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Occupant Satisfaction and Comfort in Green Buildings: A Longitudinal Occupant Survey in a Green Building in the Subtropical Climate in Australia

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Abstract: Understanding occupant expectation and feedback is an important part of building performance evaluation. This paper explores occupant satisfaction change during a 10-year period in a green building located in the subtropical zone. Occupant satisfaction at two timestamps, three and ten years after project completion, were compared. It was observed that occupant satisfaction regarding indoor air quality (IAQ), noise and overall building comfort remained unchanged during the 10-year post-occupancy period. This finding suggests that perceived IAQ, noise, and overall satisfaction with buildings may not be biased by point-in-time of surveys, the year weather or sample characteristics. However, satisfaction scores regarding the two parameters of lighting and thermal comfort are likely to be subject to change over time. The change in satisfaction scores in relation to thermal comfort and lighting might be explained in various ways. The change of climate and sky conditions, and different sample characteristics were the two assumptions considered worthy of further investigations. The study found some evidence of a possible correlation between year weather and occupant satisfaction responses. The study also showed that green buildings with natural ventilation may be more susceptible to climate change impacts.

Keywords: Building performance; green buildings; occupant satisfaction; thermal comfort.

1. INTRODUCTION

The revolution of green buildings has brought major changes in the way buildings are designed, built, and managed with great emphasis on post-occupancy building performances (Yudelson, 2010). Green building design ideas have offered opportunities to create high quality spaces for building users (Xie et al., 2017). This means understanding user expectations and satisfaction levels underpin post occupancy evaluation (POE) studies (Gou and Siu-Yu Lau, 2013). Building users are utilized as a source of information on building performance evaluations (Huizenga et al., 2002). Recently, there has been a growing interest in the performance evaluation of green buildings and many studies have investigated whether green buildings enhance user satisfaction. However, a recent study by Khoshbakht et al. (2018) analysed the global performance of green buildings and highlighted some discrepancies in the reports of POE studies comparing green buildings with their non-green counterparts (see Table 1). In comparing several indoor environmental parameters, some studies have reported that green buildings outperformed their non-green counterparts in terms of thermal comfort (Abbaszadeh et al., 2006a; Brown et al., 2009; Baird et al., 2011), air quality (Huizenga et al., 2002; Issa et al., 2011a), lighting (Pei et al., 2015) and noise (Kim et al., 2015a). However, a great body of research has shown evidence on dissatisfaction in green buildings in comparison with non-green buildings related to thermal comfort (Leaman and Bordass, 2007b; Ravindu et al., 2015), air quality (Altomonte et al., 2016a) , lighting (Brown et al., 2009) and noise (Lee and Kim, 2008). These contradictory evaluation reports of building performances were based on point-in-time or cross-sectional surveys which have raised the question of potential bias in POE studies.

Table 1. Literature review summary of green building performance in comparison with non-green counterparts, adapted from (Khoshbakht *et al.*, 2018).

Parameter	**Higher satisfaction in Green buildings**	**No significant differences**	**Lower satisfaction in Green buildings**
Thermal comfort	(Abbaszadeh *et al.*, 2006b) (Baird *et al.*, 2012) (Brown *et al.*, 2010) (Gou *et al.*, 2014) (Issa *et al.*, 2011b) (Kim *et al.*, 2015b) (Lee and Kim, 2008) (Liang *et al.*, 2014) (Lin *et al.*, 2016) (Newsham *et al.*, 2013) (Pei *et al.*, 2015) (Sediso and Lee, 2016) (Zhang and Altan, 2011) (Gou *et al.*, 2012b)	(Altomonte and Schiavon, 2013) (Altomonte *et al.*, 2016b) (Gou *et al.*, 2012c) (Menadue *et al.*, 2014) (Paul and Taylor, 2008) (Leaman and Bordass, 2007a)	(Ravindu *et al.*, 2015) (Leaman and Bordass, 2007a) (Leaman *et al.*, 2007) (Gou *et al.*, 2012b) (Leaman *et al.*, 2007)
Air quality	(Abbaszadeh *et al.*, 2006b) (Huizenga *et al.*, 2005) (Issa *et al.*, 2011b) (Kim *et al.*, 2015b) (Lee and Kim, 2008) (Liang *et al.*, 2014) (Lin *et al.*, 2016) (Pei *et al.*, 2015) (Thatcher and Milner, 2016) (Kim *et al.*, 2015b) (Tham *et al.*, 2015)	(Altomonte and Schiavon, 2013) (Gou *et al.*, 2012c) (Ravindu *et al.*, 2015) (Sediso and Lee, 2016) (Gou *et al.*, 2012c) (Paul and Taylor, 2008)	(Altomonte *et al.*, 2016b) (Leaman and Bordass, 2007a) (Ravindu *et al.*, 2015)
Lighting	(Baird *et al.*, 2012) (Issa *et al.*, 2011b) (Kim *et al.*, 2015b) (Pei *et al.*, 2015) (Sediso and Lee, 2016) (Zhang and Altan, 2011) (Issa *et al.*, 2011b)	(Altomonte and Schiavon, 2013) (Altomonte *et al.*, 2016b) (Abbaszadeh *et al.*, 2006b) (Gou *et al.*, 2012b) (Gou *et al.*, 2012c) (Huizenga *et al.*, 2005) (Leaman and Bordass, 2007a)	(Brown *et al.*, 2010) (Lee and Kim, 2008) (Brown *et al.*, 2010)
Noise	(Kim *et al.*, 2015b) (Liang *et al.*, 2014) (Pei *et al.*, 2015) (Newsham *et al.*, 2013)	(Altomonte and Schiavon, 2013) (Altomonte *et al.*, 2016b) (Abbaszadeh *et al.*, 2006b) (Baird *et al.*, 2012) (Gou *et al.*, 2012b) (Gou *et al.*, 2012c) (Huizenga *et al.*, 2005) (Leaman and Bordass, 2007a) (Paul and Taylor, 2008) (Ravindu *et al.*, 2015) (Sediso and Lee, 2016) (Zhang and Altan, 2011)	(Brown *et al.*, 2010) (Issa *et al.*, 2011b) (Lee and Kim, 2008)

This study expands existing research on occupant satisfaction studies by investigating potential biases in occupant satisfaction studies to explain the discrepancies in green building performance evaluations. Previous occupant satisfaction studies in green buildings have been based on point-in-time surveys and no longitudinal POE studies have been performed. Concerns over the validity of point-in-time surveys include common method variance bias and causal inferences attributed to measurement methods (Rindfleisch et al., 2008). This paper complements prior research by reducing concerns through enhanced measures and multiple year studies.

The study purports to investigate whether the weather has an influence on point-in-time POE results. The research aims to find correlations between occupant satisfaction and weather to conclude that the weather normalisation is necessary for POE studies to minimize the influence of that particular year's weather conditions on occupant satisfaction scores.

2. METHODOLOGY

Longitudinal user surveys were conducted in a building case study to analyse occupant satisfaction and the associated biases with subjective evaluations of building performance. POE surveys were performed to document occupant perceptions on indoor conditions and correlate the responses with the outdoor climate data. Section 2.1 provides the details of the building case study and section 2.2 gives an overview of the POE surveys.

2.1 Building case study and location

The selected building is located at Bond University on the Gold Coast, Australia. Gold Coast is in South East Queensland with a subtropical climate. The mean daily temperature reaches 28.7 °C in summer and 12.0 °C in winter. The air is usually dry and fresh except for a few months in summer with a monthly average relative humidity from 55% in winter to 70% in summer (Australian Government, 2018). As the building location is close to the ocean, the sea breeze lasts over the whole year, with annual maximum wind gust speed of 117 km/h. The use of natural ventilation could, therefore, be a suitable option on the Gold Coast due to the moderate climate.

The School of Sustainable Development building is a three-storey structure comprising of studio spaces, workshops, a lecture room on the ground level, and meeting rooms, cellular offices, and an open-plan office for higher education research students on the top two levels (Figure 1). The building has a mixed mode ventilation system with manually operated windows and individual air conditioning units for each room. The air conditioning systems shuts down automatically if users open doors or windows.

The building is used by students and teaching staff in property and real estate, urban design and planning, project management, environmental management, construction management, and quantity surveying for both teaching and research purposes. No renovation works except for minor maintenance works such as painting have been conducted in the building since 2008. No changes to building set-points or asset management have been made during the 10-year period.

Figure 1: School of Sustainable Development building, Bond University, Australia.

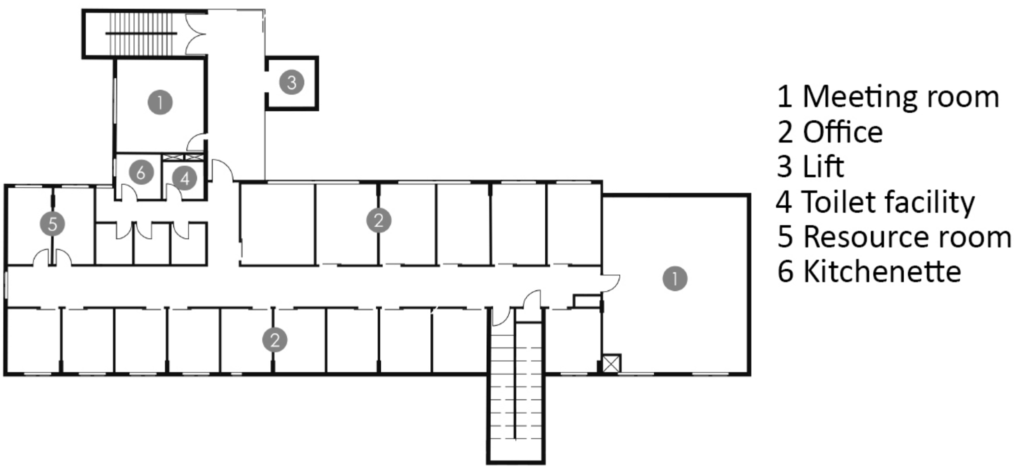

Figure 2. Typical plan of School of Sustainable Development building.

2.2 Field investigation

2.2.1 POE survey

POE is a process of building performance evaluation once it is occupied through a systematic assessment of user responses and satisfaction with buildings and designed spaces (Preiser, 2001). This study employs Building Use Studies (BUS) methodology for the POE study performed at two timestamps. The first survey data collection was performed in 2011, three years after the building was first occupied (Best and Purdey, 2012). The second survey was undertaken in 2017, ten years after the building was occupied. The survey consisted of a two-page paper BUS questionnaire (Cohen et al., 2001). The BUS methodology survey is a highly respected instrument, having been effectively applied in various research works worldwide (Leaman and Bordass, 2007b; Gou *et al.*, 2012a; Khoshbakht *et al.*, 2018).

The BUS Methodology is a free tool for identifying features that work well and those that may be improved, and can be used to optimise building operations. As a benchmarking tool, the BUS Methodology compares survey results with standardised benchmarks derived from the BUS Methodology building performance database to provide an indication of how the building performs relative to a sample of similar buildings. Benchmarking samples are selected based on common use type and geographical location. The survey questions require scores on a 7-point scale for different building parameters. The 7-point scale response has been designed based on the recommendations by ASHRAE Standards to cover a wide range of occupant satisfaction levels (ASHRAE Standard, 2010). The BUS Methodology survey consist of 45 questions including various building parameters such as indoor environmental quality, building design, and facility management. For the purpose of this research, only results related to Indoor Environmental Qualities (IEQ) including temperature, air quality, lighting and acoustics are presented. A more detailed description of the BUS Methodology questions is included in previous research by Gou *et al.* (2014). The selected survey questions cover seven key comfort variables: summer and winter temperature, air quality, lighting, noise, and overall comfort. The results aim to understand occupant subjective thermal perceptions.

The *Comfort Index* is calculated based on averaging the Z scores regarding seven key parameters: temperature in summer, temperature in winter, IAQ in summer and winter, noise, lighting and overall comfort (Baird *et al.*, 2011). The *Forgiveness Index* is determined based on dividing the mean score for the variable comfort overall by the average of the mean scores for the seven variables mentioned above. The Forgiveness Index indicates occupant tolerances of dissatisfaction in buildings (Leaman and Bordass, 2007b). The *Comfort Index* and *Forgiveness Index* were introduced by the BUS Methodology as metrics of comparison between overall comfort and individual comfort parameters. The Comfort Index is calculated by averaging the Z scores for the seven key variables (Baird et al., 2011). The *Comfort Index* is calculated with the following formula:

$$\text{Comfort Index} = (\text{Z-score } T_s + \text{Z-score } T_w + \text{Z-score } A_s + \text{Z-score } A_w + \text{Z-score N} + \text{Z-score L}) \quad (1)$$

Where:

Z-score = places variables on a common scale with the mean of 0 and the standard deviation of 1; A_s and A_w = average satisfaction scores for air in summer and winter, respectively; T_s and T_w = average satisfaction scores for temperature in summer and winter, respectively; L = the average score of satisfaction for lighting; N = the average satisfaction score for acoustics. Z-scores indicate how much individual scores deviate from different bunches of data after standardizing scores from different groups of data. Z-scores show how far a particular score is away from the mean and indicate whether it is higher, equal, or lower than the mean score (Gou et al., 2013).

The *Forgiveness Index* is calculated by dividing the mean score for the variable *Comfort Overall* by the average of the mean scores for the variables temperature in summer, temperature in winter, air in summer, air in winter, lighting and noise from the following formula:

$$\text{Forgiveness Index} = \text{Comfort Overall} \,/\, ((A_s + A_w + T_s + T_w + L + N) / 6) \quad (2)$$

Where:

Comfort Overall = the score of the overall comfort performance; A_s and A_w = average satisfaction scores for air in summer and winter, respectively; T_s and T_w = average satisfaction scores for temperature in summer and winter, respectively; L = the average score of satisfaction for lighting; N = the average satisfaction score for acoustics.

Quasi-experimental design was chosen as a sampling approach in this study because a controlled selection of participants was impossible. The quasi-experimental design allocates participants in quasi-random forms (Jones et al., 2016). A one-way analysis of variance (ANOVA) was used to evaluate means and variances. Statistical significance or p-values were also determined to investigate the significance of the change in satisfaction scores.

3. RESULTS

3.1 Occupant satisfaction surveys

The comparison analysis of IEQ over the two timestamps, with 6 years of difference, showed that overall comfort regarding IAQ and lighting improved (Figure 2). Overall satisfaction with noise slightly improved, but noise interruptions and noise from colleagues achieved lower scores in the second survey. Thermal comfort satisfaction attained a higher score in winter, while in summer, in the second survey, satisfaction scores with overall thermal comfort were lower. The temperature in summer, in the second survey, was perceived warmer than the first survey, while in winter, occupants scored temperature as slightly colder in the second survey.

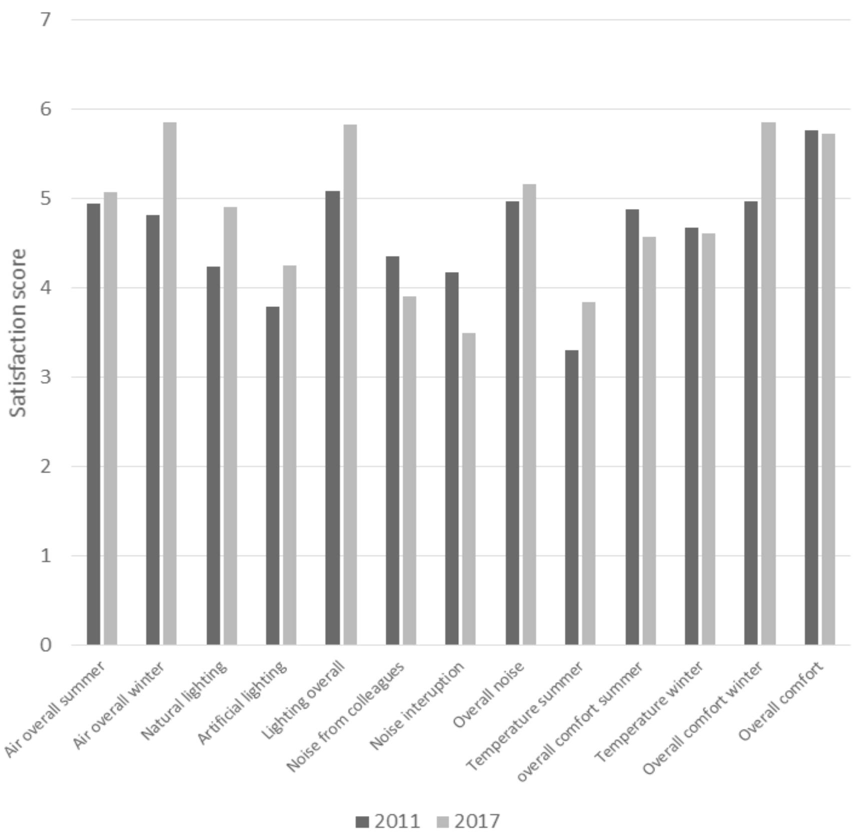

Figure 2: The change in satisfaction scores in 2011 and 2017 regarding indoor environmental qualities.

To identify the significance of the changes, the ANOVA analysis was used to examine the effect size of the mean differences (Table 1). An effect size (Rho) is an index which calculates the magnitude of the association between predictor variables (Ferguson, 2009). An effect size smaller than 0.20 is considered negligible, and equal to or more than 0.20 is attributed as substantive (Cohen, 1992).

Table 1. Mean scores, effect size and statistical significance of difference in means of IEQ parameters.

IEQ Parameters	2011	2017	ΔM	Rho	Sig.
IAQ summer	4.94	5.07	0.13	<0.20	>0.05
IAQ winter	4.82	5.86	1.04	<0.20	>0.05
Lighting	5.09	5.83	0.74	*>0.20*	*<0.05*
Comfort summer	4.88	4.57	-0.31	*>0.20*	*<0.05*
Comfort winter	4.97	5.86	0.89	<0.20	>0.05
Noise	4.97	5.16	0.19	<0.20	>0.05
Overall building	5.77	5.73	-0.04	<0.20	>0.05

Note: Numbers in italic are statistically significant.

The inferential analysis revealed that the change in satisfaction scores was substantive in lighting and thermal comfort in summer, suggesting that satisfaction scores in other IEQ parameters such as IAQ, noise, overall building, and thermal comfort in winter remained unchanged during the study period. This finding shows that the time of survey has no significant influence on satisfaction scores regarding IAQ, noise, and overall building comfort. The survey also revealed the issue of cool or cold indoor conditions in winter were significantly reduced from 2011 to 2017. The overall satisfaction with the building (Overall Building in Table 1) in 2011 was 5.77, which was only slightly higher than the value of 5.73 in 2017. This indicated that overall satisfaction with the building gained almost similar scores after the 6 years. Table 2 presents the change in *Forgiveness* and *Comfort Indices* in the studied period.

Table 2. Survey results of the BUS survey results regarding Forgiveness and Comfort Index.

	2011	2017	Avg.
Forgiveness index	1.2	1.2	1.2
Comfort index	1	1.5	1.25

The statistical analysis detected significant improvements in occupant Comfort Index, while Forgiveness Index remained unchanged during the studied period (See Table 2). The BUS database for Australian green buildings that use natural ventilation was used as a benchmark. The Forgiveness Index greater than 1 indicates a higher tolerance to the indoor environmental conditions. The results indicated that Forgiveness Index stayed unchanged, while Comfort Index increased from 1 unit in 2011 to 1.5 in 2017. This indicated that the occupant tolerance of discomfort conditions remained unchanged, while comfort slightly increased over the 10-year period.

3.2 Building context

To contextualise the results and present sample characteristics, information on occupant type, building use, and programs at the two timestamps is presented in Table 3. Although the sample characteristics are similar, there are some slight differences that could be considered as influencing factors on survey responses. The participants in 2011 were slightly younger than the group in 2017. In 2011, 89% of survey participants were 30 years or over, while in 2017 all the survey participants were 30 or over. The proportion of female participants reduced by 10% from 37% in 2011 to 27% in 2017. The percentage of the survey participants who sat next to a window also reduced from 85% in 2011 to 73% in 2017. The percentage of participants who had worked in the building and at their desk area more than a year was 83% and 44% in 2011, respectively, which reduced to 67% and 33% in 2017. This indicates that the participating group in 2011 had worked in the building and at their desk area longer than the group in 2017. Group occupancy and office sharing with others were almost similar when comparing the two groups. One conspicuous observation is the behaviour change. A larger proportion of the participants in 2011 (56%) claimed they had some experiences of behaviour change once they started working in the building than the group in 2017 (21%). This clear difference in behaviour change may be related to visions towards sustainability and green building concepts. The studied building was the first green certified building in the city of the Gold Coast and perhaps the first green building for many of its 2011 occupiers, while the second survey was conducted 10 years later. This may explain the higher number of positive responses for the behaviour change question. Another parameter worth considering, particularly in relation to sustainability vision, is how occupants travel to work. The proportion of participants who chose car as a solo driver slightly increased from 2011 to 2017. Public transport, cycling, and walking to work also slightly increased in 2017. The teaching programs and building use remained unchanged with only one exemption that urban design and planning were no longer taught at the building at the time of the 2017 survey. Regarding personal control, participants in 2011 were slightly more concerned about the control of ventilation, lighting and noise, while room temperature control was slightly more important for the group in 2017.

Table 3. Building contextual factors.

Sample	Percentage in 2011 (%)	Percentage in 2017 (%)
Age 30 or over	89	100
Gender	Female 37 Male 63	Female 27 Male 73
Next to a window	85	73
Work in the building more than a year	83	67
Work at the present desk area more than a year	44	33
Behaviour change	56	21
Group occupancy and space share	Alone 70 With one 0 With two to three 0 With four to six 20 More than six 10	Alone 67 With one 7 With two to three 0 With four to six 13 More than six 13
Request for changes from facility management	44	47
Importance of personal control	Cooling 20 Heating 19 Ventilation 22 Lighting 21 Noise 15	Cooling 25 Heating 25 Ventilation 21 Lighting 17 Noise 12
Journey to work	Car (solo) 68 Walk 6 Motorcycle 3 Cycle 0 Bus 0 Train 3	Car (solo) 53 Walk 20 Motorcycle 7 Cycle 7 Bus 7 Train 7
Programs	Property/real estate Urban design and planning Project management Environmental management Construction management and quantity surveying	Property/real estate Urban design and planning Project management Environmental management Construction management and quantity surveying

Although the sample characteristics were slightly different, major parameters including age, gender, window seat, work duration in the building and at the desk area, request for change, and the teaching program were similar.

The most dominant difference may be the visions towards sustainability. The participants in 2017 used environmentally friendly means to travel to work and were more familiar with green building concept than those in 2011 by changing their behaviours when moving to a green building. However, this finding is only an observation and more studies of this kind are needed to correlate occupant responses with sample characteristics. Understanding the correlations between certain sample characteristics would help researchers to normalise their occupant survey results based on their sample characteristics and minimise potential bias.

3.3 The influence of year climate

To test the hypothesis that the year climate may have influenced the survey responses, an analysis of climate data was performed to correlate the change in satisfaction scores with changes in climate. Figure 3 illustrates the hourly air temperature trend for a whole year in 2011 and 2017. It is clear that the prevailing air temperature in 2017 was one degree Celsius warmer than 2011, particularly in winter. This finding is in line with the change in thermal comfort satisfaction change from 2011 to 2017.

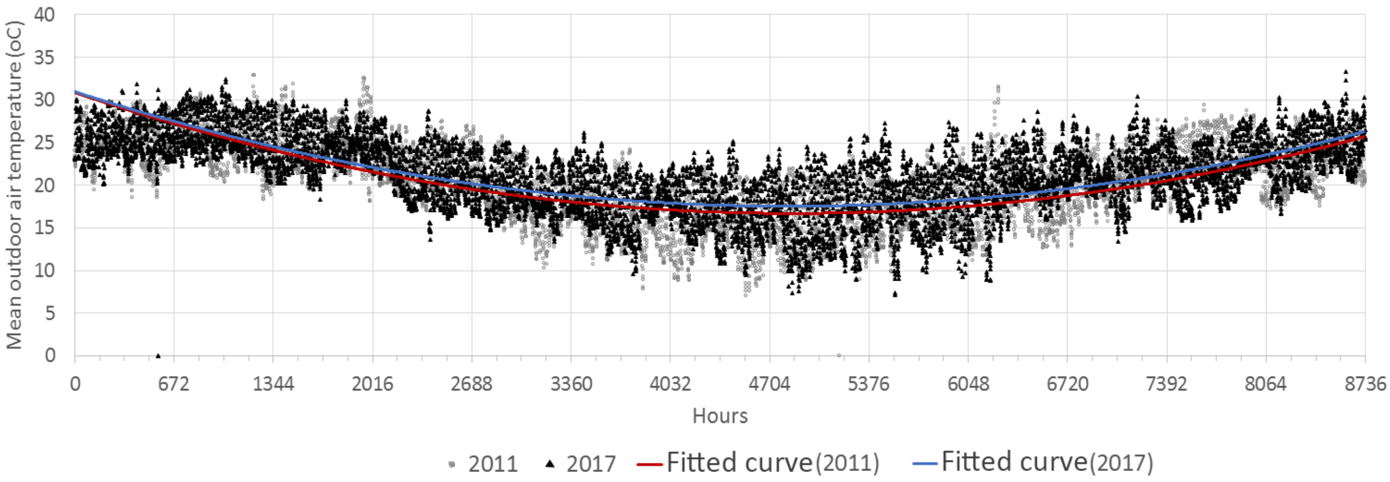

Figure 3. The fitted curve for hourly temperature for 2011 and 2017.

In order to investigate the change in lighting scores, an analysis of the climate data of solar exposure was investigated as an indicator of lighting quality (See Table 4). As seen from Table 1, solar exposure was slightly higher in 2017 than in 2011, and this was again consistent with our survey results that occupants were slightly more satisfied with lighting quality in 2017 than in 2011.

Table 1. Summary statistics of mean solar exposure (kW/m2).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	22.3	22.8	17.6	14.7	13.0	11.2	12.9	14.4	19.3	19.1	25.3	20.7
2017	25.6	25.8	17.6	17.0	13.2	11.9	14.1	17.1	20.9	18.6	24.2	27.1
Mean from 1981-2017	23.8	22.1	18.7	16.4	13.5	11.2	12.6	15.9	19.0	22.1	23.5	23.4

4. DISCUSSION

The comparison analysis of IEQ showed that overall comfort regarding IAQ, and lighting improved for this specific case study. Overall satisfaction with noise slightly improved, but noise interruptions and noise from colleagues achieved lower scores in the second survey. Thermal comfort satisfaction attained a higher score in winter, while in summer in the second survey, satisfaction scores with overall thermal comfort were lower. The temperature in summer, in the second survey, was perceived cooler than the first survey, while in winter, occupants scored temperature slightly warmer in the second survey. The winter conditions in 2017 were warmer than winters in 2011 by 1 degree Celsius. Comparing summer and winter thermal comfort results in 2011 and 2017 with climate data revealed that thermal comfort survey results were in line with climatic conditions. As the winter conditions were slightly warmer, winter perceived temperatures were higher in 2017 compared to 2011.

The discomfort cool or cold indoor conditions in winter were significantly decreased during the studied period. The building has natural ventilation and occupant satisfaction scores are strongly correlated with outdoor climatic conditions. The change in satisfaction scores in relation to thermal comfort, particularly, and also lighting might be explained in various ways. In buildings with natural ventilation, satisfaction scores are strongly correlated with outdoor climatic conditions. The building has a changeover mixed mode ventilation, and changes in thermal comfort and lighting satisfaction might be attributed to the change in outdoor climatic conditions in the studied period. Thermal comfort is affected by outdoor temperatures and humidity, while lighting may be attributed to sky conditions of overcast and sunny days. Positive correlations between year climate and occupant satisfaction scores were observed regarding thermal and lighting comfort.

Although more investigation is needed to provide a further evidence, our results only showed a positive relationship with occupant satisfaction and weather in thermal comfort and lighting. We found some evidence that occupant satisfaction surveys may be biased by year weather conditions in that year, while satisfaction with noise and air remained unchanged. However, more evidence from long-term POE studies is needed to confirm the correlations. This hypothesis of the correlation between occupant satisfaction and year weather, if proven, would emphasise the necessity of weather normalisation for user satisfaction studies in order to minimise the dilemma of using occupants to gauge a building's performance.

The finding of this research challenges how occupant satisfaction should be measured and benchmarked. While occupant satisfaction with IEQ parameters is substantively affected by the characteristics of indoor working environments, there may be some uncontrolled factors that influence satisfaction results that should be considered such as year weather. Weather in a given year may be warmer or cooler than normal climate. By accounting for the differences between the year weather and normal climate data, weather normalization reduces potential biases in benchmarking occupant satisfaction results. This could be significantly importance with consideration of climate change scenarios and the prediction of future building performances. Benchmarking policies and adaptation strategies are needed to ensure that future building performances are not compromised by climate change. This research showed that even a slight change in the climate may significantly impact perceived comfort, particularly in green buildings, which are more vulnerable to climate change impacts by utilizing features such as natural ventilation.

5. CONCLUSION

The study showed some observations of the influence of year weather on occupant satisfaction, particularly parameters related to thermal comfort and lighting. In this study, occupant satisfaction levels regarding IAQ, noise and overall building comfort were similar in the two survey studies performed 6 years apart. This research found some evidence of the impact of climate change on POE results over time. However, more evidence is necessary to verify this hypothesis in the future with more long-term occupant satisfaction studies. As an important attribute, a new insight into the impact of climate change on building performance seems necessary to further improve the implementation of benchmarking policies.

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