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Minimum Form, Maximum Performance

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Abstract
With increased sophistication of digital tools in assessing daylight and energy in buildings, a great potential exists to optimize the performance of contemporary building façades. On one hand daylight is welcome and has several benefits. On the other hand, there is a need to reduce the energy consumption in buildings. In this paper, four types of building envelopes are simulated in terms of climate-based metrics and energy consumption. The first two types have 40% window-to-wall ratio (WWR), with one of them having a light shelf. The third and fourth are 100% WWR with one of them having a parametrically driven fixed screen. This study aims to find an optimum solution in terms of daylight and energy use for cooling, heating and artificial lighting for the climate conditions of London, UK by using the integrated simulation approach (daylight and thermal simulation).

Keywords: Daylight, Climate-based metrics, Radiance, Energy, EnergyPlus

1.0 INTRODUCTION
Nowadays architects rely on computational tools in order to investigate new forms and structures. However, computational tools are not just used for form generation, but also for predicting the performance of spaces. On the other hand, environmental awareness and climate change have affected building regulations. They have become more demanding in terms of energy efficiency and reduction of CO2 emissions. Therefore, great effort has been put into the reduction of energy and the adoption of renewables in the building sector.

Windows provide a view and daylight access and therefore large areas are welcome. Conversely, they also contribute to high solar gains and heat losses which can strongly affect cooling and heating loads. It is no surprise that regulations that address conservation of energy in buildings have limited the glazing area to 40% of the wall or have reduced the glazing's solar factor. On the other hand, most office buildings have a fully glazed envelope and any reduction in glazing area may have a great impact on the indoor daylight quality. Daylight can play a major role in human wellbeing. Various research has shown that well-lit workstations will positively affect productivity, increase sales in retail shops and promote faster and better learning in schools. *(Osterhaus, 2005)* Furthermore, a reduction in the glazing area may increase the electricity spent on artificial lighting which already forms a large share of overall energy consumption (30% in office buildings). Analysing these window-to-wall ratios (40 and 100%) as well as the enhanced solutions of the two (e.g. with a shading device) in terms of energy consumption and daylight quality should result in the optimum model for conditions in London (Lat 51.4^{o}, Long 0^{o}).

2.0 CASE STUDIES

2.1 Environmental Conditions

The space analysed is 4m wide, 7m long, and 3m high. It is occupied on weekdays from 9am to 5pm with 60 W/m^2 per occupant (total no 8) and a total lighting power of 432W (to achieve a 500lx) Light controls have a dimmable daylight sensor for this lux threshold. Heating and cooling setpoints are 21^o and 25^o for the occupied times, respectively. The setback temperatures for unoccupied period for heating and cooling are 10^o and 32^o. The space has only one external facade which is south oriented, while the other surfaces are treated as adiabatic. No obstructions are present in the model.

2.2 Facade Variations

A. 40%WWR - designed according to the Part L standard (appropriate U values)
B. 40%WWR + Light shelf (enhanced A case)
C. 100%WWR
D. 100%WWR + 3d parametrically designed ‘screen’ (enhanced C case)

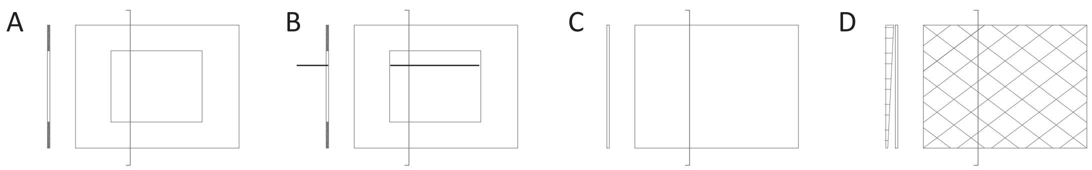

Fig 2.1 4 identified cases, section and front view

2.3 Software packages and analysed metrics

Various software packages are used for simulating the previously defined geometries. The 3d modelling software, Rhinoceros, is used for space modelling and its plug-in Grasshopper for screen generation. Galapagos is used for 40%WWR opening optimization (its XY dimensions), based on average daylight factors. Climate-based metric were not used as a criteria for this optimization, since evolutionary solvers (Galapagos) are slow in general, and such processes would be very time consuming.
Daylight and thermal analyses used the DIVA plug-in. This interfaces with Radiance (also used independently), Daysim, Evalglare and Energy Plus software.
To understand the available daylight in the test office space, Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) were measured by calculating the ‘climate-based metric’ in DIVA. Climate-based daylight modelling is any evaluation that is founded on the totality (i.e. sun and sky components) of contiguous daylight data for some location for a period of a full year. *(Mardaljevic and Nabil, 2006)* The main difference when compared with Daylight Factor calculations is that DF discards the sun contribution (overcast sky) and is a simple ratio of the indoors to the unobstructed outdoors horizontal illuminance. It is insensitive to either the building orientation or its location. *(Mardaljevic, 2009)* Therefore, climate-based metrics provide a much clearer picture of the space’s daylight performance. DA is defined as the “percentage of the occupied hours of the year where a minimum illuminance threshold is met by daylight alone.’’ (Reinhart and Wienold, 2010) In this work, the target illuminance was set at 500lux which means that the daylight autonomy reveals the percentage of the time occupied when the illuminance is over 500lux. However, DA does not tell how good the indoor daylight levels are since it does not provide information about

illuminance levels. On the other hand, UDI provides information on the quality of daylight since it defines the illuminances that fall within the range 100–2000 lx as ‘useful’. Illuminances below 100 and above 2000lux are defined as not useful. *(Nabil and Mardaljevic, 2005)*. After running a climate-based analysis in DIVA, hourly lighting schedules are generated. These schedules are used later in E+ simulations.

2.4 Screen Geometry and Parametric Variation of the Depth

The screen was designed to control solar gains. External shading devices are more thermally efficient because they intercept solar radiation before it enters the room. The screen should also improve the daylight levels because “light shelves” are integrated in its design. (Fig 2.2)

In order to optimize its performance, different types of shading were tested in terms of DA, DF and UDI. The final version is a combination of the 3D and 2D screens studied with a changeable ‘depth’ in the height. The changeable ‘‘transparency’’ of the screen according to its height is a direct result of the ‘‘zoning’’ concept. (Fig 2.2) The upper part has the highest transparency, as it contributes the most to the indoor daylight levels and allows deep light penetration into the room. The lowest part is characterized by smaller openings in order to reduce high daylight levels in the area near the window. Even though they mainly illuminate areas below the working plane, overheating may still occur. For this reason small shading fins are added to allow only diffuse light during summer. The mid-section allows the view outside.

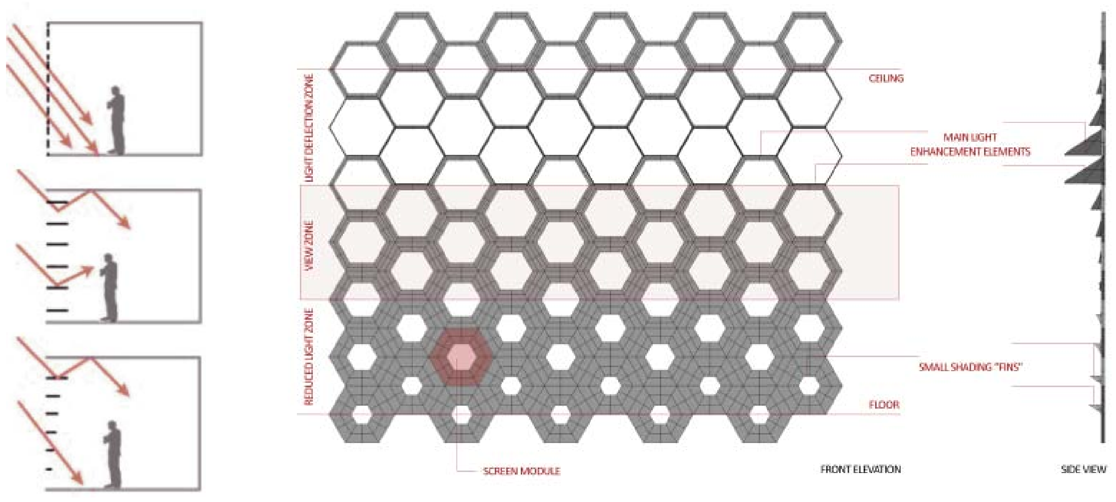

Fig 2.2 Shading Screen Concept and Screen geometry, front elevation and side views

2.5 Thermal simulations

The energy consumption for all 4 cases was calculated with Energy Plus. A limitation of the E+ is the fact that it only works with planar surfaces, which has affected the simulation of the 4th case (100%WWR + screen). A simplified shading object is defined in E+ with attributed shading coefficient schedule. The shading coefficient schedule is calculated as the hourly illuminance ratio on the vertical surface with and without the complex shading modelled in Grasshopper. It is important to emphasize that this is an approximation of the amount of light that enters the room and a simplification of its uneven distribution.

3. RESULTS

The results have shown that when the enhanced systems (light shelf and screen) are applied, each of the cases (40% and 100%WWR base case) experience significant changes in energy consumption. (Fig 3.1) For instance, 40% WWR with light shelf consumes 19% more energy for heating and 66% less energy for cooling. In the case of 100% WWR, the enhanced solution consumes 62% more energy for heating and 54% less energy for cooling.

On the other hand, the introduction of additional elements has affected the daylight levels in the back of the room, so supplemental artificial light is necessary to achieve the desired lux levels. Enhanced 40% and 100%WWR consume 21% and 61% more energy for lighting than the base cases, respectively. (Rusovan, 2012)

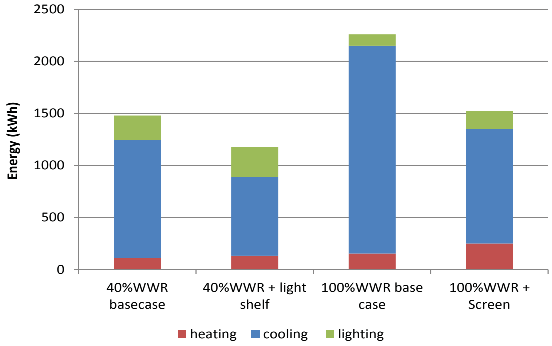

Fig 3.1 Energy consumption comparison

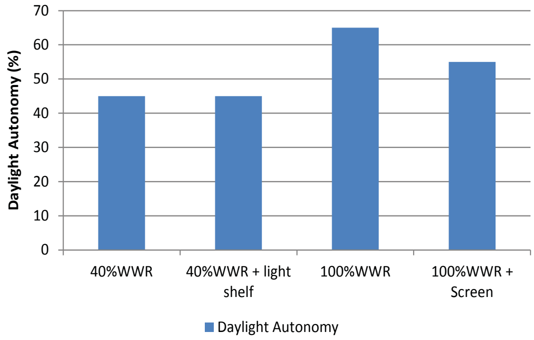

Fig 3.2 DA comparison graph

However, when considering the overall energy consumption (Fig 3.1) after applying the shelf, the energy use of the 40%WWR case was reduced by almost 20%, which is in line with the EU 20 20 20 targets (20% reduction in energy consumption, 20% renewable, 20% reduction in CO_2 emissions). The introduction of the screen on the 100%WWR case shows greater reductions of almost 25%. This comes as a confirmation that additional facade elements can help reduce the energy consumption in buildings in London, which has predominantly overcast skies.

Regarding the daylight quality, climate-based metrics have shown significantly higher DA for the 100%WWR in comparison to the 40%WWR which can result in healthier environments for the occupants (Fig 3.2). When the enhanced solutions are compared, 100%WWR with the screen performs better than the 40%WWR + light shelf in terms of DA (55% and 45%, respectively). When considering the illuminance levels, simulations have shown that the screen reduces the ‘exceeded’ (>2,000lux) illuminance in the area close to the window from 28.1% to 21.8%. (Fig 3.3)

The UDI in that range is the same (15%) for the 40% WWR with and without the light shelf. Overall, this improves the daylight uniformity in the ‘screen’ case since the ratio of the maximum illuminances to the minimum values is lower. (Rusovan, 2012)

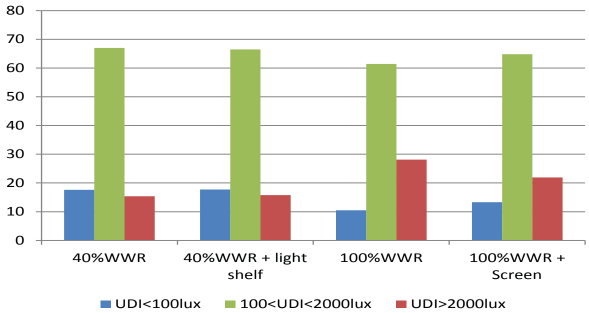

Fig 3.3 UDI comparison graph

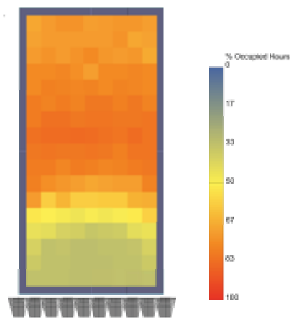

Fig 3.4 UDI screen case

On the other hand, analyses in Radiance have shown a slight increase of illuminance on a sunny equinox day in the back of the room after the light shelf is applied, while the screen resulted in an illuminance decrease. (Fig 3.5)

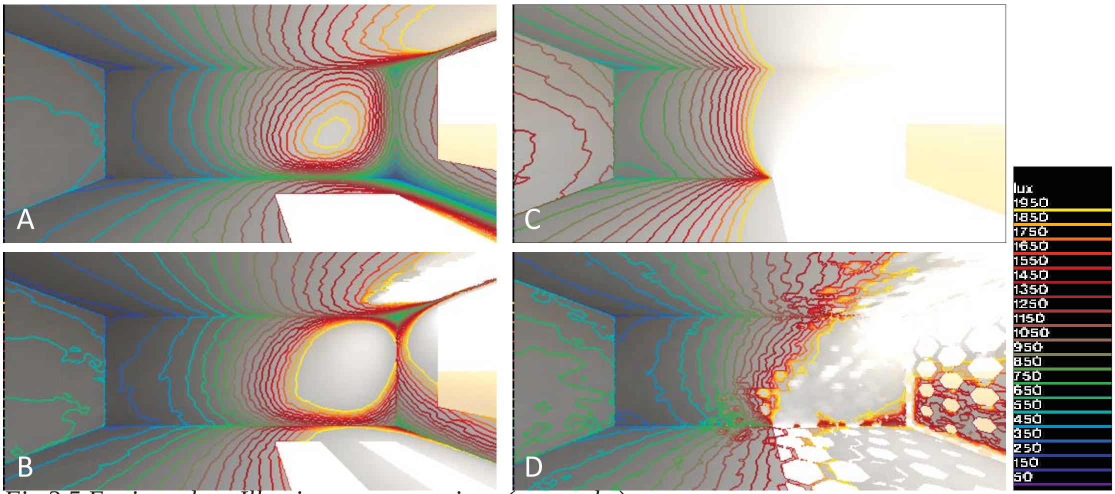

Fig 3.5 Equinox days Illuminance comparison (sunny sky)

The 3d illuminance picture (Fig 3.6) shows that the 40%WWR with light shelf and 100%WWR with screen have a similar performance, with the exception of the winter solstice day where all the cases have different light distributions. In winter, on a sunny day, most of the workplane has illuminance above 500lux. Conversely, on an overcast day (10,000lux) less than a third of the workplane area is above that threshold. Regarding the ‘not useful’ illuminance for the summer solstice, results have shown that the 100%WWR model has the greatest workplane area with illuminance above 2,000lux which can result in the greatest oversupplied area.

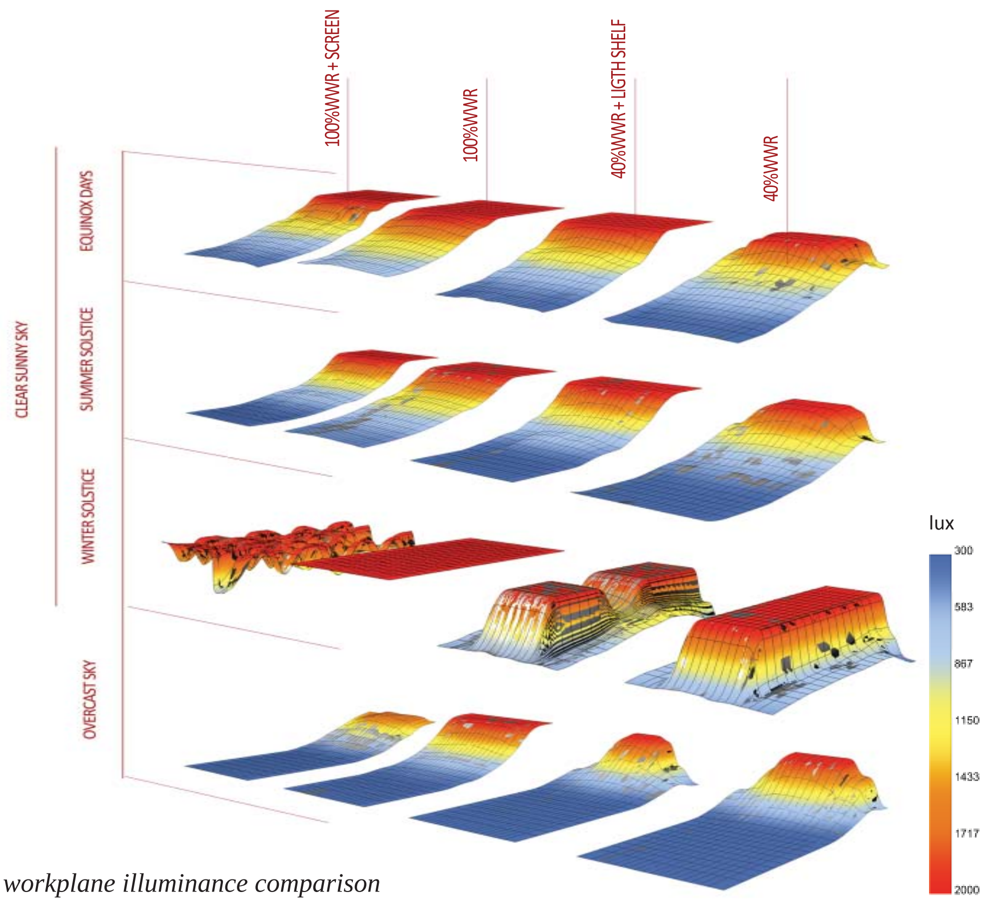

Fig 3.6 3d workplane illuminance comparison

An oversupplied area is defined as the area with illuminance ten times above the threshold (500lux) during more than 5% of the time occupied. *(Reinhart, 2010)* These can cause glare, overheating problems and intensive use of air-conditioning. (Fig 3.3) Both 40%WWR models have lower oversupplied areas than the 100%WWR model but the impact of the light shelf is minimal. The adoption of higher threshold may highlight the real impact of the light shelf. On the other hand, applying a screen to a fully glazed facade reduces the oversupplied area significantly. Since London has predominantly overcast skies, the Daylight Factor method was also addressed. (Fig 3.4) When both enhanced solutions are compared, the 100%WWR + screen shows higher ADF than the 40%WWR + light shelf (3.4% and 2.6%, respectively). However, both are within the range of 2-5% and therefore can be considered a well-lit space, occasionally needing a complement of artificial lighting. It is important to mention that both are not at the risk of overheating since the ADFs are lower than 5%. However, the 100%WWR without the screen has an ADF of 5.5% which suggests a potential overheating problem. Finally, the DF in a room for a 10,000lx overcast sky distribution highlights that both enhanced models do not increase the daylight levels.

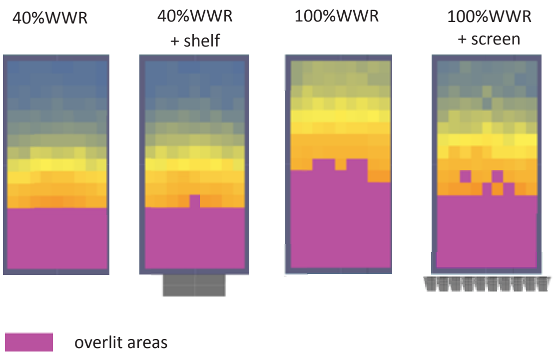

Fig 3.3 Overlit areas comparison

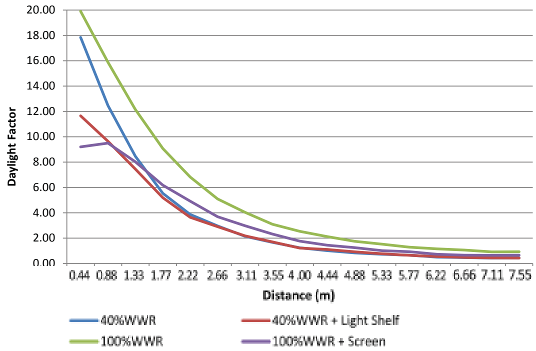

Fig 3.4 Daylight Factor comparison

4. CONCLUSION

Daylight enhancement systems such as light shelves do not significantly improve the daylight levels in London due to a high percentage of overcast skies in the city. However, a major advantage of the light shelf is to provide shading to the lower part of the windows and therefore reduce the cooling loads in summer without compromising the advantage of solar gains during winter. It has been seen that some of the tested cases perform better in terms of daylight than in energy performance or vice versa. Consequently, a compromise has to be made, or a particular issue has to be assumed as a priority. For the purpose of this paper if an equal significance was given to both daylight quality and energy consumption, the light shelf would be assumed as the better solution from the four cases analysed. In individual assessments the screen is the better solution in terms of daylight and the light shelf in terms of its energy performance.

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