7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

A picture is worth a thousand words: Smartphone photograph-based surveys for collecting data on office occupant adaptive opportunities

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ABSTRACT
In the past several decades, psychological aspects have been become important to holistic building occupant comfort and satisfaction evaluations. Psychological dimensions of comfort include occupants' opportunities to interact with their indoor environment and perceived control over the indoor environment. Current post-occupancy evaluations tend to focus on collecting quantitative data, despite overwhelming evidence that contextual factors can profoundly impact occupant comfort. This paper proposes and tests a novel method for data collection to study adaptive comfort opportunities. A smartphone-based survey was developed to concurrently collect office occupants' subjective evaluations of usability and comfort of spaces, in addition to photographs of all key building interfaces. The photos were coded to obtain quantitative characteristics of offices, such as whether the interface is obstructed. With a sample of 39 office workers, this paper reveals the effectiveness of this novel photograph-based survey method, while also providing some initial quantitative and qualitative results.

KEYWORDS
Adaptive comfort, building usability, post-occupancy evaluation, photographs

INTRODUCTION
Building designers and operators should strive to provide comfortable spaces for two reasons: (1) occupant comfort is a desirable property and because it is closely linked to occupant productivity (Leaman & Bordass, 2000), and (2) comfortable occupants are less inclined to take energy-intensive actions (e.g., opening windows when mechanical heating is on and closing blinds and turning on lights during and after periods of daylight glare). The study of occupants' thermal perception is rooted in studies addressing the relationship between physical indoor thermal conditions, physiological responses, and the perception of these conditions by humans (Fanger, 1970). ASHRAE Standard 55 (ASHRAE, 2017) defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation." Psychological and behavioral influences on perception have been recognized as being critical aspects of thermal comfort for over four decades (Humphreys, 1976). Indeed, non-physiological metrics can have a significant impact on occupants' reported satisfaction with indoor environmental quality (IEQ) (Kim & de Dear, 2012).

One of the non-physiological factors is perceived control. Through their extensive post-occupancy evaluation experience, Leaman and Bordass (2000) stated that "In study after study, people say that lack of environmental control is their single most important concern…". Laboratory studies have also shown a positive relationship between perception of thermal conditions and perceived control (Schweiker & Wagner, 2016). While adaptive thermal

comfort models used in standards (e.g., Standard 55 (ASHRAE, 2017)) implicitly recognize that providing adaptive opportunities to occupants (namely operable windows) improves occupant tolerance for a wider range of indoor temperatures, Standard 55 does not explicitly quantify the effect of differences in perceived control. Approaches towards such quantification are scarce and still lack generalizability (Schweiker and Wagner, 2015). Moreover, research on building usability is still in its infancy (Day and Heschong, 2016). More critically, there continues to be a trend towards greater automation under the false premise that taking control away from occupants improves comfort (Leaman and Bordass, 2000).

The theme of perceived control links human comfort with occupant behavior. Research on occupant comfort and occupant behavior—be it related to thermal, visual, or acoustic aspects—is typically performed in either a controlled laboratory environment or *in situ* (Parsons, 2014). Common quantitative research methods use one or both of: 1) surveys that ask occupants about their perceived level of comfort and control and the available and exercised controls, and 2) sensor measurements to collect data about environmental and/or physiological conditions. However, contextual factors such as workplace cleanliness, flexibility to move furniture, presence of other occupants, and ease of use of building systems, all play a critical role in occupants' likelihood to exercise adaptive opportunities (Kim and de Dear, 2012; O'Brien and Gunay, 2014). Traditional surveys are typically not capable of capturing these complex and subtle predictors of perceived opportunities for adaptive control. Moreover, surveys rely on self-reporting, which can yield significant error. Pritoni, Meier, Aragon, Perry, and Peffer (2015) performed a survey on thermostat-related behavior, including a request for participants to upload a photograph of their thermostat. They found that only 50% of occupants who claimed that they use programmable features of their thermostat were actually using them, according to the photographs. In general, participants may not possess the insight required to identify phenomena of interest and significance.

To understand contextual factors, researcher walk-throughs are frequently used, whereby the researcher takes notes and photographs. Such qualitative data can help explain anomalies in quantitative data and can serve as exploratory research to guide future research directions (Day, Theodorson, et al. 2012). However, walk-throughs are time-consuming, may jeopardize the safety of the researcher, and are subject to the Hawthorne effect (O'Brien, Gilani, et al. 2018).

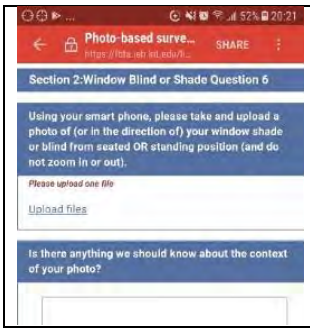
This paper proposes a new survey-based research method to yield new insights about the relationships between perceived comfort and availability of adaptive opportunities and usability of building systems and interior design elements. The aim is also to continue collecting convincing anecdotal evidence to support the philosophies and design implications of providing adaptive opportunities to building occupants. To achieve this, the researchers sought to develop a method that could yield many of the benefits of field studies and obtain large datasets about comfort and building usability without a requirement for researchers to visit properties. This paper presents the survey and then briefly provides initial analysis and discussion.

METHODOLOGY

A number of research questions were posed for this research; this paper only briefly explores these questions using the current survey campaign and resulting sample of 41 participants. The questions are fundamental (e.g., what is the correlation between presence of adaptive opportunities and perceived control?); application (e.g., what lessons can be learned for future building design?); and, methodological (e.g., are the photographs as effective as researcher

walk-throughs?). The short length of this paper limits the amount of analysis to illustrative purposes.

Stemming from the primary research objectives of this study, a survey was developed and piloted. For brevity, the survey is not included in this paper. Survey sections include questions on: (1) confirmation that the participants are currently in their primary office space (and in Canada for the current study); (2) perceived level of comfort; (3) occupants' ability to improve indoor environmental quality; (4) availability of, distance to, ease of use of, concern about disturbing fellow occupants if using, and frequency of using: *window shading devices, operable windows, desk fans, thermostats, space heaters, overhead lighting, and task lighting*; (5) nature of furniture; (6) opportunities to reorient or relocate in the event of discomfort; and, (7) general features or characteristics of offices that they like or do not like. Fundamental to the survey, participants were asked to take and upload a photo of the adaptive opportunities listed in item 4 (if applicable) and item 7; up to nine photos were uploaded per participant. Depending on whether the above seven main adaptive opportunities were available, the participants were required to respond to between 41 to 83 questions, though many were repetitive (e.g., asking about many aspects of comfort). LimeSurvey (Figure 1) was selected because of its suitability for smartphone applications and ability of participants to upload their photographs.



1. Which of the following best describes your access to control window coverings (window shades, blinds, curtains, etc.)?
2. The window blind or shade is hard to use.
3. The window blind or shade is effective at improving my visual comfort.
4. I worry that I will annoy other people if I adjust the window blind or shade
5. Approximately how often did you adjust the window blind or shade in the past two weeks?
6. Using your smartphone, please take and upload a photo of (or in the direction of) your window shade or blind from seated or standing position (and do not zoom in or out).
7. Is there anything we should know about the context of your photo?

Figure 1. Sample screenshot of survey and sample questions for window shading devices.

Ethics clearance was obtained from the university research ethics board; the ethics documentation had particular focus on ensuring that occupants, buildings, and organizations could not be identified in photographs and that the photographs would be securely stored. To encourage participation, a $10 Amazon gift card was offered to all participants who completed the survey with valid responses. Participants were recruited via three separate postings over two months on the lead author's Facebook wall. A posting on a local Reddit group yielded many incomplete and invalid responses. Survey responses were manually validated for completion and to confirm that conditions for participation were complied with, where possible. For instance, several participants responded from inside a vehicle and one participant uploaded a photo of their desk behind which a tropical plant could be seen outside (an unlikely circumstance in the Canadian winter). Approximately 50% of prospective participants who answered at least one question did not complete the survey, while approximately 20% of surveys that were completed were considered invalid (see Discussion). For valid responses, the mean and standard deviation for the completion times were 16.4 and 9.0 minutes. Despite considerable effort in recruitment and a relatively generous incentive, 41 valid responses were obtained out of the targeted 100. The responses occurred between December and February; thus, results were studied within the context of winter conditions (e.g., responses about operable windows have limited meaning). The results include between five and 33 photos uploaded for each of the seven categories of adaptive opportunities.

ANALYSIS AND RESULTS

This section describes the analysis approach and results for selected questions that were posed in the Methodology. Figure 2 shows the overall availability and proximity of adaptive opportunities.

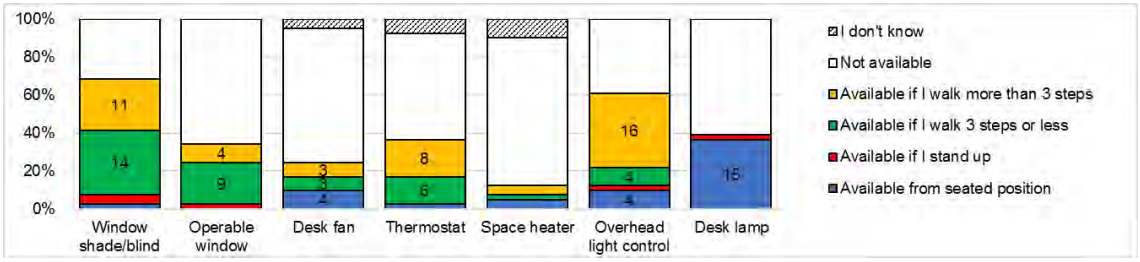


Figure 2. Availability of adaptive opportunities

Next, the influence of office type on participants' reported ability to improve comfort through adaptive actions on a five-point scale from very poor (1) to excellent (5) was explored. Given that the data are generally not normally distributed, a non-parametric test (the Kruskal Wallis test) was used to assess differences in responses between office types, as annotated in Figure 3.

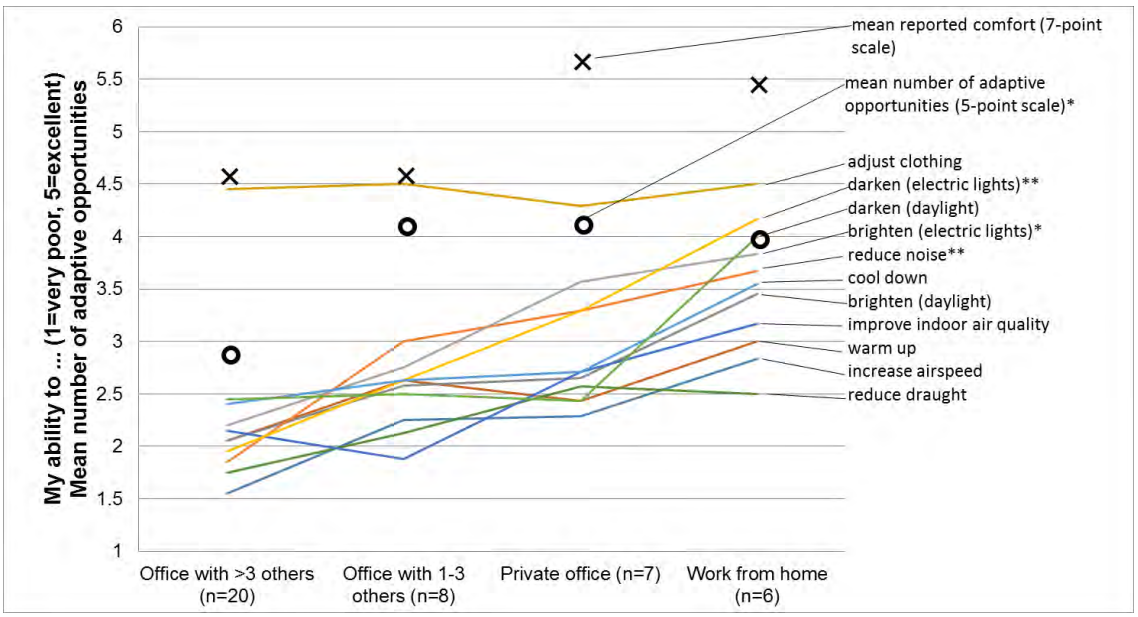


Figure 3. Relationship between office type and adaptive opportunities and comfort. The * and ** denote significance of <0.05 and <0.01, respectively. Note: mean values on the y-axis assume the Likert scale responses are equally-spaced.

To illustrate the power of photographic data to help explain outliers, the relationship between participants' rated availability of blinds/shades and ability to reduce daylight was explored (Figure 4). A best-fit line, under the assumption that the data can be converted to into equally-spaced categories, is shown on the plot. In general, the presence and proximity of a shading device is a moderately good predictor of occupants' ability to reduce daylight levels. Six outliers were examined to reveal new insights about how the participants interpreted the questions and responded. The two photos for points below the best-fit line show that although the shading devices were nearby, they were obstructed (as explicitly written by the participant).

Notably, the occupants who took the top four photographs appear to be seated quite far away from the windows, in general, and may not be subject to chronic daylight glare. These results, which cover only a small part of the collected data, demonstrate that important contextual factors are necessary to understand the quantitative responses. Moreover, they provide anecdotal evidence to support previous research that indicated the importance of minimizing obstruction of blind interfaces (Day et al., 2012). Meanwhile, Figure 3 suggests that occupants have a greater sense of control, more adaptive opportunities, and greater comfort in private spaces.

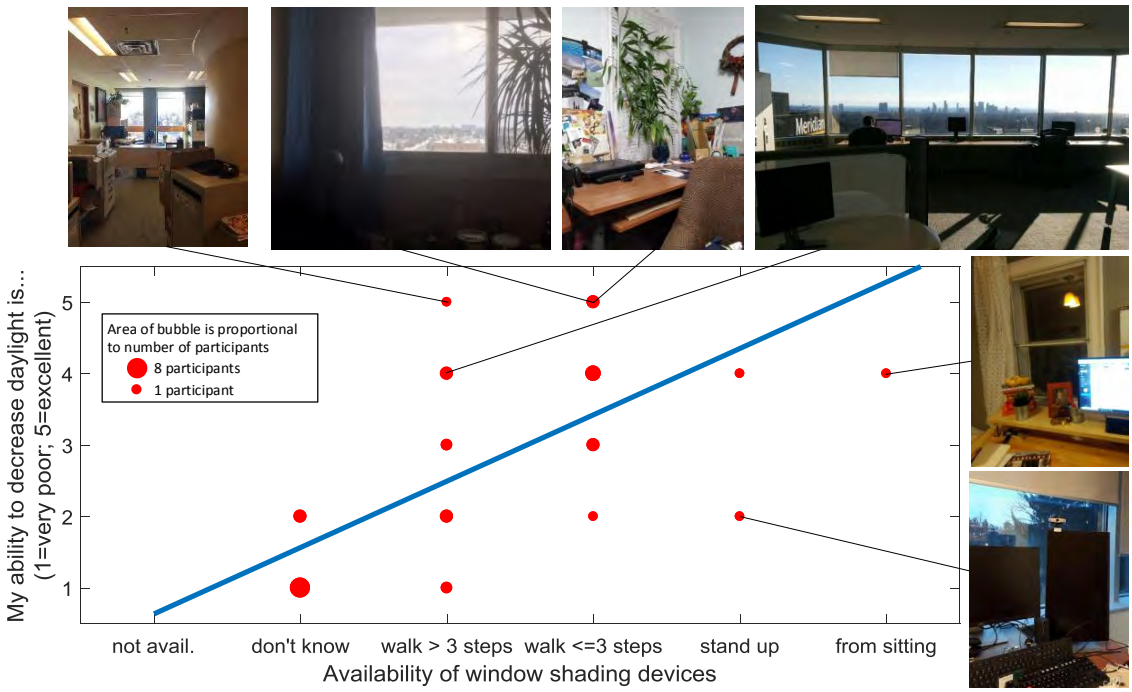


Figure 4. Example of using photographs to explain outliers in a simple correlation.

DISCUSSION

Briefly, this section provides some lessons learned and comments about the effectiveness of the photograph-based survey. The photographs were effective at providing contextual information about why a participant responded a certain way. However, this was limited to visual evidence unless the participant also provided comments to describe the photo (as was done for 109 out of 131 photos). In many cases, cases where the participant responded unexpectedly (e.g., outliers of Figure 4), interpretation of the photograph provided otherwise-missing explanation. However, in some cases photographs did not explain unexpected quantiative results. A study with walk-throughs and in-person interviews could largely resolve this limitation because the researcher could inquire about anomolies. However, on the balance, the current approach yielded significant explanatory power along with the aforementioned benefits. Recruitment of participants was significantly more difficult than expected. The researchers' acquaintances seemed to feel more responsible for supporting this project than unknown participants. However, the researchers' professional networks were avoided because of their tendency to have subject expertise (e.g., knowledge of comfort theory). One participant exited the survey early, noting that government workers cannot take photos of their workplace. In retrospect, the survey should have been slightly more specific about what to capture in photographs. There was minor confusion for overhead lights about whether to capture the luminaires or the interface. The survey specified that all photos should be taken from the

primary location of work, regardless of whether the interface was visible from this location in order to assess whether there was a clear view.

CONCLUSIONS

This paper introduced a novel post-occupancy evaluation survey that required participants to capture and upload photographs of building interfaces, adaptive opportunities, and other comfort-related items. The paper provides analysis of an initial sample of 41 participants who are office workers in Canada. Whereas previous POE surveys did not have the ability to capture contextual information about office spaces (e.g. obstruction of interfaces or presence of other occupants), the qualitative data provided by the photographs can help explain outliers and other anomalies. Future work is needed to further analyze the data, refine the survey, and expand deployment.

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