Indoor environmental quality surveys. A brief literature review

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SUMMARY
Building occupants are a valuable source of information for indoor environmental quality (IEQ) and its effects on health, comfort, satisfaction, self-reported performances, and building performance. There are no standardized methods to survey occupants. A brief literature review has been conducted to collect and describe features of IEQ questionnaires. Ten surveys have been identified and analyzed in terms of type of evaluation, objectives, investigated topics, number of applications, integration with physical measurements, questionnaire structure, types of questions and answers, length of time to complete, languages, and distribution and gathering strategies.

IMPLICATIONS
Occupants can be a useful and inexpensive source of information for assessing indoor environmental quality. This paper lists and describes features of available occupant surveys. This information is summarized in a table in order to understand the uses, scope, and history of IEQ surveys.

KEYWORDS
Post-occupancy evaluation, occupant survey, indoor environment evaluation, questionnaire.

INTRODUCTION
Building occupants are a valuable source of information about indoor environmental quality (IEQ) and its effects on comfort, satisfaction, self-reported performance, and building performance. Moreover, occupant satisfaction and perception of the environment may provide feedback for architects, designers, and building owners to assess building features and technologies.
Post-occupancy evaluation (POE) is a process to assess buildings once they've been occupied in order to improve the existing conditions and as a guide for the design of future buildings. With POE architects, planners and managers are able to create a feedback loop in order to learn how different building design features and technologies may affect occupant comfort, satisfaction and productivity. Surveys, questionnaires, cohort studies, observations, and task performance tests are tools used in the POE process, which can be used alone or in combination with quantitative physics measurements. There are currently no standardized methods to survey building occupants.
The aim of this paper is to perform a literature review of the available surveys and to describe their characteristics in order to comprehend when, why, and how subjective tools can be used for IEQ analysis.

METHODS

A literature search was performed using the key terms: post-occupancy evaluation, occupant satisfaction, occupant survey, and indoor environment evaluation. The following databases were used: Google Scholar, ISI Web of Knowledge, PubMed and Scirus. Selected proceedings and conference papers were also screened. The available surveys have been classified and analyzed in terms of type of evaluation, objectives, investigated topics, number of applications, integration with physical measurements, questionnaire structure, types of questions and answers, length of time to complete, languages, and distribution and gathering strategies.

RESULTS

Main studies, their objectives and features

In the literature review, ten surveys were identified. A summary of their features is reported in Table 1. An extended description of questionnaire features is publicly available at http://tinyurl.com/IEQSurveyReview. Table 1 includes reported information on the type of evaluation, objectives, investigated topics, number of applications, physical measurements, and questionnaire structure. The online table includes information about types of questions and answers, length of time to complete, languages, and distribution and gathering strategies.

In 1981, Building Use Studies (BUS) was founded in London. Four years later it began the development of BUS Methodology, which is still in use today (Leaman A., 2010). BUS questionnaires were used in the PROBE project (Post-occupancy Review of Buildings and their Engineering). The BUS survey has been applied in residential and office buildings (Cohen et al., 2001). Carlopio (1996) developed a survey called the Human Factors Satisfaction Questionnaire (HFSQ), also known as Physical Work Environment Satisfaction Questionnaire (PWESQ). A few years later the REF questionnaire was developed by Stokols and Scharf (1990), with the aim to research strategies for evaluating facility design, occupant productivity and organizational effectiveness. Six years later, in 1996, the US Environmental Protection Agency started the Building Assessment Survey and Evaluation Study (BASE). This study provided basic support for researchers as well as guidance on design, construction, operation and maintenance of buildings; the study focused on IAQ (U.S. EPA, 2003). During this time, de Dear (1998) and Brager (de Dear et al., 1998) collected information and analyzed a database (ASHRAE RP-884) consisting of data derived from thermal comfort field experiments in office buildings. Also at that time, the Center for the Built Environment developed a web-based survey with online reporting tools as a means to quickly and inexpensively gather, process, and present collected data. The CBE survey is currently still in use for research and commercial purposes (Zagreus et al., 2004). Subjective tools were used in the SCATS project from 1997 to 2000 to develop an adaptive thermal comfort model (Nicol and McCartney, 2000). The COPE Project, which began in 2000, aimed to investigate how the open-plan office environment may influence occupant satisfaction (Veitch et al., 2002, 2007). Between 2002 and 2005, the European project HOPE was conducted by fourteen organizations in nine European countries. The IEQ survey portion of the project aimed to provide information on how occupants perceive their indoor environment. (Roulet et al., 2006; Bluyssen et al., 2011). In 2005, the International Center for Indoor Environment and Energy developed a web-based survey that focused on occupant satisfaction, long-term building evaluation, and right-now occupant perception. Right-now surveys are often coupled with physical measurements (Toftum et al., 2005).

Table 1. Subjective survey: features

Survey name and references	Type of evaluation[1]	Objectives	Investigated topics	Number of applications	Physical measurement	Questionnaire structure
BUS occupant survey (Leaman, 2010)	Long term evaluation	Assess how well buildings work, get feedback on occupant needs and perceptions, improve services to occupants	Thermal comfort, perceived comfort, Indoor Air Quality (IAQ), occupant health, productivity (self estimated), personal control	Over 400 organizations and individuals worldwide	Not performed	24 environmental comfort questions, 10 on personal control, 17 on background info, health, productivity, and design
HFSQ (Stokols and Scharf, 1990)	Long term evaluation	Effects of the physical environment on employee behavior and attitudes. Survey on satisfaction with the physical environment and job satisfaction	Thermal comfort, IAQ, acoustic quality, structure organization and quality, health and security of occupants. Satisfaction with environmental factors	NA	Not performed	Questionnaire is composed of 42 items
REF questionnaire (Carlopio, 1996)	Long term evaluation	Research strategies for evaluating facility design, occupant productivity, and organizational effectiveness	Thermal comfort, IAQ, acoustic quality, visual quality, and structure layout quality	7 administrative units and offices	Not performed	Basic Survey: 24 items. Complete survey: 48 items
Building Assessment Survey and Evaluation (BASE) Study (U.S. EPA, 2003)	Long term evaluation	Occupant perceptions of IAQ and health symptoms	Workplace physical information, health and well-being, workplace environmental conditions, and job characteristics	100 buildings in 37 cities in 25 US states	Mobile cart: CO_2, temperature, RH, and supply air delivery. Real time monitors: CO, CO_2, temperature, RH, VOCs, $PM_{2.5}$, PM_{10}	33 questions and additional space for comments
ASHRAE RP – 884 (de Dear et al., 1998, de Dear 1998)	Right-now evaluation	Develop an adaptive thermal comfort standard for ASHRAE	Thermal sensation, acceptability and preference, air speed preference	160 buildings, approximately 21,000 subjects	Clothing insulation, metabolic rate, meteorological conditions, indoor air, mean radiant temp., air speed, indoor humidity	Background questionnaire and thermal comfort questionnaire.
CBE (Center for the Built Environment - UCB) Survey	Long term evaluation with the possibility	Evaluation of building technologies and performance, quality benchmarking, diagnosis of	Office layout, office furnishings, thermal comfort, IAQ, visual quality, acoustics quality,	600 buildings, approximately 60,500 subjects	Depending on which project the measurements are associated. Level 1 and 2 of the PMP	Core Survey (about 60 questions). Custom modules can be added to address issues not

(Zagreus et al., 2004)	of right-now evaluation	problems	building cleanliness and maintenance, general satisfaction plus customizable questions (e.g. security, etc.)		protocol (ASHRAE/USGBC/CIS BE, 2009)	covered in the core questions
SCATS (Smart Controls and Thermal Comfort) (Nicol and McCartney, 2000; McCartney and Nicol, 2002)	Right-now evaluation	Correlation between comfort temperatures and indoor/outdoor temperatures, behavioral analyses. Developing an adaptive control algorithm for Europe	Thermal comfort, IAQ, visual quality, acoustic quality, occupant productivity, general comfort	26 buildings in England, Sweden, Portugal, Greece and France. Approximately 4650 subjects	CO_2 concentration, globe temperature, air temperature, relative humidity, illuminance, air velocity, noise level, meteorological stations for outdoor parameters	Transverse questionnaire: 16 questions. Longitudinal questionnaire: 5 questions
COPE (Cost-effective Open-Plan Environments) (Veitch et al., 2007; Charles et al., 2003)	Long term evaluation	Evaluation of indoor environment satisfaction of occupants. How the physical environment influences organizational outcomes (job satisfaction, absenteeism, turnover, productivity)	Thermal comfort, IAQ, visual quality, acoustic quality, privacy, office layout, window access, lighting, work satisfaction, general satisfaction of workstation.	9 buildings	Physical measurements of each participant's workstation. Cart+chair system (illuminance, air velocity, CO, CO_2, THC, CH_4, TVOC, temperature, RH)	18 individual Environmental Features Ratings. 27 items in total
HOPE Project (Bluyssen et al., 2011; Roulet et al., 2005, 2006)	Long term evaluation	SBS research, benchmarking of healthy and energy efficient buildings	Thermal comfort, IAQ, acoustic quality, occupant health	164 buildings in 9 EU states (69 offices and 95 apartments)	Detailed measurements of chemical, biological and physical parameters	5 comfort items, 7 SBS items and 12 illness indicator
Remote Performance Measurement, ICIEE-DTU (Toftum et al., 2005)	Long term evaluation with the possibility of right-now evaluation	Evaluation of IEQ satisfaction, health conditions and personal control by occupants. Characterization of occupant perceptions and symptoms	Thermal comfort, IAQ, visual quality, acoustics quality, occupant productivity and health (SBS), personal control opportunities, general comfort and satisfaction	Approximately 30 buildings, 1500 people	Dependent upon with which project the measurements are associated	Background questionnaire: occupant general perception of the indoor environment. Instant Questionnaire: effects on occupants of any intervention performed

[1] Type of evaluation: long term evaluation refers to surveys where the aim is to investigate the occupant past experience (e.g. a week, a month, six months or a year); Right-now evaluation refers to surveys where the aim is to investigate the actual occupant sensation.

For the classification, all types of buildings were considered (see online table for more details): banks, commercial buildings, courthouses, hospitals, laboratories, offices, residential buildings, schools, and warehouses.

DISCUSSION

In the building science field there is an active discussion about if and when occupant surveys should be used in place of or in addition to physical measurements. Surveys are cheaper and quicker than measurements and trained persons are not required for their implementation. Measurements can quantify physical phenomena that surveys may only describe qualitatively According to Humphreys (2005) environmental comfort is flexible, based upon cultural and historical variation, and not completely constrained by human physiology. Available human comfort models (thermal, acoustical, visual, and perceived air quality) are limited in their ability to predict human response. Occupant responses to physical environment in buildings may be influenced by a range of complex factors that are unable to be accounted for solely by physical measurements (e.g. psychological expectations, physical conditions, past experience, etc.). Moreover, environmental conditions in buildings are transient and are frequently difficult to measure with accuracy and precision.

An answer to the above mentioned discussion was recently proposed by three leading building industry associations (ASHRAE, USGBC and CIBSE, 2009). They developed a consensus document that provides a standardized protocol for assessing building performance in the fields of energy and water use and indoor environmental quality. The document has three levels of intervention -low, medium and high- each with increasing cost and accuracy. The document suggests that the first level should be applied to all buildings, the second to all buildings with high performance/green/sustainable claims, and the third level should be used mainly for research case studies. For indoor environmental quality assessment, the document suggests using as a first step the survey, as it is the easiest and least expensive step to evaluate IEQ (ASHRAE, USGBC, CIBSE, 2009).

CONCLUSIONS

Occupants can be a useful and inexpensive source of information about indoor environmental quality. In this paper ten IEQ survey methods were analyzed in order to classify their features. Seven of the ten surveys were used for specific research projects, and are no longer in use. The CBE survey has the highest number of buildings and occupants surveyed. The surveys analyzed focused mainly on North America, Europe and Australia, noting the lack of data for Asia, Africa, and South America. There are two main types of surveys: long term evaluation and right-now evaluation. The latter is usually associated with physical measurements. As the surveys have been applied mainly to office buildings, there is a lack of data for residential buildings.

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REFERENCES

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), USGBC (U.S. Green Building Council), CIBSE (Chartered Institute of Building Services Engineers). 2009. Performance Measurement Protocols for Commercial Buildings. ASHRAE. Atlanta

Bluyssen P.M., Aries M., and van Dommelen P. 2011. Comfort of workers in office buildings: The European HOPE project. *Building and Environment*, 46, 280-288.

de Dear, R. 1998. A global database of thermal comfort field experiments. *ASHRAE Transactions*, 104(1),1141-1152.

de Dear R., Brager, G.1998. Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Transactions*, 104(1a),145-167.

Carlopio J.R. 1996. Construct validity of a physical work environment satisfaction questionnaire. *Journal of Occupational Health Psychology*, 1, 330–344.

Cohen R., Standeven M., Bordass B. and Leaman A. 2001. Assessing building performance in use 1: the Probe process. *Building Research and Information*, 29(2), 85-102.

Humphreys M.A. 2005. Quantifying occupant comfort: are combined indices of the indoor environment practicable? *Building Research & Information*, 33, 317-325.

Leaman A. 2010. BUS occupant survey method: details for licensees. http://www.usablebuildings.co.uk

McCartney K. J. and Nicol F., J. 2002. Developing an adaptive control algorithm for Europe. *Energy and Buildings*, 34(6), 623-635.

Nicol F. and McCartney K.J. 2000. Smart Controls and Thermal Comfort Project. Final Report, 89 pages.

Roulet C. A., Cox L.C., de Oliveira Fernandes E. and Müller B. 2005. Health, Comfort, and Energy Performance in Buildings Guidelines to Achieve Them All. HOPE Health Optimisation Protocol for Energy-Efficient Buildings, 64 pages.

Roulet C.A., Johner N., Foradini F., Bluyssen Ph. 2006. Perceived health and comfort in relation to energy use and building characteristics. *Building Research & Information*, 34(5), 467-474.

Stokols D. and Scharf F. 1990. Developing standardized tools for assessing employees' ratings of facility performance. In: *G. Davis and F.T. Ventre, Editors, Performance of Buildings and Serviceability of Facilities*, American Society for Testing and Materials, Philadelphia, PA, pp. 55–68.

Toftum, J., Wyon D.P., Svanekjar H. and Lantner A. 2005. Remote Performance Measurement (RPM): A new, internet-based method for the measurement of occupant performance in office buildings. In: *Proceedings of Indoor Air 2005*, Beijing, China, pp. 357-61.

U.S. EPA 2003. A Standardized EPA Protocol for Characterizing Indoor air Quality in Large Office Buildings. Washington D.C.: U.S. Environmental Protection Agency.

Veitch J.A., Farley K.M.J. and Newsham G.R. 2002. Environmental Satisfaction in Open-Plan Environments: 1. Scale Validation and Methods, Internal Report No. IRC-IR-844.

Veitch J.A., Charles K.E., Farley K.M.J. and Newsham G.R. 2007. A model of satisfaction with open-plan office conditions: COPE field findings. *Journal of Environmental Psychology*, 27(3), 177-189.

Zagreus L., Huizenga C., Arens E. and Lehrer D. 2004. Listening to the Occupants: A Web-based Indoor Environmental Quality Survey. *Indoor Air*, 14 (Suppl. 8), 65-74.