Improving Daylighting in Architecture
The SunBloc prototype

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ABSTRACT: This paper compares the application of different methods of assessing daylight in the SunBloc housing prototype developed by London Metropolitan University diploma and masters' students which was awarded an RIBA Silver Medal. Daylight is assessed with the Daylight Factor (DF), the Daylight Autonomy (DA) and the Useful Daylight Illuminance (UDI) methods at different locations in Europe; New rooflights are proposed to the existing model in order to improve daylight conditions indoors; the aim is to generate a better lit space with adequate levels of daylight, evenly spread over the space. Particular emphasis is given to recommended daylight levels, but also to the excessive levels which may cause glare and lead to overheating problems.
Keywords: Daylighting. Climate-based metrics, rooflights

INTRODUCTION

The importance of sustainable and low-energy architecture has increased with the awareness of climate change. Building regulations, design techniques and methodologies are being updated accordingly. The evaluation of well daylit spaces needs more accurate methods that assess not only illumination standards, but include performance in terms of human comfort. The traditional Daylight Factor approach benefits from its simple calculation but misses variability in time. A climate-based analysis, which employs time-varying sky and sun conditions and predicts hourly levels of absolute daylight illuminance is a step towards more realistic predictions over the study area.

Daylight is an essential resource that is freely available. It has the facility to transform an internal space from an invariable uniformity into an emotionally inspiring experience for occupants. This ability to both illuminate an area and to make it more stimulating is one of the main reasons why architects bring natural light into a space.

METHODOLOGY

Daylight conditions in a non-conventional building, conceived for different types of inner-city rooftops and other leftover urban sites, are studied and simulated with three different methods. The approaches used are: Daylight Factor (DF), Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI), see Fig. 1 [1]. The software used to run the simulations is DIVA, a highly optimized daylighting and energy modelling plug-in for Rhinoceros (Nurbs modeller) which uses weather data files from the U.S. Department of Energy and RADIANCE as the background engine for daylight calculations [2, 3].

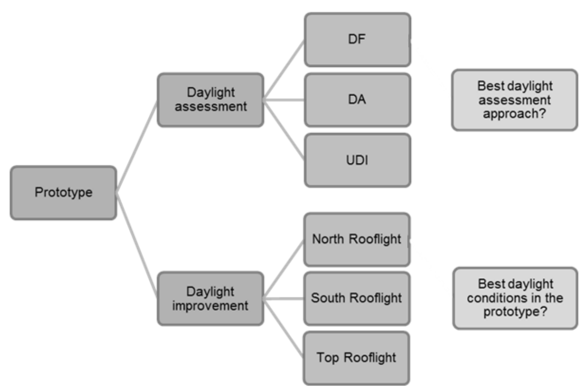

Figure 1: Scheme of the approach and daylight proposal.

A main aim of this study was to assess daylight in the model and propose further solutions to enhance its availability. There is the expectation for the space to be daylit for as many of the occupied hours as possible. The occupancy pattern has been defined from 08:00am to 18:00pm. A grid of 783 sensors has been displayed (30mm X 30mm) at a work-plane height of 850 mm.

The model was simulated in several locations (Athens, Madrid, Paris, London, Helsinki and Reykjavik) across Europe (Fig. 2) as this is a prototype that may be adopted at different locations. It is therefore important to study its performance and minimum requirements. Indoor conditions change as daylight availability is different for different locations as a result of solar geometry and local climatic conditions. In order to assess the generated outcomes, minimum percentage or recommendations are set (well-lit vs. poorly-lit).

A room is considered to have a predominantly daylit appearance if the average daylight factor is at least 2% [4]. There is still much debate on going about the levels of DA and UDI. It has been assumed that a room is well daylit when the DA in the threshold 300lx is achieved for at least 50% of the occupied hours. Likewise the UDI range of 100-2000lx should be obtained for 80% of the occupied time during daylight hours for the new Priority Schools Building Programme in the UK. This is however perceived as excessive and very difficult to achieve in most of the locations studied for this model.

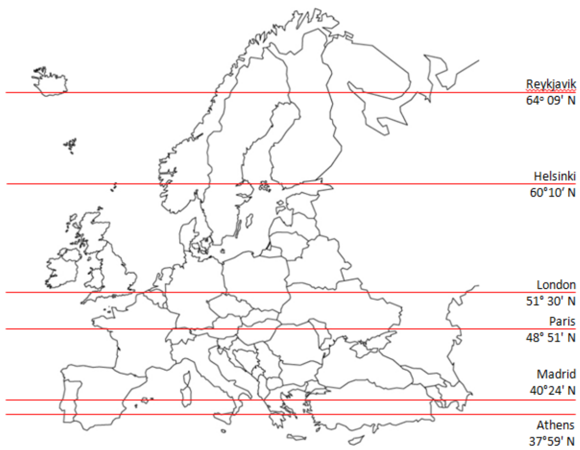

Figure 2: Latitude of the different locations studied.

MODEL DESCRIPTION

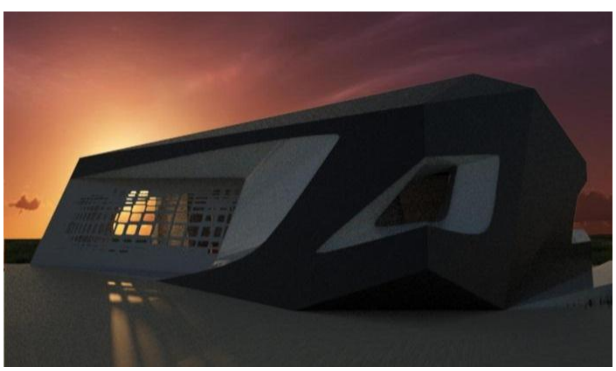

Figure 3: Sunbloc propotype, southeast view.

The SunBloc is a lightweight modular house prototype, designed to be fitted on other building's rooftop or in vacant urban sites as a response to the housing crisis and the wealth of underused urban spaces [5]. This housing prototype has a parametrically optimised façade. The south facade displays an external screen designed to minimise solar gains in summer while allowing views out and daylight penetration into the house and the courtyard during winter. North-east and north-west openings have been minimised to prevent heat losses, yet still allow daylight in and views out (Fig. 3). Openings have a non-standard shape to enhance the indoor design and therefore require a thorough daylight assessment.

The prototype has three different zones (Fig. 4). Zone 1 represents the main living space. Zone2: is the interior courtyard and its screen acts as shading device during the summer. Zone 3 is the non-daylit bathroom.

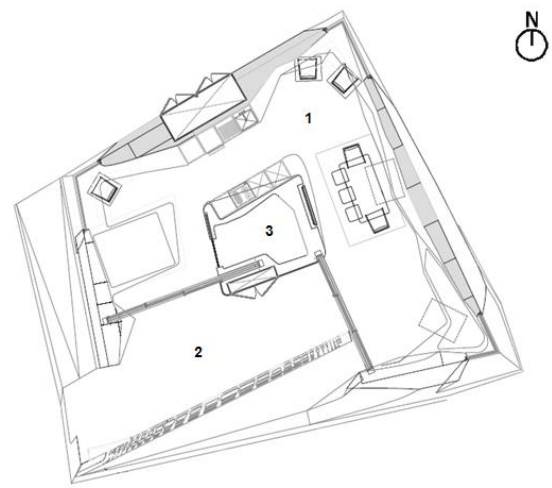

Figure 4: Plan view showing the zones of the house.

RESULTS DISCUSSION

The first sets of results are similar for all locations as they present the Daylight Factor method. This calculation assumes a CIE overcast sky condition with a sky distribution equal for all azimuths, resulting in an analysis independent of orientation. Moreover, this ratio of the indoor illuminance to the unobstructed outdoor horizontal illuminance, expressed as a percentage, will be the same for all days of the year and to different sky luminance. The Average Daylight Factor is calculated as the mean daylight factor over the horizontal working plane.

DAYLIGHT FACTOR

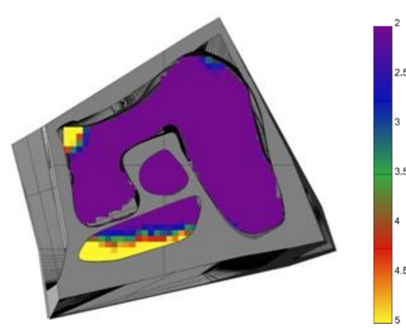

Figure 5: Values of daylight factor (DF) in London

Figure 5 presents the daylight factor distribution on a virtual working plane. Zone 1: A percentage of around 92% of the total area has a DF value below 2% (represented in purple). An increase in DF percentage is experienced near the openings; however, this increment only represents 6% of the total area within the range 2% < DF > 5% and a value of 2% of the total area reaching a DF > 5%. The Average Daylight factor is 0.80% in the main living area. Zone 1 is therefore considered poorly daylit and artificial light will be needed during daylight hours. The uneven daylight distribution will make this space look even gloomier and potential glare may occur near the windows.

Zone 2: This zone is a narrow band close to the shading screen representing the outdoors walkway. The DF range is considerably wider than in the Zone 1. A percentage of around 30% of the total area falls within the range 2% < DF > 5%. A percentage of about 27% falls under a DF value of 2% and 43% of this area exceeds the recommended DF of 5% which may cause visual discomfort and be associated with overheating. The Average Daylight Factor in this particular zone is 5.9%. Zone 2 has a predominantly daylit appearance. Artificial lighting is rarely used. However, the surplus of daylight in the walkaway may be associated with overheating and glare problems.

Table 1: Daylight Factor (DF) and Average Daylight Factor (ADF) in zones 1 and 2 of the model.

	ZONE 1	ZONE 2
DF < 2%	92% of area	26.8% of area
2% < DF > 5%	5.9% of area	30.8% of area
DF > 5%	2.1% of area	42.4% of area
ADF	0.80%	5.89%

The DF method can be used to make initial estimations of daylight in a space. As by its definition sunlight is excluded from the calculation it has been commonly adopted as the worst case for different climatic conditions. It has been argued elsewhere whether this is the correct approach to adopt in predominantly sunny climates [6]. The following methods that consider the annually variation and a climate-based may produce a richer analysis.

DAYLIGHT AUTONOMY

It was felt that the results presenting the DA method are more appropriate to judge different locations and the annual condition as varying sky (with sun) distributions are accountable. However, the results presented can be improved as the method only defines a minimum threshold illuminance of 300lx, ignoring potential problems associated with excessive daylight. Two main reasons may lead to a different method or a modification of the thresholds. Firstly, this method fails to classify the range of daylight illuminances that fall below the given 300lx threshold. The human eye can adapt and perform well under lower levels and this may be useful for dimming artificial light. Likewise DA makes no differentiation of range of illuminance levels above the threshold any particular instant. Indeed, in many parts of the model quite high illuminances are achieved during significant periods of the year, particularly at the covered walkway area, potentially causing glare to the occupants.

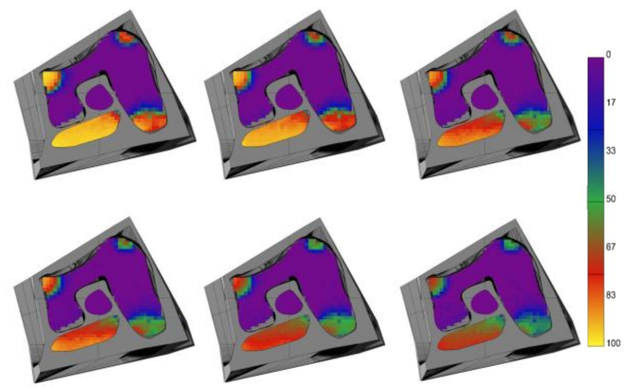

Figure 6: DA for the given locations (clockwise from top left): Athens, Madrid, Paris London, Helsinki and Reykjavik.

Very low and high levels of daylight are known to be associated with occupant discomfort. Daylight Autonomy results for this particular model are considered below the recommendations: a large area and a significant percentage of the time the light levels are below the 300lx threshold in Zone 1. This is well below the recommended 50% of the time (Athens with 18.5% and the lowest being Reykjavik (11.9%). See Figs. 6 and 7. Significant changes are suggested as the current daylight levels are not adequate. Conversely the DA levels are well above the 50% recommendation for zone 2 in all locations. This strong variation may be particular relevant and noticeable when occupants move from one space to the other.

Figure 7 also highlights a negative correlation between the DA and the latitude of the locations studied. Lower latitudes in Europe will tend to achieve a higher percentage of Daylight Autonomy.

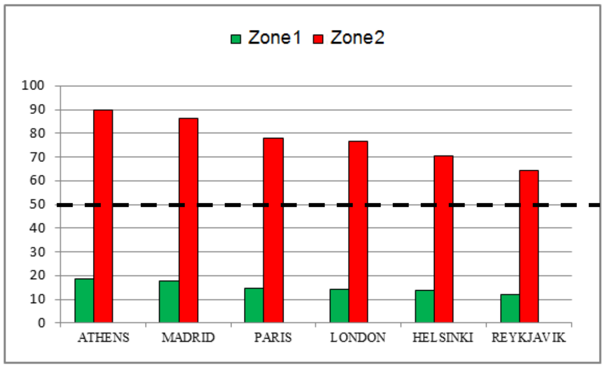

Figure 7: DA for different location on zone 1 and 2 of the model. i.e. the percentage of hours exceeding the threshold illuminance.

USEFUL DAYLIGHT ILLUMINANCE

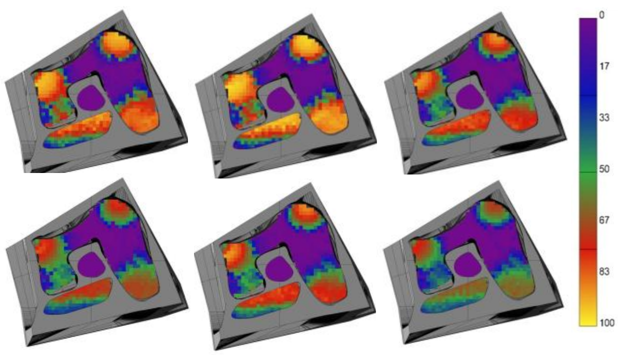

Figure 8: UDI distribution the original model for the given locations (clockwise from top left): Athens, Madrid, Paris London, Helsinki and Reykjavik.

Figures 8 and 9 present the results of the UDI (range 100-2000lx) distribution and overall percentage at Zones 1 and 2 at different locations. All locations have results in both zones well below the aimed 80% of occupied time in the UDI useful range. In Zone 2 this is due to the high illuminance levels well in excess of the maximum 2000lx. Whereas in Zone 1 the highest percentage fall short of the useful range (i.e. less than 100lx)

When looking at the results for Zone 1 (Fig 9) for all locations there is a negative correlation with low latitudes representing high percentage of illuminance in the UDI useful range. Zone 1, which is the most important area shows more significant changes than zone 2 between different locations (17.4% between the highest and the lowest UDI percentage). Even Athens, holding the highest UDI percentage (46.9%) is a long way to achieve the aimed 80% UDI.

On zone 2 Paris displays the higher percentage of hours within the range 100-2000lx. This may be a result of a combination of lower sun's position for this particular latitude which allows more daylight entering the area together with the amount of solar radiation in Paris. A similar situation could be expected for the lower solar altitudes in winter in London and other northern locations. However, a high predominance of overcast skies influences the overall percentages.

A comparison of the results of the different approaches highlights that time-varying illuminance predictions are much more realistic than daylight factor calculations. Furthermore they present the daylight conditions in a concise and comprehensible form. The UDI method is a more informative and comprehensive assessment of daylight conditions than the Daylight Autonomy. In particular, it gives a clearer indication of the propensity for high levels of illumination that are associated with visual discomfort and high solar gains that may result in overheating problems. It is particular relevant that the UDI method adopts a range of illuminations that are founded on human factors considerations. However further studies should be undertaken to define what is the recommended percentage of the time within the Useful range and/or those acceptable on the short and exceeded range.

Likewise experts are suggesting the need to clarify the 'upper threshold'. There is little research to support the selection of 2000 lux as an absolute upper threshold. It has been seen how illuminance values over this threshold appear to be uncomfortable for occupants due to either glare or overheating; the ideal paradigm would also need to assess values exceeding this limit, so designers could easily identify where a problem related to high illuminance is due to occur.

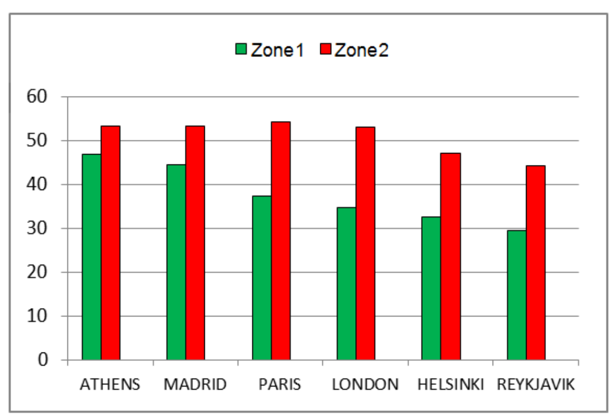

Figure 9: UDI in the range 200to 2000lx in zone 1 and 2 of the model, for different locations

In terms of daylight distribution and uniformity, Zone 1 requires most attention as the light levels do not meet the aimed percentage of 50% for DA nor 80% for UDI in any of the spots where the different daily domestic tasks are performed. To increase the overall illuminance, existing openings would need to be enlarged or new openings designed. Due to the complex shape and size of the building it is not feasible to modify the existing vertical openings. Consequently the solution relies on designing a new rooflight so daylight can be harvested to the zones where it is most needed and to increase the overall illuminance. The modified model is presented in the next section.

IMPROVING DAYLIGHT

Previous results highlighted the poor daylight distribution in the spaces. Areas near the openings show high levels of natural light whereas further away zones experience much lower values. This is expected on side lit zones but is further aggravated when the position and layout of the zone prevents a direct view of the sky and the sun. Sometimes this can be minimized with high surface reflectances that promote inter-reflections within the space. This is already the case with white walls and ceiling (Rho 0.7), but the floor reflectance (Rho 0.2) could have been increased. The zones more affected by low levels of daylight are the kitchen and dining areas where high levels of natural light are expected.

The main purpose of the new rooflight is to bring daylight to where it is most needed and to meet the UDI targeted percentage of 80% while avoiding a high contrast between different areas (well daylit vs. poorly daylit). However rooflights may increase the UDI levels in the 'exceeded' range as a result of high solar altitude in summer and the reduced angle of incidence to the horizontal glazing surface. Moreover no shading devices were projected for these openings. Given the previous studies, the UDI in useful range was the method adopted to assess daylight for the new proposal.

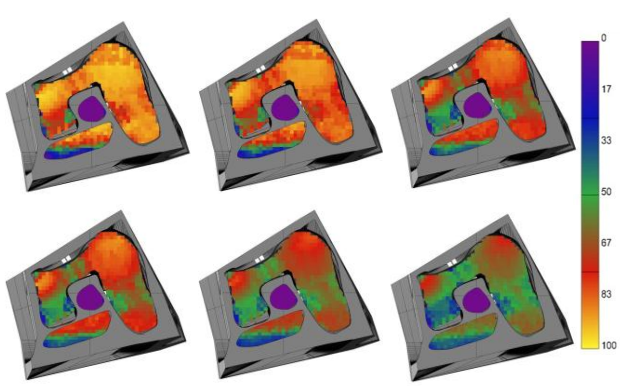

Figure 10: UDI distribution in the proposed model with a top rooflight for the given locations (clockwise from top left): Athens, Madrid, Paris London, Helsinki and Reykjavik.

The best results were obtained with the top rooflight at the ridge (vs south and north rooflights) [1]. Locating the rooflight at this point allowed, daylight to be harvested (no obstructions) and redirected to the interior through a light pipes to the spaces most needing it underneath. These arrangements have also minimised the effect of direct sunlight.

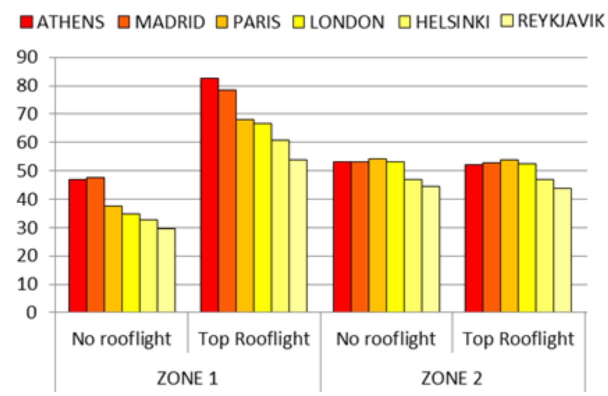

Figure 11: UDI in the range 200to 2000lx on zone 1 and 2 for the existing and proposed top rooflight for different locations

Good light distribution in a building is very important as it decreases the contrast between different areas and provides visual comfort to occupants. The addition of the top rooflight to the prototype allowed daylight deep in the space and helped to unify the well-lit areas near the windows (Fig. 10).

Figure 11 shows how the illuminance levels have increased in Zone 1. An upward trend has been registered in every location, with percentages within the range 100-2000lx nearly doubling. Athens exceeds the aimed UDI percentage of 80% with a maximum value of 82.7%, whereas Madrid is on the verge of reaching this limit, with a UDI value of 78.4%. These percentages highlight the large number of hours that the prototype can be well-lit with daylight only. On average (more hours in summer vs. less hours in winter) the prototype will be sufficiently daylit for 8.25 hours in Athens (GREECE) and 7.85 hours in Madrid (SPAIN). Daylight levels have also increased notably on the rest of the locations, registering values close to 70% in Paris and London, over 60% in Helsinki and over 50% in Reykjavik. It has to be noted that the highest UDI percentage reached in the original model in Athens (46.9%) is lower than the proposed model in Reykjavik (53.9).

CONCLUSIONS

This paper presents results of a daylight analysis comparing the DF the DA and the UDI methods. All the three methods have advantages and disadvantages from simplicity to more detailed assessments and complexity. Daylight Factor is the best-known daylight calculation and is an acceptable method to assess how well daylit a space will be under prevailing overcast sky climates. However, as this research was based on weather files from different locations in Europe, with diverse climates and skies typologies, a climate-based approach was found more useful and accurate. The two approaches (DA and UDI) have been used to evaluate daylight inside the SunBloc prototype. Results identify that both methodologies have 'weak points'. On one hand, DA sets a minimum threshold, which allows an analogy to the minimum level to perform a certain task, but misses an upper threshold or the amount the threshold is exceeded at any particular instant. By not setting an upper limit, very high illuminance levels may be considered acceptable when they could cause visual problems and overheating and strongly affect the occupants' visual and thermal comfort.

The lower and upper threshold problem is solved with the UDI approach. These allows for more 'useful illuminance' levels while rejecting undesirable high levels associated with discomfort and solar gains. The levels are considered more tailored for occupants' satisfaction as they were formulated based on human factors considerations. However further studies are required to assess the validity of these claims in a wider range of scenarios and to a larger population.

While the three methods present different results, they all identify how poorly daylit the original model was. The top rooflight proposed successfully minimised the contrast between areas which are well day-lit and poorly day-lit and enhanced the overall daylight distribution. By placing the rooflight at the top, light could be redirected to areas where it was most needed.
An analysis of the results highlights the importance of the plan depth and layout in the distribution of daylight in a space. Vertical elements may act as barriers to the passage of daylight, affecting is distribution. The bathroom position was a main reason for the poor results for the south and north rooflights. But then each project is a bespoke design and the main concern is that issues related to daylight are thoroughly assessed from the early stages of design where inefficient solutions can be amended. It is also very significant to mention that in SunBloc the penetration of daylight through vertical openings was much compromised by the thickness of the walls, which act as a permanent overhang, allowing natural light just beside the openings. Consequently, creating a rooflight was essential to achieve good levels of daylight in the prototype and an even distribution of natural light throughout the entire floor area.

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