Daylighting the retail environment

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ABSTRACT: In this paper studies related to the achievement of daylighting conditions in deep-plan retail buildings in the UK are discussed.
The context of the study is underlined by current practice in the UK of the design of 'black box' retail buildings where the use of natural resources generally does not feature. As this building type is ever increasing in the growing consumerist environment, a better understanding of its environmental performance is important.
A number of studies were carried out using a standard 80,000sqm plan building with a range of possible design solutions for using daylighting to supplement electric illumination. The tests were conducted using the hemispherical sky and heliodon at the Welsh School of Architecture in conjunction with physical modelling.
Early results indicate that a significant reduction in energy consumption can be achieved using an integrated approach to daylighting and electrical illumination without compromising the high standard of lighting levels demanded by the consumer.
The paper also outlines how the retailer in question is adopting the possible solutions.

Keywords: daylighting, energy, retail environment

1. INTRODUCTION

The retail environment accounts for a growing proportion of the built environment in the UK. The interior of a typical retail floor is brightly lit using predominantly electrical illumination.

There is normally some natural light, typically from the fully glazed entrance façade, but this tends to be made insignificant by the high bay electrical illumination created over the payment counter.

Based on their own studies of customer satisfaction, most large retail stores strive to provide brightly lit interiors with electrical lighting providing levels of around 1200lux. As a comparison it is normally recommended that general offices would be well lit if they achieved 500lux at the desktop.[1]

The result of using such high levels of electrical lighting is that the energy consumption of retail buildings is dramatically increased. With the growing concern surrounding energy performance and CO_2 emissions and their effect on the environment, the use of this high level of lighting is particularly problematic in non-domestic buildings, where lighting is one of the largest consumers of energy.

Much work has been carried out into the link between daylighting design and a reduction in energy consumption. The work done by Duncan and Hawkes[2] highlighted the potential for using daylight in designing energy efficient buildings and the potential of automatic photoelectric controls. Littlefair has also carried on this work with numerous publications looking at passive solar design and the importance of incorporating daylighting design for all architects, such as 'Daylighting as a passive solar energy option: an assessment of its potential in non-domestic buildings'[3]. In this BRE report both the advantages and disadvantages of passive solar design are investigated.

Deep-plan, retail units similarly to industrial sheds present a particular problem in getting natural light to the whole of the floor area. Work has been conducted into this area specifically in publications such as 'The design of roofs for single-storey general purpose factories'. [4]

Tesco PLC is a company aware of the environmental and financial cost of energy use within their stores and are on a drive to promote more energy efficient and sustainable design. They have recently commissioned a detailed survey of energy use across their building stock in order to highlight areas for possible energy reduction. This report, 'Tesco Energy & Environment Store Project: A Proposal – Friday 9th Sept.'[5] highlighted a number of key areas for potential improvement, which when aggregated could lead to an overall 40% improvement in energy use.

As Baker and Steemers suggest in *Energy and Environment in Architecture: A Technical Design Guide,*

> "…*nearly half the UK's energy use is accounted for in buildings.*" [6]

One area headlined for investigation was lighting, as it appeared to contribute a significant amount to the energy load of the building stock. The energy survey carried out on behalf of Tesco PLC[7], suggested that the use of natural light in the sales and back-up areas could provide an energy reduction of approx. 128,000 kWh per store.

"It is estimated that the active use of daylight in this way could save 4-8 million tonnes of coal equivalent each year throughout the EU." [8]

The retail company had already made a foray into the potential of the contribution of daylighting on an existing store. This retail unit in Diss, Norfolk included two parallel banks of north-lights clad with a translucent polycarbonate. The material has an overall transmission factor of approx. 50%. Although the resulting interior is reported to appear gloomy without supplementary electrical illumination, the daylighting will undoubtedly contribute to energy savings across the retail floor.

Tesco PLC were keen to test other possible solutions on another new retail store, to see what could be achieved with more roof-lights. The architects for the new store, HLN Architects, expressed some concern regarding the connotation of the translucent polycarbonate cladding with 'cheap and nasty' factory roofs. This would be an issue for the client in terms of customer perception and quality of the visual environment.

The model store based in Swansea, South Wales, was a typical retail unit 'shed' with a floor area of 80,000sqm, slightly larger than the store at Diss. The project was already on site at the time of the study, so the possible daylighting design solutions were limited. The design team initially decided on a scheme incorporating four ranks of north facing roof-lights following a similar 60/30 degree angle as the roof-lights on the store at Diss. (Fig. 1)

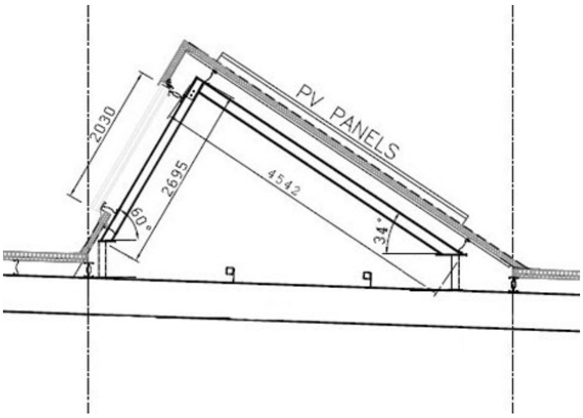

Figure 1: Suggested design of roof-light for store in Swansea

2. METHOD

A physical model was built of the store in Swansea by CRiBE (Centre for Research in the Built Environment) to a scale of 1:100 corresponding to the design team drawings. A series of tests were carried out using the hemispherical artificial sky and heliodon at the Environmental Laboratory of the Welsh School of Architecture.

Four sets of tests were carried out with the model through a range from no roof lights to using four fully glazed roof lights.

- Test of a standard retail floor daylit only from the entrance window wall.
- Test of a glazed north-lit scheme with an array of four ranks of north-lights set at a 60/30 degree angle.
- Test of a translucent north-lit scheme with an array of four ranks of north-lights set at a 60/30 degree angle, clad with a translucent polycarbonate.
- Test of a glazed north-lit scheme with an array of three ranks of north-lights set at a 60/30 degree angle. The northernmost rank is eliminated as it is assumed that the side-lighting from the entrance elevation may provide adequate supplementary daylighting top-up this zone.
- Heliodon studies tracking the path of the sun at three points during the year; on the equinox, summer mid-season and winter mid-season were carried out in order to simulate and analyse the duration and likely effect of solar penetration.

Megatron photopic, cosine corrected photocells were used to record the lighting level throughout the store for each test. This was carried out with an array of 7 by 9 cells spanning the area of the retail floor with an extra cell placed on the roof as a reference between internal and external lighting levels, taken under a CIE standard overcast sky. [9]

There were limitations to this model as the transmission value of the glazing on the model was not accurate.

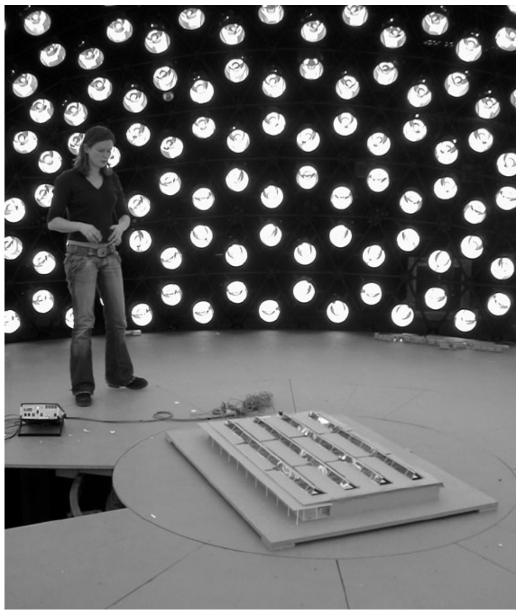

Figure 2: Physical model in hemispherical artificial sky at the Welsh School of Architecture

3. RESULTS

The results are shown in two different formats:-

- Grid referenced daylight factors measured at approximately 12m centres using an array of photocells in a scale model, tabulated.
  The daylight factor is expressed as a percentage of the actual sky condition.

- A contoured area graph corresponding to the retail floor showing, through different tones, the daylight pattern across the store.
  (Figs. 3-6)

3.1 Test 1: Test of a standard retail floor daylit only from the glazed entrance wall.

The results indicate that there was a certain amount of daylight recorded from the glazed entrance wall. However this falls away rapidly as you go into the store. It diminishes from approx. 15% daylight factor at the first photocell down to approx. 2% at the third photocell, 23m from the entrance wall. (table 1)

This version of the model is obviously designed for the retail floor to be electrically lit. It is important to note that the level of daylight over the majority of the floor would not even be enough for emergency escape purposes. The electrical lighting in this situation would need to be designed for virtual 'black box' conditions for almost 80% of the area of the store.

It is also important to note that the glare index from the window wall at the entrance would be disabling without the use of permanent supplementary electrical lighting.

It was important to test this scheme so that there was a base set of results to compare the results of the other schemes against.

Table 1: Daylight factor readings (%) taken at each photocell across the retail floor during Test 1

	north wall of retail floor - entrance								
	A	B	C	D	E	F	G	H	I
2	15.6	14.7	14.8	14	14.1	14.2	15.0	16.1	30.3
3	5.9	4.9	6.7	6.3	6.0	4.9	5.7	5.1	10.6
4	1.9	1.1	2.7	2.1	1.7	1.3	1.5	1.6	1.8
5	1.0	0.7	1.5	1.1	1.0	0.7	0.8	0.8	0.8
6	0.6	0.4	0.5	0.6	0.6	0.7	0.5	0.4	0.5
7	0.4	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
8	0.4	0.3	0.5	0.6	0.5	0.5	0.5	0.4	0.4
	south wall of retail area – delicatessen wall								

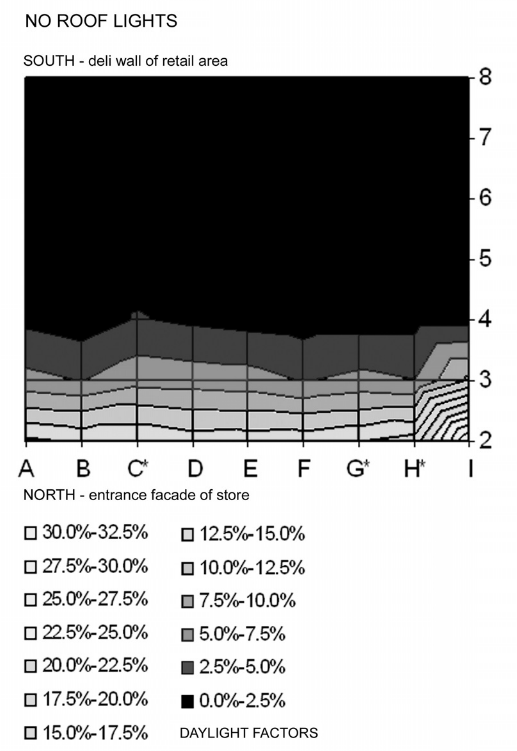

Figure 3: Contour graph corresponding to the area of the retail floor for a scheme with no roof-lights.

3.2 Test 2: Test of a north-light scheme with an array of four ranks of glazed north-lights.

The results of this test indicate that good levels of daylighting can be achieved across the majority of the retail floor. The results peak at the first two ranks of photocells where the roof-lighting and the side-lighting, from the glazed entrance façade, gives a combined daylight factor of approx 19% (this represents 950lux under a overcast sky assumed at 5,000lux) across the width of the store.(table 2)

The lighting levels then fall across the depth of the store relative to the distance from the glazed entrance wall providing side-lighting. However even in the middle of the retail floor (rank 4-6), the roof-lights provide a mean daylight level of approx. 14%, relative to 700lux under a standard overcast sky. The range across this area goes from 8% at the lowest to 17.9% at the highest.

This would be regarded as a well lit interior in many building types such as offices where quite precise visual tasks are carried out but do not necessarily require the bright interior of the typical modern retail floor.

Overall, this scheme provides high levels of daylighting that are relatively uniform.

Whilst this design could not provide a completely daylit interior to the levels that the current electrical lighting provides, over 50% of the lighting load could be provided through passive design measures.

Table 2: Daylight factor readings (%) taken at each photocell across the retail floor during Test 2

	north wall of retail floor - entrance								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
2	18.9	19.2	19.2	19.2	19.2	19.3	19.4	18.9	33.1
3	17.5	17.4	21.0	21.9	18.8	14.8	15.5	13.3	12.9
4	13.3	12.5	17.8	16.7	13.5	12.2	12.4	11.5	4.4
5	10.0	7.7	16.5	14.4	12.5	9.8	9.8	9.6	3.9
6	14.3	16.7	12.1	16.3	13.6	17.9	14.8	12.3	3.3
7	8.4	7.2	8.4	8.8	8.2	9.2	9.2	8.8	2.6
8	10.4	8.2	16.0	16.8	16.4	15.5	16.1	13.9	5.6
	south wall of retail area – delicatessen wall								

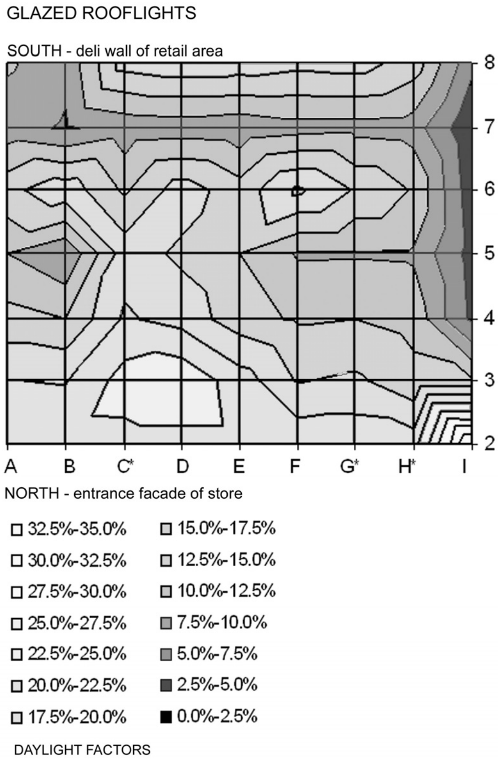

Figure 4: Contour graph corresponding to the area of the retail floor for a scheme with four glazed roof-lights.

3.3 Test 3: Test of a north-lit scheme with four ranks of translucent polycarbonate roof-lights

The results of the test are based on a simulation of the translucent polycarbonate cladding, with a transmission of approx. 50%. The results indicate lower daylight levels across the retail floor than in Test 2. The reduction in lighting amounts to 60% of the levels achieved in the glazed version.

The majority of the floor has a mean daylight factor of 9%, which approximates to 450lux under a standard overcast sky. At the high points it recorded at 12%.

Again this should be regarded as a daylit interior but the overall contribution to the lighting load would be reduced by 20% of the overall load.

The front two ranks of photocells provide levels not dissimilar to Test 2 as the window wall supplements the roof lighting in this area. This might have the effect of making the rest of the retail floor appear gloomy in comparison to the visual experience of entering the store. This could be rectified by electrical lighting but this may make the visual environment seem more reliant on electrical illumination than natural light.

One advantage of the translucent option is the elimination of solar penetration due to the transmission characteristics of the polycarbonate. This was highlighted at the retail store previously tested at Diss.

However there is a concern about consumer perception of the polycarbonate finish and possible connotations with low cost industrial sheds.

Table 3: Daylight factor readings (%) taken at each photocell across the retail floor during Test 3

	north wall of retail floor - entrance								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
2	18.3	18.4	17.9	17.6	16.8	17.9	17.7	18.5	33.2
3	13.4	12.4	16.6	17.1	14.7	11.4	12.4	11.0	13.0
4	9.2	8.0	12.7	11.5	9.1	7.8	8.4	8.0	4.5
5	6.8	4.9	11.5	10.0	8.7	6.8	7.0	6.8	3.9
6	9.5	10.8	8.4	11.3	9.4	12.0	9.7	8.2	3.3
7	5.7	4.8	5.8	6.1	5.6	6.1	5.8	5.9	2.6
8	6.9	4.7	11.1	11.3	11.0	10.4	10.5	9.4	5.7
	south wall of retail area – delicatessen wall								

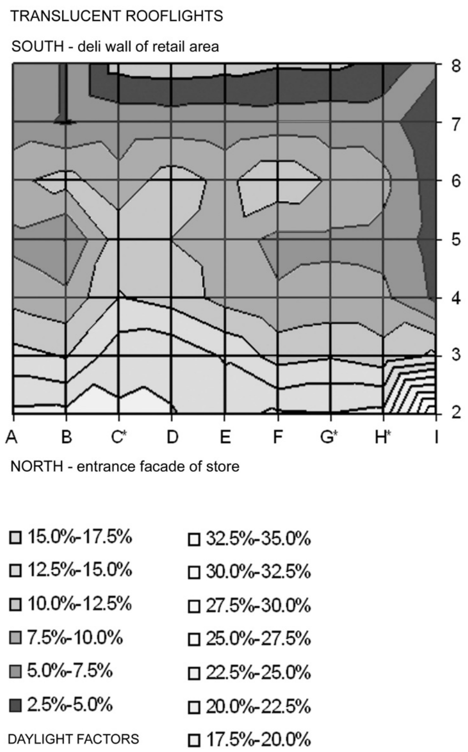

Figure 5: Contour graph corresponding to the area of the retail floor for scheme omitting the front roof-light.

3.4 Test 4: Test of the north-lit scheme with an array of three ranks of glazed north-lights.

Table 4: Daylight factor readings (%) taken at each photocell across the retail floor during Test 4

	north wall of retail floor - entrance								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
2	15.5	14.8	15.1	14.5	14.7	14.2	15.2	16.8	30.3
3	6.5	6.2	8.5	8.1	7.5	5.7	6.5	6.0	10.7
4	10.0	10.5	12.8	12.3	10.8	8.9	9.9	9.2	3.8
5	8.9	6.2	14.8	13.5	11.7	9.0	9.1	8.8	3.8
6	13.8	14.9	12.1	16.0	13.3	17.1	14.3	12.3	3.1
7	7.9	6.7	8.3	8.5	7.7	8.5	8.7	8.6	2.4
8	9.8	6.9	15.9	16.4	16.2	15.4	15.8	13.8	5.8
	south wall of retail area – delicatessen wall								

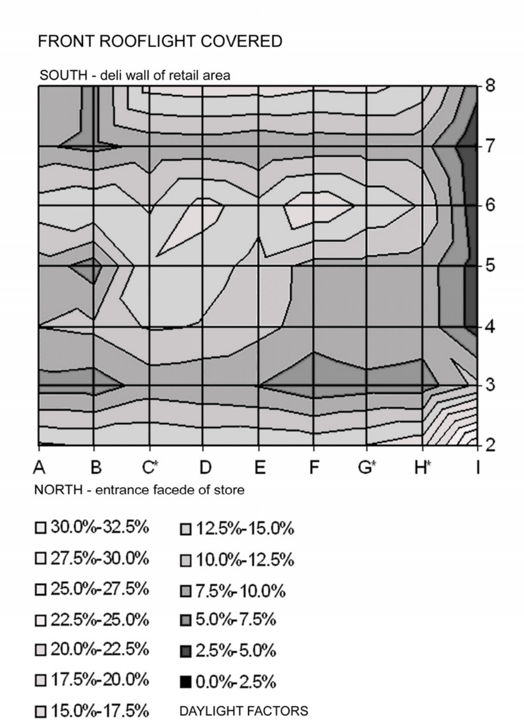

Figure 6: graph corresponding to area of retail floor for scheme with 4 translucent roof-lights.

3.5 Test 5: Heliodon Study

The heliodon tests revealed that there would be little solar penetration to the retail floor through the roof-lights during the winter and at the equinox.

During the summer however, the store would receive some solar penetration through the roof-lights. The 60° glazing angle and the solar altitude at noon are similar resulting in no penetration. However, in the early morning and late afternoon the sun path swings around to the north-east and south-west of the building resulting in a small amount of solar penetration into the store.

It would be important to consider additional solar shading in order to reduce this effect.

Also the tests carried out at all three times throughout the year indicated solar penetration through the glazed north façade in the early morning and late afternoon, particularly in the summer months.

4. CONCLUSION

The scheme with four ranks of roof-lights clearly admits the most daylight onto the retail floor.

The scheme with three roof lights (omitting the front roof-light) also gives good results which are supplemented by the glazed entrance wall.

The lighting level achieved by the natural light will have to be supplemented with electrical illumination to maintain the high lighting level required by the retailer. Local lighting will be needed on the shelving units to illuminate the products to the desired lighting level. But due to the significant level of lighting provided by the roof-lights the overall level of electrical lighting can be reduced therefore reducing the total energy load.

"If electric lighting is not normally to be used during daytime, the average daylight factor should be not less than 5%...If electric lighting is to be used throughout daytime, the average daylight factor should be not less than 2%." [10]

Unfortunately due to time constraints with the current project and cost implications of a delay to the construction process meant that the client only took on a small element of the suggested strategy. A scheme with only a single roof-light was implemented reducing the potential energy saving that could be achieved.

Although Tesco PLC decided to opt for the reduced daylighting strategy of just one glazed north facing rooflight, the services engineers, CSA, have calculated some promising energy savings. The anticipated energy savings for the lighting sector of the building services has been calculated at 498,208kWh. Although this does include other energy saving measures such as reduced external canopy lighting and reduced car park lighting levels between 12-6am, other measures are directly linked to the fact that a certain amount of light will be provided by the roof-light.

The lighting levels for the sales floor, mainly achieved by electrical illumination, have been reduced as they will be supplemented by daylight. Zoned control of the lighting system has also been introduced so that certain sections can be switched off when not needed, if for example the natural light reaching the retail floor is sufficient.

This provides promising potential for the future if and when a scheme with an increased number of roof-lights is implemented.

The client also agreed to trial the use of photovoltaic panels attached to the non-glazed, south facing side of the upstanding roof-light shown in fig. 8. This should hopefully significantly supplement the anticipated energy savings within the store.

Figure 8: Photograph of bank of photovoltaic panels attached to the south facing side of the roof-light.

5. GUIDANCE FOR THE FUTURE

It is important that architects are able to easily implement these strategies during the design process. For a daylighting strategy to be successful it is important that it is considered from the beginning of the design process as with any system based on natural resources. Siting and orientation are vital considerations at the beginning of the process as outlined by P. J. Littlefair in a BRE report. [10]

It is also important the lighting studies such as the one described within this paper are implemented at the beginning of the design process, possibly directly after the initial concept design. Therefore the results may be used as a design tool and any necessary modifications made to the design.

The Building Research Establishment have developed a simple and effective graphical method for designers to directly relate the information from lighting tests to the possible energy savings that could be made. For each specific chosen lighting illuminance it is possible to quickly see an approximation of the percentage of the year the artificial lighting could be switched off depending on the level of light provided by daylight.

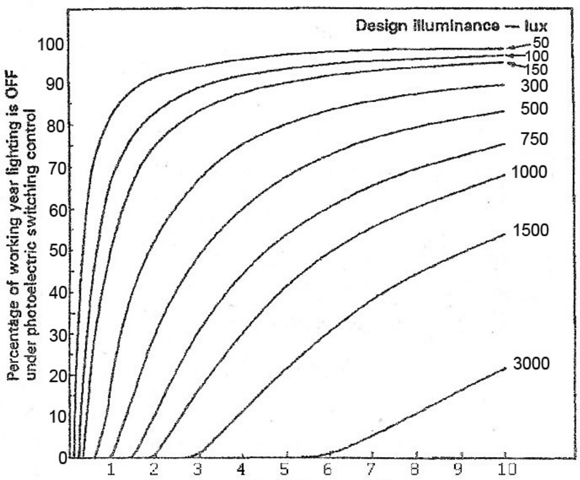

Figure 9: Graph showing the percentage of the year (assumed to be 9am-5.30pm) that a photoelectrically controlled lighting system would be switched off. Re-published with the permission of BRE

This graph would act as a simple and effective tool for designers to easily interpret light levels achieved through daylight design into energy savings. The percentage of the year that the artificial lighting systems can be switched off is directly linked to the energy saving that can be made for that building.

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