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Indoor Environmental Quality conditions in Activity-Based offices in green buildings

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Abstract: Activity-Based Working (ABW) is a trend in contemporary workspace design that encourages building occupants to work at different areas of the workspace depending on the nature of their activity. As a result, the physical environment hosts a myriad of spaces dedicated to collaboration, concentration, private conversations, socialization, etc. The adoption of this typology has increased significantly in Australia, however empirical evidence on the performance of such workspaces is scarce. Considering that ABW environments are normally more densely occupied and different zones may have distinct microclimates due to the layout and activity developed by occupants, there is a need to properly understand the Indoor Environmental Quality (IEQ) conditions in these workspaces. This paper compares monitored IEQ conditions of ten contemporary open-plan workspaces with ABW or combi layouts. Workspaces are located within green certified buildings in Australia that are of similar age, fully air-conditioned by a VAV system and hold an energy certification. Spot measurements of thermal comfort, acoustics, lighting and air quality were taken in the morning and afternoon. Readings were averaged for 15 minutes for each point and a total of 5 points per floor were monitored in each workspace, including one for each façade, interior and perimeter zones. Results indicate that combi offices were slightly warmer, had lower air speed values and were slightly less humid than ABW. Indoor Air Quality readings were similar in both settings. Higher illuminance was observed in ABW offices. Not surprisingly, considering the open plan nature observed in both layouts, there were no significant differences for sound pressure levels. Although within recommended thresholds, these results suggest the need to properly consider and adapt layouts and building features when designing Activity-Based Working environments.

Keywords: Indoor Environmental Quality (IEQ), Post-Occupancy Evaluation (POE), workspace design, green buildings.

Introduction

Recently, there was an increase on the number of organizations joining the New Ways of Working (NWoW) trend in the Australian property market. Organizations are willing to pay premium for office premises specifically designed to accommodate Activity-Based Working (ABW). A polarizing topic in industry, ABW is a way of working that requires building occupants to move and work from different areas of the office, depending on the nature of the task – work is essentially understood as an activity and as such, it should not be confined to a place. As a result, the physical environment supporting ABW features a variety

of spaces dedicated to collaboration, concentration, private conversations, socialization, etc. In Australia, such environments have been embraced by organizations occupying premium-graded, certified building premises. Organizations have increasingly been using the workspaces designed to support ABW as a key component of their business' brand, values, culture and subsequently talent attraction and retention (Vischer, 2005).

Direct financial benefits from the reduced-office footprint (and consequently rent) may continue to be one of the key drivers behind the ABW uptake, but this narrow view has been replaced by discussions around indirect gains from increased collaboration, incidental physical activity opportunities, perceived productivity and wellbeing (De Been and Beijer, 2014, Brunia et al, 2016, Candido et al 2017, Engelen et al, 2016, Engelen et al, 2017). Despite its growth in popularity in Australia, empirical evidence on the performance of such workspaces is yet to follow suit.

If we look into the physical aspects of workspace, ABW environments may be more densely occupied because of a reduced office footprint when compared to contemporary open-plan offices, and different zones may present distinct microclimates due to the layout and activity developed by occupants. When combined, these two characteristics may influence the Indoor Environmental Quality (IEQ) conditions workers are exposed to. Considering the estimations around the affect of IEQ on workers' perceived productivity, there is a need to properly understand these workspaces (Appel-Meulenbroek et al, 2016, Brunia et al, 2016) and the timing in right – recently, many Australian organizations have embraced pre-and-post evaluation surveys largely motived by requirements from the Green Building Council of Australia's Green Star-Performance tool. As a result, the property market is now being populated with potential case study-comparisons.

Recent results from case studies conducted in premium-certified ABW offices in Australia, suggest that workers occupying ABW settings were significantly higher satisfied with spatial comfort, Indoor Air Quality, thermal comfort, visual comfort and acoustics (Candido et al, 2016). Results also suggest that workers reported significantly higher satisfaction on overall comfort, overall building, perceived productivity and health questions (Candido et al, 2017). Ironically, the lack of ownership, may be a positive feature of ABW environments – by being constantly "on the move", workers' may have more freedom to find zones that may suit their individual preferences. This paper adds to this research by comparing monitored IEQ conditions of ten workspaces with ABW or contemporary open-plan layouts (combi) located in green-certified buildings.

Methodology

All ten workspaces are located within green certified buildings in Australia. They are of similar age, fully air-conditioned by a VAV system and hold an energy certification. The size of the floor plan ranged from 1,291 to 65,664m2. Table 1 shows basic information about buildings included during the IEQ monitoring period.

Floor plans analyses show that contemporary open-plan premises presented a layout typology of an ABW or combi office (De Been and Beijer, 2014). All six combi offices present a mix of open and enclosed spaces of various sizes plus meeting rooms and shared facilities. Workers are assigned to a desk and they work from the same location. All four Activity-Based Working offices present a variety of spaces designed to support workers during they day, including zones purposely assigned for formal and informal meetings, collaboration, concentration, phone calls, relaxation, etc. In Australia, ABW spaces may or may not remove

desk ownership and that is highly dependent on the organizations' interpretation of ABW, needs and culture. Even when ownership is removed, some territoriality may take place through the popular concepts of neighbourhood and villages – this means that workers' dot not own a workstation but they may work from the same zone within a floor. Demographics and basic fit-out information is summarized on Table 1 below.

Table 1. Basic information about surveyed buildings.

Building	Layout	Tenant Net Lettable Area (m2)	Number of monitored floors	HVAC
A	Combi	12,822	3	Yes
B	Combi	-	1	Yes
C	Combi	1,921	1	Yes
D	Combi	48,284	3	Yes
E	Combi	19,682	3	Yes
F	Combi	23,725	3	Yes
G	ABW	-	1	Yes
H	ABW	65,664	5	Yes
F	ABW	-	3	Yes
I	ABW	39,000	3	Yes

The BOSSA Nova mobile cart was used to conduct spot measurements of thermal comfort, acoustics, lighting and indoor air quality were taken in the morning and afternoon. The cart is able to take air temperature, globe temperature and air speed at three heights (0.2, 0.6 and 1.1m). The cart is also equipped with an indoor air quality rack. Portable light meter and sound pressure meter also available and by being attached to long cables, they can be taken from the cart for the purposes of readings. All sensors are connected to a datalogger and the readings can be monitored real time during the experiments.

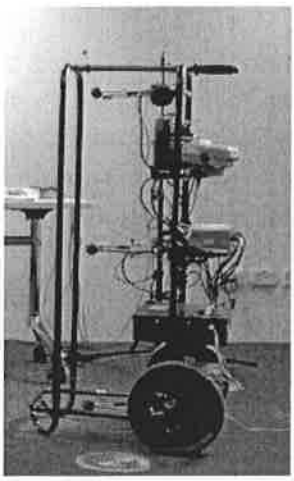

Figure 1. The BOSSA Nova IEQ cart.

All measurements were taken from the occupied zone, near a workstation (0.50m radius from office worker) and during occupied hours (9am to 6pm). Horizontal lux readings were taken from the workstation. Building occupants were allowed to develop their normal

activities while instrumental measurements were carried out. Readings were averaged for 15 minutes for each point and a total of 5 points per floor were monitored in each workspace, including one for each façade, interior and perimeter zones. With exception of building C, all others had three floors investigated during this study.

Independent sample t-test was carried out to examine whether different workplace layouts significantly affected IEQ parameters. However, one of the problems with this null hypothesis testing is that even the most trivial effect will become statistically significant if enough people are surveyed (Field, 2013). To solve this problem, the effect size (ES) measures were adopted to test how important these statistically significant differences really are. In this analysis, a common measure of ES—*Cohen's d* (Cohen, 1988, 1992), was adopted when comparing two means. It is calculated by Equation (1) and (2).

$$d = \frac{\mu_1 - \mu_2}{\sigma} \quad (1)$$

$$\sigma = \sqrt{\frac{(N_1-1)\sigma_1^2+(N_{-1}-1)\sigma_2^2}{N_1+N_2-2}} \quad (2)$$

where μ_1 and μ_2 refer to the mean value for two groups, N_1 and N_2 refer to the sample size of two groups.

Cohen suggested that d=0.2 be considered a small effect size, 0.5 represents a medium effect size and 0.8 a large effect size (Cohen, 1988, 1992). This means that if two groups' means do not differ by 0.2 standard deviations or more, the difference is trivial, even if it is statistically significant (Statistics for Psychology, accessed on 07-01-2017). The authors explain that a medium or large size effect is of more practical meaning in the real world than the small size one. All the statistical analysis was conducted in IBM SPSS, Version 22.

Results

Results from independent t-tests are depicted on Table 2 and Figures 1 to 4 below sumarise results for operative temperature, air speed, relative humidity and illuminance. The mean air temperature values recorded in ABW and combi offices were almost the same (22.7 °C and 22.0 °C, respectively), however t-tests of all data indicate a small-size effect. All workspaces investigated here are fully air-conditioned and buildings are less than 10 years old so the type and air of base building HVAC is comparable. The range of air temperature values measured during field studies were consistent with those expected in air-conditioned buildings in Australia, where a narrow temperature set point is widely used.

As depicted on Table 1, analysis of the IEQ monitored data indicate that the mean radiant temperature was significantly lower in ABW settings than in open-plan offices, representing a medium-sized effect. Relative humidity was also significantly lower in ABW offices, representing a medium-sized effect. Higher illuminance was observed in ABW settings, representing a medium-sized effect.

Table 1. Independent samples t-test results for measured IEQ variables.

		Mean	Sig. (2-tailed)	Effect Size
Ta (°C)	ABW	22.7	0.001	0.28
	Combi	22.9		
MRT (°C)	ABW	22.7	0.001	0.56
	Combi	23.1		
Top (°C)	ABW	22.7	0.001	0.42
	Combi	23.0		
Va (m/s)	ABW	.07	0.001	0.30
	Combi	.08		
RH (%)	ABW	40.9	0.001	0.47
	Combi	44.8		
CO	ABW	1.04	NS	0.09
	Combi	1.08		
CO2	ABW	814.1	NS	0.29
	Combi	787.6		
TVOC	ABW	1.34	NS	0.33
	Combi	1.31		
Formaldehyde	ABW	.050	NS	0.24
	Combi	.046		
SPL (dBA)	ABW	50.9	NS	0.00
	Combi	50.9		
Illuminance (lux)	ABW	569.3	0.002	0.50
	Combi	437.6		

NS-Not significant.

In regards to indoor air quality (including carbon monoxide, carbon dioxide, TVOC, and formaldehyde), there was no significant difference observed between ABW offices and open-plan environments, confirmed by independent samples t-test conducted for this paper. This is not surprising considering that these buildings hold a green certification and as such, have more strict requirements around materials and products in use. Readings for carbon monoxide, carbon dioxide and formaldehyde were within recommended thresholds.

In addition, there were no significant differences for sound pressure levels and results are depicted on Table 1. Considering the open plan nature observed in both layouts, this result is not surprising. That said, mean SPL values recorded during occupied hours were higher than the recommended threshold in Australia (45dBA).

Floor plan analysis may provide some insight into differences observed on IEQ measurements in ABW and combi. ABW offices investigated here present a physical arrangement that is more open, with less vertical barriers (such as partitions and walls) and have considerably more spaces purposively allocated for collaboration and overall incidental interaction including lounges, cafes and a mix of break out areas. Combined, these features may allow airflow to circulate more freely – please see Figure 3. All ABW environments

investigated here implemented biophilia principles, having significantly more indoor air plants throughout workspaces than combi offices. This may in turn be influencing relative humidity readings depicted on Figure 4.

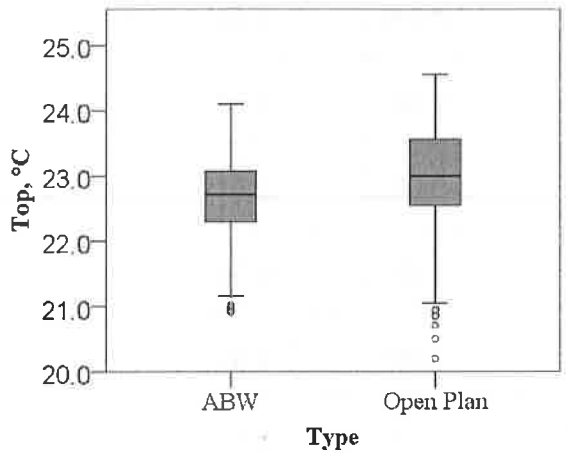

Figure 2. Operative temperature.

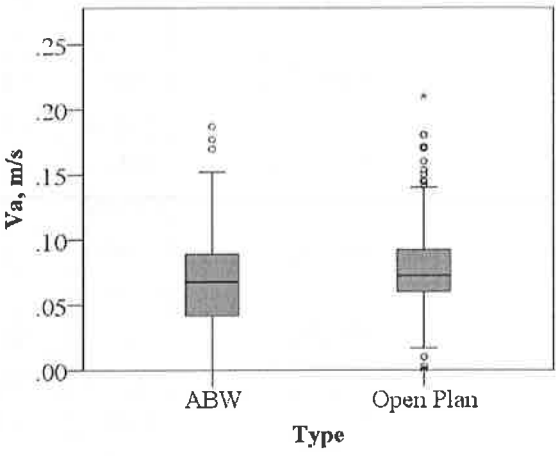

Figure 3. Air speed.

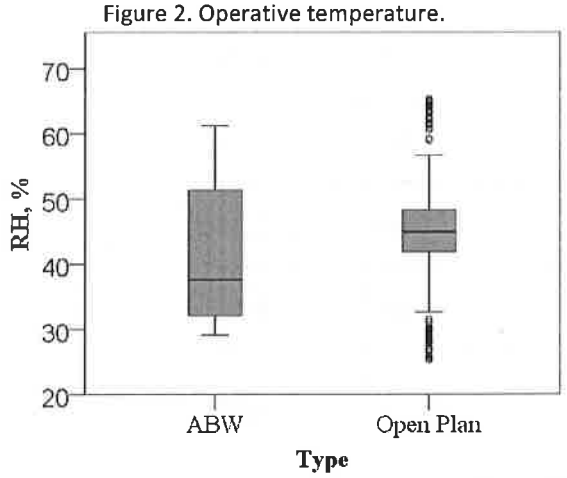

Figure 4. Relative humidity.

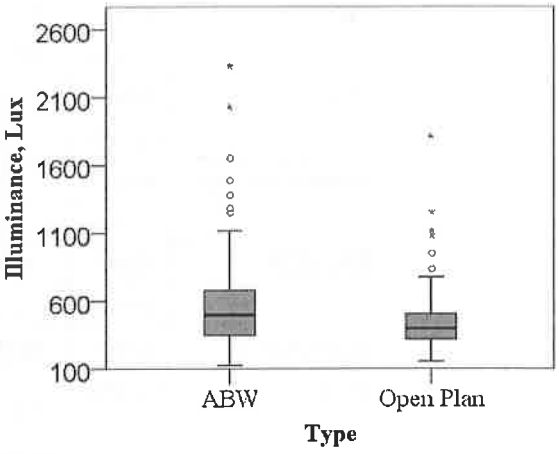

Figure 5. Illuminance.

In addition, these spaces also present more access to daylight due to the use of atriums as an architectural feature. In the ABW offices investigated here, a considerable amount of workstations in the 'interior' zone of the building are located near an atrium and these locations were sampled. In addition, there are workstations near the exterior façade of the building and these locations in ABW offices may be popular with occupants, especially if there is a view. Again, these sampling points were included during the IEQ monitoring presented here (please see Figure 5).

The activity-based mode of working may encourage building occupants to work from spaces that are more suited to their own individual preferences, including those relevant to IEQ, namely, thermal, lighting and acoustic conditions. In practical terms, if the potential to create microclimates is combined with mobility, workers may be able to select, from the space-menu available to them in ABW workspaces, zones there are less/more noisy, hot/colder, with more/less light, etc. This flexibility may help compensating for the lack of personal control systems and adaptive opportunities commonly observed in air-conditioned, open plan offices and in turn increase workers' satisfaction.

Conclusions

This paper compared monitored IEQ conditions of ten contemporary open-plan workspaces with ABW or combi layouts in green-certified buildings in Australia. Results indicate that combi offices were slightly warmer, had lower air speed values and were slightly less humid than ABW workspace. Results from Indoor Air Quality measurements of TVOC, formaldehyde, CO and CO2 were similar in both settings while higher illuminance was observed in ABW offices. All workspaces investigated here are representative of contemporary offices and, not surprisingly, there were no significant differences for sound pressure levels. Although the difference of air temperature, operative temperature and air speed between different layouts reached high statistical significance, they only represent small-sized effects. The results presented here are limited to the case studies, however, they suggest the need to properly consider and adapt layouts and building features when designing Activity-Based Working environments.

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