Adaptive strategies for office spaces in the UK climate

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ABSTRACT

This document focuses on the building envelope of office spaces in the UK climate. Analyses a case study typical office to explore strategies and design solutions for thermal and daylight comfort and energy savings. Detailed thermal simulation has highlighted an effective solution for providing thermal comfort, in terms of glazing and solid ratios of the façade. Daylight level analysis was also carried out in order to determine the effectiveness of the proposed façade and identify possible improvements. Innovative solutions were proposed, such as the use of prismatic glazing and a prototype external shading feature, which, in combination with passive design techniques, result in improvement in the indoor comfort conditions for the occupants, as well as in reduction in the energy demand of the office space.

1. INTRODUCTION

Research has established that thermal and visual comfort in the workspace is directly linked to productivity levels. Achieving the above with the minimum use of energy has placed demanding requirements on the building envelope design. The aim is to develop an envelope design with such a shape and form so was to meet the following criteria:

- Provide sufficient shading and solar control in the summer;
- Reduce heat losses through conduction in the winter;
- Ensure sufficient daylight penetration in the space throughout the year.

Offering a solution that could perform effectively for a large percentage of the occupied period throughout the year, the environment is made more "easy-to-use" for the occupants, and personal control used when needed at a local level, of conditions like glare, daylight penetration, heat losses.

2. CASE STUDY

For analysing the impact of various parameters in the design of the envelope, when assessed individually, but also looking at their combined effect a case-study module was tested under different thermal and daylight design options. A South-facing room in a typical office scenario for the area of London was chosen.

The dimensions of the room are 3m width per 6m deep per 3m high, as this is usually considered to be representative of the "passive" zone with its associated benefits (Fig. 1). The room has only one exposed façade surface, with the rest of the surfaces assumed to face identical adjacent rooms above and underneath.

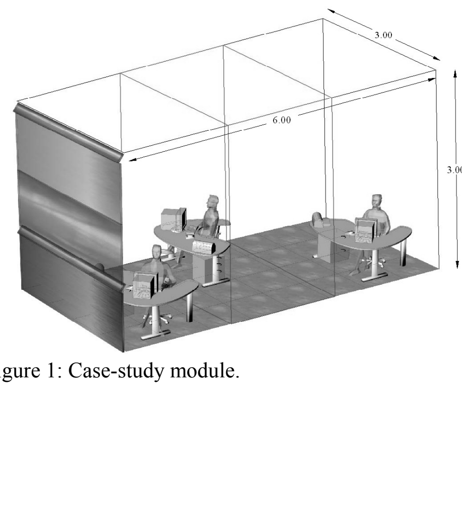


Figure 1: Case-study module.

3. THERMAL ANALYSIS

3.1 The approach

Careful consideration has been given to the design of the facade, with an aim to satisfy the following objectives:

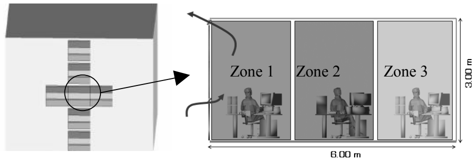
- Provide a thermal barrier, which will define the energy requirements of the space; energy-efficient operation so as to ensure that building heating and cooling loads are kept to a minimum.
- Provide thermal comfort in the office space: reduction of high radiant gains and resultant temperatures to be within the recommended levels.

Dynamic thermal analysis was carried out, using the software TAS (TAS EDSL, 2000), to assess the performance of different design options for the envelope and their impact on the energy requirements and internal comfort conditions. The analysis takes into account the building's dynamic characteristics as well as the architectural envelope, the occupants and control strategies. These are simulated on an hourly basis against a full year's typical weather data, so the analysis provides an accurate insight into the building envelope response over time.

The effectiveness of natural ventilation options was assessed by calculating the number of hours per annum that the internal temperature in the space exceeded 25^{o}C, 26^{o}C and 27^{o}C during the occupied period, and the frequencies were compared against recommended criteria. In addition, the peak internal air temperatures in the occupied areas were noted. In order to take account of the major impact on occupant comfort the Resultant Temperatures were also assessed in addition to Air Temperatures for the different options.

3.2 The thermal model

A three-dimensional model was built of the case-study office space to be examined (Fig. 2a). An office module of the exact same dimensions was assumed to be adjacent to the one tested on both sides, as well as in the floors above and underneath. The same conditions (internal gains, ventilation, glazing etc.) were assumed for all the surrounding office modules, in an attempt to simulate an "adiabatic" environment, where the only surface that would mostly



(a) (b)

Figure 2: 3D view of the building tested (a), schematic section of module with the thermal zoning (b).

affect the internal conditions would be the external façade.

The room was divided into three zones, each 2m wide (2x3=6m^2), as shown in the following images, so as to assess the impact of different parameters at different areas across the room (Fig. 2b). The zone closer to the façade was taken as perimeter zone, the other two considered internal zones.

3.3 Basis of the analysis

The following sections describe the parameters assumed for the thermal analysis;

- Internal conditions

Occupants:	Lighting:	Equipment:
1 person per zone (6m^2) => sensible gain 90W/6m^2=15W/m^2, latent gain 50W/6m^2=8.3W/m^2	12W/m^2	1 computer (120W) per person => 120W/6m^2=20 W/m^2

- Infiltration

0.25ACH for perimeter zone and 0 ACH for internal zones.

Materials/construction

- Thermally lightweight constructions assumed
- External walls Uvalue to comply with PartL2 (Building regulations, 2002)

	U-value (W/m^{2}K)	Admittance (W/m^{2}K)
External panel	0.35	0.5
Internal wall	0.76	0.9
Intermediate slab	0.52	1.1

The glazing of the main glazed panels was assumed to be High Performance glass and an internal blind with the following characteristics:

	U-value (W/m2K)	Total Trans-mission	Shading Coefficient
H.P. glass with internal blind	1.8	0.22	0.25

Ventilation

For the summer analysis, 5% of the floor area was assumed to be openable in the base option, as recommended in the Part F of the Building Regulations (Building regulations, 2002). The total openable area was split between high and low-level, to enhance stack ventilation and allow for better individual control of the openings. Options were tested with increasing this openable percentage to 10% of the floor area.

For the winter analysis, all openings were closed and 12litres/sec per person of fresh (outside) air was assumed to enter each zone, at outside temperature.

Whether data

The Hebtry weather file was used, which is one of the latest weather files released by CIBSE[2], and is the nearest one to represent the conditions nearby the London area.

3.4 Options tested

Two different scenarios were examined, winter and summer conditions, and for each one, a number of options were tested with a view to compare the resulting comfort conditions achieved. An indicative summary of the results for the summer scenario are presented below; similar analysis was carried out for the winter conditions.

- Summer scenario (4 options) (Table 1)
- Results

The relative analysis between the options showed that:

- With 70% glazing, day ventilation and no exposed thermal mass, both Air and Resultant temperatures are very high, and significantly above CIBSE (CIBSE, 1999) and BCO (British Council for offices, 2000) recommendations.
- Reducing the glazing area to 40% decreases the frequency of "overheating hours" by ~25% for Air and Resultant Temperatures. The reduction in the Resultant Temperatures is more apparent in zone 1, due to the reduction in the high radiant heat gains from the glazed area in the façade. However, reducing the glass is still not sufficient to maintain comfortable conditions. For more than 300 hours during the occupied period in the year, Air and Resultant temperatures are likely to exceed 25^{o}C in all the zones.
- Option 3 includes night ventilation. Ventilating the space during the night helps dissipate the gains that have been accumulating during the day (internal, solar gains), so that the temperatures are lower the following day; it is a way of pre-cooling the space, and even out the high fluctuations in temperature in the next day. However this strategy is most effective when combined with exposed thermal mass in the space. In this option, the night ventilation was tested without any thermal mass, keeping the same lightweight constructions as earlier. The results show that even with the space as it is, without any exposed mass, night ventilation can be effective as a strategy in reducing the impact of high heat gains. Both Air and Resultant temperatures are reduced by more than 40-50%. Taking 27^{o}C as a criterion, all Air and Resultant temperature frequencies of exceeding are now below 150 hours, which approximately equates to 6% of the occupied period.
- Finally, the impact of adding thermal mass was assessed (option 4). This brings all resultant temperatures within the recommended limits. The exposed thermal mass absorbs

Table 1: Summer scenario (4 options).

	Opaque panels	transparent panels	shading	Openable area	construction
Option 1	30% of the façade	70% of the façade	External	5% 8am to 6pm weekdays	Light weight
Option 2	60% of the façade	40% of the façade	External	5% 8am to 6pm weekdays	Light weight
Option 3	60% of the façade	40% of the façade	External	10% 8am to 6pm weekdays 5% night ventilation	Light weight
Option 4	60% of the façade	40% of the façade	External	10% 8am to 6pm weekdays 5% night ventilation	Exposed ceiling slab

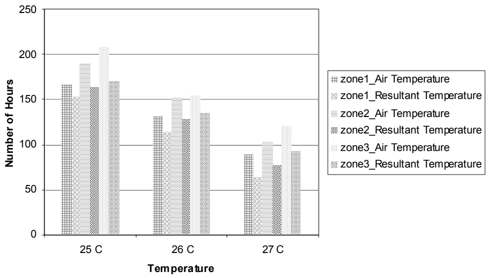


Figure 3: Number of hours the Air and Resultant temperature exceeds 25^0C, 26^0C, 27^0C

heat during the day, when the solar and internal gains are high, so the temperature in the space rises more slowly and high fluctuations are generally reduced. An Air Temperature of 26^oC is not exceeded for more than 5% of the occupied period during the year and a Resultant Temperature of 25^oC is not exceeded for more than 5% of the occupied period (Fig. 3).

4. USABLE DAYLIGHT

4.1 The approach

The term *usable daylight* encompasses objective and subjective measures for visibility and comfort:

- Higher illuminance levels, at greater depths from the daylight opening, than provided by conventional solutions under both cloudy and clear sky conditions.
- Greater uniformity of light distribution between the front and the back of the room.
- Controlling direct sunlight in order to avoid occupant discomfort.

The previous assessment has highlighted an effective solution for providing thermal comfort, in terms of glazing and solid ratios of the façade cells. To minimise the risk of overheating in hot periods, but also to reduce heat losses in the winter, only a limited area of glass had to be used during the day in the façade. However this is likely to reduce the potential for daylight to enter the space for long periods during the year.

In the sections that follow, a summary is given of the different methods that were tested, with an aim to improve the quantity and quality of daylight in the office space, particularly towards the rear of the room, which has less likelihood of access to good daylight.

4.2 Daylight level analysis

The following Daylight Level Analysis was carried out using Radiance (Wand, 2004).

	Window geometry
Option 1	Continuous window
Option 2	Vertical breaks between windows
Option 3	Horizontal separation of the window strip

	Reflectance of the internal surfaces
Option 1	Continuous window strip, average reflectance (0.7)
Option 2	Continuous window strip, high reflectance surfaces (0.9)
Option 3	Continuous window strip, low reflectance surfaces (0.2)

	Solar control
Option 1	Proposed façade solution without shading
Option 2	Proposed façade solution with shading

From the results of the assessment the following conclusions may be drawn:

- The window geometry dictates the quality of natural light and, generally, the more continuous the window, the more uniform is the daylight entering the space. Breaks between windows can create contrasts of bright and dark areas. A good approach for efficient daylighting in the back of the room is the horizontal separation of the window in view and light window. The higher the window head the greater the daylight penetration into the room (Fig. 4).
- The colour of the surrounding surfaces influences the distribution of the light, and generally, the light coloured surfaces provide better distribution. The effect of the surrounding surfaces reflectance is less severe in the front of the room than it is at the back, where the distribution of light is strongly affected by the reflection from internal surfaces (Fig. 5).
- With no protection from direct solar penetration, the strong contrast in lighting levels is likely to produce glare. The external shade reduces the amount of direct penetration

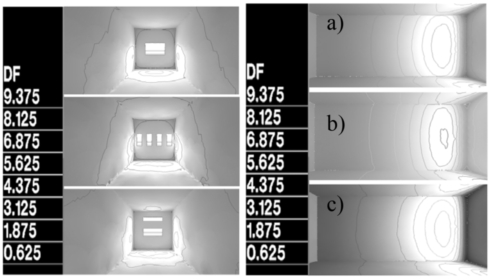


Figure 4: Daylight levels comparison with a) different window geometries b) different internal surfaces reflectance a) 0.7 b) 0.9 c) 0.2.

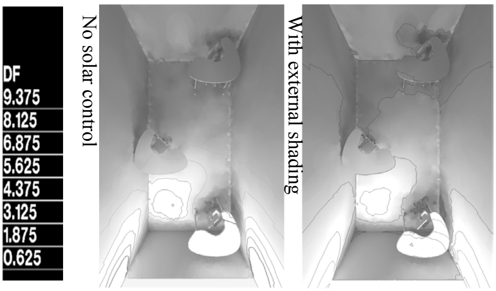


Figure 5: Daylight levels comparison with and without external shading.

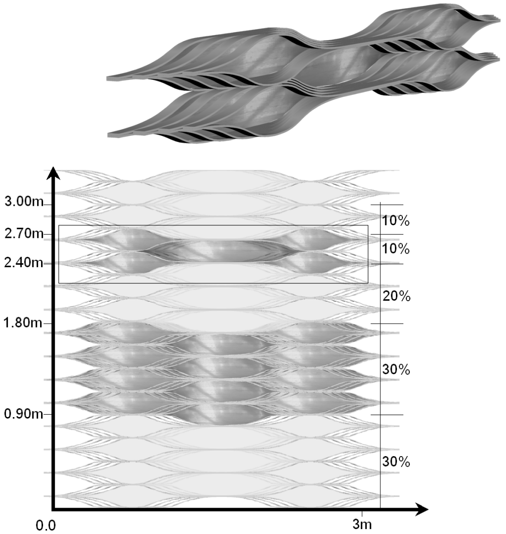


Figure 6: Glazing and solid ratios of the façade and external shading feature.

along with the risk of visual discomfort due to glare (Fig. 6). However, the light levels to the rear of the room are also reduced. For the low-level window, it is desirable to keep the glass as clear as possible for views to outside and light transmission; however the glass must be protected from direct sunlight to reduce glare and prevent sunlight from falling onto the occupants. One of the main advantages of external shading is that the internal blinds need not be deployed for as much time during the year in order to maintain solar control.

4.3 Improving uniformity and light levels across the room

This session focuses on the upper zone of the façade. Further analysis was done, aiming to improve the uniformity of light levels across the room, by reducing the excessive contrast between the front and the rear of the room.

This section does not intend to cover the whole field of daylight technology. It is focused on light redirection-refraction techniques using prismatic glazing panels, exploring the architectural possibilities that can be developed. The façade with integrated daylight redirection-refraction technology is analysed, based on the various angles of incidence at different seasons. It is studied as a control layer for transmitting energy to the interior by distributing light and the associated heat, welcome in the heating period of the year; on the other hand, it serves as a control layer for rejection of the solar energy in the summer in favour of passive cooling.

The following images show the operation of the prismatic panel, with the incident solar rays in winter and summer (Fig. 7). For each one, two different options for the solar incidence are shown, as the solar rays may fall on the two different faces of the prismatic triangular surface and be refracted to different directions.

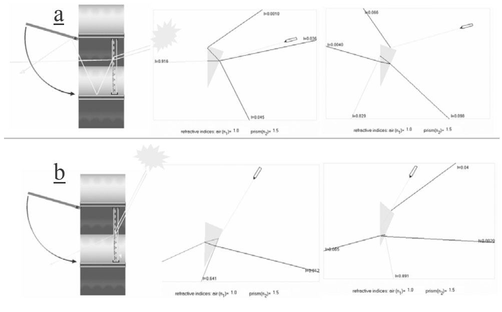


Figure 7: a) Winter operation b) Summer operation.

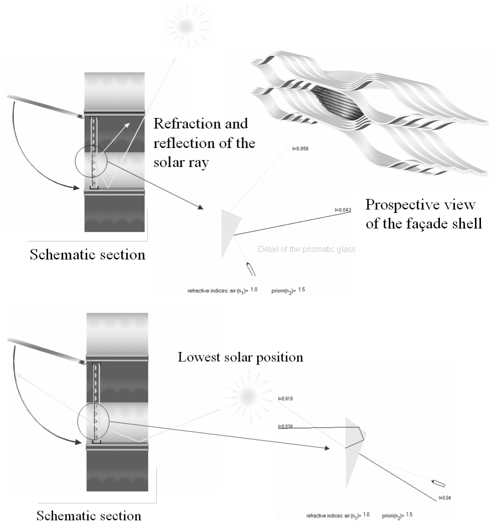


Figure 8: Synergies: Light and external shading .Summer operation top and winter operation bottom.

The schematics below illustrate the impact of integration of the external shading system with the prismatic panel (Fig. 8).

In the analysis further below the prismatic panel is compared with the clear glass in the upper window unit in both cases with external shading. The façade with the prismatic panel has a significant improvement of more than 1% DF in the rear of the room. In the front of the room near the perimeter, in both cases the DF locally are likely to exceed 5% which means for 60% of the year or more, artificial lights can be switched off.

The CIBSE code for lighting (CIBSE, 1994) recommends that the difference between minimum and maximum illuminance levels in a space may be limited by:

$J_{max}/J_{min} \leq 3$, where: J_{min} = min. daylight factor, J_{max} = max. daylight factor

The images below show that the use of the prismatic panel at high level improves the uniformity in the space (Fig. 9).

5. CONCLUSIONS

Adaptable strategies are all about creating synergies. The success of a façade is not limited only to the development of a single piece or a smart material or an electronic sensor or control.

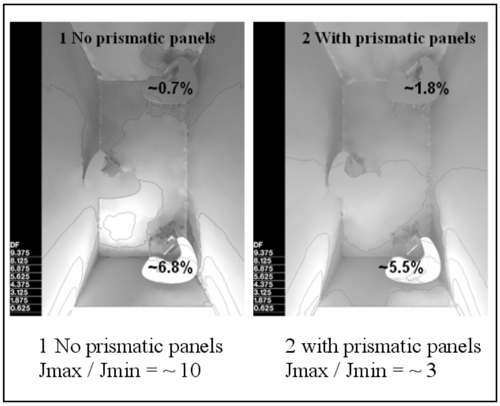


Figure 9: Improvement in uniformity.

Synergies between the façade and the interior space should be aiming to minimise the energy consumption without compromising occupants' comfort.

The relation of the outer skin with the interior space is based on the exchange of energy. Energy transfers in order to maintain the balance needed. The balance is the achievement of comfortable conditions for the occupants.

It is well known from research that when people have to interact with nature, they are more tolerable to a wider range of environmental conditions. Natural ventilation, views and daylight give to the occupant a sensation that he is in closer contact with nature and for that reason he is more tolerable to a wider range of conditions.

Synergies between the components of the façade should be aiming for the maximum of integration. The façade at this point necessitates the redefinition of the words "window" and "wall". With the introduction of new glazing and wall assemblies, what was at one moment "transparent" will become "opaque" with the flick of a switch

Moving towards higher energy efficiency, some areas of the façade trough light redirection techniques should be aiming to extend the boundaries of the "passive zone" bringing light deeper in the space.

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