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Listening to the occupants: a Web-based indoor environmental quality survey

Abstract Building occupants are a rich source of information about indoor environmental quality and its effect on comfort and productivity. The Center for the Built Environment has developed a Web-based survey and accompanying online reporting tools to quickly and inexpensively gather, process and present this information. The core questions assess occupant satisfaction with the following IEQ areas: office layout, office furnishings, thermal comfort, indoor air quality, lighting, acoustics, and building cleanliness and maintenance. The survey can be used to assess the performance of a building, identify areas needing improvement, and provide useful feedback to designers and operators about specific aspects of building design features and operating strategies. The survey has been extensively tested and refined and has been conducted in more than 70 buildings, creating a rapidly growing database of standardized survey data that is used for benchmarking. We present three case studies that demonstrate different applications of the survey: a pre/post analysis of occupants moving to a new building, a survey used in conjunction with physical measurements to determine how environmental factors affect occupants' perceived comfort and productivity levels, and a benchmarking example of using the survey to establish how new buildings are meeting a client's design objectives.

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Key words: Benchmarking building quality; Indoor environmental quality; Occupant satisfaction; Online reporting, Post-occupancy evaluation (POE); Web-based surveys

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Practical implications

In addition to its use in benchmarking a building's performance against other buildings, the CBE survey can be used as a diagnostic tool to identify specific problems and their sources. Whenever a respondent indicates dissatisfaction with an aspect of building performance, a branching page follows with more detailed questions about the nature of the problem. This systematically collected information provides a good resource for solving indoor environmental problems in the building. By repeating the survey after a problem has been corrected it is also possible to assess the effectiveness of the solution.

Introduction

Comprised of faculty and researchers at the University of California, and supported by the National Science Foundation and public- and private-sector industry partners, the Center for the Built Environment (CBE) at the University of California, Berkeley works to inform the building industry about new building technologies and design techniques. A core tenet of CBE is that everyone in the building process benefits from learning how a building actually performs in practice.

Historically, building occupants have been underutilized as a source of information on building performance. Prior to Web-based surveys, creating, distributing, and analyzing paper questionnaires was a time-consuming and expensive process, and diagnostic paper surveys necessarily took a long time for occupants to complete. In addition, surveys have tended to be project-specific and not often repeated. One exception is the Probe study in which a standardized survey was used to benchmark building performance (Leaman et al., 1997) for a large number of energy-efficient buildings. CBE has developed a Web-based survey (see http://www.cbesurvey.org for a demonstration version of the CBE occupant IEQ survey) that is similarly standardized and focused on indoor environmental quality (IEQ), but by being Web-based, it offers two additional benefits. First, it can be inexpensively administered to many buildings. Second, its interactive branching questions allow it to "drill down" into areas that the occupants rate poorly, and thus in many cases diagnose the root of the problems. A set of core questions is used to assess occupant satisfaction and comfort with IEQ issues including indoor air quality, thermal comfort, lighting and acoustics. The branching questions arise only if the occupant indicates dissatisfaction with a given issue, so that the survey does not burden the occupant with detailed questions unless problem areas are detected. The survey supports optional modules to address special issues not covered in the core questions, and can be offered in multiple languages.

The survey can be applied widely to evaluate the performance of individual buildings as well as to systematically compare the performance of groups of buildings. Case studies presented below indicate that information provided by the survey can positively influence indoor environmental quality for occupants of existing as well as future buildings. Useful feedback is provided to operations staff, supporting operational adjustments that can lead to improved IEQ in a relatively short timeframe for occupants of existing buildings. Survey results also inform the design community about the effectiveness of specific technologies and strategies. In addition, the survey is proving a useful resource for facility managers and building owners involved in acquiring, operating and improving their building portfolio.

Methods

Survey development

The survey is comprised of a core survey and optional survey modules. Each organization using the survey has the option of employing the core survey or customizing the survey to include additional modules that support specific information needs. The core survey includes modules for office layout, office furnishings, thermal comfort, air quality, lighting, acoustics, and building cleanliness and maintenance. Examples of optional modules include wayfinding, safety and security, operable windows, shading systems, floor diffusers, and washrooms. Core questions stay consistent from survey to survey to maintain data integrity for the purposes of benchmarking and trend analysis.

The survey has been extensively tested and refined, and facility managers and designers have evaluated the reporting format to determine the utility of various report designs. An established testing method called "cognitive interviewing" was used by the Survey Research Center at UC Berkeley to assess how well respondents were able to comprehend and accurately report answers to survey questions (Eisenhower, 2000). Cognitive interviews allow researchers to examine the thought processes that affect the quality of answers provided to survey questions. The primary technique used was the "concurrent think aloud" method whereby each respondent was asked to comment out loud about anything crossing his or her mind while reading, interpreting and answering each question. This technique was supplemented by paraphrasing (asking the respondents to put something in their own words) and systematic probing. Seven people participated in this testing. In addition, occupants who took surveys in the initial buildings were asked to rate the survey. Results were used to refine the survey organization, question text, graphic design of the scales, and the process required to access the survey website.

The time required to complete the survey has been monitored, and occupants have also evaluated the length of each section of the survey. The approximate time required to complete the core survey is 5–12 min; time to completion varies depending on the number of branching questions and comments answered. This length of time has not been regarded as an impediment to completion in most (but not all) of the buildings surveyed to date. Surveys that include several customized modules in addition to the core survey have had completion times of up to 20 min. Organizations that choose to implement longer surveys are briefed regarding the potential negative effect that longer surveys can have on response and completion rates.

Customization and continued survey development. As mentioned above, survey customization is possible, and clients can add new or existing modules to the core survey to suit the needs of a particular project or audience. Indeed, owing to the flexible infrastructure underlying the survey, whole new survey types have been developed. One CBE partner has commissioned a customized occupant IEQ survey, as well as the creation of two new building quality surveys. The first of these surveys, an operations and maintenance staff survey, aims to determine how satisfied the staff is with the design of the building and its effect on their ability to run and maintain the facility. Second, a design and construction process survey, polls the design and construction teams for their satisfaction with the process of building the facility. Each of the three surveys is designed for a distinct population, and during a post-occupancy evaluation (POE), all three surveys can be conducted in a building to learn how it is performing for its occupants, operators, and design team.

We also have the ability to study survey design itself. Due to the nature of the Web, and the flexibility of the survey architecture, we can randomly assign respondents to slight variations on survey instruments. We have done so in an evaluation of 5-point vs. 7-point scale sizes (Zagreus and Huizenga, 2003) and are currently conducting research into the orientation of the scales (satisfied on the left vs. satisfied on the right). Similar investigations, such as the effect of question order within and between survey categories, are also possible.

Multilingual capabilities. We have implemented the occupant IEQ survey in buildings across the USA and Canada, and in Europe. The structure of the survey scripts enables us to offer the survey and accompanying reporting tools in any language. The survey can be offered in multiple languages, with respondents choosing the desired language at the time they access the survey Web page. The strings for each language are stored centrally, and depending on the language in which the survey is being taken, the appropriate string is retrieved and displayed at survey run-time. The foreign language questions have been mapped to the English ones so that comparisons of the responses from different buildings can be made regardless of the language in which the survey was taken. The survey has already been translated and implemented in Finnish, and is also available in Danish.

Implementation

The occupant IEQ survey implementation process typically begins with an e-mail informing building occupants of the survey Web site address, start date and end date. This e-mail is drafted and sent either by CBE or the sponsoring agency. Subjects can access the survey at their convenience. After linking to the survey using a Web browser, respondents see a welcome screen informing them of the purpose of the survey. The welcome page also advises them of the amount of time it should take to complete the survey, and their rights as a research participant. Participation in the survey is voluntary and anonymous, and respondents may opt out at any time. Upon starting the survey, participants click through a series of questions asking them to evaluate their satisfaction with different aspects of their work environment (Fig. 1). Satisfaction is rated on a seven-point scale ranging from ''very satisfied'' to ''very dissatisfied'', with a neutral midpoint. In most cases, respondents who indicate dissatisfaction (the lowest three points on the scale) with a particular aspect of their work environment are ''branched'' to a follow-up screen probing them for more information about the nature of their dissatisfaction (Fig. 2). Respondents who indicate neutrality or satisfaction (the upper four points on the scale) move directly to the next survey topic. Tailoring the survey in this fashion enables diagnostic information to be gathered about potential problems in the building, and keeps questions relevant to each respondent while making the survey as succinct as possible. When applicable, respondents are also asked to assess the impact of environmental factors on their effectiveness in getting their job done.

Basic demographics are collected from respondents, as well as information about their workspace. Core survey questions elicit whether the workspace is in the core or perimeter of the building, near a window, the orientation (e.g., north), and the type (e.g., private office). Survey clients are encouraged to include zone questions with floor plan schematics in order that

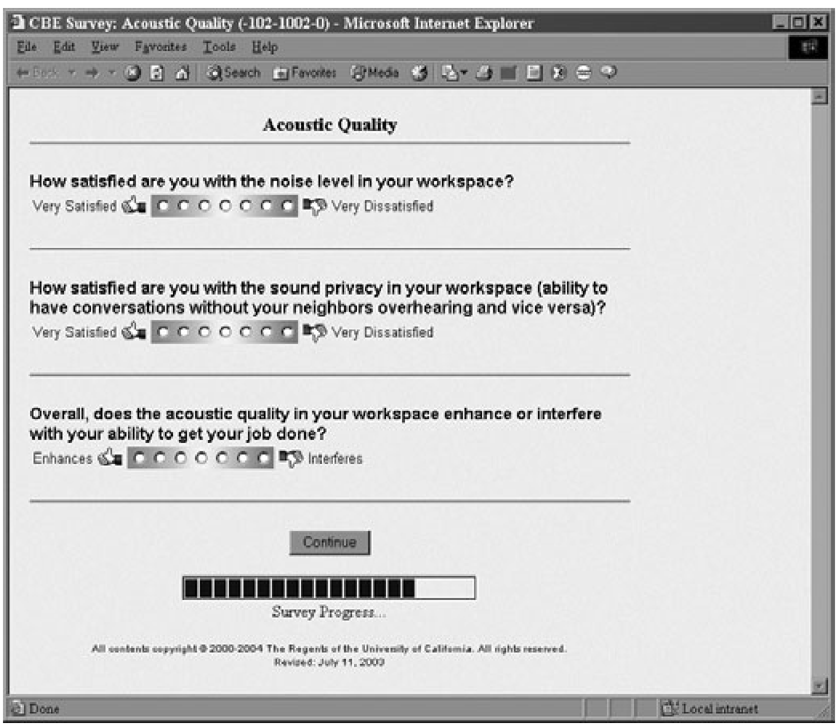

Fig. 1 Sample occupant IEQ survey page

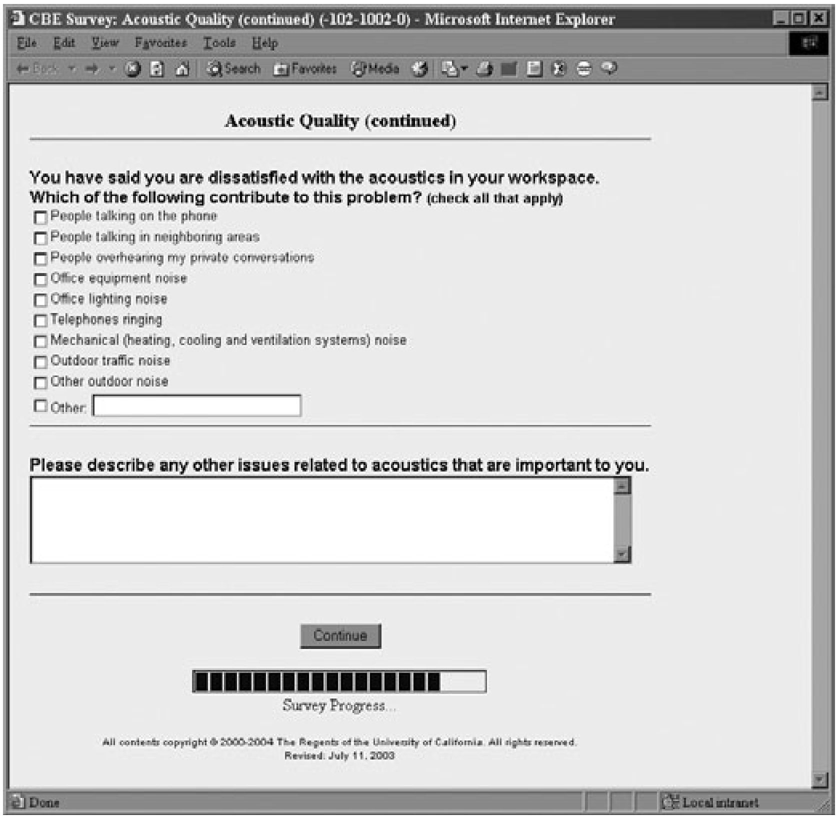

Fig. 2 Sample follow-up page

occupants can indicate proximity to specific building systems (zones must be large enough to ensure respondent confidentiality). Clients may also include custom questions about work duties so that survey data can be analyzed in light of job-specific tasks.

Occupant responses are collected and recorded in a secure SQL Server database (SQL is a standardized query language for storing, retrieving and modifying information in a database). A survey typically stays open for 1–2 weeks. The rate of participation is monitored; and if it is going slowly, reminder e-mails may be sent. Of the buildings surveyed to date, response rates have ranged from 27% to 88%, with the majority of response rates between 45% and 65%, and the mean at just over 50%. Overall, we have found that response rates are higher when the initial message introducing the survey is sent directly from a person who is well known and a decision maker within the participating organization. The introductory e-mail for the survey with the lowest response rate was poorly executed; it was forwarded three times before it reached the occupant, each time with an additional header attached. By the time it arrived to the intended recipients, the reader needed to scroll to the bottom of the message to read the original text. This diminished the perceived importance of the study and is likely to have resulted in the low response rate. The study with the highest response rate was introduced with an e-mail sent directly from the head of the organization noting an "important survey" for all building occupants. While likely leading to the high response rate, often this type of cooperation and attention from the head of an organization is difficult to orchestrate, and this is true of paper surveys as well (Zimring and Rosenheck, 2001; Leaman, 2003).

For census surveys like ours, the survey research industry rule of thumb is that a 50% response rate is required to reduce non-response bias to an acceptable rate (Hill et al., 1999). Although it is difficult to know what the non-response bias might be, we have looked for trends in our data and have found no statistically significant relationship between response rate and occupant satisfaction levels.

Reporting results

Individual building report. Data is reported using an automated Web-based reporting tool, and is quickly made available to clients after survey implementation, typically within a week following the survey close date. Responses of participants who answer less than 15 questions are removed from the final data set. The home page of the report summarizes the satisfaction ratings for each of the survey categories. Satisfaction ratings are tabulated for each point on the scale, and are also summarized into three bins: satisfied (top three points),

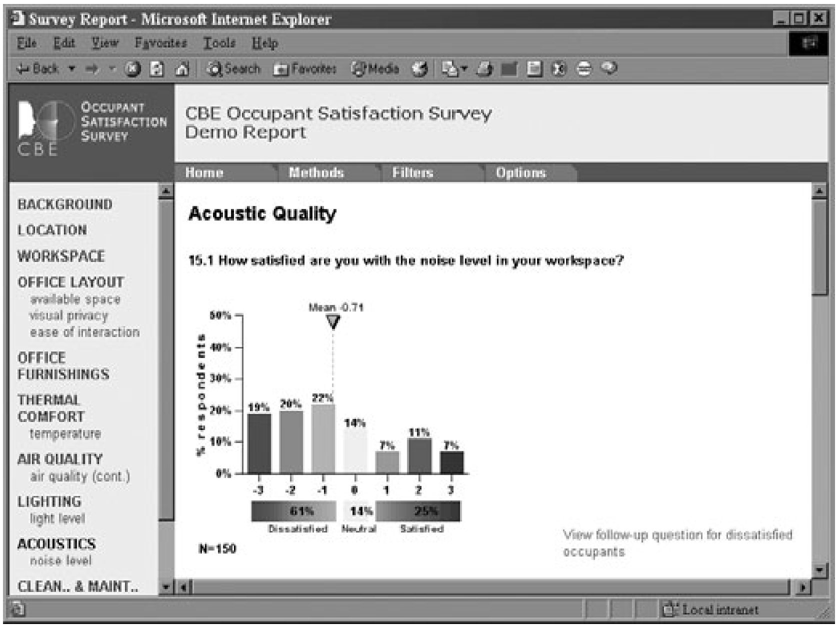

Fig. 3. Sample individual building report page

neutral (middle point) and dissatisfied (bottom three points). This executive summary is particularly useful to managers who need to see a top-level overview of occupant feedback. The report's survey category pages provide charts showing the responses to each of the survey questions (Fig. 3). Comments are also displayed for each question, and we have learned that reviewers typically scan these comments right after looking at the executive summary page (Baughman et al., 1995). To protect the confidentiality of participants, the online report contains only aggregated, anonymous results.

The report's filtering feature enables users to view relationships between questions. An intuitive filtering feature of the reporting tool allows just a subset of the responses to be displayed in the charts. For example, perhaps data for occupants who sit near an exterior wall is of special interest: with this filter enabled, the report shows only the data for those respondents who indicated that they sit near an exterior wall. Several filters can be set up and strung together in a Boolean "AND" query, further defining the results viewed in the individual building report.

Though the online report has not undergone a formal usability study, feedback from users of the report has been positive. CBE researchers and other survey clients use the charts and comments in publications to illustrate the results of POEs, field studies or other building evaluations. The US General Services Administration (GSA), for example, uses the CBE survey for a number of projects. In one of these, they are evaluating whether to switch from using a paper-based survey to the CBE Web-based one. Seriously committed to providing a high standard of service to tenants, GSA's Public Buildings Service surveys each of their buildings every few years. CBE customized the occupant IEQ survey to include all questions asked by the paper-based survey. Feedback about CBE's survey format, speed of results delivery, and information provided by the online report was overwhelmingly positive. We learned, for example, that individual comments were useful from the perspective of those directly managing the building, allowing management to formulate an action plan to address the issues raised (Zagreus and Huizenga, 2003).

Datamining tool. Currently in development, a Java-based software application will enable users to dynamically explore the data in the survey database to investigate hypotheses and examine trends in building quality satisfaction with respect to various building technologies. The tool will first be made available to in-house researchers, then as layers of permissions are added will be made available to the wider audience of the external research groups, architects/designers, building owners/managers and operators who commission surveys. The tool has tiered security access, allowing participating organizations to view their own results in full but keep detailed comments and building identifier data confidential. CBE industry partners have the option of comparing the results for their building(s) against the entire CBE database. Non-partners can conduct comparisons only among the group of buildings they have surveyed.

Raw data. A comma-separated values (CSV) file or Excel spreadsheet is made available to clients who wish to do further analysis in statistical software packages. This also allows the survey results to be analyzed in tandem with logs of physical measurements collected in the occupants' workspaces in some studies, as in the case studies explored below. Because the survey responses are stamped with a time and date, they can easily be associated with other time-stamped data for analysis of responses in relation to measured environmental conditions.

Applications and findings

The survey has been used to evaluate the performance of over 70 buildings in the USA, Canada and Europe, including office buildings, laboratories, banks and courthouses. Survey clients include government and industry organizations, including researchers, building operators, owners, architects and engineers.

The survey is often part of a POE process in which the design and operation of a new building or renovation is assessed. When studying a particular building technology, ideally two surveys are conducted for each building: one while occupants are in the old building or prerenovated space, and the other 6 months after the occupants have moved into the new building or renovations have been completed. This waiting period allows occupants to become accustomed to the new space in order that the experience of change itself doesn't bias the results. Often, however, just one POE survey is conducted, and the data collected is used for diagnostics, and to provide feedback to those involved in the building process.

Following we summarize three case studies. The first shows how survey results are currently being used to improve the environment for occupants in the building, and may also, through educating the institutional clients, improve IEQ in their future building projects. In addition, it demonstrates (as does the second case study) the survey's use as a research tool, developing our knowledge of certain building technologies and how they affect occupant comfort. The last case study illustrates the use of survey data to benchmark building quality within a real estate portfolio.

Case 1: field study – large office building with underfloor air distribution, Sacramento, California

The survey was used to conduct pre- and post-occupancy assessments of occupant comfort in a new building containing underfloor air distribution (UFAD) technology. UFAD systems are increasingly being designed and installed in buildings, but very little whole-building performance data from completed projects has been collected. This project was designed to provide detailed data quantifying the relative impacts of UFAD technology in the form of energy use; indoor environmental quality; occupant satisfaction, comfort, and productivity; and first and life-cycle (operating) costs.

Approach. The research methodology includes occupant satisfaction surveys of the State employees prior to the move to the new building (baseline), as well as a POE. The core occupant IEQ survey was used, along with a floor diffusers module newly developed for the study. To control for seasonal variation, the pre- and postsurveys were each conducted during the same time of year; the baseline survey was conducted during January 2002, and the POE took place almost exactly one year later. This was also timed to ensure that an acceptable interval elapsed between the move and the POE survey, in order to reduce any bias inherent in the disruption of the move or newness of the surroundings. The entire population was invited to participate in the POE survey, and 47% did so in the new building, resulting in 516 valid responses. Of these, 334 occupants took the baseline survey as well. (The overall response rate for the baseline survey was 56%.) Responses for an individual from the baseline and POE surveys were tracked together by means of a personal identification number entered by the respondent upon accessing the survey. The responses remain confidential and anonymous, and are never identified with an individual.

Results. The responses and comments from the baseline and POE surveys were compared to one another, for all respondents who participated in both surveys. Among the findings, Fig. 4 shows that air quality satisfaction improved significantly in the new building over baseline. (As with the other results presented in this paper, this is significant at 95% confidence level.) The increased satisfaction levels are likely to be due to the UFAD system, which delivers fresh supply air directly into the occupied zone via floor diffusers, and researchers found that this was corroborated by a corresponding increase in air movement satisfaction levels in the thermal comfort category. Not all categories showed improvement over baseline, however. Lighting satisfaction scores in the POE were significantly lower than baseline ratings (Fig. 5). Sur-

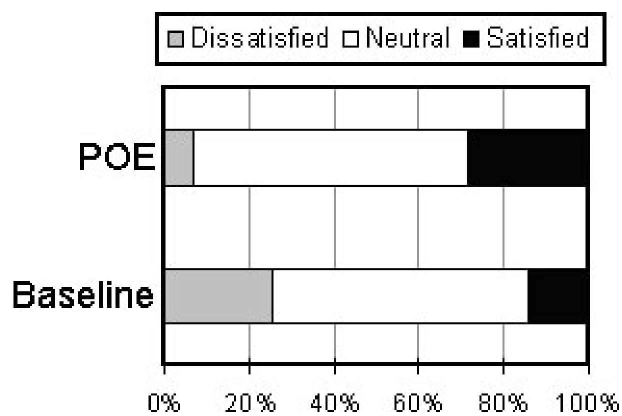

Fig. 4. Air quality satisfaction comparison of respondents who took both POE and baseline surveys (n = 315)

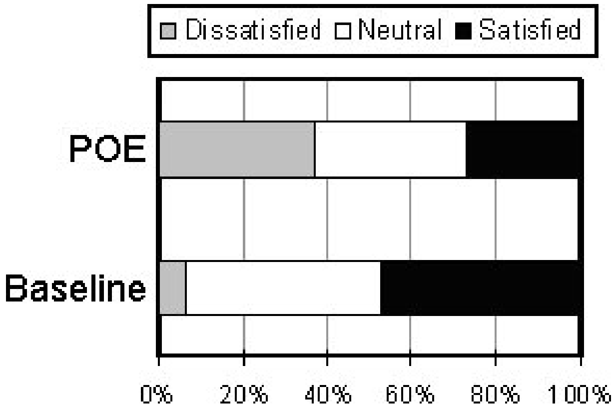

Fig. 5. Lighting level satisfaction comparison of respondents who took both POE and baseline surveys ($n = 314$)

vey comments indicated that much of the problem was due to the lamps used in the task lighting, which provided a bright light that did not illuminate enough of the work surface. This information was passed on to building management and corrective actions are underway.

Responses to the newly developed floor diffusers module indicated that occupant education could have a significant impact on comfort. Most people did not have strong opinions about the location or number of diffusers, and most adjusted them infrequently. They were split evenly as to whether adjusting the devices improved their thermal comfort, yet even so, nearly 2/3 indicated a preference for UFAD over conventional overhead air distribution – a very encouraging result for the technology. It is likely that if building occupants received adequate training on the use of their floor diffusers, comfort would improve (Shirai et al., 2003).

Discussion of preliminary findings. This case study illustrates that using the survey can positively influence indoor environmental quality by several means. When conducted as part of a POE, the survey can have a direct effect on improving the comfort of occupants by ensuring that the building is performing as designed, and that the occupants benefit from the full potential of the building features. Results of this survey enable researchers and the building community to move forward in quantifying how UFAD technology compares with other HVAC systems, and it helps promote understanding of the installation, use and maintenance of the technology among facilities staff.

Case 2: field study – operable windows and thermal comfort, municipal office building, California

The survey was used in a study exploring how the use of operable windows in office settings affects workers' thermal comfort. Thermal environments in buildings with operable windows are typically more variable and less predictable than conditions found in fully air-conditioned buildings. Research indicates that personal control affects people's preference and tolerance for a variety of stimuli (Paciuk, 1990; Leaman and Bordass, 1993; Williams, 1995), and that when given individual control, people are more accepting of a wider range of conditions. In particular, recent research demonstrated this effect with regard to thermal comfort in buildings where people had personal control of operable windows (de Dear and Brager, 2002). The work has since been incorporated into the newly revised version of ASHRAE Standard 55–2004, Thermal Environmental Conditions for Human Occupancy. This new relaxed thermal standard could encourage energy-efficient building design strategies while giving individuals means to respond to their individual thermal preferences. The new field study being described here was intended to investigate the effect of operable windows further, by trying to isolate more precisely the potential causal influence of personal control.

Approach. The study employed two different survey formats, and both were conducted during warm weather, and again during cool weather, in a building with operable windows. The first survey enabled researchers to gather background data from the occupants, using a customized version of the occupant IEQ survey that included newly developed modules assessing air movement, thermal variability, and window use patterns. All occupants of the building were invited to participate, and the response rate was approximately 40% in both seasons. The study also included a short survey format that subjects took several times throughout the day for 2 weeks to collect point-in-time thermal comfort opinions. Developed specifically for the study, this survey took 2–3 min to complete, and included questions regarding thermal sensation and thermal variability (polling for perception as well as acceptability and preference for change), and also activity levels, clothing, and window and blinds use patterns.

Of the approximately 100 subjects participating in the background surveys, 38 went on to the short surveys, and 57% of those participated for both seasons. More than 1000 valid observations (completed surveys) were collected by the short survey for each of the two seasons. Responses for a given individual across the two survey types, and seasons, were tracked together by means of a personal identification number entered by the respondent upon accessing the survey. The responses remain confidential and anonymous, and are never identified with an individual.

In addition, detailed physical measurements of conditions that affect thermal comfort were gathered at each subject's workstation, enabling researchers to sufficiently characterize the spatial and temporal

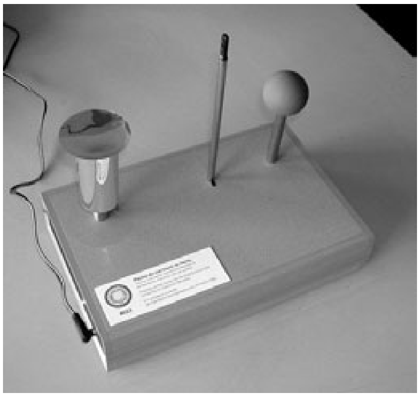

Fig. 6 Indoor Comfort Monitor, with (from left to right) dry-bulb temperature, air speed and radiant temperature sensors

variability experienced by the subjects. For the brief point-in-time survey, this included placing a special weather station device, designed and produced by CBE researchers, upon subjects' desks to continuously measure indoor conditions (Fig. 6).

Results. Survey responses were encoded with a "personal control code" based on the subject's physical location in the building and proximity to the window, and also merged with the coincident environmental physical measurements. Analysis of the data indicates the following points of interest:

- *Personal control.* People with high degrees of personal control over their environment report higher levels of satisfaction and perceived productivity than those with lower degrees of personal control (Fig. 7). In the winter season these differences were all found to be statistically significant to the 95% confidence level.
- *Thermal variability.* Respondents were willing to accept variations in the environment, as long as they had a relatively high degree of personal control. Indeed, 80–85% of the subjects responded that their mean thermal sensation was close to neutral on the seven-point scale (that is, neither too warm nor too cold). This indicates that the building is successfully meeting the intent of the ASHRAE Standard, which states that at least 80% of the occupants should find the thermal environment acceptable (defined as votes within the three central categories of the seven-point thermal sensation scale).
- *Air movement.* Respondents understood that air movement affects thermal comfort. Responses indicating that the environment was too warm had a direct relationship with a rise in the percentage of people wanting more air movement. This shows that people consciously recognize air movement as having a direct impact on their thermal comfort and their air movement preferences are for a change of air movement needed (as necessary) to return to comfort.

People indicated that they were sensing air movement (even at the lowest recordable air speed), and yet they voted for more, particularly in the summer. In fact, in both seasons, only a tiny proportion wanted less air movement (3% and 4%, respectively). This suggests that occupants in naturally ventilated buildings would accept higher levels of air movement and they are quite likely to use it appropriately to keep themselves comfortable (Brager et al., 2004).

Discussion of results. These findings not only offered strong support for the adaptive model recently incorporated into ASHRAE Standard 55-2004, but reinforced the notion that it is essential that the occupants have direct control over the windows, and not simply be working in a building in which operable

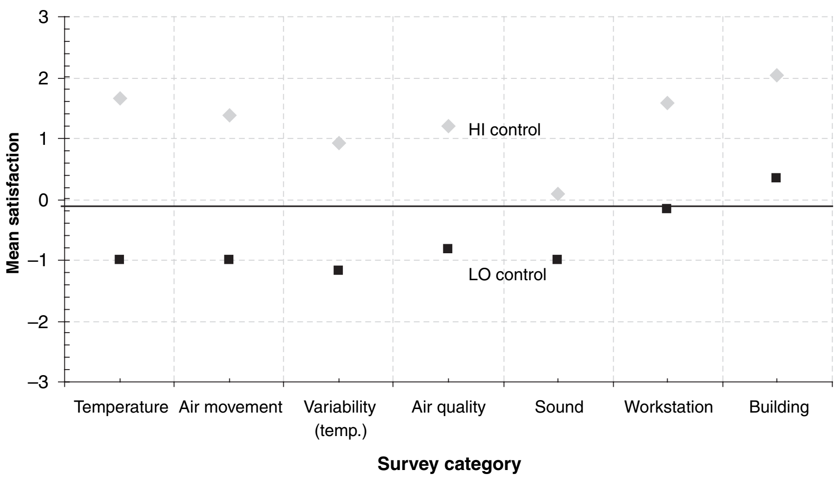

Fig. 7 Average satisfaction with the indoor environment on the seven-point scale for subjects with high and low degrees of control over the windows. Cool season background survey ($n = 93$)

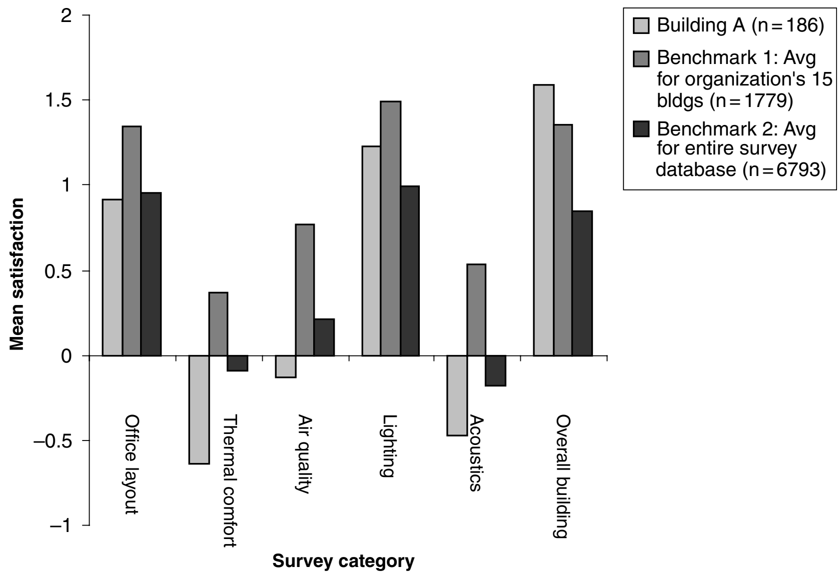

Fig. 8 Benchmark comparison of average satisfaction ratings by survey category

windows exist. This information is likely to be of interest to both the research and building design community. An improved understanding of the influence of operable windows on occupant comfort could result in more comfortable workspaces as well as significant energy savings.

Case 3: office building performance comparison study

A large organization used the survey to elicit occupant feedback on how well its recently completed buildings meet the organization's design goals. To do this, they compared ("benchmarked") the performance levels of individual new buildings against the means and distributions of the overall stock of new buildings. The survey was administered at least 1 year after occupants had moved into each of the new buildings. Figure 8 shows results from one of these buildings compared side-by-side with the results for all 15 of the organization's new buildings, and against the entire survey database.

We can see that Building A is performing well below the mean score in nearly every category, particularly in thermal comfort, air quality and acoustics, suggesting that the HVAC system has significant design and/or operational deficiencies. Interestingly, although the facility is performing poorly compared to the benchmark categories, the overall building score is significantly higher than benchmark. A scan of the comments reveals that occupants find the facility to be beautiful and well maintained, but want air quality problems to be resolved.

The chart also shows that the organization's set of new buildings (Benchmark 1) performs far better than the survey database as a whole (Benchmark 2). This indicates that the organization builds and maintains its facilities skillfully, though it should also be noted that newer buildings tend to get higher marks, and the survey database contains data for both old and new buildings.

The data collected by the surveys can be used to compare buildings to one another, and also against sets of buildings, or the entire database collected heretofore. It is useful, for example, to examine how buildings with a certain feature compare to buildings without those features. As the database of surveyed buildings grows, users of the survey will be increasingly able to explore trends for specific building design characteristics and features. We anticipate that the CBE building quality surveys, and the data they collect, will be useful tools in assessing indoor environmental quality.

Conclusion

The occupant IEQ survey is a tool that helps assess how well a building is performing from the viewpoint of its occupants. With each implementation, researchers, designers and facilities professionals have found the survey to be useful. The core survey, with its diagnostic branching questions, is directly useful to detect and solve problems, as well as to rate a building's performance. The survey infrastructure allows optional modules and custom surveys to be applied to special topics (security, effectiveness of courtrooms) and users (such as operations, maintenance, and design staff). In addition, the survey can be conveniently synchronized with physical measurements taken in the building. These allow various detailed pictures of a building's performance to be assembled, which is especially useful for field research. In the three case studies presented, the survey was used to evaluate the effectiveness of a technology, inform the guidelines for a new comfort standard, and benchmark facility performance. Overall, our goal is to create a feedback loop for building industry professionals, so that they can learn how various building design features and technologies affect occupant comfort, satisfaction and productivity. By creating this feedback loop, we hope to help move the industry towards sustainable, healthy, comfortable workspaces. More information about the survey and the case studies can be found at http://www.cbe.berkeley.edu.

Acknowledgements

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