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Exploring Information and Comfort Expectations Related to the Use of a Personal Ceiling Fan

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Abstract: Rising global temperatures have increased the need for research into human adaptability and comfort in buildings. To reduce comfort-related energy demands, low-energy-consumption alternatives for space cooling, such as personal environmental control systems (PECS), are being investigated. The implementation of PECS in office buildings is still underway, and little is known about how occupants' expectations can influence their satisfaction with PECS and indoor environmental quality. This study examines the influence of tailored information and occupants' comfort expectations on their thermal perceptions and satisfaction with a personal ceiling fan. Seventy-six participants completed an online questionnaire and attended a half-day session at 30 °C in a climate chamber in Germany. A manipulation technique to activate personal norms was used to test the influence of information on expectations. Results indicated higher reported thermal comfort in participants with more positive thermal expectations, regardless of their expectations of the building systems. These effects were largely moderated by personal norms, indicating the importance of activating normative motivations to increase thermal comfort. Occupants with negative expectations improved their perceptions of the fan when making personal adjustments to stay comfortable. However, this effect was not moderated by personal norms. Practical implications focus on manipulating occupants' comfort expectations, e.g., by providing occupants with normative messages and individual control, to achieve greater comfort and acceptance of personal building controls in naturally ventilated buildings.

Keywords: psychological adaptation; adaptive behaviors; personal ceiling fan; personal norms; test chamber; thermal perception; thermal comfort

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1. Introduction

The global climate emergency has led to a push to deliver habitable indoor spaces, resulting in a growing demand for space cooling. A compounding increase in the use of air conditioning is expected, which will sharply escalate global carbon dioxide emissions. By better understanding how humans perceive and adapt to their thermal built environment, it may be possible to reduce the comfort-related energy demands of buildings. The literature on adaptive thermal comfort has gained particular attention over the past twenty years [1]. According to the theory of adaptive thermal comfort [2], three mechanisms take place in the adaptive processes of occupants in buildings—namely behavioral, physiological, and psychological mechanisms. Although many efforts have been made to understand the different factors that influence human adaptation, there is still a gap between predicted and actual occupant comfort and behavior observed in field studies [1,3].

The concept of comfort expectations has been studied as a relevant dimension of psychological adaptation to the environment [2]. According to the expectation hypothesis, an expectation (or anticipatory attitude) affects people's attitude towards thermal comfort attainment. Thus, the expectation of specific thermal conditions is certainly a major aspect of subjective assessment and satisfaction [4,5]. Some empirical evidence from China [6] suggested that long-term thermal experiences can raise thermal comfort expectations and that it is easier and quicker to enhance an individual's thermal expectations but harder to lower them. Accordingly, occupants in air-conditioned buildings are quicker to complain whenever the indoor temperature slightly strays from the usual set point because they have come to expect thermal constancy [7].

Relaxing comfort expectations could be an alternative path to promote resilience in buildings. A strategy to transform expectations could be achieved by widening occupants' thermal acceptability through adaptive behaviors, especially in free-running and green buildings [8,9]. Adding adaptive capacity in buildings, that is, the ability to implement effective adaptation strategies, is strongly related to control strategies [10]. Luo et al. [11] suggested the implementation of personal environmental control systems (PECS) as an adaptive strategy. PECS have the advantage of controlling the localized environment at the occupant's workstation according to their preferences rather than conditioning an entire room. Thus, PECS have the potential not only to save energy but also to improve comfort by addressing intra- and interpersonal differences among occupants [12,13]. Personal fans have been widely implemented as a type of PECS, as the cooling effect of air movement increases the thermal comfort and acceptability range of occupants in moderately warm thermal conditions [14–16].

By giving occupants the responsibility of managing certain aspects of the building, more information needs to be provided related to the passive features and building control systems in order to pursue an energy-efficient approach [17]. On the one hand, this might reduce the gap between how designers expect occupants to use a building and how they actually do. On the other hand, information feedback has been shown to help occupants save energy. For example, Schweiker et al. [18] found that participants receiving training and information about passive strategies were more likely to apply such methods and to reduce high-energy-consumption devices, such as AC-units. Day et al. [19] found that individuals who reported effective training and therefore understood how to operate the building controls were significantly more likely to be satisfied with their office environment when compared to individuals who did not receive any kind of training. Brown et al. [20] found a positive relationship between knowledge of a building's systems and higher use of personal control.

Research Gap and Scientific Contribution

Although several experimental and field studies have shown the potential of providing effective information and increasing occupants' knowledge to promote energy-saving behaviors [21,22] and increase occupant satisfaction [23,24], little work has examined how tailored information may influence the interaction between comfort expectations and satisfaction with PECS in naturally ventilated buildings. Thus, this study aims to understand whether information and knowledge can manipulate occupants with different positive or negative expectations about PECS and some aspects of the indoor environmental quality (IEQ), as such expectations could, in turn, influence occupants' satisfaction with the building controls and their perception of the indoor environment. The following research questions will be examined:

- To what extent do occupants' different expectations of the indoor environment and adaptive possibilities influence their a) thermal and indoor air quality perception and b) their satisfaction with a type of PECS?
- To what extent can tailored information to activate normative motivations be used to manipulate thermal and indoor air quality perception and satisfaction with a type of PECS of occupants with different expectations?

To address the identified research questions, this study investigates the relationship between occupants with different expectations of their built environment and their satisfaction with their indoor environment, as well as how expectations of a type of PECS can be manipulated to achieve greater satisfaction with the device. The existing definitions, relevant studies in the literature, and the research hypotheses are presented in Section 2. An experimental study and an online survey were conducted to test the research hypotheses. The study design and methods for data collection and analysis are presented in Section 3. The results and related hypotheses are discussed in Section 4.

This work contributes to the research on the acceptance of a type of PECS to increase its prominence and implementation in buildings and adds knowledge to the adaptive comfort literature by deepening the concept of comfort expectations in naturally ventilated buildings. The application of a theory-based definition of comfort expectation in a case study and the relationship between occupant expectations and their acceptance of a personal control device constitute the novelty of this paper.

2. Literature Review, Definitions and Hypotheses

2.1. Thermal and Behavioral Expectations

Evidence indicates occupants' expectations of indoor building environments influence their perceptions of climatic conditions, and unmet expectations of building performance can lead to dissatisfaction with indoor conditions. To better understand the mismatch between the occupants' predicted thermal perceptions of indoor environments and reported satisfaction, expectations in prior studies have been conceptualized in different ways. Fanger et al. [25] introduced an expectancy factor that relates expectations to past experiences, such as habituation to warm environments and exposure to air-conditioned buildings. Schweiker et al. [26] investigated how observed expectations affect occupants' thermal comfort levels and found a significant influence of thermal memory on expected comfort. Comfort expectations have mainly been analyzed in relation to perceived control [6,8,27], thermal experience and exposure [28–31], and thermal memory [32].

Despite the mentioned efforts in the literature, there is a lack of evidence-based and theory-driven characterization of the psychological adaptive concept of expectation [1]. In a recent study, the authors of reference [33] proposed a framework to operationalize expectations through cognitive mechanisms from well-established psychological and comfort theories (i.e., self-efficacy, perceived control, thermal history, and personal norms and attitudes). The model was tested through a nationwide survey, and it was concluded that expectations are key drivers of comfort and comfort-related behaviors. Based on the psycho-physiological model of Auliciems [34] and the adaptive theory, the framework established that expectations can be distinguished by thermal and behavioral expectations, which can be defined as follows:

- Thermal expectations: the thermal experience foreseen by occupants; the anticipated result, their perception of what will occur.
- Behavioral expectations: the likelihood of engaging in a specific behavior to adapt to the thermal environment to improve their comfort.

The results of the study [33] showed that the more the positive thermal expectations of the indoor environment were, the greater the associated reported thermal comfort was. Similarly, a positive relationship was found between more positive behavioral expectations toward a specific behavior and the probability of performing that action. A negative correlation was found between thermal and behavioral expectations, supporting the adaptive principle. The theoretical framework was empirically tested by asking the survey respondents to envision a working space with defined adaptive opportunities, but participants' actual comfort votes and adaptive actions were not captured in real-time and under the actual thermal conditions and building settings. Although the relationship between thermal and behavioral expectations was evaluated, the combined effect of positive–negative thermal and behavioral expectations on participants' thermal comfort and behavior responses was not investigated. It would be meaningful to classify different types of thermal and behavioral expectations for groups of participants with similar cognitive mechanisms, as this may give insights into how different groups of occupants may be targeted according to their shared expectations.

2.2. Provided Information and Building Interactions

In addition to individual differences in preferences and expectations for thermal comfort, variations in occupants' behaviors may result from their inadequate understandings of the building controls and purpose design of the building [35] or from missing knowledge or feedback regarding the effect of occupant actions (e.g., [36,37]). Studies on feedback and feedforward information revealed that the decisions made by occupants can be manipulated by providing feedback about the consequences of their previous actions [38] or feedforward information advising occupants prior to their actions [21,39,40]. Only a few studies have analyzed the impact of feedback and feedforward information on the decision process of occupants with respect to their building interactions and their change in comfort level after such decisions.

Meinke et al. [41] concluded that participants tended to interact more rationally with their built environment when receiving information about the consequences of different cooling strategies on comfort and energy consumption. They also found that when occupants were more aware of their control options, it led to increased perceived control and, consequently, higher comfort. Brown et al. [20] found that occupants' knowledge of the building, i.e., awareness and understanding of the building's environmental features and control systems, was positively related to the use of personal control in green buildings. More recently, Arpan et al. [42] investigated the effect of information on building occupants' expectations of sustainable buildings. They concluded that potential building occupants who are informed about the common features of sustainable buildings and how they function may have more positive a priori expectations about the thermal and indoor air quality conditions in the building. Accordingly, it could be hypothesized that providing information about the benefits and operation of PECS could create positive expectations towards the device and, consequently, satisfaction with it.

2.3. Normative Motivations

Additional results from the above-mentioned study [33] showed that behavioral expectations were partially explained by personal norms: participants with greater motivations towards passive cooling strategies (stronger personal norms) will express higher expectations to successfully modify their indoor environment. Changes in user expectations may be reflected in expectations of building systems and occupant behavior [43]. Research conducted in intervention studies suggests that normative motivations, i.e., people who prioritize collective interests over their personal ones, have a significant impact on anticipating and designing interventions to encourage energy-saving behavior [39]. Accordingly, when activating personal norms, occupants' behavior is driven by feelings of moral obligation to act in a norm-concordant manner. In this sense, occupants with strong personal norms suggest that they are intrinsically motivated to act pro-socially—following normative considerations—and increase their sense of self-worth. For example, Hameed et al. [44] studied patterns of adoption of low-carbon practices and concluded that normative motivations were key drivers for the purchase of energy-saving air conditioners in Pakistan. Similarly, Gerhardsson et al. [45] found that lighting behaviors, such as improving lighting technology, were driven by normative goals, while Wall et al. [46] found that environmentally motivated participants who were motivated to save energy were more tolerant of the poor performance of energy-efficient energy lamps than less environmentally motivated participants. By activating personal norms, individuals tend to act according to those norms and are more willing to make concessions to meet their standards of behavior, especially those who are more environmentally engaged [47].

A theoretical foundation prominently used in psychology to analyze behavioral change and promote pro-environmental behaviors is the goal-framing theory [48]. According to this theory, goals determine or "frame" what people pay attention to, what knowledge and attitudes become most cognitively accessible, how people evaluate different aspects of the situation, and what alternatives are being considered. A "goal-frame" is the way in which people process information and act on it. If people change their goals, they will also perceive the situation differently. When it is activated or "focalized", a goal is a combination of a motive and an activated knowledge structure. There are three types of frames: gain, hedonistic, and normative frames. The latter two will be considered for the present study. Hedonistic frames activate subgoals that promise to improve how one feels in a particular situation. Their time horizon is very short, and people in this frame are sensitive to what changes their pleasure and mood. For example, feeling warm in a room may decrease a person's thermal comfort. The normative frames of "act appropriately" activate goals related to what is appropriate, and people in this frame are sensitive to what should be done according to their self or others, including, for example, turning off the thermostat when the windows are open even if the person does not pay the bill simply because it is the right thing to do.

In an experimental study, Li et al. [24] used social normative messages to investigate intended occupant interactions with a PECS, showing a positive influence of feedforward information on the intended use of a personal desk fan. Thus, informing individuals with strong pro-environmental norms about PECS features designed to protect the environment should activate their normative goals and subsequently motivate them to act—or perceive the situation—in a manner that is congruent with those personal norms. Accordingly, it might be expected that some occupants would have more positive expectations of PECS and be more tolerant of indoor conditions when these overarching personal goals are activated.

2.4. Hypotheses

The review of the state of the art has shown that there is a lack of studies assessing the effect of occupants' expectations and normative motivations on their satisfaction with thermal and indoor air quality conditions and personal controls in buildings. Based on the state of the art in combination with the definitions presented, a preliminary framework for the assessment of expectancy was developed (Figure 1), which summarizes results from a previous study on thermal and behavioral expectations [33] and proposes a new investigation to assess the effect of expectancy groups on thermal satisfactions and satisfaction with PECS tailored by normative motivations.

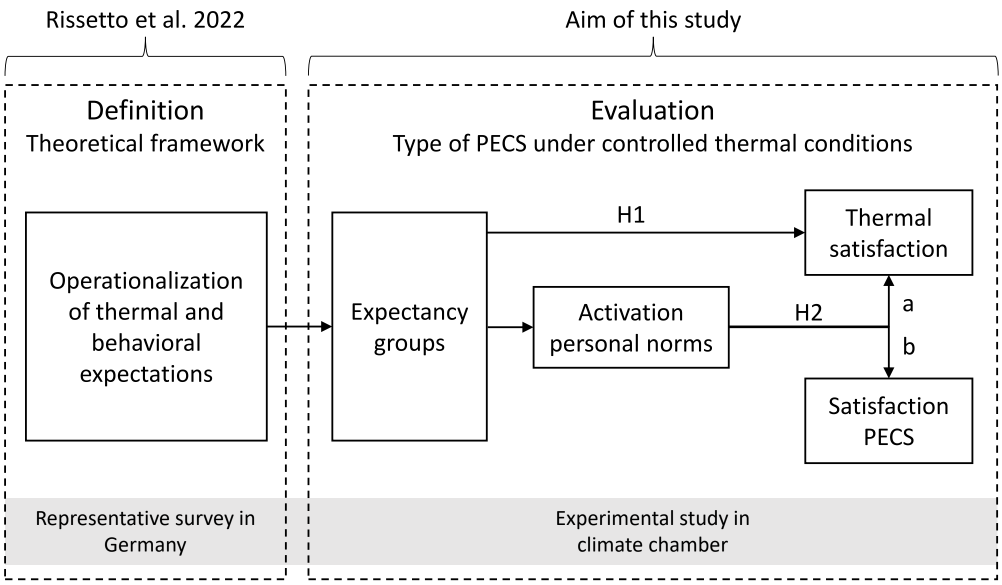

Figure 1. Proposed framework to assess occupants' expectancy, personal norms, and satisfaction with thermal conditions and a type of PECS, together with an existing theoretical framework [33]. H1, H2a and H2b are the investigated hypotheses.

Based on the above-stated research questions, the following hypotheses will be investigated:

- H1: A person with more positive expectations about the thermal conditions in the room and towards a type of PECS will find the climatic conditions more acceptable, expressing higher thermal satisfaction than a person with more negative expectations.
- H2: By activating normative motivations through tailored information, expectations can be influenced in a positive direction so that (a) participants with more positive expectations will express higher thermal satisfaction and (b) participants with more negative expectations will show a change in expectations after using the PECS.

3. Methods

In order to assess the proposed hypotheses, an experimental study in a laboratory setting and an online survey were conducted. First, participants were asked to complete an online questionnaire prior to attending a half-day session at the LOBSTER test chamber in Karlsruhe, Germany [49]. The latter consists of two identical office rooms, each with two operable windows and blinds facing north. The surface of the test facility (except for the glass facade) is activated with a capillary tube system, which allows set point temperature of each surface to be changed individually. For this study, each room was equipped with a personal ceiling fan. The sessions took place over 15 working days in August 2021. All procedures were approved by the data protection officer and the ethics committee of the Karlsruhe Institute of Technology and were conducted in accordance with the Declaration of Helsinki. The study is described as follows.

3.1. Recruitment and Participation

Participants were recruited primarily through the local newspaper and university websites. Participants had to be non-smokers and be German or have a good command of the German language to ensure that they understood and were capable of answering the provided questionnaires. They received monetary compensation for participating in the survey and the test chamber session. A total of 76 participants (35 male and 41 female), aged 18–34 and 50–70 years, took part in the half-day experiment and completed the online questionnaire. The aim of including those age groups was to increase the probability of participation and control the sample, as there was a higher probability that individuals of those groups were able to participate in the experiment during working hours and have higher motivation to receive a monetary compensation (e.g., students or retired participants). For the session in the LOBSTER, participants were asked to wear long pants, a shirt, and closed shoes. Clothing data were collected in the initial questionnaire, and the clothing level was estimated based on self-reported clothing items in the questionnaire and converted to clo values based on ISO 7730 [50]. An average value of 0.44 clo (SD = 0.12) was calculated with an additional value of 0.10 clo to account for the insulation provided by the desk chair. The participants were not allowed to change their clothing level (e.g., by taking off their sweater or shoes) during the test.

3.2. Pre-Test: Online Questionnaire

Participants completed an online background questionnaire one week before the LOBSTER session. The focus of the questionnaire was to assess participants' psychological constructs that represent expectations about the indoor environment and PECS, as well as related topics, such as sustainability or passive climate control strategies in buildings. The questions were based on the expectancy framework proposed by Rissetto et al. [33]. The questionnaires were sent via Limesurvey [51]. The purpose of this pre-test was to obtain the long-term attitudes of the participants without the possible influence of the controlled environment and the experience with the personal ceiling fan in the test chamber.

The survey consisted of three parts. The first section included an anonymous ID code to allow a comparison with the results of the session in the test chamber (see Section 3.3) and the measures of control variables, mainly current mood, experience with and evaluation of fans, experience working in an office environment (e.g., use of air conditioning and the use of building controls to adjust to climatic conditions). The second section included the main measures of this study: (1) measures of thermal expectations and behavioral expectations, (2) self-efficacy, perceived control, personal norms, thermal history, and attitudes, and (3) reported comfort and behavior. Finally, the third section included temperature type and sensitivity to indoor air quality and humidity, as well as expectations of ceiling fans. The last item was included to analyze the effect of information on a possible change in fan expectations (related to H2b).

3.3. Session in the LOBSTER

The same participants participated in a half-day session (either morning or afternoon) in the test chamber. Each session lasted three and a half hours, and a single participant occupied each room. Figure 2 describes the complete schedule before and during one session in the chamber. For the first 10 min, the study and the schedule were explained to the participants in the hallway. During the first half hour (acclimation phase), they entered the respective room and adapted to the climatic conditions. Both groups experienced warm indoor thermal conditions, so the walls' surface temperature was set to 30 °C. Participants were not able to modify the indoor environmental conditions of the rooms. During the next three hours, they engaged in personal activities, such as reading their own material or working on the computers provided. Meanwhile, they had the opportunity to perform different adaptive measures to restore their comfort with the thermal environment: (1) turning on the ceiling fan, (2) tilting the window(s), or (3) drinking water or another beverage.

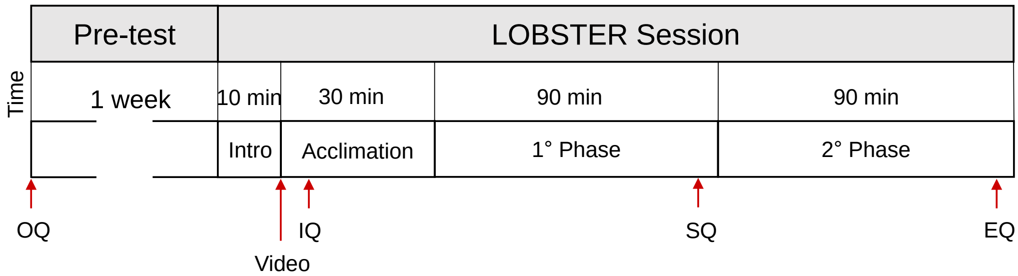

Figure 2. Timeline of surveys and experimental conditions before and during the session in the LOBSTER. OQ: online questionnaire. IQ: initial questionnaire; SQ: status questionnaire; EQ: end questionnaire.

Figure 3 shows the workstation, the personal ceiling fan, and the corresponding sensor equipment. The participants were seated 50 cm away from the center of the personal ceiling fan and 1.50 m from the windows. The personal ceiling fan corresponds to a type of PECS as it is workstation-related, i.e., each occupant owns a device, and can be individually controlled by the occupant. The axial fan had a small rotating area, and it was integrated into an acoustic panel to improve the acoustics in the room. The integrated ceiling fan had an adjustable grille to direct the airflow to the head of the participants, which in this study was directed towards the side of the participant's head. The influence of different airflow directions was previously tested for this personal fan [52], and no significant difference was found between top, back, frontal and side airflow. The air velocity of the ceiling fan could be adjusted by the participants using a remote control. Further descriptions of the ceiling fan can be found in Rissetto et al. [52].

Participants completed various questionnaires during their stay via a web interface based on pre-set schedules (Figure 2). The focus was to collect information mainly on their perception of and satisfaction with the IEQ and the personal ceiling fan. As the questions were asked in the German language, most of the questions and corresponding scales were based on the German index "INKA: Instrument für Nutzerbefragungen zum Komfort am Arbeitsplatz" to assess comfort in office buildings [53], which is based on the questionnaire of ASHRAE 55 [54]. The questionnaires were divided into three blocks according to different experimental phases: an initial questionnaire (IQ) at the beginning of the acclimation phase (first 30 min of the experiment), an intermediate questionnaire

(SQ) at the end of the first hour and a half after the acclimation phase (phase 1), and a final questionnaire (EQ) asked 10 min prior the end of the second phase of the experimental part of the session (phase 2). Participants were exposed to the same thermal conditions in phases 1 and 2, but each phase indicated the appearance of the comfort questionnaires at different points in time (SQ and EQ) to evaluate the comfort votes during the length of the study. To analyze a possible change in fan expectations, participants were asked about their experiences with fans and their expectations and preferences with the personal ceiling fan and PECS in general to examine whether the expectations reported in the background questionnaire (Section 3.2) changed after using the personal device and having received the targeted information (see Section 3.3.2). Table 1 summarizes the key variables collected on the questionnaires relevant to this paper.

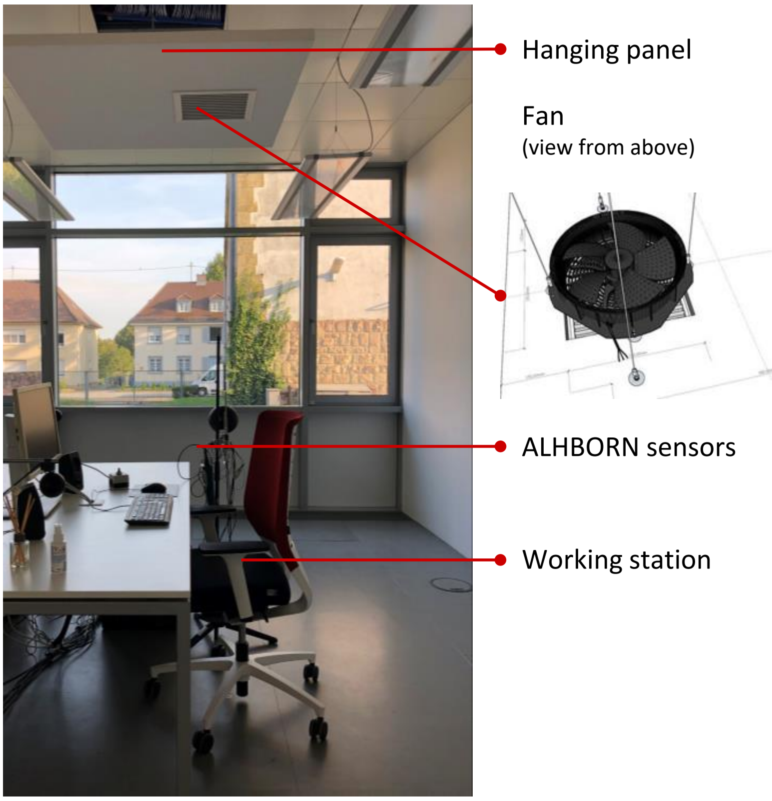

Figure 3. Setup of ceiling fan, sitting position, and sensors in the office room in the test chamber.

Indoor and outdoor parameters were collected from sensors through the building management system (BMS). Air temperature (Mean = 29.7 °C, SD = 0.6), globe temperature (Mean = 29.6 °C, SD = 0.6), relative humidity (Mean = 41.9%, SD = 4.5), and air velocity (Mean = 0.13 m/s, SD = 0.1) were collected with AHLBORN comfort meters placed at the height of 1.10 m and 0.25 m away from the participant's head. The corresponding resolutions are 0.01 °C, 0.01 °C, 0.1%, and 0.001 m/s; the accuracies are ±0.2 K, ±(0.30 K + 0.005 × T), ±2.0%, and ±(3% reading + 0.01), respectively. Interactions with the remote control and with the windows were recorded by the BMS. The fan speed chosen by participants through the remote control was recorded as a continuous variable between 0 and 100%. At the end of the sessions, participants were asked about their drink consumption. Physiological data were also collected, including heart rate (EcgMove 4: r = 12 bit, input range CM = 560 mV, DM = +/−5 mV) and skin temperature (iButton DS1921H: r = 0.125 °C, a = +/− 1 °C). The resulting analysis of the physiological data was not included in this paper. All data were recorded at 1 min intervals.

Table 1. The main information obtained by the questionnaires. All answers are integer values. Note: the provided questionnaires were in German; the English translations in the table were not used in the study and are presented only for understanding purposes. The German version is available from the authors per request.

Measure	Description of Item	Response Categories	Mean (SD)
Thermal sensation [a]	"Wie fühlen Sie sich jetzt gerade?" (*How do you feel right now?*)	−3 (cold) to +3 (hot)	4.79 (0.55)
Thermal comfort [a]	"Empfinden Sie dies als. . . " (*Right now, do you find this environment...?*)	1 (extremely uncomfortable) to 5 (comfortable)	3.87 (0.55)
Thermal preference [a]	"Wie hätten Sie es jetzt gerade lieber?" (*Right now, would you prefer to be...?*)	1 (much cooler) to 7 (much warmer)	3.29 (0.54)
Thermal acceptability [a]	"Wie empfinden Sie diese Temperaturbedingungen jetzt gerade?" (*Right now, do you find the thermal environment...?*)	1 (clearly unacceptable) to 4 (clearly acceptable)	3.47 (0.55)
Indoor air quality perception [a]	"Wie nehmen Sie die Raumluftqualität im Büro wahr?" (*How do you perceive the indoor air quality in the office?*)	1 (very good) to 7 (very bad)	4.26 (1.02)
Fan satisfaction [b]	To maintain comfortable indoor temperatures, the ceiling fan is more effective than I expected; To maintain comfortable indoor temperatures, the ceiling fan is more effective than I expected; If I could choose, I would rather use a ceiling fan than open the windows; I have control over the personal ceiling fan; The ceiling fan is easy to operate; The ceiling fan fits well with the floor plan and furnishings of the office; I can understand the advantages of the ceiling fan; The ceiling fan is quiet; Being able to adjust the air velocity myself is an advantage of the ceiling fan; Improving the indoor climate is a benefit of using the ceiling fan; If I could choose, I would use the fan as an energy-saving cooling strategy; If I could choose, I would use a ceiling fan instead of turning on an air conditioner; I consider myself capable of operating the personal ceiling fan; I should avoid opening the window when it is very warm outside.	1 (strongly disagree) to 7 (strongly agree)	8.24 (0.76) [6.05, 9.40] [d]
Fan expectations [c]	Same as before, but slightly modified and adapted in the form of *"I expect that ..."*	1 (strongly disagree) to 7 (strongly agree)	4.53 (2.11) [1.52, 8.83] [d]

[a] Measured in IQ, SQ, and EQ during the LOBSTER session. [b] Measured in EQ during the LOBSTER session. Scale reliability: 0.70. [c] Measured in background questionnaire (pre-test). Scale reliability: 0.93. [d] Unstandardized values resulting from principal component analysis (PCA) conducted with all presented questions (see Section 3.4.1).

3.3.1. Classification of Expectancy Groups

Participants were divided into groups to investigate the influence of different "levels" of expectancy on occupant satisfaction (related to H1). The clustering process was adapted from a previous study [55] following these steps:

- Using a training dataset, the cluster structure was calculated to explain a selected threshold of 80% of the variance using the k-means method [56].
- As the k-means method requires the number of clusters as an input, the elbow method was applied to calculate the optimal number of clusters.
- A test dataset was fitted to the obtained cluster structure using a support vector machine (SVM) method [57], which is a class of supervised learning algorithms that train the classifier function using labeled data.

A pre-analysis of the data from the nationwide survey to assess comfort expectations [33], explained in Section 2.1, was used as the training dataset to define the cluster structure. An expectancy value was obtained for each participant by assigning two scores: one for thermal expectations and one for behavioral expectations. The scores were obtained by principal component analysis (PCA). The obtained expectancy value was used to define the cluster centers using the k-means algorithm. The results from the elbow method showed an optimal number of three clusters. The corresponding label (cluster) was assigned to each point of the training dataset.

Prior to the LOBSTER session, the new scores for expectancy values were obtained for each participant using the data from the online survey explained in Section 3.2 (test data). With the labeled data, the SVM linear classifier was used to fit the participants' scores from the test data into the defined cluster structure. Figure 4 shows the results of the SVM. The different colors represent the three clusters. We can interpret the cluster classification as follows: participants in cluster 1 had positive fan expectations and negative thermal expectations; participants in cluster 2 had positive thermal and fan expectations; participants in cluster 3 had near-neutral thermal expectations and negative fan expectations.

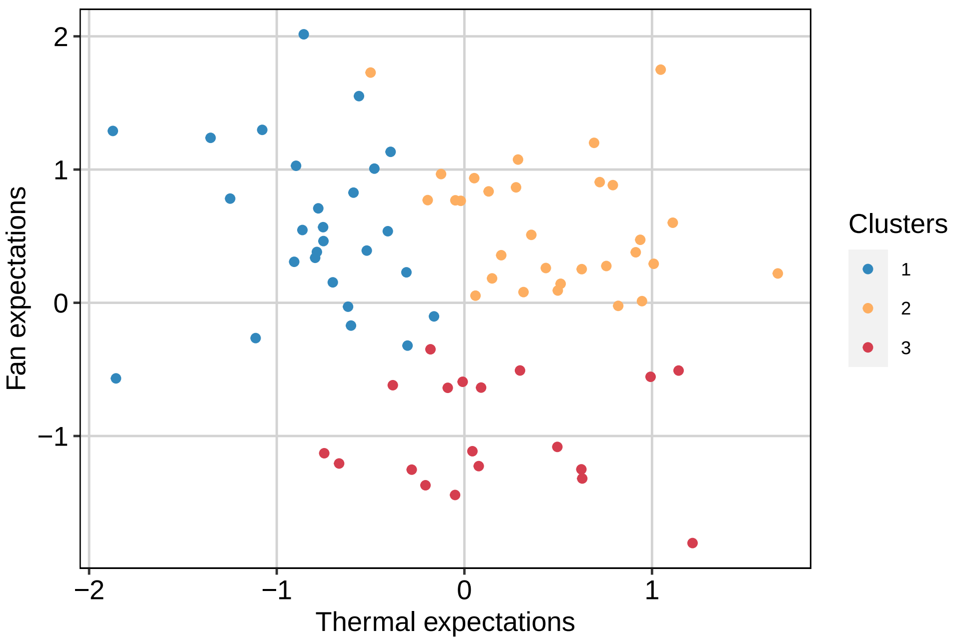

Figure 4. Classification groups for thermal and behavioral expectations based on the SVM method.

This clustering process was carried out before the session in the LOBSTER to similarly distribute participants according to daytime (morning/afternoon) and information groups (Section 3.3.2).

3.3.2. Manipulation Technique

The experimental study used a manipulation technique to test the effect of information on occupants' expectations and satisfaction (H2). The main goal of the manipulation technique is to activate hedonistic frames in all participants and to test whether normative frames predominate over hedonistic frames according to the different information provided. To activate the hedonistic frames, the office rooms were set to warm conditions, which can act as a stimulus for subjects to perform an action to restore thermal comfort (hedonistic motivation). Previous studies investigating the cooling effect of air movement under controlled conditions in test rooms [58,59] found that thermal comfort can be achieved at an indoor temperature set point of 30 °C if a personally controlled fan was provided. For this study, a setpoint of 30 °C was selected to trigger warm discomfort and encourage the use of the personal fans to achieve thermal comfort without compromising health and productivity issues that may affect occupants' satisfaction in the room. To fulfill the hedonistic frames, i.e., to restore thermal comfort, participants were provided with adjustment options, such as turning on the ceiling fan, opening the window, and drinking a beverage. Questions about the fulfillment of hedonistic frames were asked in the final questionnaire (EQ).

Participants watched a video (see Figure 2 in Section 3.3) that provided information about sustainability and energy efficiency in buildings to activate the normative frames. Two different videos were created. The control group was shown a shorter video containing general information about sustainability, climate change, and political energy targets in Germany, as well as the aim of the study. The experimental group was shown a longer video (https://www.youtube.com/watch?v=JJdQMij2kT0, accessed on 14 January 2024) that had the same initial content as the control group but included additional information about benefits and scientific explanations on how ceiling fans work.

The inclusion of general information is to set a "baseline" of information for all participants. The distinction between videos (additional information on personal ceiling fans) is intended to increase motivation to use the low-energy-consumption device in opposition to other non-energy-efficient strategies, such as opening the windows when it is too warm outside. Accordingly, participants were divided into the experimental group (long video) and the control group (short video). Both groups received instructions with a standardized text on how to operate the adaptive strategies: turning on and adjusting the air velocity of the ceiling fan, opening the tilt windows, and recording beverage intake in liters. Different adaptive opportunities to counteract thermal discomfort were given based on the work from Meinke et al. [41] to evaluate the influence of the provided information about the potential change in comfort and energy consumption of the personal ceiling fan on the experimental group. Participants were similarly distributed according to their cluster group of expectations described in the previous section.

During the session, participants were also asked to rate the educational video. All questions had a 7-point Likert scale ranging from strongly disagree (1) to strongly agree (7).

3.4. Data Analysis

All data preparation and analysis were performed in the software environment R (Version 4.1.3) [60]. The following subsections describe the assumptions and methods used for data analysis.

3.4.1. Sample Size and Checks on Random Assignment

The sample size was calculated using G*Power 3.1.9.7 [61]. Since the sample size was less than the required to achieve a small effect size, a large effect size was necessary (>0.8). For a t-test between two independent group means with an α value of 0.05, a power $(1-\beta)$ of 0.95, and an effect size of 0.8, the required sample size was 74 participants.

Before testing the hypotheses, we verified the equivalence of the participant groups in the two research conditions using t-tests and Chi-square analyses (see Appendix A for results of these equivalence tests). Table A1 shows the distribution of participants from the different clusters according to their demographics and other characteristics, as well as the experimental conditions. Body mass index was categorized into two groups according to the WHO classification [62]: BMI < 25 kg/m^2 = normal and BMI > 25 kg/m^2 = overweight. The results showed that BMI and previous experience in working in an office were significantly different between clusters. Accordingly, we controlled for those variables by entering them as covariates in the tests of H1–H2. Table A2 shows the distribution of participants from the different clusters according to their actual mood, video rating, and fan use (air velocity and duration of fan turned on). None of the variables were significantly different between groups.

Additionally, we verified differences in indoor climate perception between the expectation clusters. To capture changes in the reported thermal comfort between the acclimation phase and the rest of the experimental phase, a mean value for comfort votes was taken for the whole test. Results of the Kruskal–Wallis tests showed that participants in cluster 2 were significantly more comfortable with the thermal conditions during the whole test compared to the other two groups ($H(2) = 6.65$, $p < 0.05$, $\eta^2 = 0.06$). A post hoc analysis was performed using the Dunn test to determine which levels of the independent variable differed from each other. The pairwise comparison test showed that cluster 2 is significantly different from cluster 1 ($p < 0.05$) but not from cluster 3 ($p = 0.089$). In addition, no differences were found for thermal sensation, preference, and acceptability and indoor air quality perception between groups. Therefore, only thermal comfort was kept for further analysis as the dependent variable to test the proposed hypotheses.

To evaluate changes in participants' fan expectations and evaluation, questions related to the expectations of personal ceiling fans from the background questionnaire (Section 3.2) and the last questionnaire from the LOBSTER session were analyzed. Firstly, a principal component analysis (PCA) was conducted on 13 questions from the background questionnaire. The weights from the background questionnaire were calculated to obtain the scores for the equivalent questions in the LOBSTER session. A single component was obtained for fan expectations (pre-test) and fulfilled expectations (LOBSTER session). To obtain a value representing the change between fan expectations (before the session) and evaluation (after the session), the difference between the two variables was calculated. The resulting variable was called "fan evaluation" ($M = 3.71$, $SD = 2.25$).

3.4.2. Hypotheses Testing: Statistical Tests

To test the hypothesis that groups of occupants with different types of thermal and behavioral expectations will express different thermal satisfaction (H1), a regression analysis was conducted. The single-answer options for measuring participants' evaluation of the temperature could not be assumed to be equidistant but needed to be considered as ordered categorical data [63]. Therefore, an ordinal model was selected to test the relationship between these ordinal response variables and one or more independent variables using the *clm* (cumulative link model) function from the R package ordinal [64]. The independent variable was the expectancy group (cluster), which was treated as categorical (1, 2, or 3). The hypothesis that the effect of information on participants' thermal satisfaction would be particularly strong among participants with more positive expectations of the indoor air quality and thermal conditions and the use of the personal ceiling fan (H2a) was tested with a conditional process analysis [65] using Hayes' PROCESS model 1 of moderation for R with cluster as the multicategorical variable. To test for possible changes in the expectations of participants with negative expectations after providing information (H2b), an additional process analysis was conducted with fan evaluation as the dependent variable. Similar to the evaluation approach for thermal comfort, fan evaluation was considered ordered categorical data.

4. Results

A series of predictive models were run to examine the above-mentioned hypotheses. H1 predicted that greater reported thermal comfort would be reported by participants with more positive thermal and behavioral expectations. To test this hypothesis, the total effect model was examined by testing the simple effect of the independent variable and control variables on the outcome variable. H1 was supported, as belonging to cluster 2 (the group with more positive thermal and behavioral expectations) was associated with significantly greater reported thermal comfort (Table 2). The coefficient in the model indicates a positive relationship: the more positive the thermal and behavioral expectations, the higher comfort participants in this group reported. A likelihood ratio test was performed with an ANOVA test. The results showed that the model that includes the expectation groups as a variable is significantly better than an intercept-only baseline model ($\chi^2 < 0.05$). Control variables of BMI and previous experience in working in an office did not significantly influence thermal comfort.

Table 2. Results of the ordinal regression analysis to test the effect of expectancy cluster on thermal comfort.

	Estimate	Std. Error	z-Value	*p*-Value
Cluster 2 [a]	1.65	0.67	2.45	0.015 *
Cluster 3 [a]	0.076	0.66	0.11	0.909
BMI (overweight)	−0.42	0.56	−0.76	0.449
Experience (yes)	−0.91	0.60	−1.50	0.133

* $p < 0.05$; [a] Results against cluster 1.

H2a predicted that the effect of the expectancy cluster on thermal comfort would be especially strong among participants with greater existing personal norms to protect the environment and save energy, as activated by tailored information (long video). This hypothesis was supported (see Figure 5 for coefficients and *p*-values), as the moderation model was significant ($F(5, 70) = 3.08$, $p < 0.05$, $R^2 = 0.18$). Tailored information to activate personal norms (the long video) seems to have prompted higher reported thermal comfort in participants from cluster 2 compared to those from clusters 1 and 3. Those participants who did not receive tailored information (the short video) expressed similar reported thermal comfort regardless of their expectancy cluster, indicating no effect of video on the relationship between expectancy and thermal comfort.

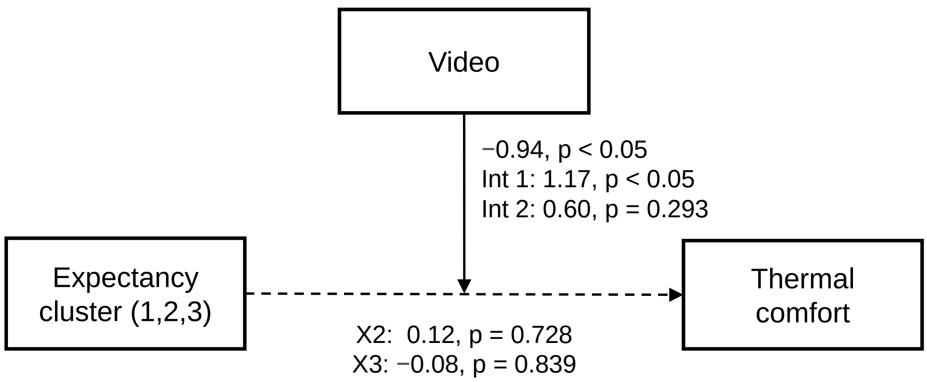

Figure 5. Model of moderating effects of video on thermal satisfaction. Unstandardized coefficients are shown. Dotted lines indicate nonsignificant relationships. Short video condition coded as 0; long video condition coded as 1. Expectancy cluster coded as dummy variables for multicategorical variables. Video significantly moderates the effect of cluster 2 on thermal comfort (Int 1).

Although data from the test of the total effect model for H1 (Table 2) identified a significant effect of expectancy cluster on reported thermal comfort, this effect was nonsignificant in the moderation model that included video (tailored information). Note that tests of direct effects (the path from expectancy cluster to thermal comfort shown in

Figure 5) reflect the influence of a predictor variable on an outcome variable while holding any moderation variables constant; this is in contrast to the total effect model, which only estimates the effect of expectancy cluster and the control variables on thermal comfort. Such findings indicate that the effect of expectancy cluster on reported thermal comfort is significant depending on the value of video. Additionally, the moderation model that included the effect of video explained higher variance ($R^2 = 0.18$) than the total effect model ($R^2 = 0.09$).

H2b predicted that by activating personal norms (the long video), the change in reported satisfaction with the personal fan would be greater among those participants with more negative expectations. This hypothesis was not supported (see Figure 6 for coefficients and *p*-values), as the moderation effect was not significant for any of the expectancy clusters. However, the expectancy cluster had a significant effect on reported fan satisfaction, and the model was significant ($F(5, 70) = 2.78$, $p < 0.05$, $R^2 = 0.17$). The negative coefficients indicate that those participants from clusters 2 and 3 may express a lower change in reported fan satisfaction compared to those from cluster 1.

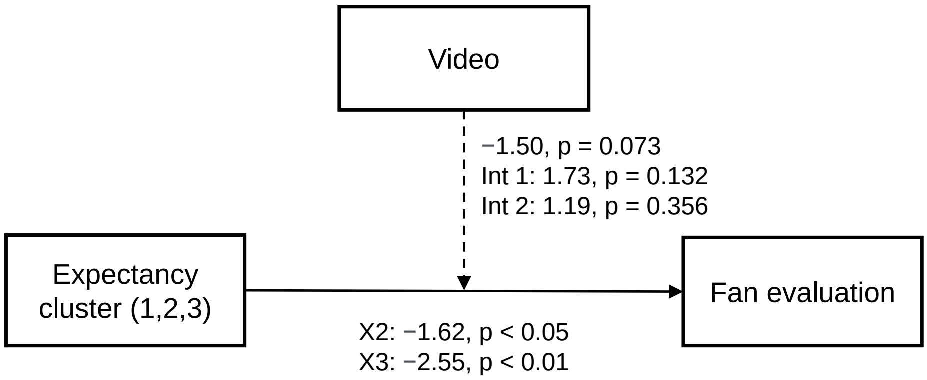

Figure 6. Model of moderating effects of video on changes in fan satisfaction. Unstandardized coefficients shown. Dotted lines indicate non-significant relationships. Short video condition coded as 0; long video condition coded as 1. Expectancy cluster coded as dummy variables for multicategorical variables. Video did not significantly moderate the effect of expectancy cluster on fan satisfaction.

5. Discussion

Previous studies have examined the effect of expectations on occupants' thermal and overall satisfaction [2,66,67], indicating cultural, geographical, and building-type differences [6]. By combining occupants' expectations of indoor thermal conditions and expectations towards building control opportunities, the current study proposed to distinguish occupants according to their expectancy levels. Thus, the relationship between participants' comfort expectations, described as thermal and behavioral expectations, and their thermal comfort in a simulated work environment was tested (H1). The study found that reported thermal comfort was greater among those participants with more positive thermal and behavioral expectations (cluster 2) and significantly differed from participants with negative thermal expectations (cluster 1) but not from the cluster expecting neutral thermal conditions and having negative behavioral expectations (cluster 3). These results may reflect the assimilation effect given by the coherence between expected and experienced indoor conditions that lead to greater thermal satisfaction [7,68]. Additionally, these findings reflect the higher importance of thermal expectations in predicting comfort compared to the effect of behavioral expectations. This could be associated with the modest expectations of occupants towards building controls in naturally ventilated buildings, which is the building type mostly found in the city where this study took place. Usually, occupants in naturally ventilated buildings do not associate their discomfort with the thermal environment provided by the building, as they may be more in contact with the outdoor conditions (e.g., by opening the window), and therefore do not expect their comfort to change due to the building's performance but through their actions [31].

Due to significant BMI differences between cluster groups, this variable was included in the model. However, BMI did not significantly influence participants' thermal perception. These results may contradict the general tendency in the literature that BMI differences exist [13,69]. However, BMI classification has recently been criticized as inaccurate and misleading [70]. Because BMI is based only on height and weight and does not take into account other body characteristics such as body fat content, muscle mass, and body composition, it is possible that some of the participants were misclassified without taking into account factors that affect human thermoregulation. Further research on the thermoregulatory process considering actual measurements of body composition should be carried out.

These first results reinforce Brown and Coles' [20] statement that expectations play an important role in shaping occupant comfort and indoor environmental behavior. However, this main effect seems best explained by the moderating role of normative motivations. The activation of personal norms was found to significantly moderate the influence of expectancy on reporter thermal comfort (H2a). Those who watched a video with detailed information about sustainable buildings and the benefits of the personal fan reported greater thermal comfort than those who watched a video with general information about the study. Although the test of H1 identified a significant influence of expectancy cluster on reporter thermal comfort, when the variable video was added to the model, that effect became non-significant. This finding suggests that the positive association between the expectancy and thermal comfort identified in the test of H1 could be largely explained by the activation of personal norms elicited among participants with more positive expectations. Additionally, greater variance in thermal comfort was explained by the moderation model that included video as compared to that explained by the total effect model, which isolated the effect of comfort expectations. Accordingly, we suggest that future studies examine the potential influence of other social-psychological constructs, such as personal norms, on perceptions of IEQ, along with additional attempts to identify which types of occupants are likely to feel more comfortable based on their social–psychological characteristics to shape their comfort expectations.

We anticipated, but did not find, a moderation effect of active personal norms on the influence of expectancy on changes in fan evaluation (H2b). An explanation for this lack of influence could be that hedonic goals were a priority for all participants rather than their normative motivations [48]. Given the moderately warm indoor temperatures, participants' comfort needs (i.e., the need to restore comfort due to the warm thermal sensation) may have become more relevant, and the potential influence of the video may not have been strong enough to rate the fan according to normative principles but rather according to its effectiveness to restore comfort (prioritizing hedonic goals). Although the moderation effect of the video was not significant in the model, there was a significant effect of expectancy on changes in fan evaluation. Greater changes in fan evaluation after participation in the experimental session (i.e., fulfilled expectations) were observed for participants with negative thermal expectations compared to participants with positive thermal expectations. These findings indicated that individually controlling the fan to increase thermal comfort may have effectively induced a change towards a more positive fan evaluation, especially in participants with lower comfort expectations. However, these results do not eliminate the possible effect of tailored information on fan evaluations and behavioral interactions, which may vary depending on the way the information is delivered. For instance, Schweiker et al. [18] found that participants who participated in a workshop were more likely to change their behavior than those who only received an information brochure. Future studies could investigate other ways of providing information to investigate whether the association of occupants' different expectations with actual normative behaviors, specifically with PECS, could be moderated by personal norms. As studied by Li et al. [24], normative messaging in personal environmental control systems could not only enhance thermal comfort but induce a higher probability of using personal devices, such as personal fans, to restore comfort.

5.1. Practical Implications

The findings of this study suggest that it may be useful to address and attempt to influence occupants' expectations of indoor thermal conditions and building operations. This is particularly relevant to the implementation of PECS in buildings as positive expectations of the indoor environment and the use of PECS may have implications for reducing energy consumption while increasing occupant satisfaction in buildings. The positive effect of information on higher tolerance of the expected indoor environment conditions, together with the provision of personal, low-intensive cooling strategies, could support the acceptance and use of PECS, such as personal ceiling fans, to ensure occupant satisfaction with the thermal environment in naturally ventilated buildings.

5.2. Limitations

This study was conducted in a laboratory setting, an unfamiliar environment to the participants. We therefore could not measure the extent to which expectations influence on-site perceptions of the thermal environment in a familiar environment, where occupants may have different expectations of the climatic conditions, as suggested by Schweiker et al. [26]. We suggest that future studies investigate such a relationship. In the present study, normative messaging was tested on the evaluation of and satisfaction with one adaptive strategy that was available for all participants. The possible effect of personal norms may be different if (1) multiple adaptive strategies with different normative impacts (e.g., low-energy-consumption strategies vs. the use of air conditioning) have been tested simultaneously, giving participants multiple adaptive possibilities, and (2) the actual behaviors have been tested in addition to the adaptive strategy's evaluation. Furthermore, the influence of information and expectancy group was examined for the personal ceiling fan for a constant temperature condition and a German sample. We suggest that additional studies be conducted with other types of PECS, different thermal conditions, and a variety of samples to examine whether the type of adaptive strategy, climatic conditions, or relevant cultural differences influence the effect of information on thermal comfort. Finally, we suggest that future studies examine the extent to which more information about the features of PECS and other types of manipulation techniques influence real-time, on-site IEQ perceptions and behaviors.

6. Conclusions

This study investigated the effect of occupants' expectations on their satisfaction with the thermal environment and a personal ceiling fan as influenced by the activation of normative goals. Our results indicate that building occupants who have more positive expectations about indoor thermal conditions may express higher levels of thermal comfort than those with more negative comfort expectations, regardless of their expectations of the building systems. Our findings also indicate that comfort expectations can be influenced by the activation of personal norms. By activating normative motivations, occupants may perceive indoor conditions as more comfortable. Those expectations should be associated with the expected satisfaction and fulfilled expectations of adaptive actions in order to stay comfortable in a building. To the extent that thermal expectations are negative, occupants might improve their perceptions of personal building controls (such as a personal ceiling fan) when making personal adjustments in order to stay comfortable. Our findings suggest that building designers could focus and manipulate occupants' comfort expectations, e.g., by providing occupants with normative messages and individual control, to achieve greater comfort and acceptance of personal building controls, such as PECS, in naturally ventilated buildings.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the data protection officer of the Karlsruhe Institute of Technology (date of approval: 10 June 2021). Note: the Ethics Committee of the Karlsruhe Institute of Technology began assigning application numbers for applications in 2023. Therefore, there is no approval number for this study. However, the approval letter is available from the authors upon request.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to privacy restrictions.

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Abbreviations

The following abbreviations are used in this manuscript:

BMI	Body mass index
BMS	Building management system
EQ	End questionnaire
IEQ	Indoor environmental quality
Int	Intercept
IQ	Initial questionnaire
LOBSTER	Laboratory for Occupant Behavior, Satisfaction, Thermal comfort, and Environmental Research
OQ	Online questionnaire
PCA	Principal component analysis
PECS	Personal environmental control system
SD	Standard deviation
SQ	Start questionnaire
SVM	Support vector machine
WHO	World Health Organization

Appendix A. Additional Tables

Table A1. Participant demographics and other characteristics, as well as experimental conditions according to expectation clusters and results of tests of equivalence of research conditions.

	Cluster 1	Cluster 2	Cluster 3	Full Sample	Test of Independence		
	N	*N*	*N*	*N*	χ^2	df	*p*-Value
Sex					0.15	2	0.928
Female	13	13	9	35			
Female	14	17	10	41			

Table A1. *Cont.*

	Cluster 1	Cluster 2	Cluster 3	Full Sample	Test of Independence		
	N	*N*	*N*	*N*	χ^2	df	*p*-Value
Age					0.15	2	0.929
Young	18	19	13	50			
Elderly	9	11	6	26			
BMI					6.12 *	2	0.047
Normal	12	20	15	47			
Overweight	15	10	4	29			
Daytime					0.47	2	0.079
Morning	12	16	9	37			
Afternoon	15	14	10	39			
Office					4.67	2	0.097
1	9	18	11	38			
2	18	12	8	38			
Video					0.52	2	0.771
Short	15	14	9	38			
Long	12	16	10	38			
Experience with fans					5.13	2	0.077
Yes	2	4	6	12			
No	25	26	13	64			
Experience with ceiling fans					2.05	2	0.359
Yes	7	8	2	17			
No	29	22	17	59			
Previous worked in office					7.25 *	2	0.027
Yes	9	3	8	20			
No	18	27	11	56			

* $p < 0.05$.

Table A2. Participants' votes and fan use according to expectation clusters and results of tests of equivalence of research conditions.

	Cluster 1 M (SD)	Cluster 2 M (SD)	Cluster 3 M (SD)	Test of Independence χ^2	df	*p*-Value
Actual mood [a]	3.04 (1.02)	2.57 (1.14)	3.21 (1.13)	4.53	2	0.104
Air velocity level [%]	55.48 (21.44)	46.52 (29.62)	48.92 (25.10)	2.29	2	0.318
Duration fan on [min]	127.99 (5.69)	123.35 (19.50)	124.00 (24.87)	2.90	2	0.235
Video rating 1 [b]	0.21 (0.89)	−0.21 (1.14)	0.04 (1.23)	3.28	2	0.194
Video rating 2 [b]	0.03 (0.99)	−0.04 (1.02)	0.02 (1.04)	0.12	2	0.940

[a] Integer values. Scale ranged from 1 (very bad) to 7 (very good): "*How is your mood right now?*". [b] Unstandarized values resulting from PCA conducted with seven questions. Two components resulted from the analysis.

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