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EFFECTS OF TREES ON THERMAL COMFORT PARAMETERS OF INDOOR SPACES

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Abstract
Thermal comfort is one of the essential indoor environmental factors that needs to be properly evaluated for an optimum user satisfaction in every building. In the hot dry climatic zone where the mean daily maximum dry bulb temperature during the dry season equals or exceeds 35°C and the relative humidity does not exceed 40%, harsh indoor conditions may arise. Studies have shown that this harshness can be counteracted or overcome by either using the mechanical means (active strategy) or natural (passive strategy) landscape elements such as trees, shrubs and grasses. This study focused on the effect of trees as a landscape element on enhancing the thermal condition of indoor spaces. This was carried out quasi-experimentally by taking both indoor and outdoor measurement of the parameters – air temperature, relative humidity, air velocity – that impact thermal comfort for two identical departmental buildings with different incidences of trees – Banking & Finance and Industrial Design – both on opposite locations in Modibbo Adama University of Technology campus, Yola. The results revealed indoor mean temperatures of 29.8 and 30.5°C in the building with more trees, and 29.7 and 29.8°C in the other; and mean cooling of 3.5°C and 4.1°C in the former, and 4.5°C and 5.0°C in the latter. Thus the effect of difference in incidence of trees around the buildings on the indoor temperatures of the spaces under study was not discernible. However, increase of 23.0 and 34.6% in indoor relative humidity in the building with more trees, and below 1.0% in the other were observed. Consequently, it was recommended that more trees should be planted on campus to foster serenity and conduciveness of the environment for learning.

Key Words: *Thermal Comfort, Indoor Spaces, Trees, Air Temperature, Relative Humidity, Air Velocity*

Introduction

Thermal comfort has been defined as the condition of mind that expresses satisfaction with the thermal environment, and it is dependent on wind speed, air temperature and relative humidity and other subjective environmental factors (Auliciems and Szokolay, 2007). When considering indoor spaces, these dependent or predictor variables, wind, air temperature and relative humidity, are largely characteristic of the site microclimate; but may be modified by the built environment (Markus and Morris, 1980; Saraydar and Arabi, 2015).

The urban climate is deprived of its natural characteristics in many ways, but open greens and landscaped spaces make an important contribution to the improvement of the deprived climate. Of the many functions of landscape in tropical climate, the use of plant material to improve environment is of importance. In the cities, plants can be used to play a revitalizing role in the continued depletion and degradation of the natural environment (Ayeni, 2012). They lower the temperature considerably by evaporative cooling and provide shading for the ground. Likewise, they provide fresh air and induce ventilation of the overheated, dirty, and polluted town centre (Bernatzky, 1982).

It is believed that greens also have modifying effects of microclimatic conditions surrounding the buildings in the form of landscape. As part of the landscape, trees acts as shade, thereby lowering the heat intensity on buildings and grounds by absorbing or reflecting direct heat from the sun rays (Riggins, 2011 as cited by Ayeni, 2012). Hence, knowledge of the character and abundance of trees is essential as they are great influencers of the local or microclimate (Kong *et al*., 2017). Trees do this through the provision of shade and the control of relative humidity and air movement. They contribute more to the attainment of thermal comfort than any other landscape element.

Tree leaves are arranged to catch as much of the sun as possible, and in the process, provide the best possible shade. The intensity and quality of shading depend on the cover, branching and twigs, structural form and transmissivity of leaf (Shahidan *et al.*, 2007; Szkordilisz and Kiss, 2015). This shading is far superior to that provided by a roof or a wall. While a roof may provide full shading, the roof heats up in the process and hot air is trapped under the roof causing discomfort. The roof also radiates heat, causing further discomfort. A tree on the other hand filters the radiation, with the upper leaves receiving most radiation and thus becomes hotter. The leaves at the bottom receive less radiation, are much cooler, and hence radiate less heat.

According to Chau (2016), greenery could lower the air temperatures in surroundings by up to 2^{o}C and the shading provided by trees could lower the ground surface temperature up to 20^{o}C. Stilbolt (2015), on the other hand, explained that shading and evapotranspiration from trees can reduce surrounding air temperatures as much as 5^{o}C; because cool air settles near the ground, air temperature directly under trees can be as much as 14^{o}C cooler than air temperatures above nearby blacktop. Earlier study by Frankfurt (cited in Bernatzky, 1982) on the effect of vegetation on two environmental conditions indicated reduction of air temperature up to 3.5^{o}C, and intensification of relative humidity by up to 10%. However, Zhao (2017) and Takabayashi *et al.* (2017) revealed that the indoor cooling effect of trees depend on location and arrangement relative to building windows, doors, façade and rooftops.

Ventilation is affected by trees through modification of wind speed and direction, and air temperature (Idowu, 2011; Idowu and Okonkwo, 2012). Guyer (2017) and Stathopoulos (2009) further explained that vegetation can create areas of higher wind velocities by deflecting winds or by funnelling air through a narrow opening. Mohammed and Wood (2015) posited that trees situated adjacent to buildings can create a significant effect on the mean wind speed and turbulence over the roof.

The environmental conditions required for thermal comfort in different climatic zones and seasons have been copiously studied and reported. For instance, a recent study in naturally ventilated buildings in composite climate of India (Dhaka *et al.*, 2015) revealed that respondents felt neutral at 25.6^{o}C, 27.0^{o}C and 29.4^{o}C during winter, moderate and summer seasons respectively. Acceptable humidity and air velocity, in the study, were 36% and 0.44m/s for all seasons. Seemingly different is a report (Modeste *et al.*, 2014) which indicated comfort temperature ranging from 26^{o}C to 36^{o}C, and wind speed from 0.2m/s to 3.0m/s.

A creative integration of trees in landscape designs around building is imperative to improve the thermal comfort of the indoor spaces. This will optimize natural ventilation and passive cooling for the spaces, and reduce or totally eliminate the reliance on the use of heating, ventilation and air-conditioning (HVAC) unit to control the indoor thermal sensation (Riggins, 2011 as cited by Ayeni, 2012). The resulting effect of this is enhanced indoor thermal comfort, energy savings on the building and financial savings for the owner (Ayeni, 2012).

Aim and Objectives of the Study

The study is aimed at enhancing thermal comfort indoors by incorporation of trees in effective and appropriate forms around buildings in the study area, through the following objectives: (a) To determine the effect of incidence of trees on temperature in the study area; (b) To determine the effect of incidence of trees on ventilation in the study area; (c) To determine the effect of incidence of trees on relative humidity in the study area.

Methodology

The study is an *Ex-post facto* or Causal comparative research design, as espoused in Koleosho (1999), in which some independent variables of thermal comfort were observed as they occurred without any attempt to manipulate them within and around spaces in two identical building blocks with different incidence of surrounding trees in the study area. The departmental buildings of Banking and Finance and Industrial Design in Modibbo Adama University of Technology, Yola, selected through convenience sampling, are the study objects (Figure 1). Equipment was deployed to observe three variables, the air temperature, speed and relative humidity, which are parameters of thermal comfort.

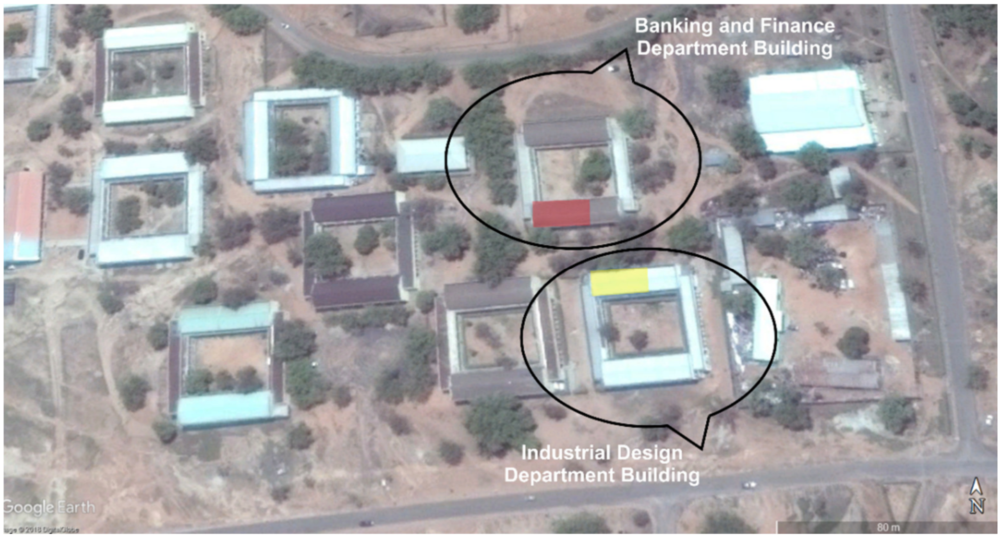

Fig. 1: Aerial view of the two buildings and surrounding trees under study
Source: Google Earth

Description of the Study Buildings

The two departmental buildings have similar spaces in size serving different functions as designated by each department. It has four closed built-up side with connecting corridors, a courtyard at the centre and the entrances on the westward side. On the North and South sides are six number large rooms which serve as lecture rooms at the department of Banking and Finance, and as studios at the department of Industrial Design. The west side where the entrances are have in addition, eight number office spaces while the east side has six number office and conveniences meant for staff only. In total each building of sixty-six louvered windows for the offices and large rooms, and seven windows for the toilets. All the exterior windows are protected with shading device to prevent direct sun penetration. On site, the two buildings are laterally mirrored, hence the study indoor spaces share a common air-space as highlighted in Figure 2.

Fig. 2: Layout of selected buildings, relative position of trees and the studied spaces

Instruments/Material

The parameters considered and observation instruments/materials used are as listed below

Parameter	Instrument/Material	Unit
Wind direction	Paper/thread (improvised wind vane	Cardinal
Air temperature	Testo 405-v1 Model (Digital Thermo-Anemometer)	(^{0}C)
Air speed	Testo 405-v1 Model (Digital Thermo-Anemometer)	(m/s)
Relative humidity	Kestrel 3000 Wind Meter	(%)

Data Collection Procedure

The required parameters were measured for Classroom 200 and Classroom 500 in the Banking and Finance Department Building (BFDC 200 and BFDC 500), and Classroom DS 100 and Classrooms DS 110 in the Industrial Design Department Building (IDDC 100 and IDDC 110) as indicated in Figure 2. Thirty readings were taken at an interval of 15-minute in each of the 4 rooms selected for the observation starting from 12:00 noon on each of the observation days. To stimulate naturally operative conditions in the study, all air-condition units and fans were switched off and windows were opened and kept unobstructed.

Data Analysis Procedure

Descriptive statistics including mean and standard deviation were deployed with the aid of *Microsoft Office Excel* to analyze the air temperature, wind speed and relative humidity data. Ventilation coefficient was derived, as a measure of natural ventilation design of a space, by dividing the indoor mean wind speed with outdoor mean wind speed. The derived thermal comfort parameters in spaces were compared between the two buildings under study, and presented in charts in order to identify or detect any likely difference in the values.

Result

Tables 1 and 2 show the observed wind speeds and temperatures within and outdoors of the spaces under study in the Banking and Finance Department (BFDC) and the Industrial Design Department Building (IDDC) respectively. The observed relative humidity in the spaces are presented graphically in Figure 3; while Figures 4 and 5 show the mean values of observed temperatures and wind speeds in the study spaces. There are more number of full grown trees in the courtyard and around BFDC than in the courtyard and around IDDC.

Outdoor temperatures for BFDC varied from 32.1 to 35.9°C,wind speeds from 0.04 to 1.61m/s, and relative humidity from 21.4 to 21.7%.Indoor temperatures varied from 29.1 to 31.9°C, with mean value of 29.84°C in BFDC 200 and mean relative cooling (mean outdoor/ indoor temperature differentials) of 4.10°C; 30.50°C in BFDC 500 and mean relative cooling of 3.52°C respectively. Indoor wind speeds varied from 0.02 to 0.80m/s, with mean value of 0.16m/s and ventilation coefficient of 0.96 in BFDC 200; mean wind speed of 0.15m/s and ventilation coefficient of 0.97 in BFDC 500. The mean indoor relative humidity in BFDC 200 is 26.7%, and in BFDC 500 is 28.8%, representing increase of 23.0 and 34.6% over outdoor values respectively.

Outdoor temperatures for IDDC varied from 30.0 to 36.8°C, wind speeds from 0.04 to 1.0m/s, and relative humidity from 23.8 to 23.9%. Indoor temperatures varied from 29.4 to 30.9°C, with mean value of 29.77°C, and mean relative cooling of 4.48°C in IDDC 100; mean value of 29.76°C, and mean relative cooling of 4.98°C in IDDC 110. Indoor wind speeds varied from 0.03 to 0.26m/s, with mean wind speed of 0.13m/s, and ventilation coefficient of 0.40 in IDDC 100; mean wind speed 0.10m/s, and ventilation coefficient of 0.73 in IDDC 110. Indoor relative humidity in the mean is 23.9% in IDDC 100, and 24.1% in IDDC 110, and these represent increase of 0.4 and 0.8% over outdoor values respectively.

Table 1: Observed wind speeds and air temperatures in the Banking and Finance building

S/N	BFDC 200:						BFDC 500:					
	***V_i* (m/s)**	***V_o* (m/s)**	***VC* -**	***T_i* °C)**	***T_o* °C**	***T_d* °C**	***V_i* (m/s)**	***V_o* (m/s)**	***VC* -**	***T_i* °C**	***T_o* °C**	***T_d* °C**
1	0.06	0.70	0.09	30.00	32.80	2.80	0.21	0.18	1.17	31.40	32.50	1.10
2	0.28	0.20	1.40	30.10	32.70	2.60	0.14	0.11	1.27	31.30	32.50	1.20
3	0.13	0.21	0.62	30.10	32.70	2.60	0.13	0.10	1.30	31.10	32.70	1.60
4	0.14	0.32	0.44	30.20	32.70	2.50	0.12	0.06	2.00	31.90	32.90	1.00
5	0.22	0.26	0.85	30.20	32.80	2.60	0.21	0.25	0.84	30.80	33.00	2.20
6	0.05	0.17	0.29	30.10	32.90	2.80	0.08	0.26	0.31	30.70	33.50	2.80
7	0.10	0.72	0.14	30.10	32.70	2.60	0.20	0.17	1.18	30.60	33.80	3.20
8	0.13	0.18	0.72	30.20	32.50	2.30	0.07	0.09	0.78	30.60	34.20	3.60
9	0.21	0.15	1.40	30.00	32.90	2.90	0.07	0.15	0.47	30.60	34.30	3.70
10	0.21	0.06	3.50	29.80	32.80	3.00	0.17	0.53	0.32	30.60	34.40	3.80
11	0.19	1.61	0.12	29.90	32.90	3.00	0.08	0.36	0.22	30.60	34.50	3.90
12	0.15	0.54	0.28	29.90	33.00	3.10	0.10	0.17	0.59	30.60	34.40	3.80
13	0.15	0.17	0.88	29.80	33.00	3.20	0.12	0.26	0.46	30.60	34.40	3.80
14	0.06	0.21	0.29	29.90	33.10	3.20	0.06	0.33	0.18	30.50	34.10	3.60
15	0.03	0.25	0.12	29.10	33.40	4.30	0.80	0.27	2.96	30.40	33.90	3.50
16	0.02	0.17	0.12	29.80	33.70	3.90	0.15	0.06	2.50	30.30	34.10	3.80
17	0.21	0.21	1.00	29.80	33.90	4.10	0.06	0.11	0.55	30.30	34.20	3.90
18	0.38	0.13	2.90	29.50	34.00	4.50	0.17	0.17	1.00	30.40	34.30	3.90
19	0.12	0.37	0.30	29.70	34.40	4.70	0.14	0.15	0.93	30.40	34.40	4.00
20	0.13	0.16	0.80	29.80	34.60	4.80	0.16	0.14	1.14	30.20	34.40	4.20
21	0.11	0.10	1.10	29.80	35.00	5.20	0.15	0.16	0.94	30.30	35.00	4.70
22	0.18	0.10	1.80	29.80	35.40	5.60	0.17	0.28	0.61	30.20	35.10	4.90
23	0.16	0.35	0.46	29.80	35.30	5.50	0.11	0.21	0.52	30.10	34.50	4.40
24	0.21	0.17	1.24	29.70	35.90	6.20	0.13	0.20	0.65	30.00	34.50	4.50
25	0.16	0.12	1.33	29.80	35.10	5.30	0.17	0.19	0.90	30.00	34.50	4.50
26	0.07	0.19	0.37	29.80	35.50	5.70	0.08	0.25	0.32	30.10	33.90	3.80
27	0.06	0.08	0.75	29.40	35.70	6.30	0.04	0.36	0.11	30.10	34.00	3.90
28	0.68	0.15	4.53	29.40	35.60	6.20	0.07	0.23	0.30	30.10	34.00	3.90
29	0.09	0.17	0.53	29.80	35.60	5.80	0.18	0.04	4.50	30.10	34.30	4.20
30	0.05	0.16	0.31	29.90	35.50	5.60	0.09	0.45	0.20	30.10	34.20	4.10
Mn	**0.16**	**0.28**	**0.96**	**29.84**	**33.94**	**4.10**	**0.15**	**0.21**	**0.97**	**30.50**	**34.02**	**3.52**
Sd	**0.13**	**0.30**	**1.04**	**0.25**	**1.21**	**1.36**	**0.13**	**0.11**	**0.94**	**0.45**	**0.68**	**1.06**

Key: V_i = indoor wind speed; V_o = outdoor wind speed; VC = V_i/ V_o; T_i =indoor temp; T_o= outdoor temp; T_d = $T_o - T_i$

Table 2: Observed wind speeds and air temperatures in the Industrial Design building

S/N	IDDC 100:						IDDC 110:					
	V_1	V_o	VC	T_1	T_o	T_d	V_1	V_o	VC	T_1	T_o	T_d
1	0.19	0.38	0.50	30.90	32.92	2.02	0.08	0.20	0.40	29.50	31.60	2.10
2	0.10	0.31	0.32	30.60	33.70	3.10	0.04	0.27	0.15	29.50	31.90	2.40
3	0.08	0.42	0.19	30.40	33.90	3.50	0.10	0.35	0.29	29.60	32.20	2.60
4	0.08	0.32	0.25	30.30	34.10	3.80	0.10	0.23	0.44	29.60	32.70	3.10
5	0.07	0.34	0.21	30.20	34.80	4.60	0.20	0.19	1.05	29.60	33.10	3.50
6	0.16	0.56	0.29	30.10	33.70	3.60	0.21	0.21	1.00	29.60	33.70	4.10
7	0.19	0.39	0.49	30.00	33.80	3.80	0.26	0.17	1.53	29.60	34.20	4.60
8	0.09	0.61	0.15	29.90	34.00	4.10	0.16	0.15	1.07	29.60	34.60	5.00
9	0.20	0.29	0.69	29.80	34.40	4.60	0.06	0.17	0.35	29.60	34.90	5.30
10	0.20	0.42	0.48	29.80	34.20	4.40	0.03	0.15	0.20	29.60	34.80	5.20
11	0.26	0.59	0.44	29.60	33.90	4.30	0.03	0.19	0.16	29.70	34.80	5.10
12	0.16	1.00	0.16	29.50	33.90	4.40	0.07	0.21	0.33	29.70	34.90	5.20
13	0.09	0.77	0.12	29.60	34.00	4.40	0.03	0.12	0.25	29.70	35.10	5.40
14	0.12	0.70	0.17	29.60	34.10	4.50	0.11	0.04	2.75	29.80	35.20	5.40
15	0.15	0.51	0.29	29.60	34.00	4.40	0.17	0.20	0.85	29.80	34.90	5.10
16	0.14	0.20	0.70	29.60	34.10	4.50	0.14	0.05	2.80	29.80	35.30	5.50
17	0.12	0.31	0.39	29.60	34.40	4.80	0.19	0.15	1.27	29.90	35.40	5.50
18	0.18	0.19	0.95	29.50	34.20	4.70	0.06	0.15	0.40	29.80	35.70	5.90
19	0.12	0.14	0.86	29.50	34.00	4.50	0.05	0.10	0.50	29.90	36.00	6.10
20	0.11	0.40	0.28	29.40	34.10	4.70	0.08	0.18	0.44	29.90	35.80	5.90
21	0.13	0.21	0.62	29.50	34.20	4.70	0.05	0.90	0.06	29.90	36.10	6.20
22	0.14	0.46	0.30	29.50	34.40	4.90	0.19	0.08	2.38	29.90	36.00	6.10
23	0.14	0.25	0.56	29.50	34.40	4.90	0.06	0.29	0.21	29.90	36.10	6.20
24	0.11	0.29	0.38	29.60	34.60	5.00	0.12	0.40	0.30	29.80	36.00	6.20
25	0.10	0.29	0.35	29.50	34.80	5.30	0.10	0.25	0.40	29.90	35.50	5.60
26	0.08	0.54	0.15	29.50	34.70	5.20	0.28	0.39	0.72	29.90	35.90	6.00
27	0.07	0.12	0.58	29.60	35.00	5.40	0.13	0.29	0.45	29.90	30.00	0.10
28	0.10	0.18	0.56	29.60	35.00	5.40	0.11	0.40	0.28	29.90	36.20	6.30
29	0.07	0.17	0.41	29.60	35.00	5.40	0.03	0.21	0.14	29.90	36.80	6.90
30	0.08	35.50	0.00	29.60	35.00	5.40	0.09	0.14	0.64	29.90	36.80	6.90
Mn	**0.13**	**0.33**	**0.40**	**29.77**	**34.24**	**4.48**	**0.10**	**0.23**	**0.73**	**29.76**	**34.74**	**4.98**
Sd	**0.05**	**6.41**	**0.23**	**0.37**	**0.48**	**0.75**	**0.07**	**0.16**	**0.75**	**0.14**	**1.65**	**1.57**

Key: V_i *= indoor wind speed;* V_o *= outdoor wind speed; VC =* V_i/V_o*;* T_i*, =indoor temp;* T_o*= outdoor temp;* $T_d = T_o - T_i$

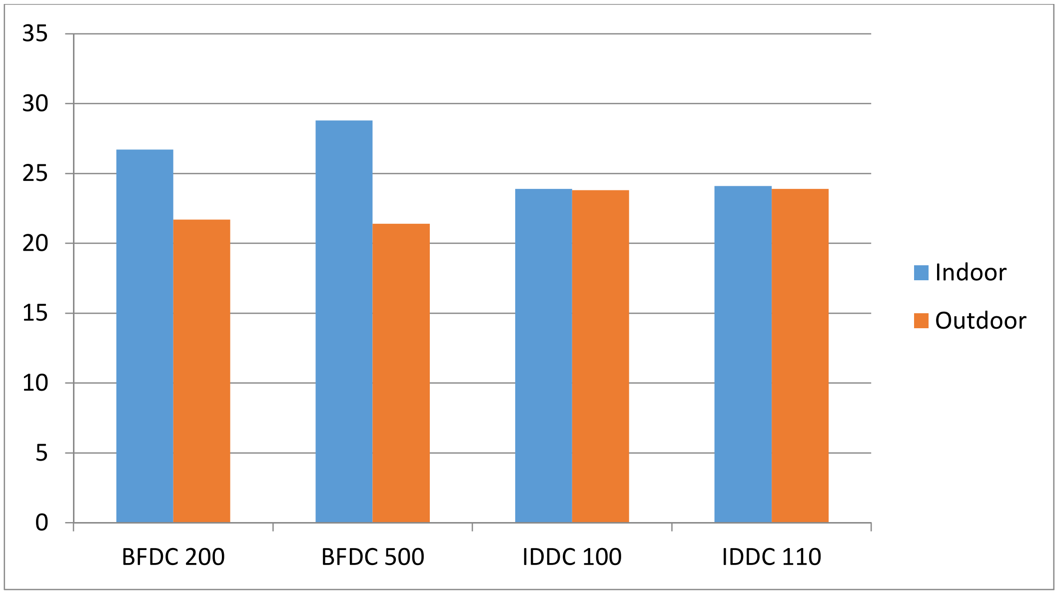

Fig. 3: Relative humidity (%) in the study spaces

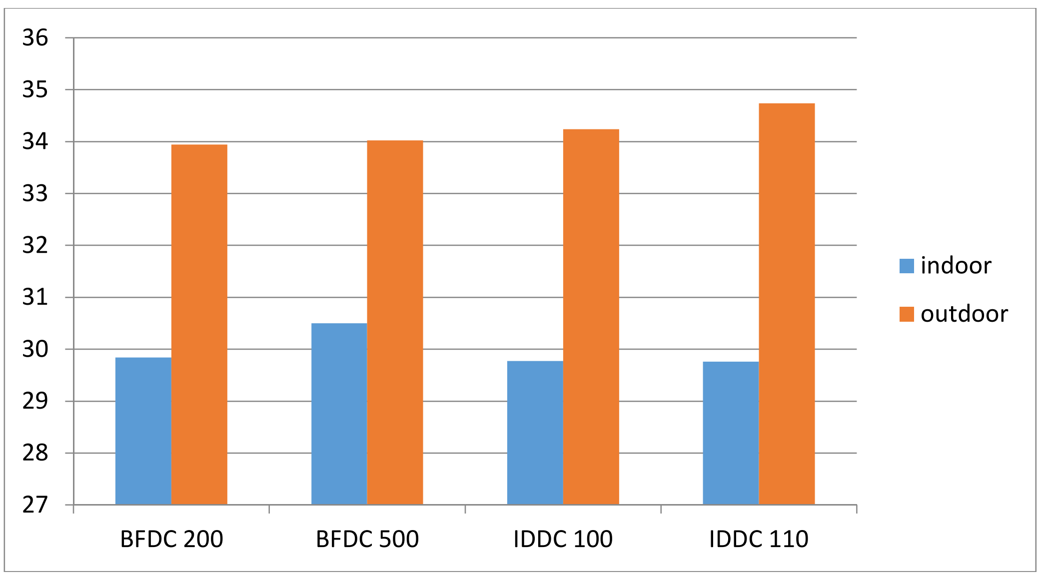

Fig. 4: Mean temperatures (ºC) in the study spaces

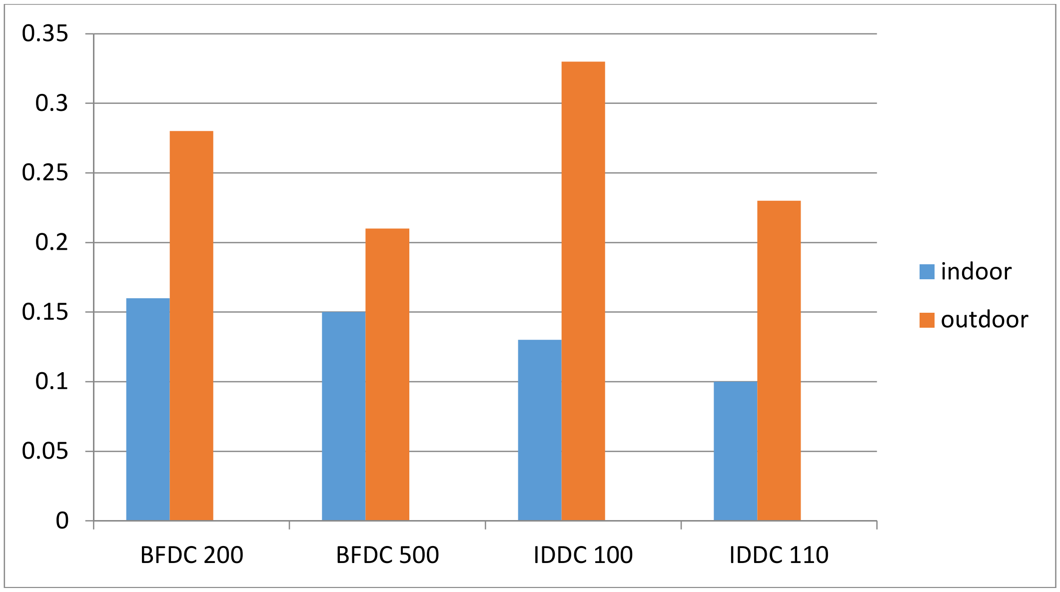

Fig. 5: Mean wind speeds (m/s) in the study spaces

Discussion

There seems to be no significant difference in the indoor mean temperatures of the spaces of the two buildings (29.8ºC in BFDC 200, 30.5ºC; 29.7ºC in IDDC 100, and 29.8ºC in IDDC 110) under study. This suggests that the number of trees in and around the buildings have no effect on the indoor temperature of the spaces under study; and this is contrary to our expectation. Paradoxically, the spaces in the building with fewer surrounding trees (IDDC) appear to be cooler than in the other building (BFDC).The mean outdoor-indoor temperature differences are 4.10ºC and 3.52ºC for BFDC 200 and BFDC 500 respectively at the department of Banking and Finance: 4.48ºC and 4.98ºC for IDDC 100 and IDDC110 respectively at the department of Industrial Design building.

Some of the factors that might have caused this unexpected outcome are the position of the trees relative to the spaces under study, the cardinal orientation of the spaces (as espoused in Zhao, 2017 and Takebayashi *et al.*, 2017), and their position relative to wind direction. The two buildings fairly equally share the same number of tree in the space between them, but the spaces (BFDC and IDDC) are at the south and the north wings of the buildings respectively. Thus, BFDC are more exposed to solar radiation than IDDC.

In the aggregate however, the effect of trees in the space between the buildings on the indoor temperature of the spaces under study is comparable with those obtained in previous studies. The cooling effect of vegetation observed in this study seem higher than in Chau (2016), almost same as in Stilbolt (2015) and Idowu *et al.* (2016), but slightly lower than obtained in Aminu *et al.* (2016).

The mean ventilation coefficient of 0.96 and 0.97 for BFDC 200 and BFDC 500, which are apparently higher than 0.40 and 0.73 observed in IDDC 100 and IDDC 110 respectively, is suggestive of southerly wind, which is more in favour of BFDC than IDDC.

When the values for the measured relative humidity are considered, an improvement (up to 34.6%) was noticed between the indoor and outdoor value for the BFDC, while the values for the indoor and outdoor for the IDDC remains approximately the same (less than 1% difference). This is a proof of an intensified relative humidity due to the presence of more trees within and around the BFDC than the IDDC. The improvement aligns in principles with, and even surpasses in quantum the findings of Frankfurt (cited in Bernatzky, 1982).

The findings about the environmental parameters have some implications on the prospects and attainment of thermal comfort in the study area. The mean indoor temperature of 29.4^{o}C, indoor wind speed of 0.15m/s and relative humidity of 28.8% attained represent the most conducive values in the study. These however seem short of the minimum environmental conditions requirement for thermal neutrality as espoused in Dhaka *et al*. (2015). It is also doubtful if the indoor wind speeds required for thermal comfort at higher temperatures, as found in Modeste *et al.* (2014), is attainable in any of the study spaces. This is because the maximum ventilation coefficient, 0.97, obtained in the study would not generate more than 1.2m/s indoor wind speed, even if the maximum outdoor wind speed reported in Idowu (2012) was to be available.

Conclusion

The study sought to determine the effect of trees around buildings on three parameters of indoor thermal comfort viz: air temperature, velocity and relative humidity. It deployed the *Ex-post facto* or causal comparative research design to collect data with observation equipment in two existing buildings with different incidence of trees around them. The results revealed indoor mean temperatures of 29.8 and 30.5^{o}C in the building with more trees, and 29.7 and 29.8^{o}C in the other; and mean cooling of 3.5^{o}C and 4.1^{o}C in the former, and 4.5^{o}C and 5.0^{o}C in the latter. Thus the effect of difference in incidence of trees around the buildings on the indoor temperatures of the spaces under study was not discernible. However, there are discernible differences in the ventilation coefficients and relative humidity between the study spaces; the mean ventilation coefficients ranging from 0.40 to 0.97, mean wind speed from 0.10m/s to 0.16m/s, and the mean relative humidity from 23.9% to 28.8%.

The study revealed that trees around buildings hold potentials for enhancing thermal comfort in the study area. It is recommended that trees with multiple layers and higher density of leaves be explored for planting in exposed spaces around buildings to enhance indoor thermal comfort in the study area.

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