A study of validation on the current POE method by using a case study in southern California

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ABSTRACT:
Post-occupancy evaluation (POE) is an architectural building evaluation tool that aims to improve indoor environmental quality and building performance using comparative metrics. POE has been performed to develop a better quality of human life through improving user satisfaction, productivity, and better matching of building design functions and occupants' needs. Despite the limitations of POE research due to its significant dependence on subjective user satisfaction surveys. researchers have developed methods that combine environmental datasets that integrate an occupant's satisfaction with real IEQ data. While these efforts have enhanced POE methodology, it still is limited by one-time data collection that is unlikely to adequately take varying degrees of human environmental perceptions into consideration in a manner that is consistant and reliable. Nevertheless, what distinguishes this study is the use of advanced POE testing, which uses multiple data collection methodologies to validate the current POE method and identify the potential necessity of an improved method. A modern office in Southern California was chosen as a testbed office to conduct plural occupant satisfaction surveys and on-site measurements were simultaneously made during two months. A statistical analysis of the aggregated data was conducted with consideration of various categories such as time differences and human factors. The result of this analysis revealed that the occupants experienced different levels of environmental satisfaction at different times even though environmental conditions at their workstations remained consistent, or only marginally changed. In addition, human factors, such as age and gender, indicated a significant relationship between occupant satisfaction and changes in human IEQ perceptions. These findings suggest a comprehensive approach is recommended to diagnose current space diagnostics and to provide optimal design solutions that boost users' well-being in a working environment.

KEYWORDS: Environmental comfort; Occupant well-being; Data acquisition; Healthy environment; Human factor

INTRODUCTION

Indoor environmental quality (IEQ), which includes air quality, lighting, acoustic and thermal comfort, has a significant impact on a building's user's health and productivity (Loftness et al. 2006). Due to its importance, various standards and guidelines have been suggested by building industry professionals to maintain a high quality of IEQ (Choi, Loftness, and Aziz 2012; Abbaszadeh et al. 2006). Post-occupancy evaluation (POE), as the primary methodology in the IEQ research domain has been used for several decades to understand and improve the quality of indoor space. Moreover, POE helps evaluate the IEQ and performance of buildings after construction is complete and been occupied for some time(Preiser 1995; Preiser et al. 2001; Watson 2013).

As a main method of POE, occupant satisfaction surveys have been used to identify significant relationships between IEQ components and user satisfaction. Kim (Kim and de Dear 2012) revealed that there are not linear relationships between individual IEQ factors and overall user satisfaction based on the analysis of the survey data. The study analyzed 43,021 respondent samples (from 351 different office buildings) that had been extracted from the database and suggested the categorization of IEQ factors. Altomonte (Altomonte, Saadouni, and Schiavon 2016) investigated occupant satisfaction in a BREEAM-Certified office building, comparing it with that in a Non-BREEAM-Certified building also shows noticeably lower IEQ satisfaction when occupants spent more than 24 months at the BREEAM office.

Due to significantly advanced sensing technologies, it is possible for current POE research to strengthen its validity by adopting multiple IEQ measuring sensory devices. Liang (Liang et al. 2014) investigated the improvement of IEQ condition in green office buildings in Taiwan by comparing occupant's environmental satisfaction survey with monitored IEQ components. In addition, Choi's recent study (Choi and Moon 2017) suggested an advanced POE method that integrates IEQ measurements of buildings and user's response of environmental satisfaction. The study collected 411 IEQ data from 14 different buildings to better diagnose the impact of IEQ factors on user satisfaction. Moreover, his study also illustrated an advanced data mining result that suggested an IEQ design guideline be created based on specific IEQ and human factors.

Although the current scientific trend in POE research has overcome one of the crucial limitations by combining survey data with IEQ measurement, it still primarily depends on one-time data acquisition instead of continuous monitoring. This limitation may affect the result of POE research and make it unreliable because it does not consider a time-varying occupant environmental perception. Since a user's environmental perceptions and behaviors are sensitively affected by dynamically changing indoor and outdoor conditions, it is difficult to fully accept these one-time data collections.

To minimise the uncertainty that one-time data acquisition gathering engenders, this research suggests the need to revise the common POE method into a more advanced method that performs data collections multiple times, continuously if possible. A revised method considers the fact that humans can be sensitive to time functions and the ambient environment because of their bio-rhythms. Instead of fully depending on one moment in time for the measurements and survey, a series of on-site measurements should form a database in which statistical and comparison analyses are conducted.

METHODOLOGIES

To overcome the limitation of current POE method, the study suggested an advanced POE method, which adopts plural data acquisition, to consider the potential variety of occupant's environmental satisfaction depending on measurement timings. In order to test the developed POE method, an office environment in a modern building in Southern California was selected as a sample office where data collection was repeatedly conducted. The office is located in the City of Irvine in climate zone 8 as established by the California Energy Commission. It is an office with an open floor plan and located on the ground level. As shown in Fig. 1, several private offices are located on two sides of the perimeter zone, therefore the data collection was mainly collected from workstations rather than the small private rooms. Two types of datasets were measured and collected from selected workstations: the first dataset was acquired through the on-site measurement of IEQ conditions (including temperature, acoustic level, illuminance, and air quality) at each selected workstation. Secondly, a user satisfaction survey was completed at the same time as the IEQ measurement to observe the occupant's environmental comfort. The data collections were performed from April to June to remove a seasonal impact on occupant's perception with no significant climate variations.

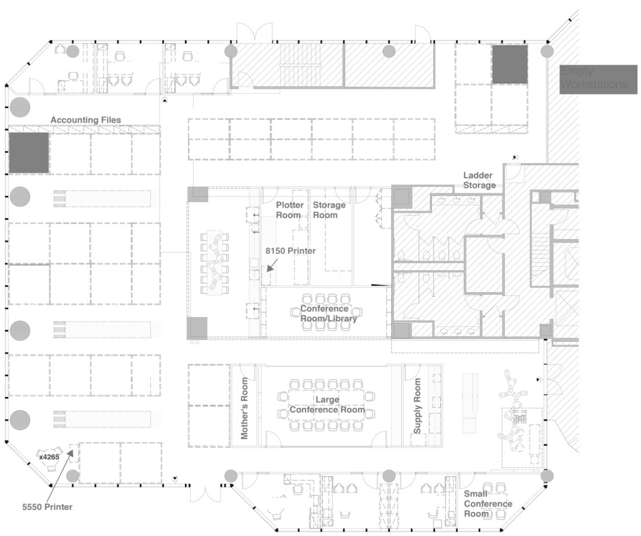

Figure 1: The plan of a selected office building. Source: (Glumac Irvine)

In total 39 datasets were collected from the sampled workstations. To identify the distribution of the collected data, the entire dataset was categorized into key factors such as month and human factor. As shown in Table 1, a total of 22 datasets and 17 datasets were collected in April and June respectively. In April, 15 male and 7 female occupants and their workstations were surveyed and measured, while 9 males and 8 females participated in June. In total, 15 users were categorized in the Junior group (18 – 29 years old), 16 in the Mid-age group (30 – 49 years old), and 8 in the Senior group (50 – 59 years old).

Table 1: Demographic Information of Occupants in Research.

		April			June			
Age group	Age	Female	Male	Total	Female	Male	Total	Total
Junior	18-29	3	6	9	3	3	6	15
Mid-age	30-49	3	6	9	2	5	7	16
Senior	50-59	1	3	4	3	1	4	8
Total		7	15	22	8	9	17	39

IEQ MEASUREMENT

IEQ measurements including lighting, air quality, thermal, and acoustic were performed with two types of sensing devices to diagnose the environmental quality of each workstation. The first device is the USC IEQ cart (named "e-BOT") that is equipped with various sensory devices which measures the temperatures at four different levels with respect to the floor, relative humidity, carbon-dioxide (CO2), and background noise. The cart also consists of air quality sensors that measure particulate matter (PM) and total volatile organic compounds (TVOC) at the height of 1.2 m (Fig. 2). In addition to the sensing cart, several hand-held sensors and a high dynamic range (HDR) camera were included to measure air velocity, illuminance, radiant temperature, and unified glare rating (UGR) at each workstation.

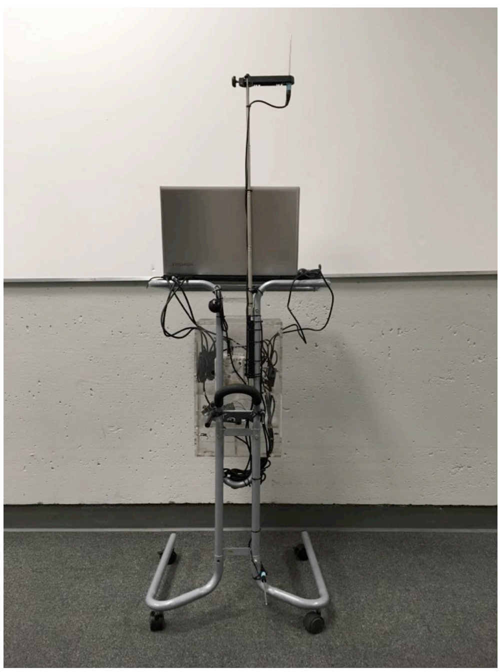

Figure 2: Indoor environmental quality measurement cart (e-BOT). Source: (USC Human-Building Integration Lab)

Table 2 summarizes the current industry standards/guidelines which indicate a comfortable range for each IEQ factor; these suggested standards have been adopted as a baseline in this study.

Table 2. Summary of adopted IEQ standards.

Variables	Guideline
Temperature floor ('C)	between 19 and 29 'C (ASHRAE 55)
Temperature 1.2m ('C)	between 23.3 and 27.8 'C (ASHRAE 55)

Vertical Air Temperature Difference ('C)	less than 3 'C (ASHRAE 55)
Radiant Temperature Asymmetry Ceiling ('C)	less than 5 'C (ASHRAE 55)
Radiant Temperature Asymmetry Wall ('C)	less than 10 'C (ASHRAE 55)
Relative Humidity (%)	65 % or less (ASHRAE 62)
CO2 level (ppm)	less than 1000 ppm (ASHRAE)
Work surface illuminance (lux)	between 200 - 500 lux (ANSI/IES RP-1-12)
Unified Glare Rating (UGR)	between 13 and 19 (CIE)
Acoustic decibel (dBA)	less than 40 dBA (ASHRAE)

SATISFACTION SURVEY

A paper-based survey was designed based on the Cost-effective Open-Plan Environments (COPE) environmental satisfaction questionnaire developed by the National Research Council Canada to support the COPE project (Newsham 2003). Based on the COPE, this study customized multiple questions to fit the research direction and goals. The survey consists of 29 questions regarding the satisfaction level of several IEQ components and spatial elements. The survey adopts a 7-point scale: -3: very dissatisfied, -2: dissatisfied, -1: slightly dissatisfied, 0: neutral, +1: slightly satisfied, +2: satisfied, +3: very satisfied.

STATISTICAL ANALYSIS

The dataset was categorized by selecting measurement time and human factors such as age group and gender. A two-sample T-test and analysis of variance with a 95% confidence level was adopted to identify the difference of user's satisfaction between two times ("Why Should I Use a 2-Sample T-Test?" 2017).

RESULTS

Table 3 illustrates a summary of measured IEQ data by using the statistical analyses of the various components of IEQ. Overall, the data were found to be mostly within the comfort zone of each IEQ element. However, 32% and 41% of the temperatures measured at the height of 1.2m were out of the recommended range. The relative humidity levels and CO_2 concentrations fall within the comfort zones, and their variations were not significant between the selected two months. The work surface illumination, UGR, and Acoustic decibel were notably outside of the recommended guidelines. The average illuminance levels in April and June were 173.9 lux and 136.6 lux respectively, which is lower than the guideline's minimum level by approximately 50 lux. UGR indicates 44% of the workstations were within the recommended comfort range. However, there was a slight improvement in lighting quality between the two different months. The mean value of the acoustic decibel was 62 dBA, which is higher than 40 dBA, the maximum level suggested by the ASHRAE.

Fig. 3 illustrates an average score for the occupants' responses to environmental satisfaction survey questions. The survey adopted a 7-point scale which ranged from -3 (very uncomfortable) to +3 (very comfortable), with "0" for neutral. In general, most of the criteria reaches a positive value of satisfaction, nevertheless the satisfaction levels of noise from other people, the operability of thermostats, and accessibility to views were relatively lower than the other factors. Moreover, the patterns of linear lines are significantly similar except for some specific criteria. In addition, statistical analysis revealed that some human factors, such as gender and age, seemed to affect the environmental satisfaction levels of respondents. A detailed discussion is available in Section 4.

Table 3: Summary of measured IEQ data by month.

	April			June		
Variable	Mean	StDev	Within guideline	Mean	StDev	Within guideline
Temperature Floor ('C)	23.02	0.419	100%	23.13	0.194	100%
Temperature 1.2m ('C)	23.31	0.378	68%	23.30	0.197	59%

Vertical Air Temperature Difference ('C)	0.302	0.195	100%	0.214	0.096	100%
Radiant Temperature Asymmetry Ceiling ('C)	0.741	0.733	100%	0.252	0.267	100%
Radiant Temperature Asymmetry Wall ('C)	1.573	1.466	100%	1.035	0.657	100%
Relative Humidity (%)	50.73	1.893	100%	57.58	0.531	100%
CO2 Level (ppm)	726.8	66.6	95%	660.2	29.04	100%
Work Surface Illuminance (lux)	173.9	203.6	14%	136.6	78	18%
UGR	11.41	4.117	41%	12.13	4.053	47%
Acoustic Decibel (dBa)	62.64	3.783	0%	62.36	2.441	0%

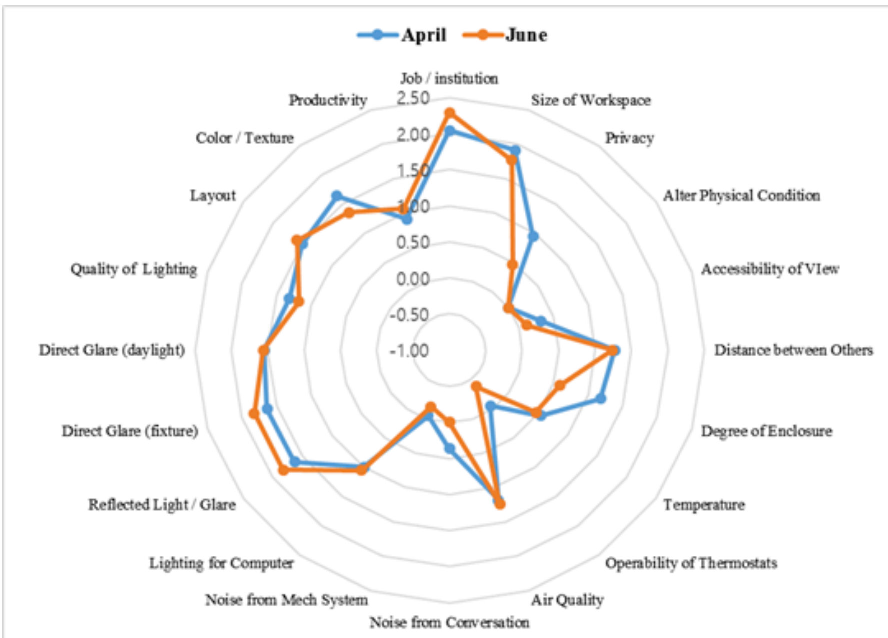

Figure 3: Rose chart of survey question by month.

DISCUSSION

As discussed in the previous section, there was a significant change in an occupant's environmental perception of specific IEQ criteria. According to statistical analysis, the differences of an occupant's satisfaction was statistically significant while their indoor environment was relatively consistent. In addition, human factors such as age and gender were observed to directly affect the users' environmental perception.

The first finding illustrates the impact of gender on an occupant's thermal perception. Fig. 4 (left) shows female occupants' response about Q13, which is about the same satisfaction level as the thermal condition. Female users were significantly more satisfied with their thermal environment in June than in April. A p-value was 0.079 which is statistically marginally significant. In general, females reported neutral or positive satisfaction in June, while they were unsatisfied with their thermal condition in April. However, unlike users' feedback, the actual temperatures were relatively similar between two months. As illustrated in Fig. 4 (right), the temperatures at the working level (1.2m) were almost consistent between the two months, although the distribution of April's data is wider than June's. Moreover, since the mean value of two datasets were nearly the same and the range of April's data is within 1.2°C, those two datasets differences are not statistically significant. This comparison reveals that the female group might have higher sensitivity to thermal condition because of physical and/or psychological factors, even though the variation of temperature was relatively small. Also, external factors, such as time function and weather conditions might affect a female's thermal satisfaction.

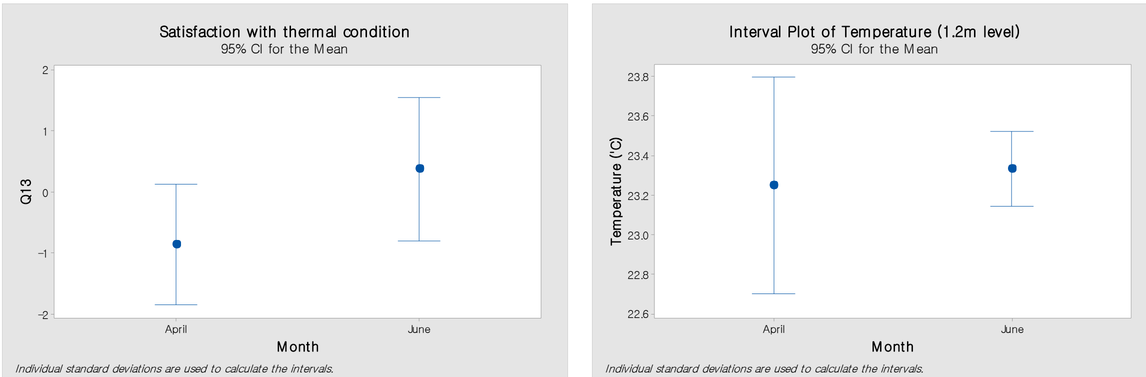

Figure 4: Comparison of the confidence interval of thermal quality satisfaction of each month (left) and measured temperature at 1.2m level (right) (Female group only).

The second analysis revealed that the age group also had an impact on users' satisfaction. According to the analysis, the age group between 18 to 29 years old showed significantly different responses to acoustic conditions as compared to answers from other age groups. As illustrated in Fig. 5 (left), the junior age group had a notably different satisfaction level for each of the two months with a p-value of 0.026. Occupants in the junior age group were neutral or marginally satisfied with their acoustic condition in April. However, they mostly had negative responses to the ambient acoustic environment in June. Despite the variation of users' answers regarding the acoustic condition, the collected acoustic data illustrated a constant distribution. Fig. 5 (right) illustrates that the distributions of both months are similar with no significant difference. Moreover, the acoustic levels were stronger than the industry standard, which is 40 dBA for the open-plan office. In conclusion, the junior age group's acoustic perceptions seemed to be easily influenced by other environmental factors. In addition, this age group showed various acoustic satisfactions, even when their background noise levels were consistent. Since the acoustic conditions were measured in dBA for sound pressure level, it is hard to define which specific frequency ranges of the sound source affected the acoustic satisfaction of the junior age group. Therefore, it is recommended to collect detailed sound pressure levels per acoustic frequency to better understand the impact of background noise on an individual's acoustic satisfaction.

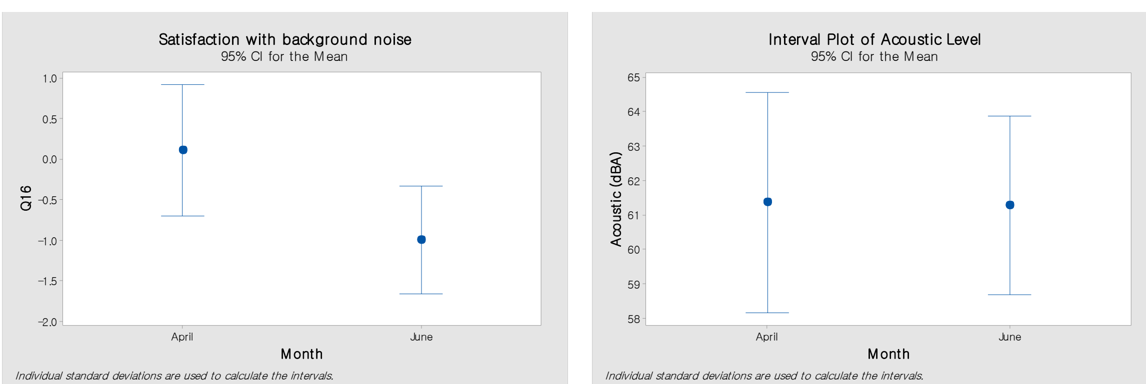

Figure 5: Confidence interval of monthly acoustic quality satisfaction (left); measured acoustic level (right) (Age group 18-29)

CONCLUSION

This research was conducted to identify the potential usage of a revised POE method that better integrates the time function of IEQ measurement in an office environment. In general, the collected IEQ data in a sample office were relatively consistent at the two measured times of April and June. However, this study revealed that the female group was more satisfied with their thermal condition in June than April, while the actual temperatures of the office were almost same during the two months. Moreover, the junior age group showed a higher acoustic satisfaction in April than in June, while the actual sound conditions had no significant difference. Findings of this case study assessed an idea that occupant's environmental satisfaction can change, depending on human factors and/or ambient elements, while the actual indoor conditions are consistently maintained. Because of the limitation of sample sizes and moderate climate conditions in Southern California, this study might find only a few statistically significant results. However, the study confirmed a possible difference or inconsistency in an occupant's environmental satisfaction. Based on these results, it is concluded that the multiple-time data acquisitions are necessary to improve the quality and accuracy of POE research methods that improve the consideration of human factors and time-relevant parameters. Also, multiple IEQ measurements and satisfaction surveys may provide evidence for establishing optimal design solutions with a better understanding of a user's satisfaction that is affected by human factors and outside conditions. Some improvements for future study should be considered as followed: firstly, the number of datasets need to increase to conduct more sophisticated analyses with consideration of various human factors, which provide a high impact on a user's satisfaction.

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