Visual and Thermal Performance in Façade Design

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ABSTRACT: The design of façades is highly complex but extremely important in determining the success of a building. The façade not only has to integrate with the architectural context, but also plays a key role in the building performance. To fulfil this duty, the façade designer faces a number of difficulties; one of those is achieving an optimum balance between visual and thermal performance which may be in conflict with each other in terms of both energy consumption and internal comfort. In this parametric study, the authors explored how this balance could be achieved by manipulating the building envelope.

The chosen case study is the Gateway Building - a new building located in Nottingham, United Kingdom, designed to house offices and laboratories with a strikingly different façade. Initially, the Light and Thermal method (LT Method) was used, to understand how building envelope changes the building overall energy performance. In the second stage, to carefully investigate how the façade configuration affects the visual and thermal comfort in internal spaces, three typical cellular office rooms adjacent to different parts of the façade were used to conduct measurements, physical model testing and computer simulations. The comparison between these rooms illustrated the changes in indoor environment when the façade changed. Possible solutions were proposed for detected limitations to improve the internal spaces condition. The conclusions derived from this study were the correlation of the façade design with the office indoor environment, and the recognition of how façade design techniques can promote indoor quality.

Keywords: balance, visual comfort, thermal comfort

INTRODUCTION

The majority of the conventional office designs rely on the use of mechanical operation; hence, the external design has poor connections with the indoor environment. However, today, when energy is a huge issue, office buildings have more liability on energy saving and need to integrate with passive solar design to enhance internal comfort. On the other hand, in modern life, the time people spend at work is comparable with the time they spend at home; therefore, the spatial quality standards for workspaces are rising continuously over time [7]. Those prove that the role of façade design, one of the main elements of architectural design, becomes more and more important in manipulating indoor environment. Facades need to ingeniously adapt in the building context and provide internal comfort at the same time.

One of the most challenging tasks in designing façade is achieving balance between thermal and visual comfort because they are easily in conflict with each other. Most of the time, better thermal performance leads to worse light performance and vice-versa. Depending on the context and the building's function, the design may put visual or thermal as a priority. However, small change in the window size might slightly enhance visual environment but considerably consume more energy for heating. The aim of this study was to find the optimum balance between light and thermal performances.

THE GATEWAY BUILDING

The Gateway building is a combination of laboratories and offices spaces; this building was designed by Make architects and the construction was finished in May – 2011. The building was located in the university's agricultural campus at the village of Sutton Bonington, 12 miles away to the South from Nottingham city centre. In agriculture context (Fig. 1), the building was placed in an exposed open plan with very little obstruction; hence, the building has many opportunities to exploit environmental strategies.

Figure 1: The Gateway building.

The building was designed with simple rectangular shape plan; the long edge is orientated mainly to South. The ground floor and two floors above share one unheated buffer space in the West which acts as entrance lobby. The room's layout follows the long edges toward North and South for maximum daylight distribution; rooms are connected by internal corridor as a "street" in the middle of the plan (Fig. 2). The building contains two typical kinds of room: cellular rooms for private offices or laboratories and open plan rooms for public uses such as computer room, seminar room, etc. The building was not designed for natural ventilated due to the variation in functions of laboratories and offices, some laboratories may need special air treatment according to the study requirements.

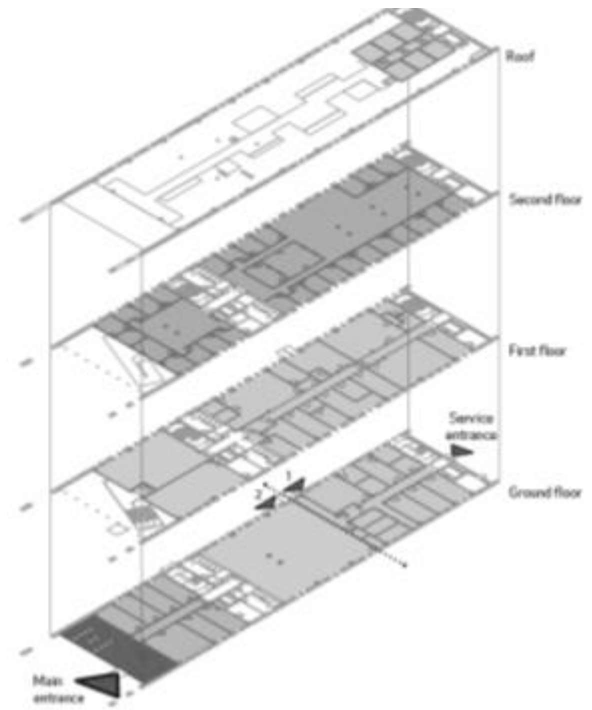


Figure 2: The building's layout [5]

For natural lighting strategies, the building used high windows for deeper light penetrations. Glazing ratio (GR) is higher in the North and lower in the South to maximize diffuse light and minimize direct sunlight. For thermal strategies, rooms are denser in the North side to prevent heat loss and scattered in the South side to maximize solar gain. The building load bearing structure is kept within the cover façade to be protected from thermal bridge. The building façades were composed with alternate vertical windows and straw bale panels. The use of straw bale material is a special feature of this building. Straw bale is well known as a renewable material providing very good thermal insulation [10]; using this material, the building external wall (or the straw bale panel) achieved the U value of $0.15 W/m^2K$, (Fig. 3).

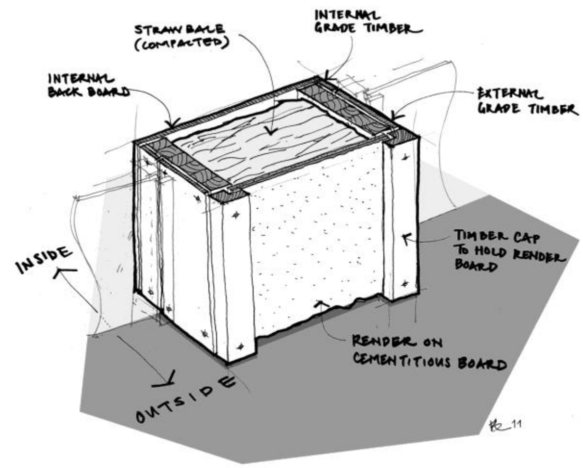


Figure 3: Straw bale panel section [5]

FAÇADE DESIGN CONTRIBUTION AND ENERGY PERFORMANCE

To have a quick and general idea of how the façade contribute to the building energy performance, the authors used the LT method to study. "LT method is a manual design tool for calculation of energy consumption in non-domestic building" [2]; this method is useful for users because of its quick and simple approach. LT method should not be regarded as a precise tool for testing, however, this method is very good for initial analyse. The method uses two main inputs: building form data inputs: passive zone (PZ) and non passive zone (NPZ) areas) and façade design inputs (glazing ratio). First, the energy consumption of the building was calculated and called Base case. The GR of the building were referred to the appropriated LT curves set to read off annual energy consumption per square meter. All the data were then putted in the LT worksheet to calculate the potential energy consumption.

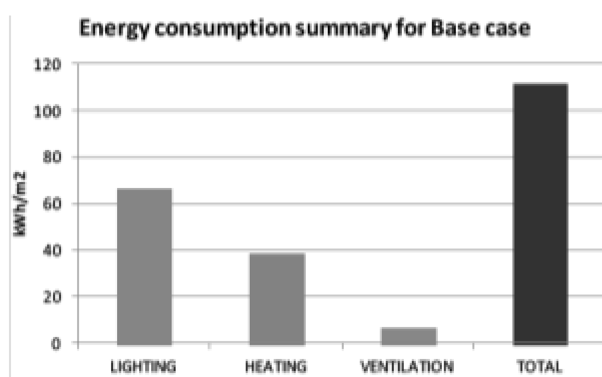


Figure 4: Energy consumption results for Base case

As described above, the LT method results are not precise enough for solid conclusion; however, we could see if the building is on its way to reach efficient office building or not. According to the article"White Collar CO2: Energy consumption in the service" [9], the author stated that in a Good Practice Office, annual energy consumption should achieve 112 kWh/m2 [9]. The total energy consumption of the Gateway building according to LT method calculation is 107.9kWh/m2 (Fig. 4); hence, the Gateway building is likely to be on its way achieving Good Practice Office.

Different cases were then developed based on the LT curves to study the impact of façade design on building energy consumption. To do this step, the building data inputs (PZ and NPZ) were kept as constant and the façade data inputs (GR) were used as variables to see how energy performance change according to the change of façade design.

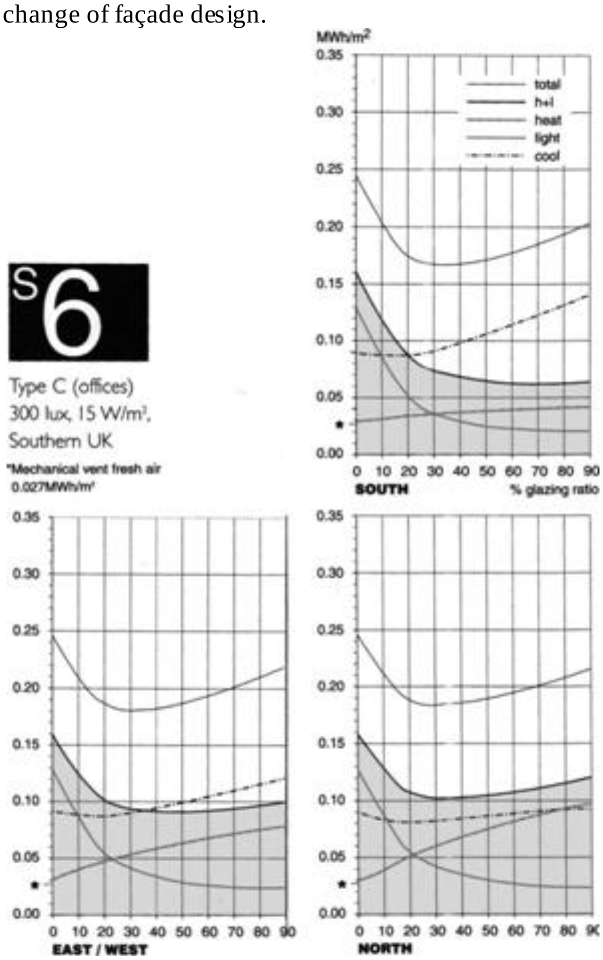


Figure 5: LT curves [2]

The LT curves are interesting to study, from the curves (Fig. 5), lighting and thermal confliction is visible; lighting energy always goes in opposite direction with heating energy. For example, when there are more openings on the façade which means the building becomes brighter but poorly protected by the wall, the energy for light decreases and the energy for heat increases. When the bold lines (total energy for light and thermal) reach the lowest point - lowest energy usage, the façade achieves the best energy performance. Based on that, GR which will perform best energy performance could be read off: South façade: 70%, West façade: 45%, North façade: 35%. Similarly, when these black lines reach highest point – highest energy usage, the façades meet the worst energy performance. All the graphs show the worst cases with GR of 0%. Base on the findings from the curves, 4 cases are developed to study (Table 1).

Case 1: subtract 7% GR from the base case.

Case 2: Plus 7% GR from the base case.

Good case: the best GR from the LT curves.

Bad case: the worst GR from the LT curves.

(*): The West GR in Case 1 and Case 2 is kept as 90% because the study focus more in the changes of North and South side

Table 1: Glazing ratio input

	South	West	North
Base case	27%	90%	35%
Case 1	20%	90% (*)	28%
Case 2	34%	90% (*)	42%
Good case	70%	45%	35%
Bad case	0%	0%	0%

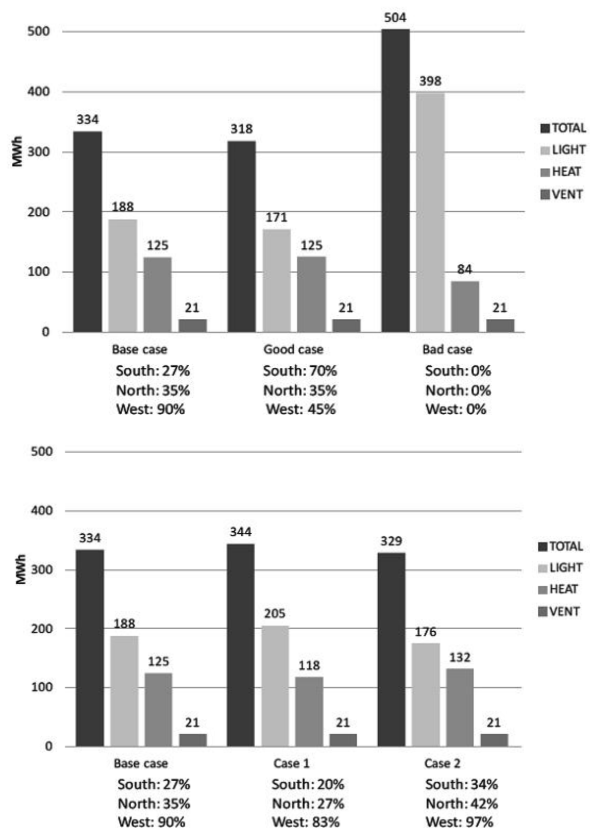


Figure 6: Annual energy consumption results for 5 cases

LT method was used again to calculate 4 new cases; Figure 7 shows the results for all cases.

Case 1: When the GR were decreased and the building became darker, the lighting energy consumption increased considerably by 17MWh; meanwhile, the heating energy consumption decreased positively by 7MWh. This result trend is predicted because lower GR means the building is better thermally protected by the wall. However, the increasing energy for lighting is much higher than the decreasing energy for heating.

Case 2: When the GR were increased, the lighting energy consumption decreased by 12MWh, whilst the heating energy consumption increased by 7MWh. From now, we realize that energy for lighting is more vulnerable than heating; the lighting energy is easier to increase and decrease due to the change of the façade.

Good Case: When GR that produce best energy performance for every façades were applied, the lighting energy consumption decreased dramatically by 17MWh while the heating energy consumption remains the same.

Bad Case: When the GR were all 0% which means the building is totally independent with the outside environment and rely 100% on mechanical operation, the energy consumption for lighting became very high. However this case thermally performed the best.

Table 2: Base case and good case GR comparison

Base case	Good case
South: 27%	South: 70%
North: 35%	North: 35%
West: 90%	West: 45%

Obviously, Good case GR are suggested for all façades to achieve best energy performance. However this GR set is needed to be carefully applied. Table 2 shows GR comparison between base case and good case. 70% GR suggested for South façade would cause numbers of problems from direct sunlight such as glare or machinery impairment and these issues were not considered by the LT method. Therefore, high GR in the South façade and careful façade design treatment such as shading is needed. Compare with the Good case, the Gateway building can achieve better energy performance if the South façade GR considerably increased. It seems that building has applied appropriate GR for the North façade, and the West façade GR should be decreased.

From the LT method, a lot of useful lessons to improve energy consumption of a public building could be learnt. The first step to achieve good energy performance is maximizing PZ areas in building plan, the less non PZ areas the building has, the more energy it save. If the building plan needs to be deep, atrium, top lighting could be provided to increase PZ areas. The second step is choosing the appropriate GR for each façade based on the LT curves; try to apply GR of the best case to the design. The last step is applying appropriate treatment, choose the right material for the façade to produce most comfortable indoor environment in term of both visual and thermal.

FAÇADE DESIGN AND THE INDOOR ENVIRONMENT

The Gateway building has a wide range of spaces to investigate indoor environment; in this research, three cellular offices were selected to study due to some reasons: these cellular rooms have the same dimensions (width, length and depth); however, they have different facades (Fig. 7). Therefore, by investigating these rooms, the study could be able to look at how façade design affects the indoor environment in different cases.

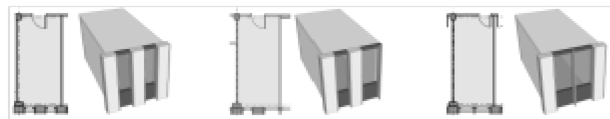


Figure 7: Three typical cellular rooms

Day-lighting performance

In order to evaluate the cellular offices' day lighting performance, three rooms were modelled in Ecotect and simulated by Radiance. In every room, the working plane was assumed at 700mm from the floor.

Table 3: Lighting calculation summary of three cellular rooms

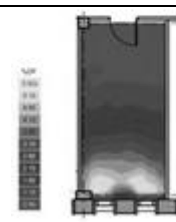
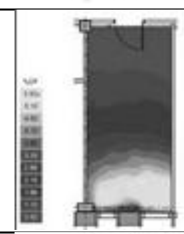
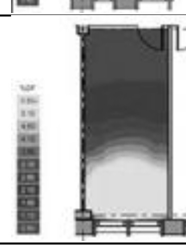
Cellular room 1 	Average daylight factor: 2.17% Uniformity ratio: 0.13 Limiting depth rule: 4.18 < 4 -> not satisfied	
Cellular room 2 	Average daylight factor: 2.62% Uniformity ratio: 0.12 Limiting depth rule: 4.18 < 4 -> not satisfied	
Cellular room 3 	Average daylight factor: 3.62% Uniformity ratio: 0.1 Limiting depth rule: 4.18 < 4 -> not satisfied	

Table 3 shows the simulation results of each space, average daylight factor, uniformity ratio and limiting depth rule calculation were taken. The cellular room 3 with highest GR achieved ADF of 3.62% while the other two rooms achieved lower values: 2.62% and 2.17%.

Although these achievements higher than office day lighting benchmark of 2% [8], these results show poor luminous indoor environments in all rooms, all of them were not be able to satisfy the limiting depth rule. On the analysis grid, the daylight uneven distributions are also visible; this point is further confirmed by the low uniformity ratios. Therefore, artificial lights are needed in these rooms throughout daytime to achieve required luminous environment. In sunny sky condition, the rooms might become brighter; however, glare problems started to appear. In summary, with the long, narrow shape plan and limited opening to the outside environment, it is difficult for these cellular offices to achieve desirable visual comfort.

Thermal performance

The building's heating strategies relies on the highly insulated and air-tight envelope, which reduces the active heating requirements of the spaces. The use of straw bale panel helped the wall reach a U-value of $0.15W/m^2K$. The plan layout was designed as tight as possible with limited opening to the outside environment for minimum heat loss.

Regard to thermal comfort benchmarks, CIBSE recommends 18^oC is the minimum temperature during winter time and 25^oC is the maximum temperature in a non air conditioned building [4]. The thermal performance of the building was assessed by TAS simulation. Cellular room 1 is defined as Zone 1, cellular room 2: Zone 2 and cellular room 3: Zone 3. The rooms were simulated in different internal conditions, based on that; the study could see how three rooms with different façades work in different conditions.

Condition 1: Unoccupied building, no internal gains, no nature ventilation. In Figure 10, zone 1 appeared to be the room having the best thermal performance with the hour's percentage within thermal comfort of 53.23% compare with other zones. The percentage of cold hours is prominent in all rooms. Zone 1 has highest percentage of cold time while this value in Zone 3 is the lowest. This can be explained that with highest GR, zone 3 has higher solar gain than other rooms. However, with the lowest GR, zone 1 couldn't have much solar gain but the room is better protected and stable in temperature.

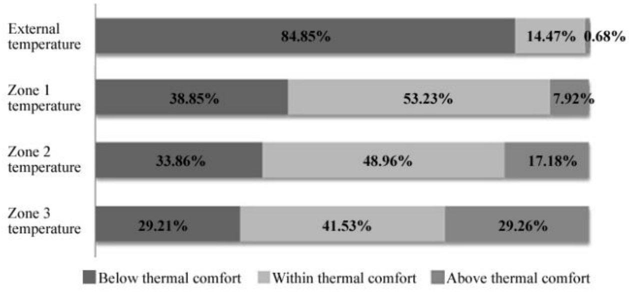


Figure 8: Annual percentage of hours below, within and above thermal comfort of internal condition 1

Condition 2: Occupied and large opening for nature ventilation. In figure 9, zone 1 still achieved highest percentage of time within thermal comfort. However, this value is not as different as it is in condition 1.

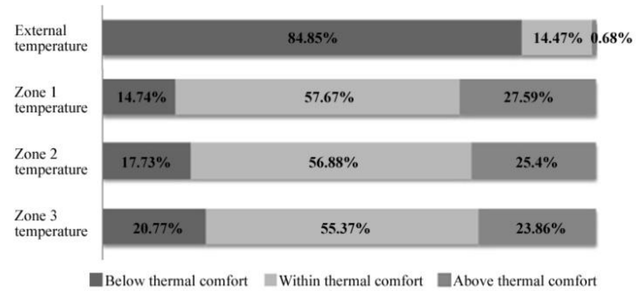


Figure 9: Annual percentage of hours below, within and above thermal comfort of internal condition 2

Condition 3: Occupied and smaller opening for nature ventilation. In Figure 10, all rooms have equal percentage of time within thermal comfort.

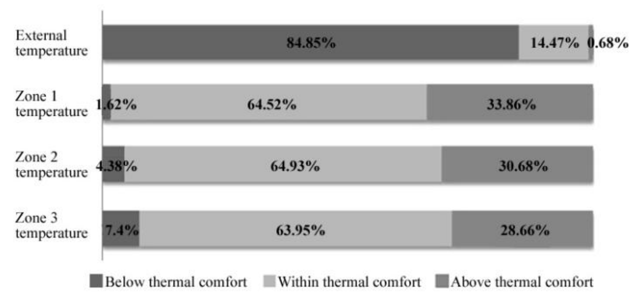


Figure 10: Annual percentage of hours below, within and above thermal comfort of internal condition 3

In summary, in every condition, the zone 1 always appears to have better thermal performance by showing highest percentage of hours within thermal comfort or having the temperature line closest to thermal comfort temperature. However, by the change of internal condition, with more careful ventilation, the difference among them are not clear. Based on that, three rooms with slightly change of opening size, the same use of material, the same room dimensions, in the same conditions, thermal performance of them are not very different.

CONCLUSION

In conclusion, through studying the Gateway building, numbers of interesting information could be learnt. The use of LT method is simple and easy to manipulate, helping the study come up with clear results and conclusions. When the building form is kept and the façades are change, the lighting energy and heating energy change accordingly. The lighting energy consumption is more vulnerable, it could increase and decrease considerably when façade changes. The heating energy is much more stable than the lighting energy. The LT curves treasure a lot of information that is useful for design public building. To achieve lower energy consumption, the building should maximize the PZ and minimise the NPZ; then, choosing the best GR according to LT curves for the façades; finally, applying appropriate materials, air tight envelope, façade treatment, etc for the building.

In the detailed study of the internal spaces of the Gateway building, the lighting performances of the cellular rooms were found to be poor due to the room's configurations and window types. The room 3, which had the highest GR, was apparently the room with the best daylight performance; however, this room still did not achieve satisfactory luminous environment. The room 1, with the lowest GR, appeared to have the best thermal performance in unoccupied condition. However, in occupied condition and natural ventilation, three rooms thermal performance remains approximately the same. As the result, it could be concluded that in rooms with the same use of material, same dimensions, in the same conditions but different façade, should present similar thermal performance. On the other hand, small changes of the façade lead to significant change in luminous environment and the lighting energy consumption fluctuating dramatically.

In office buildings with highly insulated envelopes, the thermal environment can be fairly stable due to generally high internal gains. However, careless day lighting design may lead to high energy consumption for artificial lighting throughout the year. Lighting and thermal are related to each other in a special way in the design process. and should be considered at the same time. If the light and thermal relationship is carefully understood, the balance is not difficult to achieve, and should lead to energy efficient and comfortable buildings.

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