Assessing the Effects of Floor Levels on Daylight Distribution in Mid-rise Office Buildings in Composite Climate of Nigeria.

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Abstract. Studies have shown that, 83% of people living in the tropics prefer to live within a wider climatic condition than a narrow one and this is only possible within a natural environmental settings. One of the major challenges in achieving optimum daylight distribution in mid-rise office buildings is the variations of climate with altitude. Studies on the effects of building height on the daylight distribution in office buildings are fewer in number. The aim of the study was to assess the effects of building height on daylight distribution in mid-rise office building in composite climate of Nigeria. It was achieved by: determining the effects of building floor levels on spatial daylight autonomy ($S_{DA}$) on four facades; and determining the effects of building floor levels on the optimum $S_{DA}$. The google sketch-up 2017 and Radiance in openstudio simulation tool were used to evaluate 8 sets of offices in Ahmadu Bello University senate building Zaria Nigeria, from January to December 2018. An exploratory design approach with the quantitative research strategy were employed in the study and the data generated was then analysed using an independent-samples t-test technique with significance threshold of 0.05, bar charts, column charts, graphs and tables. The results showed that, 75% of each of the spaces in 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th floor areas received at least 300 lux for at least 50% of 4, 6, 6, 8, 10, 12, 12, and 12 months of the annual occupied hours, respectively. The study concluded that, 2 floors are significantly difference in sDA in western, eastern, northern, and southern facades when they are 17m; 12m; 14; and 35m apart, respectively.

Keywords: Daylight, Mid-rise office, OpenStudio, Spatial daylight Autonomy, T-test

1. Introduction

A number of studies have shown that, people prefer to live within a wider range of climate conditions than a narrow one [1], and this is possible within a natural environmental settings. For example, [2] observed that, 96% of office occupants are more delighted to work in daylight condition as against the artificial lighting. Moreover, 86% of the office occupants are more delighted to get sunlight in their offices throughout the year as against the contrary. It has also been opined that, employees tend to leave their offices on the slightest opportunities due to the inadequate lighting [3]. One of the major challenges in achieving daylight distribution in mid-rise office buildings is the variations of climate with altitude as observed by [4]. For example, [5] have opined that, 76% of people in HongKong prefer living in upper floor of the high-rise buildings than contrary, and the choice were influenced by the three major reasons, which are view (30%), ventilation (25%) and daylight provision (21%). Another study by [6], revealed that, high amount of light, are found on upper floors of multistorey buildings, while [7] proposed the typical daylight zone in an office building to be within 5m deep from the window wall or the upper floor of a building, especially with the skylights. However, all these might have come as a result of external obstructions by the neighbouring multi-storey buildings which might have caused the reduction of the natural light in the interior of the lower floors, as observed by [8].

The aim of this study was to assess the effects of floor levels on daylight distribution on mid-rise office building in Nigerian composite climate. The objectives were: to determine the effects of floor levels...
on spatial daylight autonomy (sDA) on each facades; and determining the effects of building heights on the optimum sDA of ABU senate building. In realizing this goal, the following research questions were raised: to what extent does the different floor levels differ in sDA in the 4 facades of ABU senate building; to what extent does the floor levels affect the optimum sDA in single-banked office building (ABU Senate building) in Nigerian composite climate? These brought about the following hypothesis: the null hypothesis (HO) stated that, the mean effects of sDA is significantly the same for all floor levels of all facades of single-banked mid-rise office building in composite climate of Nigeria; The alternative hypothesis (HI) stated that, the mean effects of sDA is significantly different for at least one of the floors of one of the facades of single-banked mid-rise office building in composite climate of Nigeria.

2. Literature Review

Literature review has shown that, effects of light on the building users can be categorised into two: Visual effect, which enable people to see the world in order to interact with it, enhances human performance, health, wellbeing and productivity [9]; and Non-visual effect, which has vast impacts on human behaviours such as alleviating seasonal depression [10], increase of length and quality of sleep [11], reduction of anxiety and depression [12], reducing risk of Heart disease [13], to mention a few.

Another important determinant of daylight distribution in office building is window to wall ratio (WWR) as revealed by [14] who noted that, an increase of WWR of 0.1 produces an increase lighting saving of 2.719 W/m2 in sunny day as well as 1.687 W/m2 in cloudy day. Many researchers have come up with different results regarding optimum WWR. For example, [15] recommended the use of 24% as the optimum value for daylight and natural ventilation, and considered value below that as poor, while value above 30% overheated. Studies such as [16] gave different values, depending on building orientation, having 30% for East and west orientated offices; 25% for South oriented offices; and 20% for the corridor on the North 20%. This study used the same window to wall ratio (WWR) on all the four tested façades to eliminate the effect of WWR in the building interior.

Some of the leading simulation tools for assessing energy include: EnergyPlus; Ecotec; Design Builder; and OpenStudio, to mention a few. It was noticed by [17] that, one of the limitations of using Energyplus alone is the inability to visualise the building geometry by the researcher, and also its engine cannot accurately model daylight flux transfer into complex spaces. Design Builder is slow in analyzing a multiple simulation, while Ecotec has limitation in predicting natural ventilation as observed by [18]. OpenStudio was released in April 2008 by the National Renewable Energy Laboratory, a part of the U.S. Department of Energy. It has overcome the limitations of EnergyPlus, Ecotec and DesignBuilder, such as being easier to visualise the building geometry and very fast in analysing a multiple simulations. It has also been validated by a number of researchers such as: [19]; [20]; [21]; and [22]. The results showed that, the OpenStudio simulation tool can reliably reproduce real world conditions with errors within the acceptable level as recommended by [23]. Another validation study on the Openstudio simulation tool was by [24], who found out a strong positive correlation between the measured and simulated data with the average measure Correlation Coefficient of 0.97 at 95% confidence level and the average p-value of .015.
There are various models to go about determining daylighting in buildings, among which are: Daylight factor; Permanent Supplementary Artificial Lighting of the Interior Model, etc. The most effective daylight model is the Climate-Based Daylight Modelling (CBDM) as opined by [23]. Spatial Daylight Autonomy is the best daylight specific performance indicator in computing CBDM as recommended by [25]. Spatial Daylight Autonomy of 75% and above is recommended by [25] in regularly occupied space, such as office or classroom, and at-least 55-74% in areas where some daylight is important such as corridors.

3. Methodology

3.1 Microclimate data

There are many different types of climate classifications, but all can be generally be distinguished into three fundamental types, which are: empiric; genetic; and applied climate classifications [17]. This distinction is based on the nature of the data used for classification. Most climates classifications that are based on human comfort have their origin from Atkinson (1953)’s climate classification as observed by [27]. Atkinson classified climate as: Warm Humid; Hot dry Desert; and Composite Climates [27]. The study has therefore adopted Atkinson’s climate classification based on the fact that, it has been tested by a number of researchers, especially those that have worked within Nigerian climates, which include: [28]; [29], etc. The Composite Climate was chosen to study due to its annual temperature range. Some of the area it covers in Nigeria include: Zaria; Plateau; Mina etc.

3.2 Research design

A mid-rise office building in this study is any office building with 4 to 12 floors, as classified by [30]. An exploratory design approach using quantitative research strategy were employed and a convenience probability sampling technique was used in selecting the building. Ahmadu Bello University (ABU) senate building Zaria was selected as a case of single-banked office building as illustrated in figure 1.

Figure 1. Aerial Floor Plan and 3-D Elevation of ABU Senate Building Zaria, Nigeria
The criteria used in selection of this building was based on the building type, number of storeys, access to buildings and HVAC system. It was then modelled using google sketch-up 2017, Radiance, and open-studio simulation tools. The 8 sets of offices were selected, each from first to eighth floors consecutively, making a total of 64 offices, for simulation and analysis. Each set of offices has the same dimensions, orientation, window to wall ratio (WWR), and arrangement. It was also noted by [31] that, with the courtyard aspect ratio greater than 0.65, and courtyards parameter to height ratio less than 5, the courtyard of ABU Senate building has no effect on the microclimate of the building as recommended by [32] and [33] respectively.

The window parameters used in the simulation are as follows: 3mm thick glass as window material of 0.331 solar transmittance at normal incidence; 0.6189 front side solar reflectance at normal incidence; 0.44 visible transmittance at normal incidence; 0.51 front side visible reflectance at normal incidence; and 0.0133 W/MK conductivity.

The methods used in conducting the research was based on the [22]. Based on this document the following steps were followed:

i. ABU senate building was modelled in google sketch-up 2017;
ii. In order to simulate daylight, EnergyPlus weather (EPW) was used as the type of weather file;
iii. Sketch-up plugging called Open-studio was used to set weather files of Zaria, from weather Analytic;
iv. Radiance measure in OpenStudio was used for daylight;
v. Run period from January to December of 2018 was selected from Simulation settings;
vi. Simulation button was pressed for the final analysis.

Data generated was then analysed using an independent-samples t-test technique with significance threshold of 0.05, bar charts, column charts, graphs and tables to find out the effects of building height on daylight distribution of single-banked mid-rise office building in composite climate of Nigeria.

4. Results and Data Analysis

The results of the effects of building floor levels on the daylight distribution with respect to sDA is presented in table 1. A study by [25] recommended a minimum sDA of 75% in office space.

| Latitude and longitude | FACADE SPACE | DIMENSION | WWR | 1st floor | 2nd floor | 3rd floor | 4th floor | 5th floor | 6th floor | 7th floor | 8th floor |
|------------------------|-------------|-----------|-----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| West Elevation | 11°00'03.11"N / 7°39'02.32"E, 11°00'01.98"N / 7°39'21.21"E, 11°00'02.95"N / 7°39'22.33"E, 11°00'03.96"N / 7°39'21.41"E | 111 to 811 | 6.5m x 6.6m x 3.048m | 15.70% | 74 | 78 | 77 | 83 | 89 | 94 | 96 | 97 |
| 109 to 809 | 4.5m x 6.6m x 3.048m | 25.04% | 65 | 69 | 71 | 78 | 89 | 93 | 93 |
The research was analysed and discussed based on the Hypothesis testing and research questions raised earlier in this paper as follows:

The first question was that: to what level does the different floor levels differ in sDA in the 4 facades of single-banked office building in Nigerian composite climate. The result as indicated in figure 2, 3, 4, and 5 show that, there are average percentage differences in sDA of each floor in relation to the first of: 2.88%, 5.04%, 10.8%, 23.7%, 31.65%, 35.97%, and 36.69% in the offices of west elevation; 0.79%, 6%, 12.7%, 17.46%, 35.7%, 46.8%, and 47.62% in the offices of the East elevations; 2.7%, 5.4%, 14.4%, 26.13%, 45.05%, 57.66%, and 59.46% in the offices of the North elevation; and 7.09%, 10.24%, 14.17%, 18.9%, 37.0%, 40.16%, and 43.31% in the South elevation. This shows that, the daylight distribution increases as the floor levels increases as shown in figure 2, 3, 4, and 5.

Figure 2. Comparison of Spatial daylight autonomy among the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th floors in 16 offices of the west elevation of single-banked office building in composite climate of Nigeria.
A further analysis from figure 2, 3, 4, and 5 indicate that, there are average percentage differences in sDA between the two successive floors starting from the first floor of: 2.88%, 2.1%, 5.48%, 11.69%, 6.4%, 3.29%, and 0.53% in the offices of west elevation; 0.79%, 4.72%, 6.77%, 4.22%, 15.5%, 8.18%, and 0.54% in the offices of East elevation; 2.7%, 2.63%, 8.55%, 10.24%, 15.0%, 8.7%, and 1.14% in the offices of the North elevation; and 7.09%, 2.94%, 3.57%, 4.14%,
15.23%, 2.3%, and 2.25% in the offices of South elevation. The difference also increases as the floor levels increases from one to six and then start declining from seven and eight.

The next research question was that: to what extent does the floor levels affect the optimum sDA in single-banked office building in Nigerian composite climate?

Figure 6 shows that, 75% of each of the spaces in 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, and 8th floor areas received at least 300 lux for at least 50% of 4, 6, 8, 10, 12, 12, and 12 months of the annual occupied hours, respectively. It therefore means that, as the floor levels increases the optimum daylight distribution also increases.

### 4.1 Hypothesis Testing

**Null hypothesis (H₀):** stated that, the mean effects of sDA is significantly the same for all floor levels of all facades of single-banked mid-rise office building in composite climate of Nigeria.

To test this hypothesis, a series of independent-samples t-test were conducted to check the significance difference of the effects of floor levels on sDA as shown on table 2. N.S.D stands for not significant difference. The result as indicated in table 2 shows that, each façade exhibits different effects on daylight distribution. For example, when floor heights and the corresponding significance values were correlated for the offices of the western, Eastern, Northern and Southern façades, the following equations were respectively obtained: $y = -0.0094x + 0.2103$; $y = -0.0091x + 0.166$; $y = -0.0069x + 0.1478$; and $y = -0.0009x + 0.0817$. Where $y$ represents the floor levels in metres, and $x$ represents significance values, as indicated in table 2.

| FLOOR LEVELS | WEST ELEVATION | EAST ELEVATION | NORTH ELEVATION | SOUTH ELEVATION |
|--------------|----------------|----------------|-----------------|-----------------|
|               | DAYLIGHT DISTRIBUTION | DAYLIGHT DISTRIBUTION | DAYLIGHT DISTRIBUTION | DAYLIGHT DISTRIBUTION |
| Mean significance difference of sDA | P-value | Mean significance difference of sDA | P-value | Mean significance difference of sDA | P-value | Mean significance difference of sDA | P-value |

Fig. 6. Comparison of the adequacy of sDA among the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th floors in offices of ABU Senate building in composite climate of Nigeria.
### 5.0 Conclusion

From table 1 and 2, the null hypothesis was rejected and concluded that, daylight distribution has significance difference on floor levels in all offices at northern, southern, western and eastern facades of single-banked mid-rise office building in composite climate of Nigeria. It has also been deduced after each of the floor heights and the corresponding significance values were correlated for the offices in Western, Eastern, Northern and Southern façades that, 2 floors are significantly difference in daylight distribution (SDA) when they are 17m; 12m; 14; and 35m apart, respectively. This research has revealed that, apart from the effects of shading of tall neighboring buildings on the lower floors, building heights has its own effects on the amount and distribution of daylight in the building interiors.

### 5.1 Recommendations

The Scope of this work was to focus on the effects of floor levels on daylight distribution without necessary considering thermal discomfort and glare, and therefore, reference to sDA without studying the Annual Sun Exposure (ASE) can result in unacceptable delighting performance, this is one limitation of the research.

### References

[1] ASHRAE Standard 55 2013 *Thermal Environmental Conditions for Human Occupancy,*

| 1st & 2nd | 2 | N.S.D | 0.5 | N.S.D | 1.5 | N.S.D | 4.5 | 0.0352 |
|---------|---|-------|----|-------|----|-------|----|--------|
| 1st & 3rd | 3.5 | 0.0452 | 3.5 | 0.0452 | 3 | N.S.D | 6.5 | N.S.D |
| 1st & 4th | 7.5 | N.S.D | 8 | N.S.D | 9 | N.S.D | 9 | N.S.D |
| 1st & 5th | 16.5 | N.S.D | 11 | N.S.D | 14.5 | 0.0544 | 12 | N.S.D |
| 1st & 6th | 22 | 0.0289 | 22.5 | 0.0219 | 25 | 0.0254 | 23.5 | 0.0471 |
| 1st & 7th | 25 | 0.0381 | 29.5 | 0.0270 | 32 | 0.0298 | 25.5 | 0.0434 |
| 1st & 8th | 25.5 | 0.0311 | 30 | 0.0212 | 33 | 0.0193 | 27.5 | 0.0403 |
| 2nd & 3rd | 1.5 | N.S.D | 3 | N.S.D | 1.5 | N.S.D | 2 | N.S.D |
| 2nd & 4th | 5.5 | 0.0289 | 7.5 | 0.0212 | 6.5 | N.S.D | 4.5 | N.S.D |
| 2nd & 5th | 14.5 | 0.0328 | 10.5 | 0.0452 | 13 | N.S.D | 7.5 | N.S.D |
| 2nd & 6th | 20 | N.S.D | 22 | 0.0434 | 23.5 | N.S.D | 19 | N.S.D |
| 2nd & 7th | 23 | N.S.D | 29 | 0.0436 | 30.5 | 0.0568 | 21 | 0.0599 |
| 2nd & 8th | 23.5 | N.S.D | 29.5 | 0.0376 | 31 | 0.0452 | 23 | 0.0548 |
| 3rd & 4th | 4 | N.S.D | 4.5 | N.S.D | 5 | N.S.D | 2.5 | N.S.D |
| 3rd & 5th | 13 | N.S.D | 7.5 | N.S.D | 11.5 | 0.0138 | 5.5 | N.S.D |
| 3rd & 6th | 18.5 | 0.0258 | 19 | 0.0167 | 22 | 0.0572 | 17 | N.S.D |
| 3rd & 7th | 21.5 | 0.0369 | 26 | 0.0244 | 29 | 0.0543 | 19 | N.S.D |
| 3rd & 8th | 22 | 0.0289 | 26.5 | 0.018 | 30 | 0.0422 | 21 | N.S.D |
| 4th & 5th | 9 | N.S.D | 3 | N.S.D | 6.5 | N.S.D | 3 | N.S.D |
| 4th & 6th | 14.5 | N.S.D | 14.5 | N.S.D | 17 | N.S.D | 14.5 | N.S.D |
| 4th & 7th | 17.5 | N.S.D | 21.5 | N.S.D | 24 | N.S.D | 16.5 | N.S.D |
| 4th & 8th | 18 | N.S.D | 22 | 0.0573 | 25 | N.S.D | 18.5 | N.S.D |
| 5th & 6th | 5.5 | N.S.D | 11.5 | N.S.D | 10.5 | N.S.D | 11.5 | N.S.D |
| 5th & 7th | 8.5 | N.S.D | 18.5 | 0.02 | 7.5 | N.S.D | 13.5 | N.S.D |
| 5th & 8th | 9 | N.S.D | 19 | N.S.D | 18.5 | N.S.D | 15.5 | N.S.D |
| 6th & 7th | 7 | N.S.D | 7 | 0.0452 | 7 | 0.0452 | 2 | N.S.D |
| 6th & 8th | 3.5 | 0.0452 | 7.5 | 0.0212 | 8 | 0.000 | 4 | N.S.D |
| 7th & 8th | 5 | N.S.D | 0.5 | N.S.D | 1 | N.S.D | 2 | N.S.D |
[2] Markus T A 1967 The Significance of Sunshine and View for Office Workers Proc., of the CIE Conference on Sunlight in Buildings (Rotterdam: Bouwcentrum) pp. 59–93

[3] Oldham G R, Fried Y 1987 Employee reactions to workplace characteristics Journal of Applied Psychology 72 pp. 75-80

[4] Sohail M 2017 An attempt to design a naturally ventilated tower in subtropical climate of the developing Country Pakistan Environmental and Climate Technologies 21 pp. 47–67

[5] Ming L F, and LAU S S Y 2007 A Qualitative Study on Daylight Design Parameters in High Rise High Density Residential Buildings in Hong Kong Proc. of International Conference on Sustainable building Asia (Seoul: in-house publishing) pp. 411-416

[6] Bgnol S 2008 A Prediction Model For Daylighting Illuminance For Office Buildings Unpublished MSc thesis of Department of Architecture School of Engineering and Sciences of Gzmir Institute of Technology

[7] Leslie RP 2003 Capturing the daylight dividend in buildings: why and how Building and Environment 38 pp. 381-385

[8] Li BHW, Wong SL, Tsang, Gary H W and Cheung 2006 A Study of daylight Performance and energy use in heavily obstructed residential buildings via computer simulation techniques Energy and Buildings 38 pp.1343-1348

[9] Edwards L and Torcellini P 2002 A literature review of the effects of natural light on building occupants National Renewable Energy Laboratory ( U.S. : Department of Energy)

[10] Rosen L, Targum S, Terman M, Bryant M, Hoffman H, Kasper S, …. Rosenthal N 1990 Prevalence of seasonal affective disorder at four latitudes Psychiatric Research 31 pp. 131-44

[11] Kareem E, Nevin Z and Lamis E 2016 The Associations between daylight sufficiency in hospital wards and patient satisfaction with mental healthcare services: An Egyptian Sample Acta Medica International 3 pp 101-111

[12] Öztürk G, Moreno C R and Lowden A 2017 Daylight exposure, depression and sleep in adolescents Technical report Stress Research Institute (Stockholm: Stockholm University)

[13] Yamada T, Hara K, Shojima N, Yamauchi T and Kadowaki T 2015 Daytime napping and the risk of cardiovascular disease and all-cause mortality: A prospective study and dose-response meta-analysis Sleep 38 pp1945-1953

[14] Chen H and Wei P 2013 Utilization of Natural Daylight in Office Buildings International Journal of Smart Grid and Clean Energy 2 pp 301-306

[15] ANSI/ASHRAE/IES Standard 90.1 2007 Energy standard for buildings except low-rise residential buildings (Atlanta: Author)

[16] Harmtia N and Magyarb Z 2015 Influence of WWR, WG and glazing properties on the annual heating and cooling energy demand in buildings Energy Procedia 78 pp 2458 – 2463

[17] Guglielmetti R, Macumber D and Long N 2011 Open-studio: An open source integrated analysis platform Proc., of Building Simulation of 12th International conference of Building Performance Simulation Association (Sydney: NREL) pp 442-449

[18] Crawley D B, Hand J W, Kummert M and Griffith B T 2005 Contrasting the capabilities of building energy performance simulation programs Proc., of 9th International IBPSA Conference Montréal (Canada:Building Simulation) pp 231-238

[19] Guglielmetti R, Pless S and Torcellini P 2010 On the use of Integrated Daylighting Energy Simulations To Drive the Design of a Large Net-Zero Energy Office Building Presented at SimBuild, (New York)
[20] An J and Mason S 2010 Integrating Advanced Daylight Analysis Into Building Energy Analysis Proc., of 4th National Conference of IBPSA-USA (New York: IBPSA)

[21] Guglielmetti R and Ball B L 2016 A Framework for Daylighting Optimisation in Whole Buildings with Openstudio, Presented at ASRAE and IBPSA-USA SimBuild, (Salt Lake City: UT)

[22] Kamel E and Memari A M 2018 Automated Building Energy Modelling and Assessment tool Energy, 147 pp 15-24

[23] Salisu A S 2015 Optimising Fenestration for Daylight for daylight provision in the Architecture of Secondary Schools in Nigeria using Climate-Based Daylight Modeling, Unpublished PhD thesis, Department of Architecture, Ahmadu Bello University Zaria, Nigeria, 2015.

[24] Musa M A 2019 Validation Study of OpenStudio Simulation tool for Optimising Indoor Environmental Comfort in Mid-rise Office Buildings in Composite Climate of Nigeria Unpublished Second Seminar of PhD thesis, Department of Architecture, Ahmadu Bello University Zaria, Nigeria

[25] Lighting Measurement 83 LM-83 2013 Approved Method: IES Spatial Daylight Autonomy and Annual Sunlight Exposure (USA: IES Daylight Metrics Committee)

[26] Rafferty J P 2016 Classification of major climatic types according to the modified Köppen-Geiger scheme table revised and updated

[27] Koenigsberger O H, Ingersoll T G, Mayhew A and Szokolay S V 2013 Manual of Tropical Housing and Building Climatic Design (India: Universities Press)

[28] Nwalusi D M, Anierobi C M, Echefi K O and Nwokolo C N 2015 Climatic Considerations in Architectural Design of Buildings in Tropics: A case study of hot dry and warm humid climate in Nigeria Journal of Environmental Management and Safety 6 pp 54-63

[29] Eludoyin O M and Adelekan I O 2012 The physiologic climate of Nigeria International Journal of Biometeorology 3 pp 549-553

[30] Alcox H 2017 Multi-storey buildings; Classification and benefits http://www.alcox.in/blog/multi-storey-buildings-classification-benefits

[31] Musa M A and Garba A I 2019 Assessing the Effects of Building Floor Levels on Passive Ventilation rate in Courtyard Mid-rise Office Building in Temperate Dry Climate Of Nigeria, Proc., of the National Conference of Nigerian Association of Architects Educators (Nigeria : AARCHES) pp 320-334

[32] Meir I A, Pearlmutter D and Etzion Y 1995 On the microclimatic behavior of two semi-enclosed attached courtyards in a hot dry region Building and Environment 30 pp 563–572.

[33] Muhaisen A S and Gadi M B 200b, Shading performance of polygonal courtyard form Building and Environment 41 pp 1050-1059