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Assessment of users' responses to air change rates in free running office buildings

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Abstract. Often, building assessments do not account for users' social concerns in relation to buildings' physical characteristics. This study, therefore, assessed the responses of free running office building users to the objective measurements of air change rates in the spaces they occupy. This was done with a view to define a suitable quantitative expression for the social concerns of the users in building assessments, as well as with a view to examine the relationships between the users' responses and the physical characteristics of free running buildings. Measurements were taken in eight low-rise office buildings regarding indoor/outdoor air parameters to capture the air change rates in the buildings. These were done in 50 different spaces within the buildings at different floor levels and different fenestration orientations. The air change rates were correlated along social and physical dimensions with the responses of the occupants captured through questionnaire. Some relationships were observed among the social characteristics of the users and their rating of air change rates in the spaces, but none were statistically significant. Linear regression analysis, however, shows that one of the buildings' physical characteristics has a strong relationship with the users' responses to air change rates.

Keywords: air change rate / natural ventilation / free running buildings / warm humid climate

1 Introduction

The importance of free running buildings to the built environment cannot be over-emphasized. This is because out of all sectors of human endeavour; studies have shown that the built environment contributes the greatest percentage to the total global energy use [1–5]. This has resulted in contemporaneous concerns over global warming and escalating fossil fuel prices. This suggests that free running buildings have the greatest potential to mitigate global warming and its attendant negative effects on the sustainability of the built environment.

In view of the foregoing, building designers have been exploring the possibility of using purely natural forces to ventilate buildings in all climates. The built environment is replete with such outstanding free running buildings expected to add desirable value to its sustainability. For example, in a study in Singapore, Liping and Hien [6] stated that 86% of residential buildings there were designed to be naturally ventilated. Similarly, Tuohy and Murphy [7] highlighted sustainable design features in some notable buildings like the Environmental Office Building in Garston, England and the Great Glen House in Scotland. In addition, Olaniyan (1983) [8] featured many office buildings on the campus of Obafemi Awolowo University, Nigeria, whose designs were premised on the use of natural ventilation.

The real value being added to both these buildings and the built environment in general is, however, being called to question. It has been observed that there may be an undesirable disconnect between the intended as well as the actual performance and use of these free running buildings. Tuohy and Murphy [7] observed that advanced buildings do not achieve their intended performance especially in relation to ventilation systems. Liping and Hien [6] corroborated this by reporting an increase in the use of mechanical ventilation systems in Singapore, which is a country where most of the building were designed to be naturally ventilated. This shows that despite the enormous time and other resources that are invested into making such buildings free running, users of the buildings may be adopting ventilation systems different from the designers' intent. This is presenting an undesirable paradoxical situation, which has not yet been fully addressed empirically.

Foruzanmehr and Vellinga [9] studied the rationale behind this situation and remarked that, all around the world, vernacular traditions (which include passive cooling strategies offered by natural ventilation) are been associated with an outdated past and poverty. The study, however, faulted Bourgeois [10] and Heyman [11],

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whose argument suggested that passive cooling strategies like the wind-catchers of the Middle East being replaced with electro-mechanical cooling systems by their owners, just because they are not perceived to present a contemporary and progressive outlook to life. Foruzanmehr and Vellinga [9] noted that this explanation only intuitively seems to make sense but is not based on actual research.

Furthermore, while rationalizing the often large deviations between theoretically calculated and measured comfort in buildings, Roetzel et al. [12] stated that one main reason is the fact that the theoretical calculation procedures do not account for users' behaviour in relation to the characteristics of the local climate or the specific building. This suggests that assessment of comfort ventilation of building occupants should extend beyond bio-climatic issues.

In the same vein, in a study on social and environmental dimension in tropical sustainable architecture, Bay and Ong [13] observed that the challenge to define a modern characteristics style for tropical architecture is not just a climatic issue but also one that is related to the problem of adapting to the modern lifestyle, of the transformation of local cultures to the modern city. The study further stated that while it is possible to retain enough of the vernacular for residential designs to be naturally ventilated, other building typologies like offices and shopping centres have not been so lucky.

After assessing environmental issues in buildings within the context of Olygays' [14] bio-climatic approach and Fanger's [15] concept of thermal comfort, which was based purely on physiological studies, Bay and Ong [13] concluded that physiological standards of comfort only do not translate readily to design. The study emphasized the influence of social and cultural dimensions in the application of building studies into architectural design, and observed that social–cultural concerns are yet to find a suitable quantitative expression in building assessments. It, therefore, recommended deeper reflections and more research into the issues of tropical sustainable architecture that engages both the environmental and social dimensions.

Similarly, Foruzanmehr and Vellinga [9] remarked that only a thorough examination of a variety of cultural and environmental variables and the way in which they dialectically interrelate in a particular local context has the potential to reveal the motivations behind the choices people make in relation to the continuation or abandonment of specific traditions. The study came up with a number of both environmental and cultural factors that influence the choices made by users of indoor space regarding comfort. It further stated that it is difficult to identify the degree to which specific factors play a more deterministic part than others because of the dynamic, complex and context-dependent way in which all these factors interrelate. The study concluded by calling for in-depth research on the dynamic and complex way in which all the environmental, technical, social, cultural and economic dimensions are intricately related regarding comfort of users in indoor spaces.

The foregoing, therefore, suggests that an assessment of use of ventilation systems that engages both environmental and social dimensions in such free running buildings could present an enhanced appreciation of the likely difference between intended against actual performance and use of such buildings. The significance of such a study was emphasized by Deuble and De dear [16], who studied the responses of green occupants towards two green office buildings in Sydney, Australia. The study highlighted the increasing awareness to the psychological dimensions of occupant adaptation, such as attitudes, expectation and control.

Since the primary requirement of ventilation systems is to meet specified airflow rates [17], this study, therefore, aimed at assessing the responses of free running office buildings users to the objective measurements of air change rates in the spaces they occupy. This was done with a view to define a suitable quantitative expression for the social concerns of the users in building assessments, as well as with a view to examine the relationships between the users' responses and the physical characteristics of the free running buildings they occupy.

Different studies have used different approaches and models to study ventilation rates in buildings. Among others, Bastide et al. [18], Mahdavi and Proglhof [19] and Ajibola [20] adopted the empirical models. Khoukhi et al. [21], Maatouk [22] and Sohn et al. [23] used the multi-zone network models; some other studies were premised on computational fluid dynamics (CFD) models, whereas Livermore and Woods [24], Tapsoba et al. [25], Kang and Lee [26], Hummelgaard et al. [27] and Stathopoulou et al. [28] employed either small-scale or full-scale experimental approaches. Each of these models, however, has its own setbacks.

The empirical models are based on simple assumptions, one of which is that the same airflow rate and air velocity permeate the entire building. This may be misleading under real situations. The multi-zone network models assume still air and uniform air temperature in a zone; this could cause significant errors in some cases. The long calculation time for accurate prediction or evaluation may make the study of practical cases using CFD models not feasible (Santamouris and Allard [29]). According to Cheng [30], full-scale experimental approach has been giving realistic predictions and evaluations of ventilation performance for buildings. It is however very expensive and time consuming.

In view of the above, this study, therefore, evaluated the air change rates within some spaces in the free running buildings within a university campus using the full-scale experimental approach with in-situ measurements, assessed the users' responses to the air change rates within the spaces in the buildings, and analysed the relationships between the air change rates and the users' responses in the spaces within the buildings.

2 The study area

The study was carried out in the academic area of Obafemi Awolowo University, Nigeria. The university community is located within Ile-Ife, which is a small city

Fig. 1. Faculty of Administration building.

Fig. 2. University Hall Extension building.

in South-Western Nigeria. It is located between latitude 7°28′ N and 7°34′ N and longitudes 4°27′ E and 4°35′ E with an elevation of about 275 m above sea level. The climatic data for the city showed that the climatic context combined high temperature (mean$_{max}$ of 31.4 °C), high humidity (mean$_{max}$ of 83.3%) and low air velocity (mean$_{max}$ of 1.55 m/s) with high precipitation (1691.1 mm annual). The maximum temperatures are above 30 °C for all months with the exception of August and September. This shows that the free running office buildings being studied are within the rain forest vegetation belt and a tropical thermal environment in a warm humid climatic zone.

Generally, all the buildings on the campus are orientated linearly from east to west, with main elevations having operable windows facing north and south to protect them from the sun, heat and glare and to ensure cross-ventilation by the prevailing breezes. All the eight buildings used for the study are within the central core of the university; they are of either three or four floors each but different gross floor areas. The buildings are all of the same fabric. The walls are of sandcrete unfilled cavity block with an overall coefficient of heat transmission (U-value) of 1.0 Wm^{-2} K, and the operable windows are of transparent glass with a coefficient of heat transmission of 5.8 Wm^{-2} K. As shown in Figures 1–4, sustainable design features meant to enhance their free running status are apparent in the buildings. These include large operable windows that are fully shaded from direct solar radiation, open ground floor to enhance airflow, and soft landscape elements lavishly employed to envelope each building. The facade of some of these free running buildings are, however, dotted with window unit air conditioners. This is suggesting that some of the users may be adopting ventilation systems that are in outright discordance with the designer's concept, resulting in unsightly buildings and consequently an unpleasant cityscape.

The buildings are majorly occupied by academic and non-academic staff of the university as well as students. The greater percentage of the occupants is of the black race largely from the Yoruba socio-cultural group known for traditional building styles quite different from that of the buildings being studied. Hence the issue of the transformation of local cultures to the modern city highlighted by Bay and Ong [13] may have had strong influence on their responses.

Fig. 3. Faculty of Education building.

Fig. 4. Faculty of Social Sciences building.

3 Methodology

The study used primary data majorly. The primary data was obtained from three sources. First, the indoor and outdoor air properties were captured using some measuring instruments. The air velocity was measured with the LM-81AM compact vane anemometers along with Testo 405-pocket-sized thermal anemometers particularly precise in the range between 0 and 2 ms^{-1}. The temperature and relative humidity were measured by wireless colour weather stations with outdoor sensors by La Crosse Technology. Its indoor temperature and relative humidity ranges are 0–50 °C and 19% to 99% (RH), respectively. Its outdoor temperature and relative humidity ranges are −40 °C to 60 °C and 19% to 97% (RH), respectively. The weather stations were used along with TIM 10 desktop CO_2, Temperature meters and Relative humidity meters, which also measured CO_2 concentrations. This has a measuring range of 0–10,000 ppm for CO_2, −10 °C to 60 °C for temperature, and 0.1% to 99.9% for relative humidity. It also has an accuracy of ±40 ppm, ±3% of reading for CO_2, ±0.6 °C for temperature and 5% for relative humidity. Its response time is less than 2 min for both CO_2 and temperature, whereas for relative humidity it is less than 10 min.

The data were all taken at about 1 m from the workstations and at the work plane of each indoor space taken to be 1.2 m from the floor level. The data were also taken at 10 min interval during the typical working hours of the space users which is between 8 am and 4 pm. These data were taken with the help of hired field assistants during the months of January to March 2015 being the most critical period for natural ventilation as evident in the climatic data of the study area.

Second, physical characteristics of the buildings were obtained through physical measurement to obtain the external wall area, operable windows area, window to wall ratio, window to floor ratio, distance to adjacent buildings and occupancy ratio of the selected spaces.

Third, the subjective responses of the users of the buildings in relation to the air change rates by the natural ventilation systems in the buildings were elicited through a well-structured, multiple-choice questionnaire which was administered with the help of hired field assistants.

Table 3.1. Main spaces and number of users of each building.

	Offices	Reading room/library	Laboratory	Classroom/ lecture room	Seminar room	Canteen	Number of users
Faculty of Arts (Humanities 1, 2 and 3)	121	2	2	8	2	–	1224
Faculty of Law	49	–	–	10	1	1	1040
Faculty of Administration	71	2	–	3	1	1	484
Faculty of Education	95	3	4	5	3	1	1112
Faculty of Social Sciences	111	4	7	2	2	1	715
University Hall Extension	164	–	–	–	–	–	492
Total	611	11	13	28	9	4	5067

There are a total of 676 relevant indoor spaces within the eight low-rise office buildings at main core of the university campus (Elais and Owolabi [31]). Table 3.1 shows a breakdown of the spaces and their users. Out of these, 7.5% of them were selected for the study comprising offices, reading rooms, laboratories, classroom/lecture theatres and canteen. Stratified random sampling technique was adopted to select 7.5% of the users giving a sample size of 375 respondents. A total of 375 questionnaires were distributed with 319 being returned. The stratification for the respondents was based on status of the space users, i.e. academic staff, non-academic staff and students. Stratification for the spaces was based on fenestration orientation and floor levels.

At the end of the data collection the air change rates in the spaces for different times of the day were calculated using two methods. The first method was based on a simplified empirical model presented by British Standard [32] as described by Santamouris and Allard (page 64) [29]. It is premised on the assumption that the airflow through the spaces is a two-directional flow. The model also ignores all internal partitions. It shows that the air change per hour (N) in a space is estimated with the empirical models stated below:

$$N = 3600Q/v, \qquad (3.1)$$

where N is the air changes per hour; Q is the fresh airflow through the space (m^3/s); and v is the volume of the space (m^3).

The fresh airflow Q was calculated using both the measured buildings physical characteristics and the measured indoor/outdoor air properties. These included the surface area of the inlet and outlet openings, the pressure coefficient, the discharge coefficient strongly related to the dimension of the openings, and the air velocity. The second method calculated the air change rates based on carbon dioxide (CO_2) measurements (Haverinen-Shaughnessy et al. [33]). According to Santamouris and Allard [29] this technique is efficient to estimate the air change rates in buildings where the number of occupants, physical characteristics as well as the activity level of the occupants in the spaces are known. These are conditions satisfied by the spaces studied. Measured CO_2 concentrations were then analysed using the equation below (Santamouris and Allard [29]).

$$V\mathrm{d}C/\mathrm{d}t = Q(C_e - C) + F, \qquad (3.2)$$

where V is the effective volume of the enclosure (m^3), Q is the specific airflow rate through the enclosure ($m^3\,s^{-1}$), C_e is the external concentration ($m^3\,m^{-3}$), C is the internal concentration ($m^3\,m^{-3}$), and F is the production of CO_2 by the occupants ($m^3\,m^{-1}$).

The results showed significant correlations between the two methods. The calculated air change rates were then correlated with the responses of the occupants of the building spaces captured through questionnaire.

4 Results and discussion

4.1 Airflow rates in the selected spaces

The study found that about 52% of the spaces are having air change rate that is less than $4\,h^{-1}$. For spaces in the buildings studied the acceptable air change rate per hour is between 4 and $6\,h^{-1}$ (Szokolay [34]). Table 4.1 shows the different categories of the air change rates in the selected spaces and revealed that 48% of the selected spaces met this standard whereas 52% fell below the standard during the study period.

A chi square test analysis revealed that the air change rates in the selected spaces are strongly related to the orientation of the external operable windows. Table 4.2 shows that the entire cross ventilated spaces have their air change rates falling either within the recommended range of 4–6 and beyond. Among single-sided ventilated spaces however, only 36% of them have air change rates within the recommended range.

This disagrees with the studies of Gratia et al. [35], which showed that single-sided ventilation is more efficient than cross-ventilation. This disparity may be expected because that study was carried out in the Belgian climate where outdoor air temperature is lower than indoors, at both day and night, except for a few hours a year. This is different from the warm humid climate in which this study was carried out where outdoor air temperature is almost always higher than indoors.

Table 4.1. Air change rates in selected spaces.

	Valid percent	Cumulative percent
1. 0–3.99/h	52.0	52.0
2. 4.00–6.00/h	8.0	60.0
3. 6.10/h and above	40.0	100.0
Total	100.0	

Table 4.2. Cross-tabulation of orientation and calculated air change rates in the spaces.

	Air change rates			Total
	1 Poor	2 Average	3 Good	
Orientation				
1. Windward	14	0	5	19
2. Leeward	12	3	4	19
3. Cross-ventilated	0	1	11	12
Total	26	4	20	50

Table 4.3. Air change rates and floor level of spaces.

	Floor level	Air change rates
Floor level		
Pearson correlation	1	0.161
Sig. (2-tailed)		0.292
Air change rates		
Pearson correlation	0.161	1
Sig. (2-tailed)	0.292	

Moreover, as against the findings of Gratia et al. [35] which showed that air change rates decrease in a rather significant way with the height or floor level of the office spaces both during the day and night, this study found no such relationship in the spaces studied during the day when the data was collected as shown in Table 4.3. No data was however collected during the night.

Further analysis was carried out to examine the relationships between the calculated air change rates and the indoor and outdoor air properties. Table 4.4 shows that while there is a significant relationship between the air change rates and the indoor–outdoor relative humidity difference, the same cannot be said about the indoor–outdoor air temperature difference.

This is at variance with the observations of Wallace et al. [36] as well as Howard-Reed et al. [37], who concluded that indoor–outdoor temperature difference had a clear effect on air change rates. Wallace et al. [36] found that extreme temperature difference of 30 °C resulted in an increase of about 0.5–0.6 air changes per hour. Wallace et al. [36] observed this in a study where no attempt was made to determine the effect of temperature difference on air change rates when windows were opened. This current study was carried out in spaces with opened windows. This may account for the reason why no significant relationship was established between the calculated air change rates and the indoor–outdoor air temperature difference. The highest temperature difference recorded during this study was 2.68 °C, which may be too small to significantly influence the air change rates.

Table 4.4. Air change rates and indoor–outdoor air properties.

	Indoor–outdoor air temperature difference	Indoor–outdoor relative humidity difference
Air change rates		
Pearson correlation	0.089	−0.401**
Sig. (2-tailed)	0.539	0.004
N	50	50

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.5. Rank or status of respondents.

	Valid percent	Cumulative percent
1. Academic staff	14.3	14.3
2. Non-academic staff	34.1	48.4
3. Students	51.6	100.0
Total	100.0	

4.2 Characteristics of space users

The respondents cut across the entire categories of users of the selected buildings. These included academic staff, non-academic staff and students. Table 4.5 shows that the ratio of staff students that responded was almost 1:1. Although there are far more students using the selected buildings than staff, the ratio is justified because the study revealed that staff spend more time in the spaces than students do as shown in Table 4.6. Hence, the staff may be able to present a more reliable subjective assessment of the natural ventilation systems and the air change rates in the selected spaces.

The data analysis revealed that 61% of all the respondents are male whereas 39% are female. Over 87% of the total respondents are between young adult and middle age. Regarding their socio-economic status 58.6% of the respondents are single whereas 40.5% are married. Moreover only 27.5% of the respondents earn more than ₦200,000 (about $700) in a month.

The effect of the activities carried out in an indoor space and the general mode of dressing are significant factors that influence users' perception of the ambience of the space, according to Szokolay [34]. Hence, the data were analysed

Table 4.6. Average hours spent in space per day according to rank of respondents.

	1–3 h	3–6 h	6–9 h	9–12 h	Above 12 h	Total
1. Academic staff	6	6	18	12	3	45
2. Non-academic staff	6	3	81	15	2	107
3. Students	90	57	15	0	0	162
Total	102	66	114	27	5	314

Table 4.7. Activities in selected spaces.

	Valid percent	Cumulative percent
Reading and writing	56.1	56.1
Listening to lectures	29.2	85.4
Others	14.6	100.0
Total	100.0	

along these dimensions. Regarding the activities carried out in the selected spaces the analysis showed that the major ones are reading and writing as well as listening to lectures as shown in Table 4.7. These are sedentary activities that require minimal level of airflow for the space users to be satisfied with the ambience.

Regarding the mode of dressing of users in the selected spaces, 57.5% responded that they dress formally most times they use their space. Out of these, 71% are staffs whereas 29% are students. Furthermore 42% of the users responded that they dress casually most times they use their space. Out of these, 84% are students whereas only 16% are staff. It was earlier established that staff spend more time in the selected spaces than students. This further shows that it is this same category of respondents that dresses formally most times in the space. The combination of these factors may influence their subjective assessment of the air change rates in the selected spaces.

Analysis further shows that 64% of the respondents preferred a combination of both natural and mechanical ventilation systems in their spaces. This is followed by those who preferred only natural ventilation systems with 23%. It is significant to note that the least percentage of respondents, which is 12%, preferred only mechanical ventilation systems in their space. Table 4.8 shows these relationships. This suggests that a significant percentage of the users ordinarily desired to maintain the free running status of the buildings.

This is in line with the findings of Hummelgaard et al. [27] in a study of occupants' satisfaction in five mechanically and four naturally ventilated open-plan office buildings. The study reported that 70% of the occupants in naturally ventilated offices were generally satisfied with the indoor environment as compared with 59% in mechanically ventilated offices. Among others studies, Seppänen and Fisk [38], Wargocki et al. [39] and Deuble and de Dear [16] gave similar indication. Most of these studies were not specific regarding a statistically significant justification for this trend. This study is neither claiming to be able to provide such justification. This study, however, observed that the low preference for only mechanical ventilation system by the respondents does not harmonize with their attitude towards operable windows in the spaces. The possible explanations for this are discussed below.

Table 4.8 further revealed that the strong preference for mechanical ventilation system was noticeable more among respondents who are academic staff. The preference was, however, not strong among non-academic staff and students. Table 4.8 shows that the percentage of those who preferred natural ventilation systems only in their space is the least among the academic staff, which is 16%. This is expected because a significant percentage among academic staff dress formally in the space as earlier confirmed. This suggests that the specified air change rate of $4\,h^{-1}$ for office buildings needs to be re-examined if formal dressings are to be made desirable in free running office buildings.

Regarding the user's attitude toward windows opening, the study observed that users were not opening the windows 100% of the time of occupation as shown in Table 4.9. This is especially so with those along the corridors in both the single and double banked buildings. The predominant reasons given by the space users for this include operable windows being at various stages of disrepair as well as avoiding distractions, not from the activities at the street level but from the corridors. This identifies with the observation of Longo et al. [40], who concluded that when the internal windows are facing an indoor corridor in institutional buildings the natural ventilation of the spaces within the building is undermined. The measured drawings of the buildings showed that the windows are below the eye level; this explains why some respondents gave distraction and lack of privacy as reasons behind their reluctance to open them. Window opening has been identified in the literature as a significant variable that could produce the greatest increase in air change rates in spaces (Wallace et al. [36]); Howard-Reed et al. [37]. Hence, the disparity between the occupants' desire to maintain the free running status of the buildings and their attitude toward operable windows in the spaces need to be further explored.

4.3 Users' responses to the natural airflow rates within the selected spaces

The data collected from the field made respondents to rate the air movement through the selected spaces when only natural ventilation system was in use in the spaces. Table 4.1 shows that only 40.6% of the respondents rated the air change rates in the spaces as good.

Table 4.8. Users' preferred ventilation systems.

		Users preferred ventilation system			Total
		Natural ventilation	Mechanical ventilation	Combination of the two	
Status of respondents					
1	Count	8	15	23	46
	% within academic staff	16.1%	32.3%	51.6%	100.0%
	% within all respondents	10.2%	37.0%	11.8%	14.6%
2	Count	26	13	67	106
	% within non-academic staff	23.9%	12.7%	63.4%	100.0%
	% within all respondents	34.7%	33.3%	33.1%	33.5%
3	Count	40	12	103	155
	% within students	24.5%	7.3%	68.2%	100.0%
	% within all respondents	55.1%	29.6%	55.1%	51.9%
Total	Count	74	40	193	307
	% within all respondents	23.1%	12.7%	64.2%	100.0%

Table 4.9. Percentages of windows opened when there is no mechanical ventilation.

	Valid percent	Cumulative percent
Small part	7.1	7.1
Almost half	16.4	23.6
Half	15.6	39.1
More than half	22.7	61.8
All	38.2	100.0

Table 4.10. Rating of air change rates in selected spaces by users.

	Valid percent	Cumulative percent
1. Poor	27.1	27.1
2. Average	32.3	59.4
3. Good	40.6	100.0
Total	100.0	

On the other hand, calculated air change rates in the spaces were categorised in such a way that values between 0.0 and 3.99 h^{-1} were categorised as poor, those between 4.00 and 6.00 h^{-1} were categorised as normal or average, whereas those above 6.00 h^{-1} were categorised as very good. This is shown in Table 4.10.

Tables 4.1 and 4.10 were then cross-tabulated and chi-square analysis was used to determine the correlation between the two measurements. It was carried out at 95% confidential interval ($p < 0.05$).

From Table 4.11, asymmetrical significance is 0.407, which is much higher than 0.05 critical values. Similar results were gotten using bivariate correlation analysis as well as ANOVA as shown in Table 4.12. This suggests that there is no statistically significant correlation between the users rating of the air change rates and the calculated air change rates based on measured parameters.

Table 4.11. Chi-square analysis of users rating of airflow and calculated air change rates.

	Value	d*f*	Asymp. sig. (2-sided)
Pearson Chi-square	3.989[a]	4	0.407
Likelihood ratio	5.459	4	0.243
Linear-by-linear association	0.171	1	0.679

[a] Seven cells (77.8%) have expected count less than 5. The minimum expected count is 0.59.

An analysis of the frequency of use of mechanical ventilation systems in the selected spaces as shown in Table 4.13 confirmed this stance. A comparison of Tables 4.10 and 4.13 shows that despite the fact that 32.3% of the respondents rated the air change rates in the space as average and 40.6% rated it as good, more than 45% of the respondents use one form of mechanical ventilation system or the other in their spaces.

This suggests that the responses of users to the air change rates are clearly influenced by factors beyond physical or environmental parameters. This is in conformity with the observations of Bay and Ong [13] who concluded that only physiological standards of comfort do not translate readily to design and emphasized the influence of social and cultural dimensions in building assessments.

Table 4.12. Relationships between user's responses and calculated air change rates.

	Rating of air change rates in the spaces
Air change rates	
Pearson correlation	−0.201
Sig. (1-tailed)	0.093

Table 4.13. Use of mechanical ventilation systems in selected spaces.

	Valid percent	Cumulative percent
None	8.7	8.7
Standing or table fan	4.8	13.5
Ceiling fan	40.6	54.1
Window unit air conditioner	24.0	78.2
Split unit air conditioner	20.5	98.7
Package unit air conditioner	1.3	100.0

Table 4.14. Relationships among user's responses, calculated airflow rates and the buildings' physical characteristics.

	Users rating of natural air movement in space
Airflow	
Pearson correlation	−0.201
Sig. (1-tailed)	0.093
External window to external wall ratio	
Pearson correlation	−0.390**
Sig. (1-tailed)	0.004
Window to floor ratio	
Pearson correlation	−0.355**
Sig. (1-tailed)	0.008

** Correlation is significant at the 0.01 level (1-tailed).

4.4 Relationships among air change rates, the buildings' physical characteristics, and the users' responses.

Two measured parameters were used to examine the buildings' physical characteristics in relation to the calculated air change rates and the responses of the users. These are the window area to floor area ratio and the external window area to external wall area ratio of the spaces. Table 4.14 shows the result of a bivariate correlation analysis of these variables. The table shows that the respondents' rating of the natural airflow in the selected spaces is having an inverse significant relationship with both parameters used to measure the buildings physical characteristics at 0.01 level of confidence. When the rating of respondents is correlated with the measured air change rates, however, no statistically significant relationship was observed even at $p < 0.05$.

Furthermore, a linear regression analysis was carried out with the users rating of the airflow in the spaces as the dependent variable, whereas the independent variables are the measured air change rates, the window to floor ratio, and the window to wall ratio of the spaces. The regression analysis was done using stepwise method. The analysis showed that two of the independent variables, namely measured airflow and the window to floor ratio of the spaces, have no significant relationship with the respondents rating of the airflow in the spaces, as are shown in Table 4.15.

It shows that their relationships with the respondents rating of the airflow in the spaces is not significant at 95% confidence level because their levels of significance are 0.54 and 0.18, respectively, whereas their t values are 0.619 and 1.356, respectively.

Further analysis showed that none of the social parameters of the users that were captured in the study have any significant relationship with the rating of airflow in the spaces by the respondents. Table 4.16 shows the statistical value of some of these social variables. The linear regression analysis however shows that the window area to wall area ratio has a strong relationship with the respondents rating of airflow in the spaces as shown in Table 4.17.

The social characteristics of the users captured in this study were however not exhaustive. There might be some other users' social and psychological concerns, as highlighted by Deuble and De dear [16], having significant influence on their responses to air change rates in such spaces. These need to be further explored.

5 Conclusions

The study captured air change rates in some free running office buildings and analysed its relationships with the responses of their users both from physical and social perspectives. It found that air change rates in the buildings spaces were satisfactory, and hence a significant percentage of the users preferred either only natural ventilation or a combination of both natural and mechanical ventilation systems in the spaces they occupy. A linear regression analysis shows that the window area to wall area ratio of the buildings' spaces has a strong relationship with the users' responses to air change rates.

The study found that a couple of their social characteristics influenced their responses. First is their rank and status, which influenced their mode of dressing and consequently their responses. Second is their need for privacy and concentration in the spaces, which influenced the extent to which the operable windows were being utilised and consequently the air change rates in the spaces.

Table 4.15. Statistical values of the insignificant buildings physical characteristics variables.

Model		Beta In	t	Sig.	Partial correlation	Co-linearity statistics Tolerance
1	Airflow	−0.092	−0.619	0.540	−0.095	0.909
	Window to floor ratio	−0.216	−1.356	0.182	−0.205	0.761

Table 4.16. Statistical values of the users social variables.[a]

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	2.616	0.769		3.404	0.001
	Rank or status of space user	0.022	0.039	0.084	0.549	0.585
	Users monthly income	−0.040	0.098	−0.062	−0.408	0.685
	Users form of dressing	0.236	0.246	0.116	0.957	0.342
	Mechanical ventilation used in respondent residence	0.078	0.118	0.077	0.664	0.509

[a]Dependent variable: rating of natural air movement in space.

Table 4.17. Statistical values of the significant building physical characteristics variable.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	5.021	0.633		7.934	0.000
	External window to external wall ratio	−3.482	1.253	−0.390	−2.779	0.008

No statistically significant relationship was, however, found among the social characteristics of the users and their responses to the air change rates in the spaces.

This, therefore, suggests that the specified air change rate of $4\,h^{-1}$ for office buildings needs to be re-examined if formal dressings are to be made desirable in free running office buildings in warm humid climates. Moreover, the design of operable windows should be re-examined to accommodate users' need for privacy and concentration on the tasks carried out in the spaces within free running buildings.

6 Implications and influences

A significant percentage of the users desired to maintain the free running status of the buildings, but their formal dressing influenced their poor rating of the air change rates. This suggests that the specified air change rate of $4\,h^{-1}$ for office buildings needs to be re-considered if formal dressings are to be made desirable in free running office buildings especially in warm humid climates. Furthermore, the design parameters for operable windows, especially those along adjoining corridors, should be re-examined to accommodate users' need for privacy and concentration on the tasks carried out in the spaces.

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