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Percentage of commercial buildings showing at least 80% occupant satisfied with their thermal comfort

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Percentage of commercial buildings showing at least 80% occupant satisfied with their thermal comfort

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Abstract: Most thermal comfort standards prescribe that buildings must provide satisfactory thermal comfort to at least 80% of their occupants. To assess how many buildings meet this criterion, we analysed temperature satisfaction votes from 52,980 occupants in 351 office buildings, obtained via a web-based seven-point satisfaction survey over 10 years, mainly in North America. 43% of the occupants are thermally dissatisfied, 19% neutral and 38% satisfied. The percentage of buildings meeting 80% satisfied occupants was only 2% if one considers votes from +1 to +3 ('slightly satisfied to very satisfied') as representing satisfaction, 8% if one includes votes from 0 to +3 ('neutral to very satisfied'), and 33% if one includes votes from -1 to +3 ('slightly dissatisfied to very satisfied' – a seemingly generous criterion suggested in ASHRAE Standard 55). These results are concerning because they suggest that buildings are far from creating thermal environments that their occupants consider satisfactory. This might be due to inability of the large majority of HVAC systems to provide adequately personalized conditioning or control. This paper also discusses the relevance of the 'satisfaction' metric used for long-term building evaluations.

Keywords: Thermal comfort, satisfaction, occupant survey, post-occupancy evaluation.

1. Introduction

Thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation" (ANSI/ASHRAE 2017). This definition, first adopted in 1992, may not be intelligible to all, and the means by which a 'condition of mind' can 'express satisfaction' is potentially unclear. Nevertheless, this definition simplifies the more delicate and culturally loaded notion of 'comfort' (Shove 2004) into the more tangible idea of 'satisfaction'. This definition further provides a path to measure thermal comfort through 'subjective evaluation'. Satisfaction questionnaires have been widely used in post-occupancy evaluations. The two principal thermal comfort models (Fanger's predicted mean vote (PMV) model (Fanger 1970) and the adaptive thermal comfort model (De Dear et al. 1998, Nicol and Humphreys 2002)) can estimate the 'predicted people dissatisfied' (PPD). For both models, the PPD defines an area around an ideal (neutral) condition in order to provide satisfaction to a given percentage of the people, often 80 or 90%.

The rising interest in workplace well-being, the rapid growth in sensing and actuating technologies, and the potential to link occupant comfort with productivity provide a fertile ground to address and rethink thermal comfort in commercial buildings. Over the last couple of years, we have seen new products (e.g. NEST, Comfy) and new building certification programs (e.g. WELL Building Standard (IWBI 2014)) directly tackling thermal comfort with new methods to both assess and address it. Many certification programs

(LEED, WELL, GreenMark) give points for a post-occupancy survey. This may lead to an increase in the assessment of thermal comfort in buildings. We can observe that most recent studies and product developments addressing thermal comfort are re-orienting their scope towards occupant-centric approaches. While this innovative environment can be mesmerizing, it may be worth reflecting on our understanding of comfort in the current building stock, and what levels of comfort have been observed over the last decades.

The objective of this paper is to estimate, based on the Center for the Built Environment (CBE)'s Indoor Environmental Quality (IEQ) Survey results, how many buildings fulfil the comfort standards objective of providing satisfactory thermal comfort to at least 80% of their occupants. This paper is also an opportunity to reflect on thermal comfort definitions and assessment method limitations, and to discuss different approaches.

2. Method

2.1. CBE Occupant IEQ survey database

We used the Occupant IEQ survey database to perform our analysis. This web-based survey, administered by CBE at the University of California Berkeley, first asks building occupants a set of basic questions about demographics, followed by nine core categories of IEQ, including thermal comfort (Zagreus et al. 2004). It measures occupant satisfaction in each of the categories using a 7-point Likert scale with answers ranging from +3 ('very satisfied') to -3 ('very dissatisfied') with 0 as the middle option ('neutral') (see Figure 1). The rating applies to 'general' or 'background' conditions as opposed to 'right now' conditions. ASHRAE Standard 55-2017 (ANSI/ASHRAE 2017) prescribes the use of this type of 7-point Likert survey for building post-occupancy assessments.

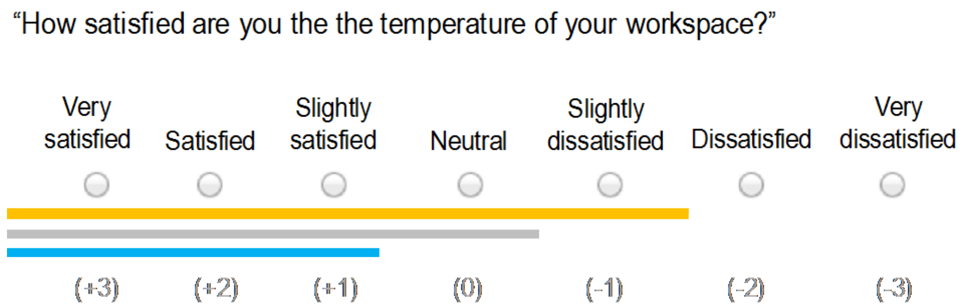

Figure 1: Satisfaction with temperature using a 7-point Likert scale; the coloured lines represent the three satisfaction intervals used in the analysis: "-1 to +3" (gold), "0 to +3" (grey) and "+1 to +3" (blue)

To perform our analysis, we used a subset of the CBE survey database that consists of commercial buildings surveyed up until 2010 and whose building characteristics were verified by our team (Frontczak et al. 2012). This subset involves 52,980 occupants in 351 office buildings, mainly in North America. For our analysis, we only looked at the results for temperature satisfaction.

2.2. Defining satisfaction

Section 7.4.1 of the current version of ASHRAE Standard 55 (2017) requires the use of a 7-point satisfaction question, and states that for long term evaluation (not 'right-now') it should include votes fall between '-1' ('slightly dissatisfied') and '+3' ('very satisfied') inclusive. This widely inclusive range could be due to the desire to transform satisfaction judgements into acceptability judgements. Yet, in the 2013 version (ANSI/ASHRAE 2013), the standard did not involve the same interval: ratings were restricted to votes between '0' ('neutral) and '+3' ('very satisfied'), and in the 2017 version, in the Informative Appendix L it allows for both options. If we look at the thermal comfort definition, it is also possible to argue that satisfaction should include only ratings explicitly stating a 'satisfied' condition, i.e. from '+1' ('slightly satisfied') to '+3' ('very satisfied'). Based on these observations, we will conduct our analysis for 3 satisfaction intervals: "-1 to +3", "0 to +3" and "+1 to +3".

Per ASHRAE Standard 55-2017 (ANSI/ASHRAE 2017), thermal satisfaction shall be measured with a scale ending with the choices: "very satisfied" and "very dissatisfied". The standard specifies how to calculate the percentage for a given building, by dividing the number of satisfied votes by the total number of votes. This implies that people who did not vote are not counted. The standard does not explicitly provide a target percentage of occupants satisfied for background long-term evaluations.

3. Results

Figure 2 shows the distribution of *occupant* responses for temperature satisfaction. This graph does not consider the difference between buildings but aggregates all individual responses. If we cluster negative and positive votes, we observe that the 43% of the occupants are dissatisfied, 19% are neutral and 38% are satisfied with their thermal environment. This means that the proportion of dissatisfied occupants is higher and that the proportion satisfied. If we assume that an environment is thermally acceptable if we also include 'neutral' and 'slightly dissatisfied' votes, then 'acceptability' would be 57% (from 0 to +3) and to 73% (from -1 to +3).

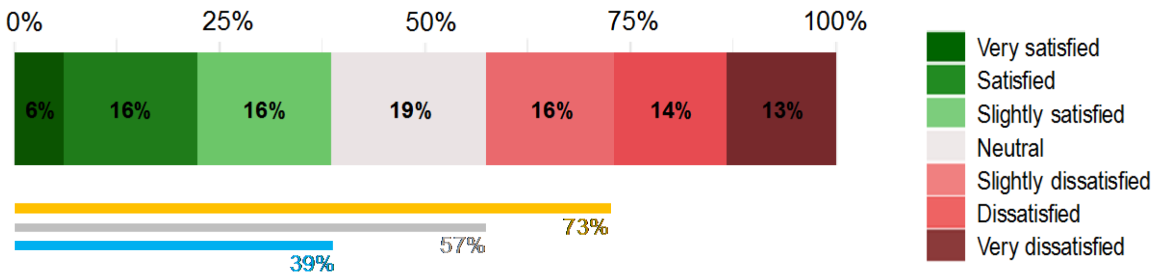

Figure 2: Bar chart showing the distribution of temperature satisfaction votes for 52,980 occupants (in 351 office buildings).

Figure 3 displays the percentage distributions of *buildings* whose occupants meet the three different definitions of temperature satisfaction. On the left side, the results are presented in five bins of satisfied occupants per building: 50%, 60%, 70%, 80% and 90%. On the right side, the results are presented as a continuous line graph. Looking at these graphs, we observe that the percentage of buildings meeting 60% satisfied occupants is 11% if one considers votes from +1 to +3 as representing satisfaction, 47% if one includes votes from 0 to +3, and 83% if one includes votes from -1 to +3. If we look at 80% satisfied occupants per building, the number buildings meeting satisfaction dramatically decreases to 2% for +1 to +3 votes, 8% for 0 to +3 votes, and 22% for -1 to +3 votes. If we look at 90% satisfied occupants per building, the number buildings meeting satisfaction further decreases to 0% for +1 to +3 votes, 1% for 0 to +3 votes, and 12% for -1 to +3 votes.

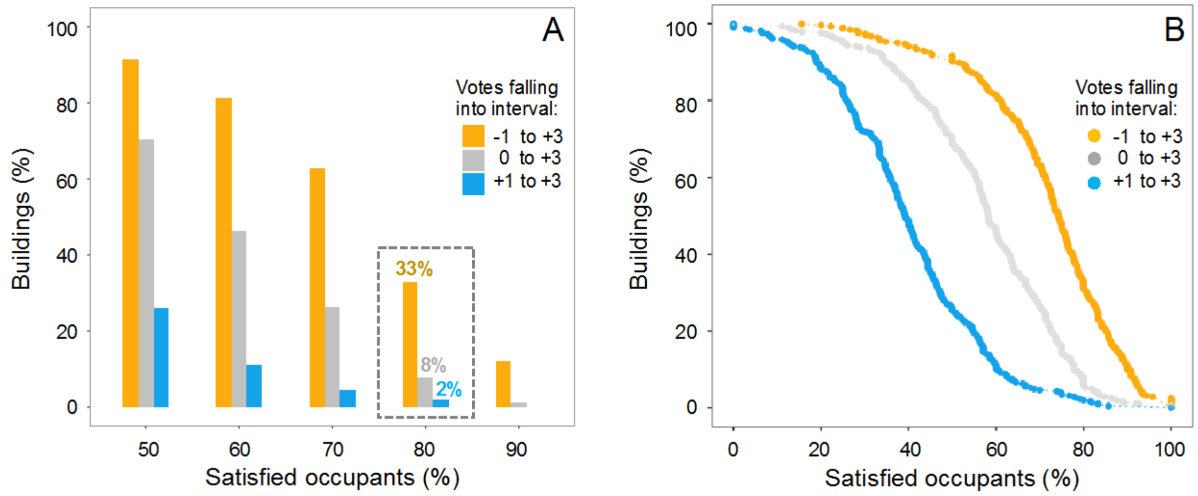

Figure 3: Bar chart (left) and line graph (right) showing the percentage of buildings meeting given percentages of occupants satisfied with temperature. The analysis is conducted for 3 satisfaction criteria ("-1 to +3", "0 to +3", "+1 to +3") based on surveys from 351 office buildings (52,980 occupants).

While occupant satisfaction used in framework of the long-term evaluations are not bound to a performance objective, ASHRAE Standard 55 details the metrics of thermal acceptability (for short term assessment) and PPD (for design purposes) having both a performance objective set at 80% occupants reaching comfort. This shift in metrics and assessment methods can lead to misunderstanding in the interpretation of the standard. If we were to assume a similar threshold for temperature satisfaction, the number of complying buildings would remain extremely low even when including 'slightly dissatisfied' among positive responses. This analysis questions the interval range and the potential survey performance objective that may be considered in the future certification programs.

4. Discussion

Many building certifications programs have recently adopted occupant comfort surveys into their credit structure. While this development positively addresses the need to assess and improve indoor conditions, the results observed on this study warn us about the dominance of negative feedback in regard to thermal comfort. The wider adoption of surveys in buildings leads us to discuss: (1) the difference in temperature satisfaction between certified and non-certified buildings, (2) the role that non-conventional HVAC systems may play in improving occupant satisfaction rates, and (3) the appropriateness of definitions, metrics and methods currently used for the assessment of thermal comfort.

4.1. Green certified vs. non-certified buildings

The wider adoption of surveys into green certifications programs (e.g. WELL Building Standard (IWBI 2014), LEED BD+C v.4 (USGBC 2013), LEED O+M v.4 (USGBC 2017), Green Mark (BCA 2015)) brings the question of occupant satisfaction for green-certified. IEQ is commonly part of the credit structure and therefore one may expect differences between certified and non-certified buildings. A study from 2013 involving 65 LEED certified (10,129 occupants) and 79 non-LEED certified buildings (11,348 occupants) have shown no practical difference in temperature satisfaction ratings between the two types (Altomonte and Schiavon 2013). The dominance of negative feedback observed in this study is likely to apply to current green certified buildings considering the current methodologies.

4.2. Non-conventional HVAC systems

The analysis conducted in this paper mainly reflected US conventional all-air buildings. We may wonder if radiant systems or occupant-centric approaches to comfort (personal comfort systems (PCS) and occupant vote-based HVAC control) have potential to address this concern.

We compared thermal satisfaction in 26 radiant (1645 subjects) versus 34 all-air (2247) buildings (Karmann et al. 2017). We found that radiant and all-air spaces have equal indoor environmental quality, including acoustic satisfaction, with a tendency towards improved temperature satisfaction in radiant buildings. Therefore, radiant systems may not be a strong enough solution. It is worthy to notice that this dataset had better buildings than the one described in this paper, in fact, both radiant and all-air buildings showed higher satisfaction (e.g. 54-59% of the buildings meeting the criteria for the -1 to +3 range, instead of 33% here).

PCS consist of heating and cooling devices (such as a heated/cooled chair, foot warmer, desk fan) used by individuals to control their local thermal environment and meet their comfort needs or desires (Zhang, Arens and Zhai 2015). Field studies involving PCS have shown considerably higher levels of temperature satisfaction than in conventional systems (Bauman et al. 2015, Zhang et al. 2015, Schiavon et al. 2016) suggesting positive effects of individual control and instant feedback over thermal comfort conditions. Yet, there is still limited survey data (especially over longer time periods and with a larger building count) confirming these promising results.

Occupant vote-based HVAC control (e.g. Comfy^{tm} (Comfy 2016)) allow occupants to directly interact with their building's air systems using their desktop or smartphone. The algorithm used in the background organizes occupant feedback and actuates thermal changes within the workspace. This ability for occupants to decide and the gratification resulting from instant reward (warm/cold input) is currently proving its success from a market perspective. Yet, there is a lack of third party field data able to confirm thermal comfort improvements.

4.3. Survey methodology

Long-term evaluations surveys were primarily developed as a diagnostic tool. Building managers interested in understanding how indoor environment affects occupants could request it. Dissatisfied temperature votes would generally be followed by branching questions intended to capture source of discomfort. Building managers could decide if survey results would be disclosed and whether actions (improvements to the building services) were taken. Using surveys as a compliance tool naturally brings up two issue. First, how many people should be satisfied to get the certification points, and second, what should be done if a building performs poorly. Transferring occupant survey methodology from diagnostic tool to compliance mechanism may be more delicate than it first appears, making it all the more relevant to clarify the metrics, scales and interval ranges used.

A key question relates to the use of 'satisfaction' as primary metric for long-term assessments. In short-term thermal evaluation, we can use thermal preference (wanting warmer, cooler or no change) or occupant behaviour to assess occupant desire, and the standard suggests using thermal sensation and acceptability. Thermal preference does not work well in 'long-term' assessment where we are trying to get an overall assessment of the thermal environment. Yet, by definition, 'satisfaction' depends on the fulfilment of 'wishes, expectations, or needs' one person may have (Oxford Dictionaries 2017). Therefore, we may wonder if thermal conditions are judged fairly across buildings or whether they depend on occupant's expectations for a given building or type of building leading to a certain bias in the assessment. This leads us to question the appropriateness of the metric used and its desirable level of tolerance.

The ASHRAE 55 standard has the objective to "specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space." It also defines a thermal acceptable environment as "a thermal environment that a substantial majority (more than 80%) of the occupants find thermally acceptable." We could argue that the long term assessment of the environment could be carried out using a 'long term' thermal acceptability question. This would reduce the issue related to satisfaction but would imply a change in many post occupancy evaluation tools that used satisfaction for decades.

5. Conclusions

We used a subset of the CBE Occupant IEQ survey database (52,980 occupants in 351 office buildings) to determine how many buildings fulfil comfort standards objectives. We found that 43% of the occupants are thermally dissatisfied, 19% neutral and 38% satisfied. The percentage of buildings providing a 'satisfactory' thermal comfort to at least 80% of their occupants is 2% if one considers votes from +1 to +3 ('slightly satisfied to very satisfied') as representing satisfaction, 8% if one includes votes from 0 to +3 ('neutral to very satisfied'), and 33% if one includes votes from -1 to +3 ('slightly dissatisfied to very satisfied' – the seemingly generous criterion suggested in ASHRAE Standard 55). If surveys are to be commonly and systematically used in building certification programs, it may be worth verifying the quality of the information captured, and the appropriateness of metrics, scales and interval ranges used.

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