on the basis that building designers, operators, occupants, and associated building professionals cannot understand these challenges without discussing them. Qualitative studies are not generalizable, but the interviews conducted for this research supply valuable insight into the feelings, expectations, and communication challenges operators face as they balance performance and comfort in the buildings they manage. While conducting social science studies, one must be diligent in upholding research protocols, rigor, and reliability measures to ensure the merit of work produced [21, 94, 95]. Utilizing qualitative methods energy and design research is a strategy that can build empathy, improve satisfaction, and spark advocacy within the built environment that addresses genuine human problems [91, 96]

3.2 Methodological Approach

An international group of researchers created this study's methodological design and questionnaire as a part of the IEA EBC Annex 79 *Subtask 4: Development and demonstration of occupant-centric building controls.* The questionnaire design was informed by the researchers' backgrounds and experience with building management practices, existing industry knowledge, management tools, feedback and communication mechanisms, operator challenges, and suggestions for improving current building management practices. See Figure 1 for more details on the steps of this study's methodological approach.

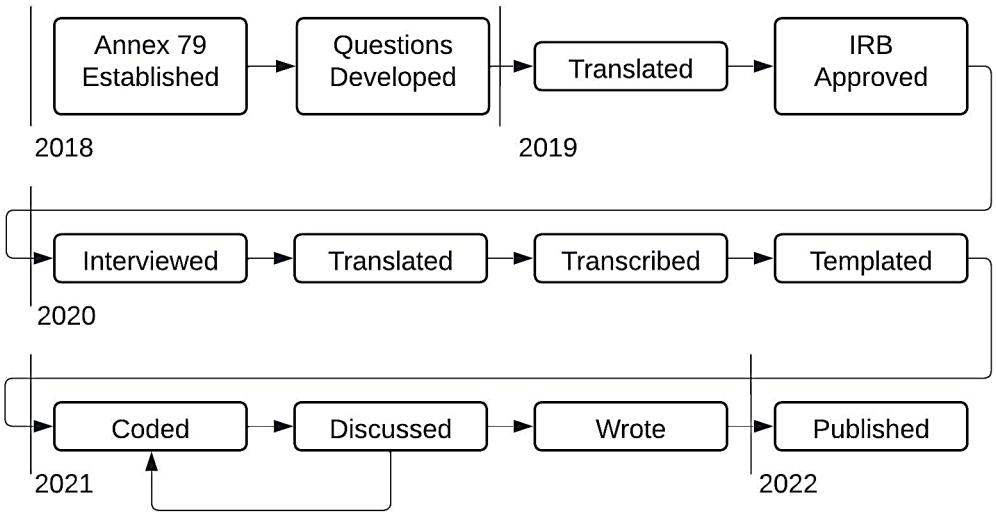

Figure 1. Flowchart describing methodological steps of data collection, analysis, and dissemination.

The study was initially approved by the *Northeastern University* Institutional Review Board (IRB) and subsequently by each participating institution. Interviews were held in seven countries: the United States, Canada, Brazil, Italy, Germany, Poland, and Singapore, which represents five climate zones.

The interview script or questionnaire consisted of twenty-three semi-structured questions, including participant titles, training and experience levels and their opportunities as operators to interact with the building's systems and occupants. The series of open and close-ended questions investigated relationships between facility managers and building operators with building occupants. The interviewer used a semi-structured interview guide to lead the discussion with participants during the interviews, hitting major primary questions and follow-up questions to elicit further details on participant responses.This international study used a qualitative approach to conduct 72 interviews between January and November of 2020. Due to COVID-19, none of the interviews were held in person. Interviewees included purposively sampled building operators/managers who varied in job titles, locations, and experience levels. The building operators and facility managers interviewed for this study primarily ran private and/or public buildings including offices, hospitals, college campuses, hotels, retail spaces, laboratories, and multi-family residential complexes. The square footage of these buildings ranged from 10,756 SF (1000 m^2) to 1,291,669 SF (120,000 m^2), ranging from 100 occupants to 15,000 occupants. The interviewees were often responsible for managing more than one building, some managing more

than a dozen in their portfolio. Participants spoke to one of their more familiar projects in the interviews if they managed an extensive portfolio.

Most interviews were recorded virtually, transcribed, cleaned/spell checked, and in some cases, translated to English. In some cases, participating countries had specific laws about audio recording, in these instances interviewers took detailed handwritten notes to capture participant sentiments. To meet international data privacy requirements, participants remained anonymous, and no personal identification or sensitive data was collected. Before interviewing, each participant was provided informed consent for the study (including audio recording and transcription of the interviews if applicable).

Transcribed interviews were translated into English for data analysis using a pre-established template to ensure that data was placed in the questionnaire correctly. To ensure normative equivalence of questionnaire responses, translation to the target language (English) was an iterative process with multiple checks and balances to remove mistakes, inconsistencies, language barriers, cultural terms, and any linguistic differences that may occur in such translation processes.

This manuscript will address the findings of a narrower scope of focus regarding the aforementioned valuable occupant and operator relationship that was not extensively addressed in other manuscripts from the larger study [97, 98]. The research methodology used qualitative research tactics and a literature review to inquire in the following research questions for this manuscript:

RQ1. What factors influence the quality of relationships between occupants and operators?
RQ2. How can the relationships between operators and occupants be improved?

In the next section, the specific data analysis methods are discussed. This is followed by the results section, which is organized by the research questions.

3.3. Data Analysis

Qualitative data gathered in the interview process were analyzed using a computer-assisted qualitative data analysis software, QSR NVivo 10, commonly used in mixed-methods and qualitative research projects to analyze interview transcripts and other forms of qualitative data. Transcripts were written in templates that facilitated auto-coding. These templates accelerated manual coding tasks by focusing coding review on interviews questions of interest for each coding theme.

The interviews were reviewed and analyzed using the Saldana (2016) method of qualitative coding, which uses iterative coding cycles [99]. For example, in the first cycle a descriptive coding approach was used to assign labels to summarize the basic topics from the operator interviews. As necessary, segments of codes ranging in size from short phrases to entire paragraphs were assigned to nodes, many being coded to more than one node. The researchers kept a chronological memo of emergent ideas as they read the interview responses by question. Codes were given code definitions to demonstrate the kind of responses that were coded to each node, although node definitions transformed as data analysis progressed. In the second cycle data was codified to consolidate meaning and explanation. New responses were reviewed (i.e., codes were renamed, combined, redefined, etc.) in an iterative fashion. In the final cycle, key patterns were revealed to deduce themes and concepts as listed below. As a result of these iterations, our nodes were structured as seen in Figure 2.

- relationships,
- communication (or lack thereof),
- attitudes,
- challenges in the relationships, and
- positive interactions.

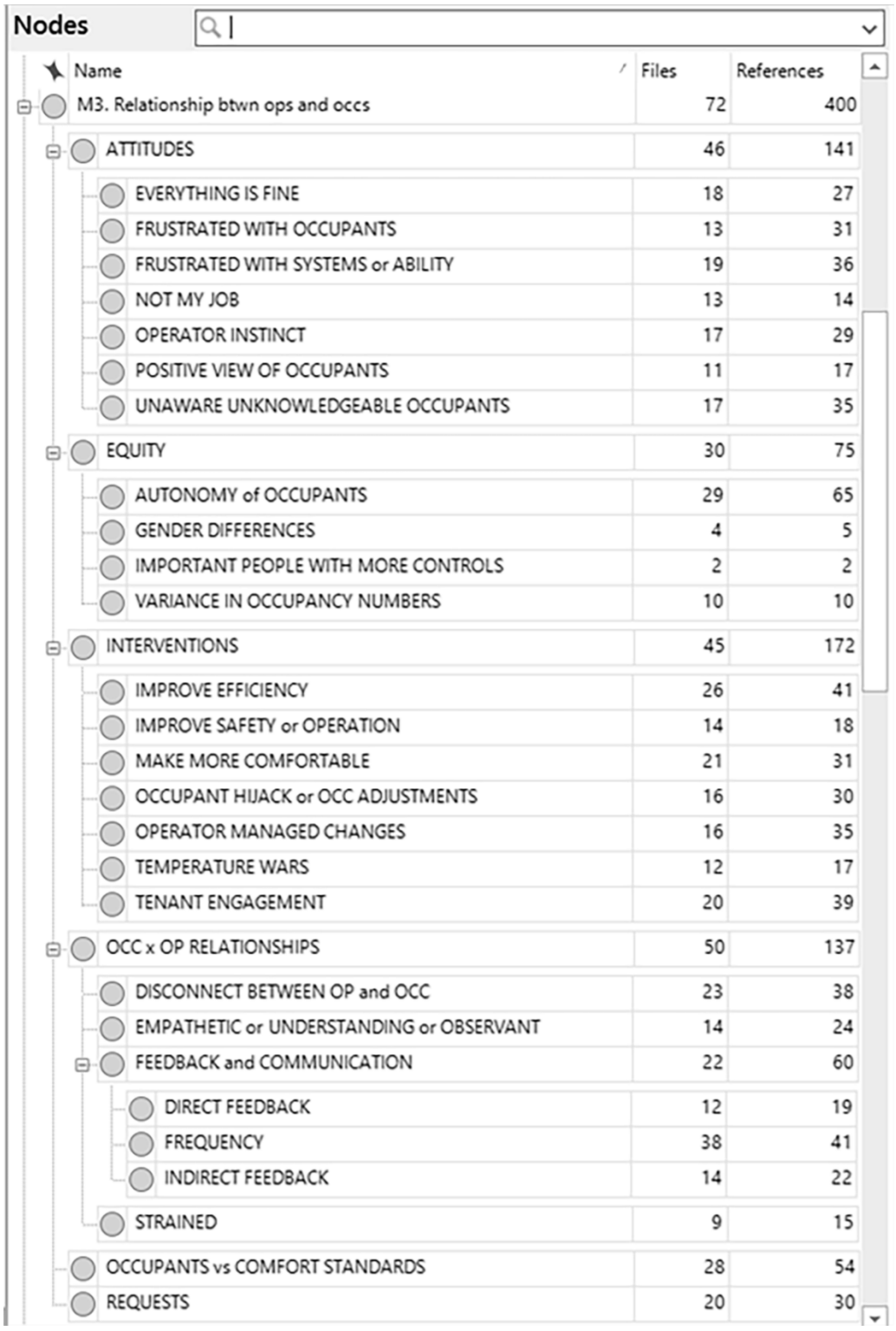

Figure 2: Nodes developed through coding analysis.

3.4 Research Limitations and Implications

There were limitations to this research that affected the outcomes and results. These interviews were conducted with building operators, conveying only one perspective of this relationship. Operator perspectives are shaped by many factors including, but not limited to: personality, education, job experience, and culture. Another limitation of this study is that interviews were conducted internationally. Therefore, language barriers, legal ability to record/transcribe interviews, and the reporting method of participant responses varied by researcher, country, and participant. Depending on the interviewer, some interviews were open-ended, while others were more direct in how questions were asked or responses were gathered. For this paper, the researchers responsible for coding had a limited understanding of the overall study, participant demographics, and questions asked before qualitative analysis via QRS Nvivo software. This decision could be seen as a limitation on the one hand or as a benefit in limiting the coder's biases and predefined assumptions. The following subsection further discusses the validity, reliability, and generalizability of the methods employed in this research.

3.5 Validity, Reliability, and Generalizability

In qualitative research, validity refers to the appropriateness of the selected research tools, processes, and data [100]. As outlined above, the sampling procedure, the chosen methodology, and the data analysis procedures were all well suited to answer the research questions and based on well-founded methods and precedent. In terms of reliability, the conclusions drawn in this paper would be replicable based on the method and analyses procedures described. It should be noted that qualitative research aims to study a specific issue or phenomenon in a particular population. Therefore, the results are not generalizable in all cases of building operators and occupants globally.

4. Results

The results are first organized by research questions RQ1 and RQ2 defined above, and then subsequent emergent themes also guide further discussion.

4.1 *RQ1: What are the factors that influence the quality of relationships between occupants and operators?*

In order of prevalence within the responses, the factors that tended to impact building operators' relationships with (and perceptions of) occupants included (1) occupant comfort and respective behaviors taken to regain comfort, (2) the amount and type of interpersonal interaction, communication, and feedback, and (3) the tug of war between energy goals/building standards and thermal comfort complaints, as well as job requirements and expectations of building operators.

Many of the interview responses showed a disconnect between building operators and occupants. Operator perceptions of building occupants were primarily based upon positive and/or negative interactions with occupants or how empathetic operators were to the occupants' experiences and their comfort. Several factors impacted these perceptions, including the number of occupants that responded to post-occupancy evaluations (POE), the frequency of interactions with building occupants (if at all), and the autonomy of occupants in their environments.

Several operators indicated their interactions with occupants were positive and that they had a good understanding of their building occupants' comfort. Interviewees reported the comfort level of their building occupants as satisfactory, and those operators understood when and where

problems existed. On the contrary, other operators noted that it was difficult to know where problems occurred until occupants notified them of the issue. Many interview responses spoke to nuanced participant attitudes about the conflicts between occupants and operators. These responses ranged from occupants not knowing the “right” behaviors to perform (and the operators understanding that) to occupants becoming serious causes of frustration and thwarting building performance. Occupant interactions with the building such as blocking vents or aggressive setpoint manipulation presented challenges for operators. These interactions were often a trigger or source for contempt, which is further discussed in the key findings of this section. Some responses also showed the advantages of trust and understanding between building operators and the occupants (Quote 1 Figure 3).

The interview responses showed a pattern of quality over quantity, meaning that the operators who had better feedback mechanisms and direct communication with the building occupants could better manage complaints and comfort challenges with more grace and understanding. (Quote 2 Figure 3).

Quote 1	*“Look, I think the big secret is having good inter-personal relationships. As I said at the beginning, being very close to the customer is important. To understand the client's pain, needs, and then try to build the best solution together.”*
Quote 2	*“I said because if I don't know what's happening, I can't fix it. And so they understand where I come from, and they've been very good about it….And that's why when they do send a complaint in with the work order saying that their room has been cold for the last 30 days or three months or a year, sorry, I wasn't aware of it, yes, I will take care of it now that you've put it on an email.”*

Figure 3: Selected quotes demonstrating feedback challenges.

The amount and quality of interpersonal interaction between building occupants and operators depended on the location, job title, portfolios of work, organizational structure, and management style of the operators interviewed. These interviews revealed vast differences in interactions between occupants and operators who manage the building remotely or in person. The ratio of occupants to operators also impacts the possibility for direct communication. This section describes the interactions between occupants and operators and the varying ways they communicate with each other.

Without open, direct, and empathetic interactions with building occupants, operators often do not have the information they need to make informed decisions about occupant needs. As shown in the “feedback and communication” node, interactions varied in frequency andtype, as well as level of action taken. Operators reported only hearing about issues after occupants have reached elevated levels of discomfort and complained of poor methods of receiving feedback from occupants (see Figure 4).

Many interview responses expressed sentiments of appreciation for the direct methods of learning about and responding to complaints. Less direct forms of communication between occupants and operators tended to come through channels of tenant administrators passing complaints up the chain of command until it they reached someone who could make system changes (see Quote 2 Figure 4). Other organizations primarily gathered occupant feedback from occupant surveys. As reported in the interview data, POE’s did not produce a frequent or consistent mechanism of gathering occupant feedback. Several respondents said that surveys' frequency, accuracy, and reliability made it hard to discern where and when problems occurred. As revealed by the following

quote, "*I wish I had access to occupant's engagement in occupant comfort survey because most of the occupants do not respond to these surveys*." There were significant communication and interaction differences across building manager styles and professional roles that impacted operator relationships with the occupants of their buildings.

Quote 1	*"Never/not on a regular basis, rather only when there are complaints."*
Quote 2	*"And as far as, as far as I know that there have been no complaints that have bubbled up to me, which meant, that, that means that either there's been zero complaints, or they're kind of minor complaints that were fixed by themselves."*
Quote 3	*"Typically, each company has a liable person who defines the level of access to the portal. From there on, the user interacts with the system according to their internal rules. Generally, the access to this portal is not given to everyone."*

Figure 4: Selected quotes illustrating lack of direct and timely feedback.

Building operators showed frustration with their building occupants regarding interpersonal conflicts and unsatisfiable tenants. Many operators believed occupant dissatisfaction was a personal preference over a performance problem. Some interviewees were clear that their role was solely to manage and reduce energy use in the building while meeting minimum legal or contractual requirements. In these instances, the operator/occupant relationship was much more strained. Other operators revealed that their employer's organizational structure enforces strict energy, emission regulations, and municipal code requirements disregarding occupant comfort entirely. Several responses also implied that operators were apathetic or expressed a negative attitude toward occupants. There were a few instances where this "not my job" mentality (coded as such) became hostile in the interview responses.

Many of the building operators interviewed for this study oversaw a varying number of occupants in their facilities. Participants of this study manage large portfolios of buildings, but it appears that those with smaller occupant numbers were more in tune and familiar with individuals' needs and comfort levels. From the responses collected, operators had as few as 100 regular occupants to upwards of 15,000 occupants in their portfolios. Variable occupancy numbers seemingly affected the operator's relative location and ability to communicate with building users directly.

A common sentiment expressed by many operators was that "*If [they] had access to detailed feedback from the occupants, [they] could provide [occupants with] better comfort*." This leads into the next key factor that impacted these operator and occupant relationships; thermal (dis)comfort was a pervasive source of contempt and misunderstanding (see Quote 1 Figure 4). Results also showed a common theme that operators often had to navigate between meeting stringent performance goals or the comfort of occupants (see Quote 2 and 4 in Figure 5). Operators recognized that these two goals are often in opposition, and many have accepted that some occupants will never be comfortable (see Quote 3 Figure 5).

Quote 1	*"Last year's survey shows that many people are uncomfortable, and its reasons are mostly unknown."*
Quote 2	*"The standard thermal comfort temperature is between 20 °C and 24 °C, so I have to follow this range. People normally do not know that and use 19°C of set point temperature, which will be bad for thermal comfort and for the energy consumption."*
Quote 3	*"It is hard to please everyone and to reach optimal operation."*
Quote 4	*"The first priority is to respect the standard. I follow a temperature range in the first place, the range proposed in the standard…Normally we can find a temperature that maintains 90% of people comfortable. However, there will always be some complaints, i.e., someone asking for a lower or higher temperature."*

Figure 5: Selected quotes denoting the complicated nature of achieving comfort for all.

While some positive relationships were described, there was often a disconnect, contention, and frustration between operators and occupants.

4.2 *RQ2: How can the relationships between operators and occupants be improved?*

As mentioned previously, many operators are not effectively communicating with occupants about building conditions or receiving valuable information from the building users. Further concerns or gaps in the relationships between occupants and operators result from a disconnect between the operation of a building efficiently and safely and the conflicts surrounding occupant comfort. Requests from the building operators included more frequent and reliable occupancy surveys and better communication channels.

Other operators suggested that even in buildings that conduct semi-regular occupancy surveys, they may not accurately describe when and where problems occur. Others requested a better understanding of how many occupants are in the building (and when they are in the building) for the ability to tune their systems to meet real-time demand.

Many operators also said that tenant engagement training for the building occupants surrounding building systems and guidance for occupants to interact with those systems would benefit everyone. Some operators also explained that they had made efforts to educate their building occupants of behaviors to avoid potential issues (see Figure 6).

Quote 1	*"Motivate the occupants to practice energy efficient behavior."*
Quote 2	*"Occupants are skeptical about centralized control of systems - not being able to intercept arises concerns. The occupants have to be informed and sensibilized, in order to increase/reach occupant acceptance."*
Quote 3	*"We have stickers that say "don't block [univents], your fresh air depends on it". We're also moving to utilize a user's guide for the occupants of new buildings to let them know what are all of the, what is the equipment that's in their classroom and how it functions so that they can better understand their role in their own comfort."*

Figure 6: Selected quotes about possible tenant engagement and education strategies.

Yet, other operators did not see the value in occupant in feedback as it was redundant to known issues: "*I think the only time where there was widespread communication to occupants, were times where there were known issues with the mechanical systems*."

The data provided valuable insights into how operator and occupant relationships can be repaired, including more frequent and reliable occupancy surveys, improved feedback mechanisms, better communication, and tenant engagement and education.

4.3 Key Themes Found within the Interview Data

The following sections address three overarching themes from the interviews: occupant autonomy, effective communication, and job requirements and contractual obligations.

4.3.1 Occupant Autonomy

Uncomfortable occupants try to find ways to correct their environment. When operators are not available/able to repair issues, occupants' own actions can cause disruptions to a sensitive operation environment, other occupants' discomfort, and frustration in operators. In these cases, some operators must intervene. Specific examples of disruption actions by occupants are presented in Figure 4. To further challenge the role of the building occupant in managing occupant thermal comfort, evidence of "temperature wars" or occupant disagreements on their individual comfort needs were pervasive throughout the data. Responses showed that operators frequently received complaints of users requesting conditions outside of required thermal comfort requirements for performance and code. Some responses illustrated occupants' lack of control and/or how their autonomy was taken away when people could not "get along" or agree on temperature setpoints (e.g., see Figure 7).

Quote 1	*"Some departments used to have control of the splits, but due to improper behaviors (turning on machines on days that it was unnecessary, with low temperature, or turning it on with open windows) and not managing these controls correctly, we removed these "benefits."*
Quote 2	*"It happened a lot. For this reason, the privilege of some of them regarding control ended up being extinguished."*
Quote 3	*"We really try to discourage people, Jerry rigging and messing with the equipment because then it just damages it. So, we oftentimes are the ones that engage directly with the occupants on their comfort."*
Quote 4	*"If one occupant makes an adjustment for their benefit, it'll be to the detriment of others."*
Quote 5	*"Some companies restrict the occupants' access only to viewing because otherwise users make too many requests and temperature control becomes a war."*
Quote 6	*"You'll go on site, and you see that they've been manipulating it and so, the first thing you say is, well, it's because you put the wet paper towel on it. This is an electronic device and you have ruined it. So, the reason you're hot is because you broke it." "*

Figure 7: Selected quotes demonstrating aspects of occupant autonomy.

In some cases, operators elected to remove occupant autonomy to regain complete control over building operations. Operators expressed that "*If [occupants] were informed on system operations, [occupants] could make better decisions about their comfort without detriment to the building's performance."*

4.3.2 Effective Communication

Many of the operators interviewed communicated with occupants to understand their level of thermal comfort. However, the communication frequency and method varied greatly. For example, occupants provided direct feedback to the operator in-person, over the phone, via email, through an online portal, or their feedback was passed to the operator through an organizational chain of

command. Formality of exchanges is variable in these cases, as is its opportunity for better or worse communication between occupant and operator. If the occupants were to have more direct and physical interaction with the operators, there is opportunity for trust and communication improvement.

Some operators indicated that they had a good understanding of their building occupants' comfort. Others believed occupant dissatisfaction was a personal preference problem over a performance problem. Noticeably, some operators expressed a negative attitude towards outlier occupants. Several operators reported they did not receive regular feedback. Many operators indicated they only receive negative feedback from occupants when the problem has escalated. Less direct forms of feedback between occupants and operators tended to come through varying communication channels until they reached someone who could make system changes. Existing POEs are infrequent and inconsistent, as reported in the interview data. Operators indicated that having more specific prompts in surveys that help them understand when and where occupant comfort problems occur would be beneficial.

The interview responses showed that the operators with better feedback mechanisms and direct communication with the building occupants could better manage complaints and comfort challenges. However, even when feedback was provided, the feedback was often inaccessible or lacked information, leaving operators unable to make necessary changes. A common sentiment expressed by many operators was that "*if [they] had access to detailed feedback from the occupants, [they] could provide [occupants with] better comfort."* Many of the interview responses indicated a lack of effective communication between building occupants and the operators regarding thermal, visual, and environmental comfort. This trend shows the importance of open communication and regular feedback from occupants to operators and an opportunity for future research.

4.3.3 Job Requirements and Contractual Obligations

The operator's priorities are outlined in their job requirements, and several interview responses provided great details surrounding specific responsibilities. For example, several operators identified that their main priority is to meet environmental goals such as energy use or emission regulation and adhere to occupational goals such as municipal code requirements. Other operators prioritized occupant comfort and reducing occupant complaints.

Most operators understood that their job requirements, and the guidelines they must adhere to, do not always support every occupant's thermal comfort. As a result, occupants sometimes requested conditions outside of required thermal comfort requirements for performance and code. For those who design and determine the requirements of these code and energy efficiency guidelines, consideration of occupant comfort as a factor for performance success may be necessary.

These interviews revealed vast differences in communication between occupants and operators who manage the building remotely or in person. Operators with fewer occupants appeared to be more in tune and familiar with individuals' needs and comfort levels. The ratio of occupants to operators also impacted the possibility for direct communication. These findings indicate that the job requirements of the operator influenced their ability to communicate with their occupants effectively. These findings, emergent themes, and key research questions are further discussed in the next section.

5. Discussion

The interview results showed that the relationship between occupants and building operators is often strained but can be improved through operators adopting a customer service mindset and flexibility in communication. The factors that affect occupant and operator relationships are multifarious. While buildings are constructed for people, there are discrepancies between building design standards and actual needs from occupants in terms of comfort, control, and preferences [12]. By improving the relationship between operators and occupants, occupants' thermal comfort and building performance can be better balanced.

As evidenced by the data, there was often a communication breakdown between building occupants and operators. Overall, the data collected illustrates how this relationship is developed and maintained. Existing communication is negative, infrequent, and inconsistent. Therefore, demonstrating the need for better feedback channels and occupant education to remove barriers for operators and building performance.

5.1 Summary of Key Outcomes and Recommendations for Best Practice

Key themes and useful outcomes were discovered through this research. The following section offers concise and actionable steps for improving the relationships and outcomes between building operators and occupants. These recommendations are based on findings from the study and the larger body of literature that was reviewed.

5.1.1 Occupant Autonomy

Occupants with Autonomy

Occupants with autonomy may adjust their environment themselves. These adjustments include changing the thermostat, operating windows, and using vents. Occupants who have autonomy and are uncomfortable will often interact with the building and its systems, sometimes in unwelcome ways [59, 73].

Occupants who make thermostat changes outside of the standard ranges may cause harm to the system, decrease system performance, or discomfort in other building occupants. These actions can be a disruptance to the operators' requirements of meeting specific building performance goals and symbolize the occupant escape of predetermined "control".

Occupants may physically alter their environment by adjusting vents or windows which can decrease building performance.

Occupants without Autonomy

In cases where occupants do not have autonomy, effective communication is the only way their concerns can be addressed. Without effective communication and subsequent action to address concerns, occupants will take matters into their own hands [25].

Occupants may attempt to deceive systems. These actions can cause damage, additional discomfort, and frustration. Therefore, operators should actively encourage occupants to answer POE surveys and submit formal feedback regularly [101, 102].

Operators remove Occupant Autonomy

Operators may knowingly or unknowingly remove occupant autonomy, potentially causing strife and resentment between parties. The results showed that the operators “learned” to restrict occupant autonomy based on past occupant behavior in some cases. Therefore, there is an opportunity for interventions to lead the operator to other solutions such as occupant education. These responses demonstrate that operators did not initially want to limit autonomy but rather only did so when prompted by occupant interventions that harmed their systems.

Occupant Education

In most cases, all occupants should receive training about the building and its systems [25, 75, 76]. Occupants should understand how to manipulate their environment appropriately and how these manipulations will impact their environment, other occupants, and overall building performance.

Additional training for occupants with autonomy may be needed to understand system limitations and the consequences of inappropriate actions.

Occupant integration at the design level

Some buildings implement certain design strategies to encourage occupant interaction and autonomy with the building to improve comfort. These examples include use of window control signaling systems [103] or satisfaction measurement feedback points, and free address office reservation systems [36, 104] to help occupants gain control over their environmental conditions and preferences. For example, the WELL standard offers an optional credit for projects that offer free address across open work spaces with a thermal gradient and the ability for occupants to select a workspace with a desired temperature [105]. Through free address strategies occupant comfort, choice, and control of occupants can be improved.

5.1.2 Effective Communication

Consistent Feedback

Frequent and regular occupant feedback results in higher occupant satisfaction and the opportunity for improved building performance [16, 19]. Therefore, operators should reduce barriers to occupant feedback, encourage it, and provide regular formal opportunities (e.g., POE surveys) [102, 106]. Conversely, irregular or delayed feedback offers little value as occupant insights are difficult to connect to specific and actionable issues with mechanical systems.

All Feedback is Good Feedback

As is, negative feedback is the majority of feedback provided, however, negative and positive feedback is important in this relationship [37]. **Occupants should formally submit all feedback to building operators based on their real-time experiences** [35]. This feedback may be in the form of work orders, occupant app, ticket requests, or service requests. The work order system can track when and where problems occur, how quickly they can be resolved, and if there are repeated problems for specific occupants [20]. Positive feedback often only is received through regular POE surveys, and should be sought after more frequently, as work order systems imply negative feedback surrounding something that “needs to be fixed.” Therefore, POEs can be significantly improved to benefit the operator-occupant relationship and improve building performance, including additional context for timely reporting and opening communication channels between the operator and the occupant.

Direct Feedback
In some cases, complaints are passed through many hands before reaching the operator that can make a change or never reach them. Confirmation mechanisms of feedback getting to the right person ensures that complaints do not go unaddressed or lost in a system while occupants remain uncomfortable.

Flexibility for Outlier Occupants
If specific occupants continue to be uncomfortable, operators should develop individualized thermal comfort plans. These plans may include moving the occupant to a more suitable space, purchasing personal comfort devices such as a fan or a heater, and discussing appropriate adaptive clothing [36].

5.1.3 Job Requirements and Contractual Obligations

Transparency
In cases where occupants do not have autonomy, effective communication is the only way their concerns can be addressed. Building operators should be clear about their role and the performance goals they hope to achieve. Transparency is essential in all relationships.

Priorities
It would benefit operators to prioritize occupant comfort alongside building performance standards and requirements. These criteria are inherently interdependent. There is an opportunity for organizations that design these guidelines to reconsider their modern applicability to create a more inclusive indoor environment.

Occupancy Information
Operators with more information about occupants such as office layouts, occupancy schedules, live occupancy sensors data, and historical occupancy data can make better decisions about a building's operation.

Operator-Occupant Ratio
If possible, the ratio of occupants to operators should be reduced to improve effective communication and promote understanding.

Effective communication between operators and occupants becomes more critical as the ratio of occupants to operators and cases of remote operation increases.

Operator Management Styles and Role
The quality of interpersonal interactions between building occupants and operators depends on the job title, portfolios of work, organizational structure, and management style of the operator [28, 30].

Remote Work
As building automation systems (BAS/BMS) advance and the planet faces the fallout of COVID-19, building operators and occupants will increasingly complete their work remotely [107]. As a result, methods of effective online communication will be even more critical to this relationship.

5.2 Key Take-aways

In summary, occupant comfort and building performance can be balanced by improving the relationships between operators and occupants through modifying operator job requirements,

creating effective communication, and encouraging appropriate occupant autonomy. Further research should investigate the relationships between occupant discomfort and occupant-operator communication and how poor communication can be resolved in individual situations. Additional key takeaways from this research study are outlined below.

5.2.1 Practical Implications

The true nature of the relationships between operators and the occupants of the buildings they oversee is a difficult and widely variable topic. The types of relationships formed, the reasons they exist, and the challenges they face all affect the built environment. Operators can immediately apply a key finding of this work: reduce barriers to communication, → improve the quantity of communication → improve the balance between occupant satisfaction and building performance. Additionally, designers and researchers play a role in improving this relationship by integrating occupant-centric design, requiring POEs, and studying this relationship and its impact on occupant satisfaction and building performance.

5.2.2 Social Implications

For those with responsibility in the performance of buildings, it may be challenging to see building occupants as beneficial members of their work, especially if those relationships are strained by poor communication, immovable organizational structures, or personal issues. Building performance and occupant comfort are more nuanced than just the systems that are in operation and the people who are showing up to buildings. This study brings to light several potential concerns that building operators have about their relationship with occupants and proposes solutions to improving this relationship, including a transition toward standards like LEED, fitwel, and WELL that encourage feedback and comfort as a priority.

5.2.3 Originality/Value

The 72 interviews this research utilized were the largest study of occupant-centric building operation ever conducted. This paper describes the relationships between those occupying buildings and those responsible for the building operation. Additionally, this paper discusses how these interactions affect the overall climate and culture of the built environment. The relationships discovered through this research encourage a human-centric approach to solve building performance issues instead of automating people out of buildings. This scientific work illuminates best practices and challenges in operators' own words from a diverse international sample.

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References

[1] M. Goulden and A. Spence, "Caught in the middle: The role of the Facilities Manager in organisational energy use," *Energy policy,* vol. 85, pp. 280-287, 2015, doi: 10.1016/j.enpol.2015.06.014.

[2] IEA and O. Publishing, *Transition to Sustainable Buildings: Strategies and Opportunities to 2050*. Paris: Paris: IEA, 2013.

[3] EIA, "Annual Energy Outlook 2020," U.S. Department of Energy, Washington, DC, 2020. [Online]. Available: https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf

[4] ASE. "Buildings initiative - Energy in buildings." Alliance to Save Energy. https://www.ase.org/initiatives/buildings#:~:text=Energy%20Use%20in%20Buildings&text=Buildings%20also%20emit%20over%20one,efficiency%20in%20buildings%20incredibly%20important. (accessed 2020).

[5] Biden-Harris. "Climate Change: The Biden-Harris plan to create union jobs by tackling the climate crisis." Biden-Harris Transition. https://buildbackbetter.gov/priorities/climate-change/ (accessed.

[6] J. R. New, J. Kumar, and F. M. Hoffman, "Potential impacts of climate change on the built environment: ASHRAE climate zones, building codes and national energy efficiency," ed. United States: United States, 2017.

[7] R. A. Enker and G. M. Morrison, "The potential contribution of building codes to climate change response policies for the built environment," *Energy efficiency,* vol. 13, no. 4, pp. 789-807, 2020, doi: 10.1007/s12053-020-09871-7.

[8] S. Hu, D. Yan, E. Azar, and F. Guo, "A systematic review of occupant behavior in building energy policy," *Building and environment,* vol. 175, p. 106807, 2020, doi: 10.1016/j.buildenv.2020.106807.

[9] Z. Yu, B. C. M. Fung, F. Haghighat, H. Yoshino, and E. Morofasky, "A systematic procedure to study the influence of occupant behavior on building energy consumption," *Energy and Buildings,* vol. 43, no. 6, pp. 1409-1417, 2011, doi: 10.1016/j.enbuild.2011.02.002.

[10] T. Hong and H.-W. Lin, "Occupant Behavior: Impact on Energy Use of Private Offices," *Ernest Orlando Lawrence Berkeley National Laboratory,* p. 12, 2013.

[11] D. Yan *et al.*, "IEA EBC Annex 66: Definition and simulation of occupant behavior in buildings," *Energy and buildings,* vol. 156, no. C, pp. 258-270, 2017, doi: 10.1016/j.enbuild.2017.09.084.

[12] W. O'Brien *et al.*, "Introducing IEA EBC annex 79: Key challenges and opportunities in the field of occupant-centric building design and operation," *Building and environment,* vol. 178, p. 106738, 2020, doi: 10.1016/j.buildenv.2020.106738.

[13] A. Luna-Navarro, I. Gaetani, A. Law, and F. Anselmo, "Can we make our office buildings more responsive? Energy-efficiency and behaviour in the post pandemic office," presented at the BEHAVE 2020: 6th European Conference on Behavior and Energy Efficiency, Copenhagen, DE, 2020.

[14] M. Awada *et al.*, "Occupant health in buildings: Impact of the COVID-19 pandemic on the opinions of building professionals and implications on research," *Building and Environment,* vol. 207, p. 108440, 2022/01/01/ 2022, doi: https://doi.org/10.1016/j.buildenv.2021.108440.

[15] M. Aune, T. Berker, and R. Bye, "The missing link which was already there: Building operators and energy management in non-residential buildings," *Facilities (Bradford, West Yorkshire, England),* vol. 27, no. 1/2, pp. 44-55, 2009, doi: 10.1108/02632770910923081.

[16] S.-H. Kwon, C. Chun, and R.-Y. Kwak, "Relationship between quality of building maintenance management services for indoor environmental quality and occupant satisfaction," *Building and Environment,* vol. 46, no. 11, pp. 2179-2185, 2011/11/01/ 2011, doi: https://doi.org/10.1016/j.buildenv.2011.04.028.

[17] M. C. Katafygiotou and D. K. Serghides, "Indoor comfort and energy performance of buildings in relation to occupants' satisfaction: investigation in secondary schools of Cyprus," *Advances in Building Energy Research,* vol. 8, no. 2, pp. 216-240, 2014/07/03 2014, doi: 10.1080/17512549.2013.865554.

[18] L. E. Thomas, "Evaluating design strategies, performance and occupant satisfaction: a low carbon office refurbishment," *Building Research & Information,* vol. 38, no. 6, pp. 610-624, 2010/12/01 2010, doi: 10.1080/09613218.2010.501654.

[19] J. Goins and M. Moezzi, "Links between occupant complaint handling and building performance," in *7th Windsor Conference: The changing context of comfort in an unpredictable world*, Windsor, UK., April 12-15 2012. [Online]. Available: https://escholarship.org/uc/item/7sw762jk

[20] J. Goins and M. Moezzi, "Linking occupant complaints to building performance," *Building research and information : the international journal of research, development and demonstration,* vol. 41, no. 3, pp. 361-372, 2013, doi: 10.1080/09613218.2013.763714.

[21] M. V. Bavaresco, S. D'Oca, E. Ghisi, and R. Lamberts, "Methods used in social sciences that suit energy research: A literature review on qualitative methods to assess the human dimension of energy use in buildings," *Energy & Buildings,* vol. 209, 2020, doi: 10.1016/j.enbuild.2019.109702.

[22] A. Aryal and B. Becerik-Gerber, "Energy consequences of comfort-driven temperature setpoints in office buildings," *Energy and Buildings,* vol. 177, pp. 33-46, 2018, doi: https://doi.org/10.1016/j.enbuild.2018.08.013.

[23] S. Gauthier and D. Shipworth, "Behavioural responses to cold thermal discomfort," *Building research and information : the international journal of research, development and demonstration,* vol. 43, no. 3, pp. 355-370, 2015, doi: 10.1080/09613218.2015.1003277.

[24] J. Liu, R. Yao, J. Wang, and B. Li, "Occupants' behavioural adaptation in workplaces with non-central heating and cooling systems," *Applied Thermal Engineering,* vol. 35, no. 1, pp. 40-54, 2012, doi: 10.1016/j.applthermaleng.2011.09.037.

[25] J. K. Day, "Occupant training in high performance buildings: An assessment of environmental satisfaction, learning, and behaviors in buildings," Dissertation, Thesis (Ph. D.)--Washington State University,2014, Pullman, Washington], 2014.

[26] J. K. Day and D. E. Gunderson, "Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction," *Building and Environment,* vol. 84, pp. 114-124, 2015, doi: 10.1016/j.buildenv.2014.11.003.

[27] J. K. Day and W. O'Brien, "Oh behave! Survey stories and lessons learned from building occupants in high-performance buildings," *Energy Research & Social Science,* vol. 31, pp. 11-20, 2017, doi: 10.1016/j.erss.2017.05.037.

[28] M. Aune, T. Berker, and R. Bye, "The missing link which was already there," *Facilities,* vol. 27, no. 1/2, pp. 44-55, 2009, doi: 10.1108/02632770910923081.

[29] K. O. Roper and R. Payant, *The Facility Management Handbook, 4th Edition*, 4 ed. AMACOM, 2014.

[30] X. Zhao, B.-G. Hwang, and H. N. Lee, "Identifying critical leadership styles of project managers for green building projects," *International Journal of Construction Management,* vol. 16, no. 2, pp. 150-160, 2016/04/02 2016, doi: 10.1080/15623599.2015.1130602.

[31] J. K. Day and L. Heschong, "Understanding behavior potential: the role of building interfaces," *ACEEE Summer Study on Energy Efficiency in Buildings,* 2016.

[32] C. R. Ahn, M. Alahmad, H. Rafsanjani, and C. Ahn, "A review of approaches for sensing, understanding, and improving occupancy-related energy-use behaviors in commercial buildings," *Energies,* vol. 8, no. 10, pp. 10996-11029, 2015, doi: 10.3390/en81010996.

[33] H. Li, Z. Wang, and T. Hong, "Occupant-Centric key performance indicators to inform building design and operations," *Journal of Building Performance Simulation,* pp. 1-29, 2021, doi: 10.1080/19401493.2021.1876771.
[34] P. Li, T. M. Froese, and G. Brager, "Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review," *Building and Environment,* vol. 133, pp. 187-202, 2018/04/01/ 2018, doi: https://doi.org/10.1016/j.buildenv.2018.02.024.
[35] T. Sood, M. Quintana, P. Jayathissa, M. AbdelRahman, and C. Miller, "The SDE4 Learning Trail: Crowdsourcing occupant comfort feedback at a net-zero energy building," *Journal of Physics: Conference Series,* vol. 1343, p. 012141, 2019/11 2019, doi: 10.1088/1742-6596/1343/1/012141.
[36] T. Sood, P. Janssen, and C. Miller, "Spacematch: Using Environmental Preferences to Match Occupants to Suitable Activity-Based Workspaces," (in English), *Frontiers in Built Environment,* Original Research vol. 6, no. 113, 2020-July-30 2020, doi: 10.3389/fbuil.2020.00113.
[37] S. Assaf and I. Srour, "Using a data driven neural network approach to forecast building occupant complaints," *Building and Environment,* vol. 200, p. 107972, 2021/08/01/ 2021, doi: https://doi.org/10.1016/j.buildenv.2021.107972.
[38] M. Frontczak, S. Schiavon, J. Goins, E. Arens, H. Zhang, and P. Wargocki, "Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design," *Indoor Air,* vol. 22, no. 2, pp. 119-131, 2012, doi: 10.1111/j.1600-0668.2011.00745.x.
[39] ASHRAE, *Standard 55-Thermal environmental conditions for human occupancy*. Atlanta. GA: ASHRAE, 2017.
[40] T. Hong, Amp, Apos, S. Oca, W. J. N. Turner, and S. C. Taylor-Lange, "An ontology to represent energy-related occupant behavior in buildings. Part I: Introduction to the DNAs framework," *Building and Environment,* vol. 92, no. C, pp. 764-777, 2015, doi: 10.1016/j.buildenv.2015.02.019.
[41] T. Hong, S. C. Taylor-Lange, S. D'Oca, D. Yan, and S. P. Corgnati, "Advances in research and applications of energy-related occupant behavior in buildings," *Energy and Buildings,* vol. 116, pp. 694-702, 2016, doi: 10.1016/j.enbuild.2015.11.052.
[42] A. Leaman and B. Bordass, "Productivity in buildings: the 'killer' variables," *Building Research & Information,* vol. 27, no. 1, pp. 4-19, 1999, doi: 10.1080/096132199369615.
[43] W. Fisk, "Health and productivity gains from better indoor environments and their relationship with building energy efficiency," *Annual Review of Energy and the Environment,* vol. 25, p. 537, 2000.
[44] T. Y. Chang and A. Kajackaite, "Battle for the thermostat: Gender and the effect of temperature on cognitive performance.(Research Article)(Report)," *PLoS ONE,* vol. 14, no. 5, p. e0216362, 2019, doi: 10.1371/journal.pone.0216362.
[45] J.-H. Choi and D. Yeom, "Development of the data-driven thermal satisfaction prediction model as a function of human physiological responses in a built environment," *Building and Environment,* vol. 150, pp. 206-218, 2019, doi: https://doi.org/10.1016/j.buildenv.2019.01.007.
[46] S. Karjalainen, "Thermal comfort and gender: a literature review," vol. 22, ed. Oxford, UK, 2012, pp. 96-109.
[47] N. D. Sintov, L. V. White, and H. Walpole, "Thermostat wars? The roles of gender and thermal comfort negotiations in household energy use behavior," *PloS one,* vol. 14, no. 11, pp. e0224198-e0224198, 2019, doi: 10.1371/journal.pone.0224198.
[48] L. Schellen, W. D. Van Marken Lichtenbelt, M. G. L. C. Loomans, J. Toftum, and M. H. De Wit, "Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady-state condition," vol. 20, ed. Oxford, UK, 2010, pp. 273-283.

[49] J. W. Anderzhon, *Design for aging: International case studies of building and program*. Hoboken: John Wiley & Sons, 2012.
[50] M. C. Ashe, W. C. Miller, J. J. Eng, and L. Noreau, "Older adults, chronic disease and leisure-time physical activity," *Gerontology,* vol. 55, no. 1, pp. 64-72, 2009, doi: 10.1159/000141518.
[51] A. Chen and V. W. C. Chang, "Human health and thermal comfort of office workers in Singapore," *Building and Environment,* vol. 58, p. 172, 2012.
[52] W. H. Ko *et al.*, "The impact of a view from a window on thermal comfort, emotion, and cognitive performance," *Building and environment,* vol. 175, p. 106779, 2020, doi: 10.1016/j.buildenv.2020.106779.
[53] F. Davoodi, H. Hasanzadeh, S. Alireza Zolfaghari, and M. Maerefat, "Developing a new individualized 3-node model for evaluating the effects of personal factors on thermal sensation," *Journal of Thermal Biology,* vol. 69, pp. 1-12, 2017, doi: 10.1016/j.jtherbio.2017.05.004.
[54] S. Schiavon, D. Rim, W. Pasut, and W. W. Nazaroff, "Sensation of draft at uncovered ankles for women exposed to displacement ventilation and underfloor air distribution systems," *Building and Environment,* vol. 96, no. C, pp. 228-236, 2016, doi: 10.1016/j.buildenv.2015.11.009.
[55] K. New, A. Gormally, A. Friday, and M. Hazas, "We can send a man to the Moon but we can't control the temperature in our office': A considerate approach to workplace thermal comfort by older women," presented at the Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan, 2021. [Online]. Available: https://doi.org/10.1145/3411764.3445127.
[56] C. Criado-Perez, *Invisible women : exposing data bias in a world designed for men*. London: London : Chatto & Windus, 2019.
[57] K. Sun and T. Hong, "A framework for quantifying the impact of occupant behavior on energy savings of energy conservation measures," *Energy and Buildings,* vol. 146, pp. 383-396, 2017, doi: 10.1016/j.enbuild.2017.04.065.
[58] D. Yan *et al.*, "Occupant behavior modeling for building performance simulation: Current state and future challenges," *Energy and Buildings,* vol. 107, pp. 264-278, 2015, doi: 10.1016/j.enbuild.2015.08.032.
[59] S. D'Oca, T. Hong, and J. Langevin, "The human dimensions of energy use in buildings: A review," *Renewable & sustainable energy reviews,* vol. 81, no. P1, pp. 731-742, 2018, doi: 10.1016/j.rser.2017.08.019.
[60] H. Rafsanjani, C. R. Ahn, and M. Alahmad, "A review of approaches for sensing, understanding, and improving occupancy-related energy-use behaviors in commercial buildings," *Energies,* vol. 8, no. 10, pp. 10996-11029, 2015, doi: https://doi.org/10.3390/en81010996.
[61] M. Luo *et al.*, "Can personal control influence human thermal comfort? A field study in residential buildings in China in winter," *Energy & Buildings,* vol. 72, pp. 411-418, 2014, doi: 10.1016/j.enbuild.2013.12.057.
[62] A. Levinson and S. Niemann, "Energy use by apartment tenants when landlords pay for utilities," *Resource and Energy Economics,* vol. 26, no. 1, pp. 51-75, 2004/03/01/ 2004, doi: https://doi.org/10.1016/S0928-7655(03)00047-2.
[63] K. Healey, "Energy efficient behaviors and decisions at home and at work," Association of Energy Services Professionals, AESP Resource Library, 2012.
[64] H. Allcott, "Social norms and energy conservation," *Journal of Public Economics,* vol. 95, no. 9-10, pp. 1082-1095, 2011, doi: 10.1016/j.jpubeco.2011.03.003.
[65] A. Faruqui, S. Sergici, and A. Sharif, "The impact of informational feedback on energy consumption—A survey of the experimental evidence," *Energy,* vol. 35, no. 4, pp. 1598-1608, 2010, doi: 10.1016/j.energy.2009.07.042.

[66] M. B. C. Aries, J. A. Veitch, and G. R. Newsham, "Windows, view, and office characteristics predict physical and psychological discomfort," *Journal of Environmental Psychology,* vol. 30, no. 4, pp. 533-541, 2010, doi: 10.1016/j.jenvp.2009.12.004.

[67] N. Pivac, S. Nižetić, and V. Zanki, "Occupant behavior and thermal comfort field analysis in typical educational research institution: A case study," *Thermal Science,* vol. 22, no. Suppl. 3, pp. 785-795, 2018, doi: 10.2298/TSCI170915013P.

[68] K. Amasyali and N. M. El-Gohary, "Energy-related values and satisfaction levels of residential and office building occupants," *Building and Environment,* vol. 95, pp. 251-263, 2016, doi: 10.1016/j.buildenv.2015.08.005.

[69] *ISO 7730 - Ergonomics of the Thermal Environment*, ISO, 2015. [Online]. Available: https://www.iso.org/standard/39155.html

[70] *Ventilation for buildings - Indoor Environmental input parameters for design and assessment of energy performance of buildings, addressing indoor air quality, thermal environment, lighting, and acoustics. Module M1-6*, EPBD, Brussels, Belgium, April 30, 2019 2019.

[71] S. Carlucci, L. Bai, R. de Dear, and L. Yang, "Review of adaptive thermal comfort models in built environmental regulatory documents," *Building and environment,* vol. 137, pp. 73-89, 2018, doi: 10.1016/j.buildenv.2018.03.053.

[72] *Feature 76: Thermal Comfort*, IWBI, 2021. [Online]. Available: https://standard.wellcertified.com/v6/comfort/thermal-comfort

[73] A. Karatas, C. C. Menassa, and A. Stoiko, "A Framework for Delivering Targeted Occupancy Interventions to Reduce Energy Usage in Buildings," *Procedia Engineering,* vol. 118, no. C, pp. 752-759, 2015, doi: 10.1016/j.proeng.2015.08.510.

[74] A. Karatas, A. Stoiko, and C. C. Menassa, "Framework for selecting occupancy-focused energy interventions in buildings," *Building Research & Information,* vol. 44, no. 5-6, pp. 535-551, 2016, doi: 10.1080/09613218.2016.1182330.

[75] J. K. Day, "Occupant behaviors, energy use, and education: Creating high performance people for high performance buildings," presented at the The First International Symposium on Sustainable Human-Building Ecosystems, Carnegie Mellon University, Pittsburgh, PA., 2015.

[76] Z. Brown and R. J. Cole, "Influence of occupants' knowledge on comfort expectations and behaviour," *Building Research & Information,* vol. 37, no. 3, pp. 227-245, 2009, doi: 10.1080/09613210902794135.

[77] SBER, "Occupant engagement for sustainability," ed. SBER Summit on sustainable business IV: Sustainable Business & Enterprise Roundtable, 2012.

[78] M. Hafer, W. Howley, M. P. Chang, K. Ho, J. Tsau, and H. P. Razavi, "Occupant Engagement Leads to Substantial Energy Savings for Plug Loads," presented at the IEEE Conference on Technologies for Sustainability, Phoenix, Arizona, 2017. [Online]. Available: https://docsend.com/view/znnew3y.

[79] T. Harputlugil and P. de Wilde, "The interaction between humans and buildings for energy efficiency: A critical review," *Energy research & social science,* vol. 71, p. 101828, 2021, doi: 10.1016/j.erss.2020.101828.

[80] J. Chen, R. K. Jain, and J. E. Taylor, "Block Configuration Modeling: A novel simulation model to emulate building occupant peer networks and their impact on building energy consumption," *Block Configuration Modeling: A novel simulation model to emulate building occupant peer networks and their impact on building energy consumption,* vol. 105, pp. 358-368, 2013.

[81] Z. Deng and Q. Chen, "Simulating the impact of occupant behavior on energy use of HVAC systems by implementing a behavioral artificial neural network model," *Energy and Buildings,* vol. 198, pp. 216-227, 2019, doi: https://doi.org/10.1016/j.enbuild.2019.06.015.

[82] J. Kim, Y. Zhou, S. Schiavon, P. Raftery, and G. Brager, "Personal comfort models: Predicting individuals' thermal preference using occupant heating and cooling behavior and machine learning," *Building and environment,* vol. 129, pp. 96-106, 2018, doi: 10.1016/j.buildenv.2017.12.011.

[83] D. Li, C. C. Menassa, and A. Karatas, "Energy use behaviors in buildings: Towards an integrated conceptual framework," *Energy Research & Social Science,* vol. 23, pp. 97-112, 2017, doi: 10.1016/j.erss.2016.11.008.

[84] Q. Zhao, Y. Zhao, F. Wang, Y. Jiang, and F. Zhang, "Preliminary study of learning individual thermal complaint behavior using one-class classifier for indoor environment control," *Building and Environment,* vol. 72, pp. 201-211, 2014, doi: 10.1016/j.buildenv.2013.11.009.

[85] G. Happle, J. A. Fonseca, and A. Schlueter, "A review on occupant behavior in urban building energy models," *Energy and Buildings,* vol. 174, pp. 276-292, 2018, doi: https://doi.org/10.1016/j.enbuild.2018.06.030.

[86] J. Day, S. Ruiz, W. O'Brien, and M. Schweiker, "Seeing is believing: A mixed methods approach to understanding the human-building interface," *Energy Efficiency,* pp. 1-13, 2018, doi: DOI 10.1007/s12053-019-09817-8.

[87] J. K. Day *et al.*, "Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies," *Building and environment,* vol. 154, pp. 107-121, 2019, doi: 10.1016/j.buildenv.2019.02.037.

[88] J. K. Day, Z. Moore, and S. N. Ruiz, "Snuggies at work: Case study examples of thermal [dis]comfort, behaviors, and environmental satisfaction in the workplace," presented at the Windsor Conference on Thermal Comfort, Windsor Park, UK, 2020.

[89] D. L. Driscoll, P. Salib, and D. J. Rupert, "Merging qualitative and quantitative data in mixed methods research : how to and why not," *Ecological and Environmental Anthropology,* vol. 3, no. 1, pp. 18-28, 2007.

[90] V. L. Plano Clark and J. W. Creswell, *Designing and Conducting Mixed Methods Research*. Thousand Oaks, Calif.: Thousand Oaks, Calif. : SAGE Publications, 2007.

[91] C. Brown, "The power of qualitative data in post-occupancy evaluations of residential high-rise buildings," *Journal of Housing and the Built Environment,* vol. 31, no. 4, pp. 605-620, 2016, doi: 10.1007/s10901-015-9481-2.

[92] D. L. Morgan, *The SAGE Encyclopedia of Qualitative Research Methods*, Volume 1&2 ed. Thousand Oaks, California: SAGE Publications, Inc., 2008, pp. 815-816.

[93] A. Onwuegbuzie and N. Leech, "Generalization practices in qualitative research: a mixed methods case study," *Quality & Quantity,* vol. 44, no. 5, pp. 881-892, 2010, doi: 10.1007/s11135-009-9241-z.

[94] B. K. Sovacool, J. Axsen, and S. Sorrell, "Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design," *Energy Research & Social Science,* vol. 45, pp. 12-42, 2018/11/01/ 2018, doi: https://doi.org/10.1016/j.erss.2018.07.007.

[95] J. W. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 4th ed. Thousand Oaks, California: SAGE Publications, Inc., 2013, pp. 398-398.

[96] J. K. Day, "Losing metrics … finding heart," *Journal of Global Responsibility,* vol. 10, no. 2, pp. 176-192, 2019, doi: 10.1108/JGR-10-2018-0055.

[97] J. Hahn, S. Heiler, M. B. Kane, S. Park, and W. Jensch, "The information gap in occupant centric building operations: Lessons learned from interviews with building operators in germany," *Sustainability,* vol. 13, p. 18, 2021, doi: 10.3390.

[98] T. Abuimara, B. W. Hobson, H. B. Gunay, W. O'Brien, and M. Kane, "Current state and future challenges in building management: Practitioner interviews and a literature review," *Building and Environment,* 2021.
[99] J. Saldaña, *The coding manual for qualitative researchers*, 3E. ed. London ; Thousand Oaks, California: London ; Thousand Oaks, California : SAGE, 2016.
[100] L. Leung, "Validity, reliability, and generalizability in qualitative research," (in eng), *Journal of family medicine and primary care,* vol. 4, no. 3, pp. 324-327, Jul-Sep 2015, doi: 10.4103/2249-4863.161306.
[101] E. Azar and C. C. Menassa, "Optimizing the Performance of Energy-Intensive Commercial Buildings: Occupancy-Focused Data Collection and Analysis Approach," *Journal of Computing in Civil Engineering,* vol. 30, no. 5, 2016, doi: 10.1061/(ASCE)CP.1943-5487.0000521.
[102] *Feature 86: Post-Occupancy Surveys*, Building Standard IWBI, 2020. [Online]. Available: https://standard.wellcertified.com/mind/post-occupancy-surveys
[103] K. Ackerly and G. Brager, "Window signaling systems: Control strategies and occupant behavior," vol. 41, no. 3, pp. 342-360, 2013, doi: 10.1080/09613218.2013.772044.
[104] L. Engelen, J. Chau, S. Young, M. Mackey, D. Jeyapalan, and A. Bauman, "Is activity-based working impacting health, work performance and perceptions? A systematic review," *Building Research & Information,* vol. 47, no. 4, pp. 468-479, 2019/05/19 2019, doi: 10.1080/09613218.2018.1440958.
[105] *Feature 82: Individual Thermal Comfort*, IWBI, 2020.
[106] *Occupant comfort survey*, USGBC, 2021. [Online]. Available: https://www.usgbc.org/credits/eq51
[107] M. Ganser, "Solving the remote building management challenge," in *FacilityExecutive* vol. 2021, ed. Red Bank, NJ., 2020.