A study of the application of the BRE Average Daylight Factor formula to rooms with window areas below the working plane

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ABSTRACT

In urban canyons where, apartment buildings can be beneficial in terms of their close proximity to offices, shops etc, causing less traffic congestion and pollution, saving fuel costs and bringing people in close proximity to city centres. At the same time trying to accommodate people in city centres, leads to the development of congested and confined narrow deep apartments which have to be mechanically ventilated and artificially lit. To reduce costs, in 1962 designers began building narrow structures with light curtain walls and thin frames to increase daylight and natural ventilation. These factors bought about overheating and noise pollution in buildings. More focus then went on to the design of windows and their fixtures to prevent heat loss, overheating and internal acoustical treatment of ceilings and floors to prevent acoustical reverberations[1]. The above views that windows were net energy debits disregarded the net solar heat gains in winters and reduction in electric lighting loads through out the year. Experience now shows that well day-lit buildings have lower running costs and are more energy efficient. In restricted sites, designers tend to design spaces with maximum window areas' specifically using full height windows to compensate for deep spaces in maintaining daylight. This study lead to investigating the validity of the BRE Average daylight factor formula for how windows with increased areas below the working plane contribute to the ADF in 'Site planning,etc'[4].

1. INTRODUCTION

The paper discusses the results of an investigation of model rooms comparing different window areas for rooms that comply and not comply with the limiting depth criteria a measure of adequate daylight distribution [4].

$L/W + L/H \leq 2/(1-Rb)$

where L is length, W is width, H is height and Rb is average reflectance of surfaces

23 THE AVERAGE DAYLIGHT FACTOR (ADF):

Th ADF is defined by [4];

"Ratio of total daylight flux incident on the working plane to the area of the working plane, expressed as a percentage of the outdoor illuminance on a horizontal plane due to an unobstructed CIE Standard Overscast Sky" Originally Lynes[5] derived the Average daylight factor based on Sumpners work. Lynes formula took the average daylight on the surfaces and not on the working plane.

$$\text{ADF (Lynes)} = \frac{T\,Aw\,\Theta}{2A(1-R)}\ \%$$

The modified formula derived by Crisp and Littlefair[2] at the BRE gives the ADF on the working plane and is now widely adopted in particular by CIBSE.

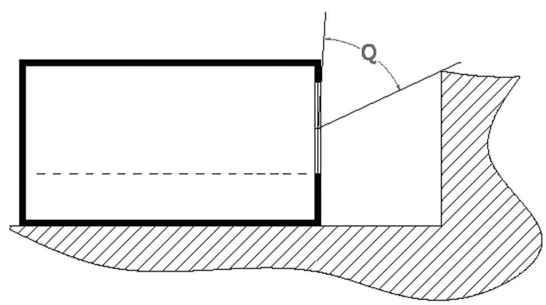


Fig 1: Showing the angle of obstruction (θ) that is used in the ADF formula

$$df = \frac{T\,Aw\,\theta}{A(1-R^2)}\ \%$$

T is the diffuse visible transmittance of the glazing.
Aw is the net glazed area of the window (m^2)
A is the total area of the room surfaces: ceiling floor, walls and windows (m^2)
R is their average reflectance of the room surfaces ie walls, floors and ceilings.
θ is the angle of visible sky in degrees.

When the prediction of the this formula was compared against existing daylight factor data measured in side lit model rooms, the formula gave results with a standard error of ±10% of the measured values[5]. P.Tregenza[7] had proposed a modification formula using the split flux method. His formula takes into account large and complicated external obstructions forming an irregular skyline, while the BRE ADF formula assumes a continuous horizontal obstruction.

$$DF\ avg = tW\left(\frac{C}{Afw} + \frac{Cp\ fw + Dp\ cw\ pg}{A(1-p)}\right)$$

Where,

$$IRCmean = t\ \frac{W}{A}\ \frac{Cp\ fw + Dp\ cw\ pg}{1 - p}$$

t transmittance of windows, taking into account the correction factors.

W window area

A total internal area of the room

Afw Area of the floor and wall surfaces below the centre height of the windows, excluding the window wall surfaces.

pfw Mean reflectance of the floor and wall surfaces below the centre-height of the windows, excluding the window wall surface.

pcw Mean reflectance of the floor and wall surfaces above the centre-height of the windows, excluding the window wall surfaces.

p Mean internal reflectance: floors, walls, ceilings, windows

pg Mean ground reflectance (the effective ground extends from the building some 3 to 3.5 times the height of the ceiling above the ground)

A validation study was conducted by Edward[6] comparing the BRE ADF method and Tregenza's modified split-flux method. He measured the lab results to determine which calculation method is more suitable for use in highly obstructed environments under overcast skies.

Table 1: Results from NG's investigation of both the formulas and measure results.[6]

Q Angle of visible sky	BRE ADF Method	Modified Split-flux Method	Measured Results
20º	0.65	0.11	0.09
30º	0.98	0.28	0.31
40º	1.31	0.56	0.62
50º	1.63	0.95	1.01
60º	1.96	1.41	1.53
70º	2.29	1.89	2.1
80º	2.61	2.31	2.4

From the results above, he concluded that Tregenzas' formula gave closer results to the measured ones then the BRE ADF formula. For low obstruction angles the BRE ADF formula gave close results but with a higher degrees of obstruction big differences were recorded.

3. MODEL STUDIES

It was decided to compare the differences between the average daylight results for full height windows and average daylight results for windows with the sill height at the level of the reference plane (0.85m). This was done to understand the performance of both window types and how they contribute in increasing the ADF on the working plane. This would further help establish if the BRE ADF formula is the most appropriate method to measure the ADF in a room with a full height window.

Two models were constructed. The models differed only in having windows in different walls such that one complied with the limiting depth criteria and the other did not. Both physical scale models and computer models were constructed.

For this investigation, the correction for transmission was taken to be 0.7 and the study was carried out in the following stages.

No obstructions were placed in front of the model. The room was modelled with both a full height window and a window with a sill height of 0.85 m above the floor level. With the physical scale model, measurements were taken on a grid using a Megatron Architectural model daylight factor meter under the artificial sky at the London Metropolitan University. The calibration of the Megatron photocells was checked with an Optronik miniluxmeter.

The second step was to compare the same model using three different software programmes; Radiance, Eco-tect and Relux, their results were compared with the measured ADF results. The simulations further investigated the contribution of the Internally Reflected Component by assuming no external obstruction. These results were compared to the BRE average daylight factor method results.

The models had the following reflectances which were measured using a Minolta CR 300.

Ceiling Reflectance = 82.4%

Wall Reflectance = 48.2%

Floor reflectance = 21.1%

External horizontal illuminance in the artificial sky at the London Metropolitan Universtiy was 2800 lx ± 1%

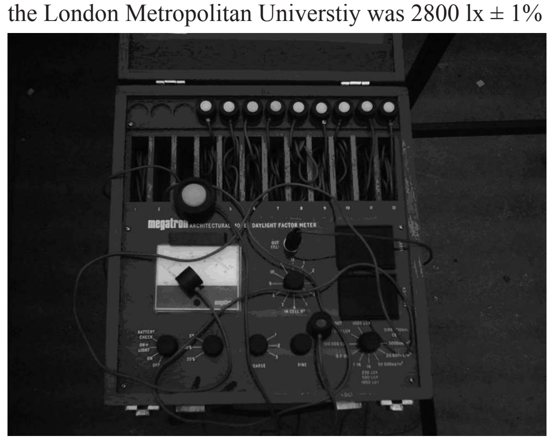


Fig 2: Megatron Daylight Factor Meter used for the measured results.

3.1 Model Description;
Model 1:

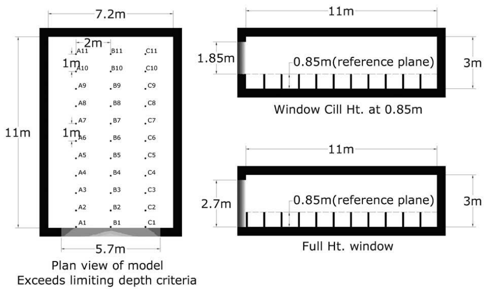


Fig 3: Model 1 showing the plan, section of both full height and sill height windows with placement of the photocells.

Model 2:

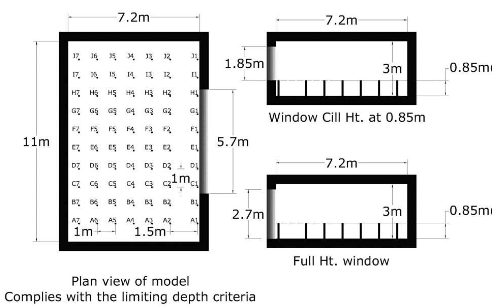


Fig 4: Model 2 showing the plan, section of both full height and sill height windows with placement of the photocells.

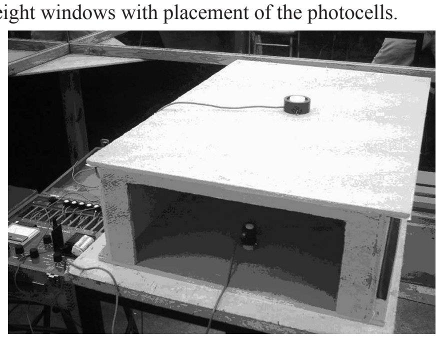


Fig 5: Model A4 with full height window. This model does not comply with the limiting depth criteria. For measured results see table 2.

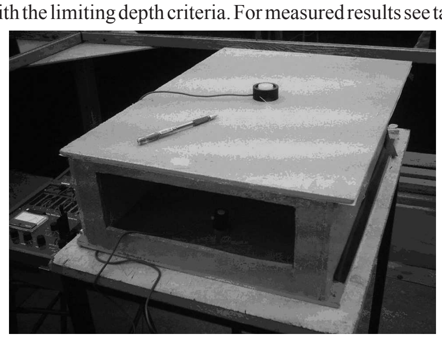


Fig 6: Model A3 with a window sill height at 0.85m. This model does not comply with the limiting depth criteria. For measured results see table 2.

Fig 7: Model B4 turned around with a full height window and complies with the limiting depth criteria. For measured results see table 4

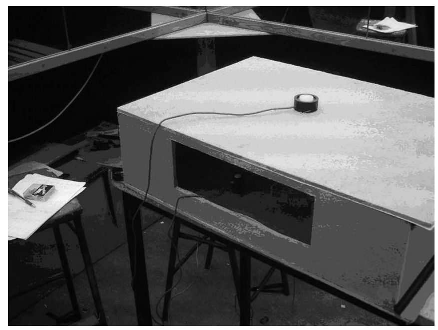
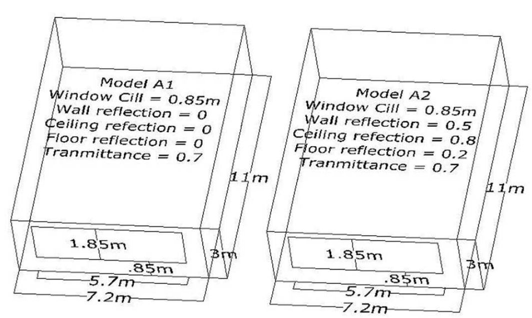


Fig 8: Model B3 turned around with window sill height at 0.85m and complies with the limiting depth criteria. For measured results see table 4.

4. SIMULATIONS

More studies were conducted by simulating the same geometrical parameters for the room that was used in the artificial sky study using three accredited simulation programmes: Radiance, Eco-tect and Relux. Because of known potential inaccuracies with physical scale model studies, these would potentially be more accurate, in particular those with Radiance. There were two sets of models created, Set A and Set B. Each set contained 4 models as shown below with different reflectance and window areas;

4.1 Set A Models;



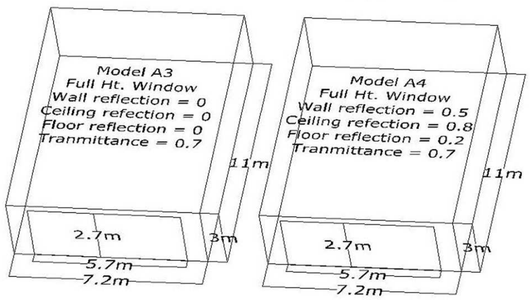


Fig 9: Model proportions for Set A models A1, A2, A3 & A4

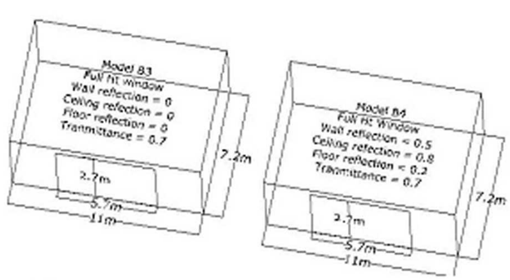
Table 2: ADF results for the simulated and measured models for Set A

Simulated results compared with the BRE formula and Measured results for Set A				
	Model A1	Model A2	Model A3	Model A4
Radiance	2.73568	3.34348	2.73485	3.5358
Eco-Tect	2.45	3.22	2.45	3.54
Relux	2	2.7	2	2.9
BRE Formula	X	3.31	X	4.82
Measured Results	X	4	X	4.65

Table 3: Comparing the percentage increase in the ADF between model A4 and model A2 for Set A

Percentage increase in the ADF by adding a full height window for Set A		
	Model A4 - Model A2	*PERCENTAGE INCREASE IN ADF*
Radiance	3.53588- 3.34348 = 0.1924	5.75%
Eco-Tect	3.54– 3.22= 0.32	10%
Relux	2.9 – 2.7 = 0.2	7.4%
BRE Formula	4.82– 3.31= 1.51	**45%**
Measured Results	4.65– 4 = 0.65	16.5%

4.2 Set B Models;



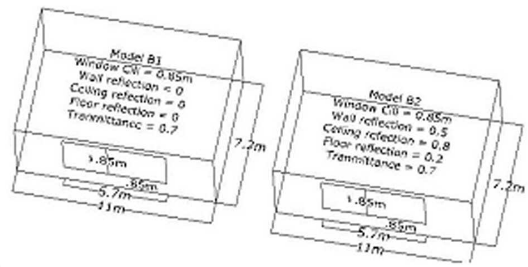


Fig 10: Model proportions and material applications for Set B

Table 4: ADF results for the simulated and measured models for Set B

Simulated results compared with the BRE formula and Measured results for Set B				
	Model B1	Model B2	Model B3	Model B4
Radiance	2.86724	3.42531	2.86707	3.4956
Eco-Tect	2.52	3.31	2.52	3.6
Relux	2	2.4	2	2.5
BRE Formula	x	3.31	x	4.82
Measured results	x	3.75	x	4.2

Table 5: Comparing the percentage increase in the ADF between model B4 and model B2 for Set B models

Percentage increase in the ADF by adding a full height window for Set B		
	Model B4-Model B2	*PERCENTAGE INCREASE IN ADF*
Radiance	3.49561- 3.42531= 0.0703	2.05%
Eco-Tect	3.6– 3.31= 0.29	8.76%
Relux	2.5 – 2.4 = 0.1	4.16%
BRE Formula	4.82– 3.31= 1.51	**45%**
Measured Results	4.2– 3.75 = 0.45	12%

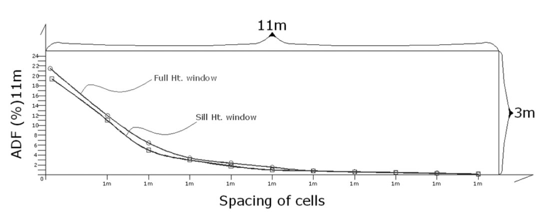


Fig 11: Set A models, graph showing the comparison and distribution of the ADF with full height windows and windows will cill heights at 0.85m above the floor finish level.

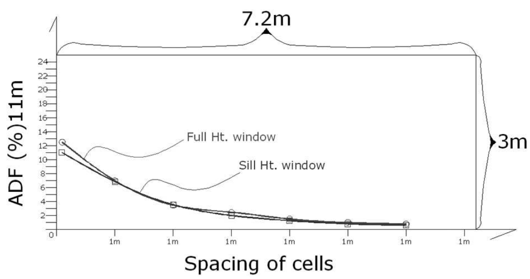


Fig 12: Set B models, graph showing the comparison and distribution of the ADF with full height windows and windows with cill height at 0.85m above the floor finish level.

5. CONCLUSIONS

From the study above it shows by adding a full height window to a side lit room, the window area below the working plane does not contribute much to the Average Daylight Factor

results. It also shows that the BRE formula overestimates the ADF results by about 34% to 35% increase in the ADF results. For windows with sill heights at 0.85m above the floor finish level the formula produces satisfactory results. In order to reach the working plane daylight entering the room from the sky below the working plane must have undergone at least two reflections. Even with light surfaces, say 0.2 for the floor and 0.8 reflectance for the ceiling this reduces the light by 0.16. Analysing the results rather differently, ignoring the physical scale model studies because of their greater likelihood of errors' the average increase of all the simulation studies for the full height as opposed to sill height windows was 6.35%. For the BRE formula it was 45%. Simple division suggests that daylight entering below the working plane should be multiplied by 14% in the BRE formula. At planning stage in the UK daylight and sunlight issues are the only energy and environment issues considered at present. In urban areas architects encouraged by developers are designing deeper spaces and using full height windows to claim they meet minimum daylight criteria. They use the BRE formula to justify their results. Further work might usefully give a better average value than 14%. Maybe for the moment 15% could conservatively be adopted.

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