# IMPROVING NATURAL LIGHT IN CLASSROOM SPACES WITH LOCAL TREES: SIMULATION ANALYSIS UNDER THE DESERT CONDITIONS OF THE UAE

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## ABSTRACT

The study investigates the use of local trees in the UAE to improve visual performance and lighting quality in typical classrooms. The methodology depended on analysis of luminance ratios and illuminance levels using simulation (Radiance.) The effect of two design variables (i.e., tree type: Ghaf and Neem, and tree spacing: 2m and 4m parallel to outside north wall, on task's illuminance levels and interior-surfaces' luminance levels were investigated. Lighting quality and visual comfort issues such as acute contrast, high brightness, and daylight distribution were discussed.

## KEYWORDS

Visual comfort, luminance ratios, illuminance

## INTRODUCTION

The United Arab Emirates lies between latitudes 22°–26.5°N and longitudes 51°–56.5°E. Being on the tropic of cancer (24 deg N) results in that the UAE region receiving the highest annual rate of solar radiation. In such a harsh climate of the UAE, which is characterized by high levels of solar radiation and intense sunlight, the proper window design is the one which minimizes direct sunlight by means of shading and provides diffuse daylight reflected from the ceiling. Most buildings in the UAE are not designed to achieve proper shading. In educational buildings, many classrooms have deep spaces that are lit from one side. This sometimes creates serious problems of high brightness contrast and acute glare that result in deteriorating visual comfort and in some cases causing health problems such as headache and fatigue. It was recommended in previous studies by the author (Al-Sallal et al. 2003, Al-Sallal 2004a, Al-Sallal 2004b, Al-Sallal et al. 2004c, Al-Sallal 2006) to overcome the high brightness and glare problems in educational spaces in the UAE by a system that can help to redistribute and filter daylight coming from windows and skylights; plants and trees can achieve this in addition to providing other benefits such as: aesthetics, noise reduction, and passive cooling.

## BACKGROUND

The external radiative exchanges that took place between one tree and a west wall was analyzed in a previous study (Manglani 2001). The study proposed a methodology for collecting, analyzing and evaluating relevant data for the study of vegetation shade as a means of attenuating the incident solar radiation. The methodology consisted in collecting the values of solar radiation (incoming and outgoing), the air temperature, surface temperatures of the trees and wall, both in direct sunlight and shade through field measurements and calculating the long-wave radiation flux.

Quantification and measurement of trees effect on scattering sunlight and providing quality daylight in buildings is an area of research that has not been examined closely in past studies of tree shading. This study aims to cast the light on the importance of tree shading and provides a methodology to analyze the effect of tree shading on daylight performance and lighting quality.

Quality daylight can be achieved by blocking direct sunlight while encouraging reflected sunlight. At all times the light should be diffused by reflecting it off the ceiling; in all cases it must be shaded before it enters the space (Lechner 2002). Plants can provide sun shading and improve the quality of daylight entering through windows by scattering direct sunlight and reducing its intensity while moderating glare coming from the bright sky. This can be achieved by vines across the windows or trees farther away. These natural methods (i.e., plants and trees) provide better quality of daylight than the use of light drapes or translucent glazing (Al-Sallal 2004b) because of the problem of glare. In fact, light drapes or translucent glazing can make the direct-glare problem much worse since they often become excessively bright sources of light especially in desert climates such as in the UAE.

The author with a research team investigated in previous studies (Al-Sallal et al. 2003, Al-Sallal 2004a, Al-Sallal 2004b, Al-Sallal et al. 2004c, Al-Sallal 2006) the daylight factors levels inside the studios located in architectural studios using physical model testing under actual sky and simulation. These studies found that most points in the new architectural engineering building studios of the UAE University were highly illuminated (i.e., 4-24 DF for the first floor and 8-27 DF for the third floor), yet the back points of the first floor studio had less than the minimum requirement of 4.0 DF. It was recommended to use solutions that can help to redistribute and filter the daylight coming mainly from the north façade such as plants and trees.

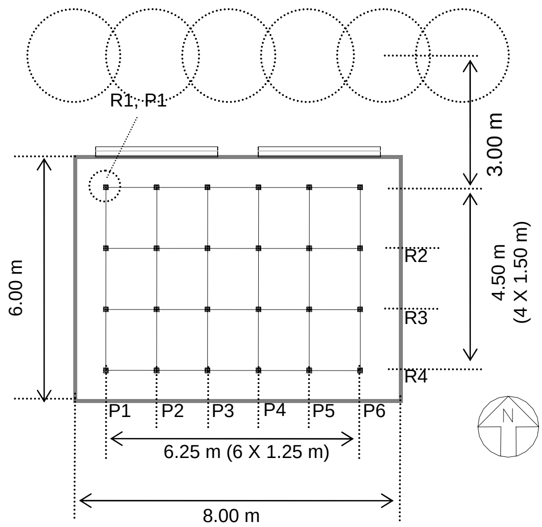


*Figure 1. Plan showing the classroom, the trees, and the analysis grid.*

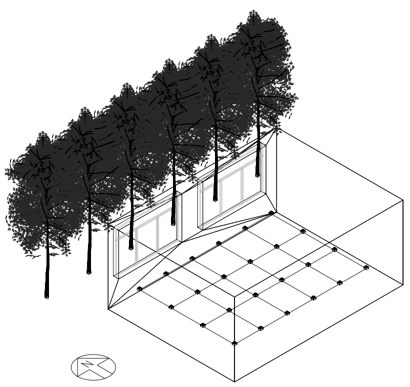

*Figure 2. Axonometric view of the 3D model.*

## METHODOLOGY

Literature survey has been conducted to search for tree types that grow in the UAE, and select the ones that have potential to scatter sunlight and improve lighting quality in indoor spaces such as Ghaf and Neem. Three-dimensional models of the work space (standard classroom) and the chosen trees (young Ghaf and Neem) were developed (Figures 1-2). Imitating the density of the tree canopy structure was done based on photographs of actual trees. The accuracy of the 3D models is maintained by matching canopy density between actual and modelled trees, based on image analysis of black (representation of leaves) and white (representation of sky) pixels. The 3D models are used to run simulations of the trees effect on daylight performance using Radiance. Improving performance is conducted using simulation and analysis through changing and controlling some important variables.

*Table 1. Experimental design, the simulated cases.*

| | Base (no tree) | Ghaf | Neem |
|---|---|---|---|
| *Initial test – Detect the effect of arrangement (4m, 3 trees; 2m, 6 trees) on performance using a certain date/hour condition (Mar 21, 10 AM).* | | | |
| **Mar 21, 10AM** | Bse_21Mar_10 | Gf4m_21Mar_10<br>Gf2m_21Mar_10 | Nm4m_21Mar_10<br>Nm2m_21Mar_10 |
| *Development – Conduct further analysis for the best arrangement using other dates/hours* | | | |
| **Dec 21** | Bse_21Dec_10<br>Bse_21Dec_12 | Gf2m_21Dec_10<br>Gf2m_21Dec_12 | Nm2m_21Dec_10<br>Nm2m_21Dec_12 |
| **Mar 21** | Bse_21Mar_10<br>Bse_21Mar_12 | Gf2m_21Mar_10<br>Gf2m_21Mar_12 | Nm2m_21Mar_10<br>Nm2m_21Mar_12 |

*Table 2. Material properties for the setting.*

| Item | Properties | Remarks |
|---|---|---|
| Walls, ceiling, window sill | Material: Off-white paint<br>Reflectance: 68% | ▪ Classroom size is 6×8 m (48 $m^2$)<br>▪ Classroom Height: 3m<br>▪ Properties reflect common construction materials used in the UAE school buildings |
| Glazing | Material: Clear coated low-E<br>Transmittance: 75.30%<br>Reflectance: 11.20%<br>Thickness: 3.84 mm | |
| Window frame | Material: Brushed aluminium<br>Reflectance: 79%<br>Specula: 50%<br>Roughness: 10% | |
| Ghaf Trees | Reflectance: 31.50%<br>Canopy density: 47%<br>Colour: Green<br>Height: 5m | ▪ Canopy density of actual trees is estimated based on image analysis of black and white pixels. |
| Neem Trees | Reflectance: 31.50%<br>Canopy density: 66%<br>Colour: Green<br>Height: 5m | |

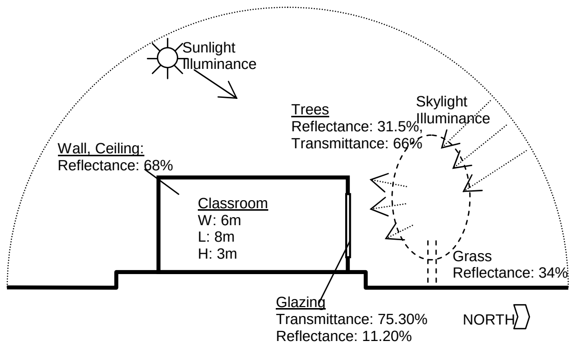


*Figure 3. Conditions of the simulation.*

Finally, the last stage involved analysis of simulation results and developing design guidelines. The experimental design involved several improvement tests (cases), in addition to the base case, as shown in Table 1. Two independent (design) variables are tested; i.e., tree type and tree spacing. Clear sky with sun conditions, for December 21 and March 21 at 10:00 AM and 12:00 Noon, are used based on Dubai location coordinates (Latitude 25◦ 16' N, Longitude 55◦ 20' E). Other conditions of the simulation and material properties for the building and trees are described in Table 2 and Figure 3.

## ANALYSIS

### Visual Performance

Contrasting luminances in the field of view should be comfortable and aid to improve visual performance. It is desirable to make the visual task the brightest object in the field of view. According to previous findings in the literature (Baker et al. 1993), the following luminance ratios within the field of view should be aimed at: between task and darker surrounding 3:1; between task and remote darker surfaces 10:1; between light sources and surroundings 20:1; maximum contrast 40:1; highlight object for emphasis 50:1.

Before performing the main experiemnt, an initial test was done to detect the effect of tree spacing (3 trees with 4 meter spacing versus 6 trees with 2 meters spacing) on visual performance using a certain date/hour condition (Mar 21, 10 AM). Although the 4-meters spacing for both Ghaf and Neem trees showed potential of improving performance over the Base case (no tree), the 2-meters spacing provided the best performance. Accordingly, it was decided at this point to use only the 2-meters spacing for any upcoming tests. With reference to Figure 4, one can describe the visual performance results as follows:

### Base Case

Some visual discomfort problems can be observed in the space:

Contrasting luminances: the luminance contrast between the left side of the blackboard surface (the lighting task; around 150-250 cd/m$^2$) and the left side of the front wall (50-150 cd/m$^2$) lies within the recommended luminance ratio (i.e. 3:1) on December 21 at both 10 AM and 12 PM. However, one can notice an increase in luminance levels on the left side of the blackboard and wall on March 21, especially at 12 PM. This created higher luminance contrast between the blackboard (150-350 cd/m$^2$) and the lower part of the front wall (50-150 cd/m$^2$) that exceeded the recommendation. The luminance contrast between the blackboard surface and other remote surfaces such as the left windows' wall in all tested instants (10 AM and 12 PM on December 21and March 21) exceeds the recommended luminance ratio 10:1. Both 10 AM and 12 PM cases of March 21 (250-350 cd/m$^2$) show higher luminance contrast than those of December 21 (50-150 cd/m$^2$). Other contrasting luminances are also observed: between the north wall (N-wall) and the far left side of the ceiling (L-ceiling), the N-wall and the east wall (E-wall), and the N-wall and the far left side of the floor (L-floor).

High brightness: this is caused by the luminance of sky portions seen through the north windows. The luminance ratio at both 10:00 AM and 12:00 PM between these surfaces (>2000 cd/m$^2$) and its surroundings (<40 cd/m$^2$) exceeds the recommendation (20:1) for contrast between light sources and surroundings, and also exceeds the recommendation (40:1) for maximum contrast in the space.

Uneven distribution of daylight**:** several spots of uneven distribution of daylight are observed.

### Ghaf-2m

To improve the effect of shading, six Ghaf trees, 2 meters apart, are placed outside at 3 meter distance parallel from the north wall. With this modification, better visual performance was achieved:

Contrasting luminances: On December 21 (10 AM and 12 PM) the Ghaf-2m configuration helps to achieve better visual performance on the blackboard due to reduction in luminance distribution area between the luminance iso-contours 150-250 cd/m$^2$. This also helps to mitigate the luminance contrast between the blackboard surface (>150 cd/m$^2$) and the left windows' wall (<50 cd/m$^2$). Similar improvement can also be observed on March 21, yet not as much significant.

High brightness: the Ghaf-2m configuration also helps to reduce the sky portions seen through the windows significantly - by approximately 80%. The average luminance of the tree-covered portions ranges between 350 cd/m$^2$on December 21 to 500 cd/m$^2$ on March 21. The luminance ratio between these tree-covered portions and its surroundings (<40 cd/m$^2$) satisfies the recommendation (20:1) for contrast between light sources and surroundings.

Uneven distribution of daylight: It provided more uniformly distribution of daylight compared to the base case as can be noticed between the opposite sides of the E-wall and between the opposite sides of the floor (Figure 3C).

### Neem-2m

Significant improvement can be achieved after placing 6 Neem trees, 2 meters apart, at 3 meter distance parallel from the north wall compared to previous cases:

Contrasting luminances: the Neem-2m configuration helps to almost eliminate the luminance contrast between the blackboard surface (>150 cd/m$^2$) and the

left windows' wall (<50 cd/m$^2$), especially on December 21, compared the previous cases.
High brightness: it also helps to reduce the sky portions seen through the windows significantly, by approximately 90%. The luminance ratio between these tree-covered portions (average: 350 cd/m$^2$; range: 50-650 cd/m$^2$) and surroundings (<40 cd/m$^2$) satisfies the recommendation (20:1) for contrast between light sources and surroundings.

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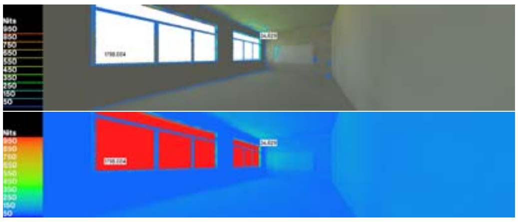
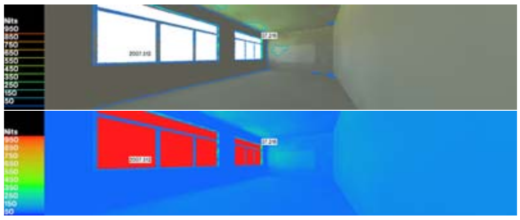
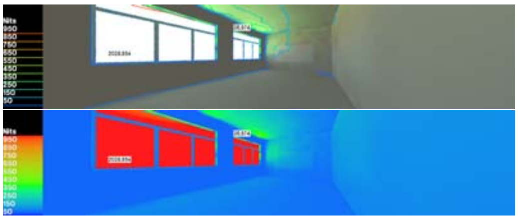
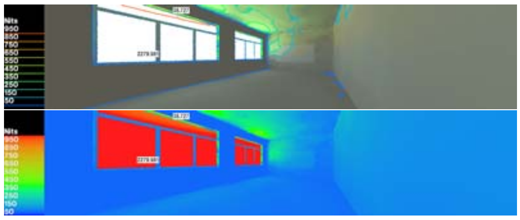
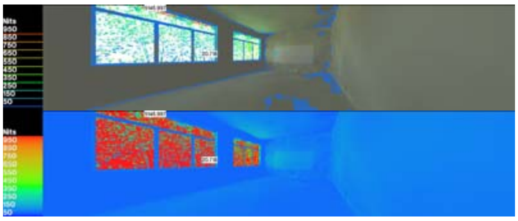
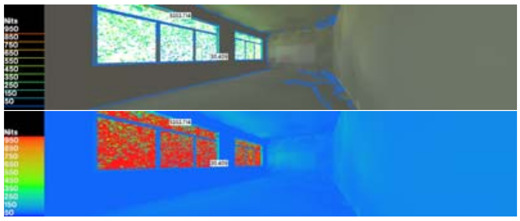
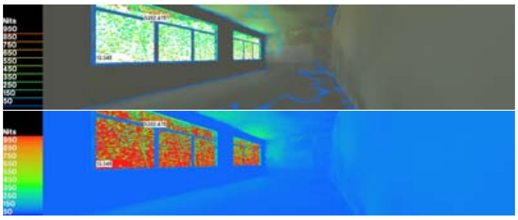
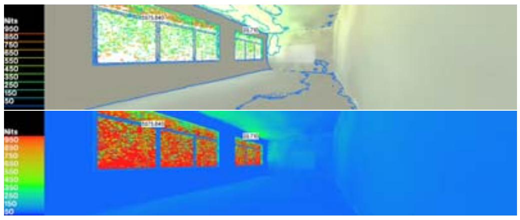
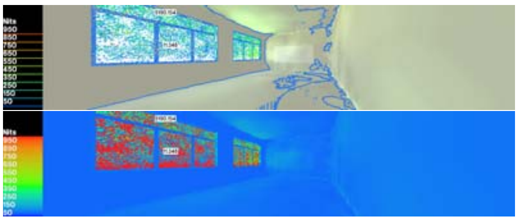
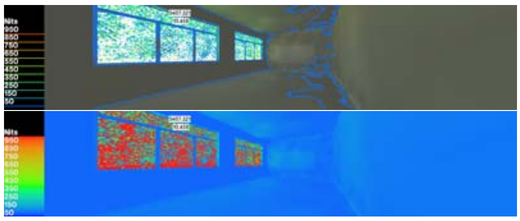
| Bse_21Dec_10_cam_iso.tif  | Bse_21Dec_12_cam_iso.tif  |
| Bse_21Mar_10_cam_iso.tif  | Bse_21Mar_12_cam_iso.tif  |
| Gf2m_21Dec_10_cam_iso.tif  | Gf2m_21Dec_12_cam_iso.tif  |
| Gf2m_21Mar_10_cam_iso.tif  | Gf2m_21Mar_12_cam_iso.tif  |
| Nm2m_21Dec_10_cam_iso.tif  | Nm2m_21Dec_12_cam_iso.tif  |

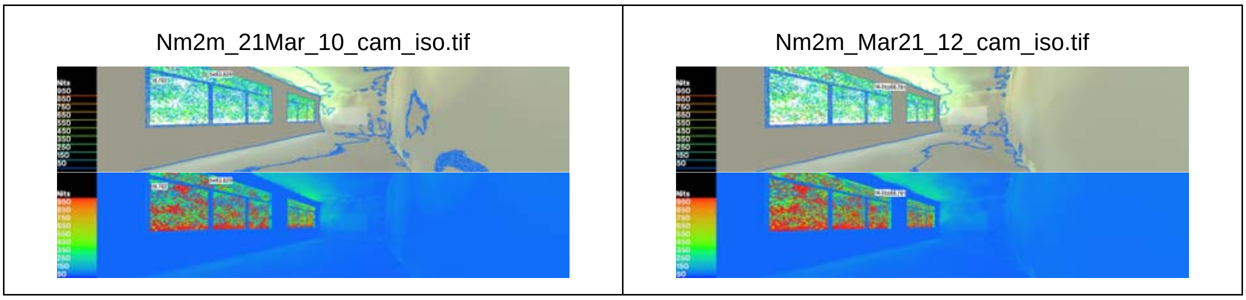



*Figure 4. Radiance results: produced images of luminance is-contours and false colors.*

The sky-seen portions are almost eliminated compared to the previous cases.

Uneven distribution of daylight: It provides significant improvement in uniform distribution of daylight compared to the previous cases (Figure 3E).

*Table 3. Illuminance levels on Dec 21 for all cases.*

| **Dec21** | **Base** | | **Ghaf** | | **Neem** | |
|---|---|---|---|---|---|---|
| **Points** | **10 AM** | **12 PM** | **10 AM** | **12PM** | **10 AM** | **12 PM** |
| *D1, L1* | 388.5 | 439.9 | 296.8 | 360.8 | 292.7 | 292.1 |
| *D1, L2* | 503.9 | 559.5 | 379.7 | 446.5 | 375.2 | 436.0 |
| *D1, L3* | 431.1 | 448.6 | 399.0 | 410.9 | 447.6 | 389.8 |
| *D1, L4* | 416.0 | 414.6 | 401.6 | 373.3 | 320.9 | 350.6 |
| *D1, L5* | 522.5 | 575.2 | 497.5 | 504.7 | 628.2 | 419.7 |
| *D1, L6* | 499.1 | 505.4 | 452.0 | 463.4 | 396.2 | 393.5 |
| *D2, L1* | 264.9 | 296.8 | 198.9 | 255.0 | 157.9 | 208.9 |
| *D2, L2* | 315.8 | 340.4 | 223.4 | 271.3 | 176.9 | 233.2 |
| *D2, L3* | 328.6 | 371.7 | 262.6 | 308.0 | 186.8 | 241.8 |
| *D2, L4* | 335.2 | 344.8 | 256.3 | 284.6 | 238.2 | 244.8 |
| *D2, L5* | 339.9 | 355.8 | 312.9 | 283.3 | 223.3 | 238.6 |
| *D2, L6* | 324.7 | 296.7 | 292.6 | 258.8 | 236.3 | 239.2 |
| *D3, L1* | 173.3 | 198.4 | 120.9 | 134.0 | 89.4 | 141.1 |
| *D3, L2* | 190.3 | 221.6 | 158.2 | 182.8 | 106.5 | 127.4 |
| *D3, L3* | 222.1 | 257.6 | 178.4 | 172.3 | 129.6 | 127.4 |
| *D3, L4* | 206.0 | 224.0 | 181.8 | 193.9 | 143.7 | 125.6 |
| *D3, L5* | 229.9 | 228.9 | 157.1 | 152.7 | 136.8 | 142.1 |
| *D3, L6* | 192.4 | 189.6 | 163.5 | 148.6 | 141.4 | 124.4 |
| *D4, L1* | 131.2 | 153.6 | 87.5 | 114.6 | 55.5 | 58.6 |
| *D4, L2* | 158.4 | 179.8 | 114.3 | 144.6 | 70.9 | 84.9 |
| *D4, L3* | 177.7 | 199.0 | 150.3 | 106.1 | 74.8 | 83.5 |
| *D4, L4* | 190.4 | 211.4 | 162.0 | 160.6 | 101.0 | 76.7 |
| *D4, L5* | 167.4 | 184.1 | 141.2 | 155.4 | 90.1 | 92.0 |
| *D4, L6* | 151.0 | 161.6 | 98.4 | 122.4 | 78.9 | 86.7 |
| **AVG** | 285.8 | 306.6 | 236.9 | 250.4 | 204.1 | 206.6 |
| **r-10*** | 1.00 | -- | 0.83 | | 0.71 | |
| **r-12**** | | 1.00 | | 0.82 | | 0.67 |

* **r-10**: ratio from the Base case at 10AM; ** **r-12**: ratio from the Base case at 12PM. Grey cells indicate illumination < 300 Lux.

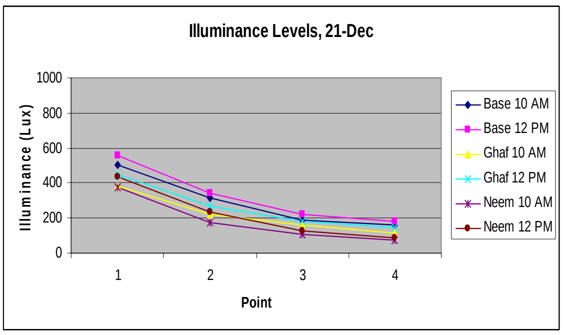
*Table 4. Illuminance levels on Mar 21 for all cases.*

| **Mar21** | **Base** | | **Ghaf** | | **Neem** | |
|---|---|---|---|---|---|---|
| **Points** | **10 AM** | **12 PM** | **10 AM** | **12PM** | **10 AM** | **12 PM** |
| *D1, L1* | 692.3 | 723.2 | 477.8 | 533.1 | 443.2 | 487.8 |
| *D1, L2* | 822.0 | 932.0 | 643.6 | 724.2 | 531.2 | 647.7 |
| *D1, L3* | 702.3 | 767.9 | 550.5 | 642.9 | 433.2 | 588.0 |
| *D1, L4* | 709.5 | 733.1 | 548.4 | 541.7 | 493.2 | 497.7 |
| *D1, L5* | 840.2 | 900.0 | 717.5 | 698.8 | 612.5 | 603.5 |
| *D1, L6* | 720.5 | 818.8 | 572.4 | 623.4 | 551.4 | 570.4 |
| *D2, L1* | 472.7 | 496.0 | 309.1 | 369.1 | 218.1 | 307.1 |
| *D2, L2* | 531.7 | 600.8 | 386.2 | 435.9 | 323.1 | 345.1 |
| *D2, L3* | 555.8 | 616.6 | 402.8 | 435.6 | 372.0 | 386.3 |
| *D2, L4* | 551.3 | 628.5 | 406.8 | 428.4 | 314.9 | 370.2 |
| *D2, L5* | 576.3 | 596.8 | 399.9 | 444.8 | 329.4 | 365.3 |
| *D2, L6* | 522.1 | 537.0 | 372.1 | 373.5 | 254.1 | 306.1 |
| *D3, L1* | 325.2 | 336.8 | 162.2 | 186.8 | 135.9 | 172.4 |
| *D3, L2* | 363.7 | 398.9 | 208.8 | 262.3 | 163.7 | 196.3 |
| *D3, L3* | 401.3 | 410.1 | 222.5 | 296.4 | 192.8 | 226.9 |
| *D3, L4* | 374.3 | 420.5 | 237.4 | 303.9 | 169.5 | 219.8 |
| *D3, L5* | 364.3 | 420.1 | 247.2 | 269.0 | 198.0 | 238.2 |
| *D3, L6* | 330.5 | 348.5 | 211.9 | 215.6 | 183.0 | 174.5 |
| *D4, L1* | 211.1 | 235.2 | 105.6 | 134.4 | 74.3 | 115.7 |
| *D4, L2* | 254.9 | 277.1 | 133.3 | 156.1 | 94.0 | 129.7 |
| *D4, L3* | 266.3 | 302.3 | 159.8 | 190.3 | 101.4 | 165.0 |
| *D4, L4* | 275.1 | 305.1 | 159.0 | 188.1 | 108.7 | 148.1 |
| *D4, L5* | 245.9 | 291.5 | 162.3 | 188.8 | 111.4 | 127.7 |
| *D4, L6* | 215.7 | 238.5 | 132.8 | 150.8 | 113.3 | 113.5 |
| **AVG** | 471.9 | 514.0 | 330.4 | 366.4 | 271.8 | 312.6 |
| **r-10*** | 1.00 | | 0.70 | | 0.58 | |
| **r-12**** | | 1.00 | | 0.71 | | 0.61 |

* **r-10**: ratio from the Base case at 10AM; ** **r-12**: ratio from the Base case at 12PM. Grey cells indicate illumination < 300 Lux.

## Illuminance levels

The illuminance levels across the width of the space depend on the locations of the measurement points on the grid's raws perpendicular to the window wall. For instance, the illuminance levels at the length axis L2 (i.e., the third raw from the front), on depths D1-4 (1 m, 2.5 m, 4 m, and 5.5 m), are shown in Figure 5. It ranges from 504 Lux near the window to 158 Lux near the back wall for the base case on December 21 at 10 AM. After adding the trees, the range went down to 380-114 Lux and 375-80 Lux for the Ghaf and Neem cases, respectively. On March 21 at 10 AM, it ranges between 822-255 Lux, between 644-133 Lux, and between 531-94 Lux for the base, the Ghaf, and the Neem cases, respectively.



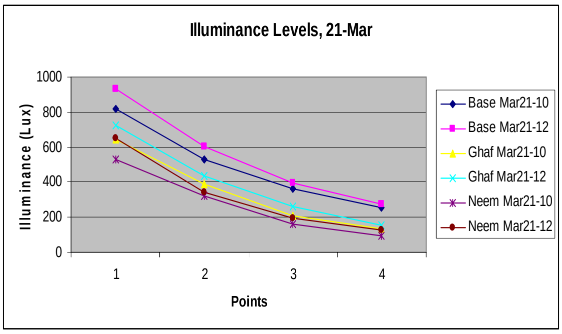



*Figure 5. Illuminance levels across the classroom depth for the different simulated cases*

The Illuminance level across the classroom length (L1-L6) near the windows (at 1 m depth) in all cases is above the min. requirement (300 Lux; 27.87 foot-candles for general reading). At 1 m depth (D1), the highest illuminance levels were measured on the length axis L5, while the lowest illuminance levels were measured on the length axis L1. On December 21 at 10 AM, the Illuminance level across the length of the classroom at 1 m depth ranges between 390-523 Lux in the base case, between 297-498 Lux in the Ghaf case, and between 293-628 Lux in the Neem case. On March 21 at 10 AM, it ranges between 692-840 Lux in the base case, between 478-718 Lux in the Ghaf case, and between 433-612 Lux in the Neem case. The Illuminance level in the backspace (5.5 m depth) in all cases is below the minimum requirement. The base case suffered from insufficient illumination (< 300 Lux) on December 21 at 4 m depth and beyond. When trees were used, the illumination levels decreased and as such the classroom would lack sufficient lighting at 2.5 m and beyond. On March 21, the classroom would suffer from insufficient lighting at 5.5 m depth and beyond in the Base case, and at 4 m and beyond for the trees cases. On December 21 at 10 AM, the Illuminance level across the length (L1-L6) at 5.5 m depth (D4) ranges between 131-190 Lux in the base case, between 88-162 Lux in the Ghaf case, and between 56-101 Lux in the Neem case. On March 21 at 10 AM, it ranges between 211-275 Lux in the base case, between 106-162 Lux in the Ghaf case, and between 74-113 Lux in the Neem case. The effect of using trees on the overall average reduction of illuminance levels (compared to the Base case) were observed. Out of the Base case, it decreased 17% and 29% at 10 AM for the Ghaf and Neem cases, respectively; and 18% and 33% at 12 PM for the Ghaf and Neem cases, respectively.

## CONCLUSION

After carrying out daylight analysis (luminance ratio, llluminance levels) in a typical classroom space in the UAE using Radiance, three sources of visual discomfort were found: acute contrasting luminances between the task surface (i.e., blackboard) and other near surfaces, high brightness coming from the windows, and uneven distribution of daylight in the space. That was evident in the base case. To solve these problems, the study used two types of local trees (i.e., Ghaf and Neem) to scatter sunlight and reduce its intensity, and moderate high brightness coming from the sky. The use of trees showed a potential to mitigate the visual discomfort as related to these three factors; especially when the spacing between the trees was reduced from 4m to 2m. The case Neem 2m-spacing provided the best performance with regard to luminance ratios. The illuminance analysis showed that all cases suffered from insufficient lighting in the backspace (5.5 m depth and beyond). Although the backspace experienced less illuminace levels with the trees (about 23% on average out of the base case), the added improvement in visual performance after adding the trees could justify it. Accordingly, it is recommended to use trees on front of classrooms' north windows in the UAE to provide visual comfort. The trees will be also useful in providing other significant environmental benefits such as solar shading, passive cooling, noise reduction, and healthier environment. In the future, a survey of other types of trees, trees arrangement, and classroom orientation should be added. Comparing simulation results against actual measurements will also be needed to validate the results.

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## APPENDIX – DESCRIPTION OF TREES

Ghaf - The Ghaf tree (scientifically named: Prosopis cineraia or Prosopis spicigera) belongs to the Leguminosae family. It is a slow growing evergreen tree that exists in the deserts of India, Iran, and the Arabia Peninsula. It exists widely and lives in several ecologies in the UAE including sand dunes. The average height for trees with an interplant distance of 2-2.5 m is 6.45 m. The average canopy cover per plant is about 57 $m^2$. It withstands slight frost (-6°C minimum) and high temperatures (40–50°C maximum shade). The tree occurs in areas with Mean Annual Rainfall (MAR) as low as 150 mm and extends to the sub-humid zones with up to 800 mm MAR. (after Prosopis cineraria (L.) Druce, http://www.fao.org/ag/AGP/AGPC/doc/GBASE/DATA/PF000371.HTM)

Neem - The Neem tree (scientifically named: Azadirachta indica) belongs to the Meliacae family. It is a large evergreen tree, 12 to 18 meter in height and 1.8 to 2.4 meter in girth with a straight bole and long spreading branches forming a broad crown as much as 20 metres across. It generally performs well on areas with Mean Annual Rainfall varying from 400 - 1200 mm. It thrives under the hottest conditions where maximum day temperature reaches 50°C. Considering the versatile nature, uses & growing global importance of neem the United Nations declared it as the "Tree of the twenty first century". Its large scale production promises to help alleviate several global environmental problems: deforestation, desertification, soil erosion & perhaps even global warming (If planted on a truly large scale). Large scale neem plantations can help in rehabilitation of degraded forest lands & vast tracts of wastelands & greening the environment. (after NABARD, http://www.nabard.org/roles/ms/fw/neem.htm)

*Figure 6. The Ghaf tree (left) and its leaves (right)*

*Figure 7. The Neem tree (left) and its leaves (right).*