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Light and Thermal balance by Façade Design
An investigation of the Gateway building

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Abstract:
Nowadays, façade design is becoming more and more important in contributing to environmental performance success of a building. The façade design not only has to integrate with the architectural context, but also plays the key role in promoting building performance. To fulfil this duty, façade design faces numbers of difficulties; one of those is achieving balance of light and thermal performance which was proved to conflict each other in both energy consumption and internal comfort. This paper explored how this balance could be achieved by manipulating the building envelope. Gateway building - a new office and laboratories building located in Nottingham, United Kingdom, which reflected typical modern office façade design with vertical glazing, is a good case to study. Initially, the architectural implication of façade design was critically discussed to see if the façade help the building perform a "sense of place" in its context or not. Then, to understand how building envelope changes the building overall energy performance, Light and Thermal Method (LT Method) was undertaken. In the second stage, to carefully investigate how façade configuration affects the visual and thermal comfort in internal spaces, three typical cellular office rooms were used to conduct measurements, physical model testing, and computer simulations. When limitations are detected, possible solutions would be proposed to improve internal spaces condition. The derived conclusion for this study was the correlation of the façade design with office indoor environment, identify how façade design techniques can promote indoor quality whereas internal spaces can react and adapt with external design.

Keywords: façade design, office building, balance, visual comfort, thermal comfort

1 INTRODUCTION

The majority of conventional office designs relied on the use of mechanical operation; the architects had freedom in designing façade to express aesthetic quality and their architectural attitudes. Hence, external designs had very poor connections with indoor environments because the buildings were supported by active strategies such as air-conditions or artificial lights. However, along with global task of responding to climate change, office buildings have more responsibility on energy saving and need to rely on passive design to create internal comfort. Moreover, in modern life, the time people spend at work is comparable with the time they spend at home; therefore, the spatial standard for workspace quality is rising continuously over time. 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 for users. Meanwhile, the building envelope still has to encompass its role of contributing harmonically to surrounding visual environment. These facts require more effort in designing façade to well fit with inside and outside, ingeniously adapt with building context and provide internal comfort in the same time.

2. THE GATEWAY BUILDING

The Gateway building is a combination of laboratories and office spaces which brought together two academic departments: Biosciences and Veterinary Medicine Science; this building was designed by Make architects and the construction was just 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. The building was placed in an exposed open plan with very less obstruction, giving the building opportunities to develop environmental strategies.

Figure 1: the Gateway building

The building was designed with simple rectangular shape plan; the building's long edge is orientated mainly to South. The ground floor and two floors above share one unheated buffer space in the West of the plan which acts as entrance lobby. The room's layout is basically following 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. In Figure 2, although the three floor plans are slightly different from each other because of the room size changes, the layout configuration with rooms in the South and the North side linking by corridors in the middle is repeated in all floor plans. The building contains two typical kinds of room: cellular rooms for private offices as well as 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.

3. FAÇADE DESIGN CONTRIBUTION TO INDOOR ENVIRONMENT

The Gateway building has a wide range of spaces to investigate indoor environment; in this paper, 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. Therefore, by investigating these rooms, the study could be able to look at how façade design affects the indoor environment in different cases. Figure 2 shows three rooms' plans and there 3D models, cellular room 1 are the room with two small windows- smallest GR; cellular room 2 is the room with one small window and one big window- medium GR; cellular room 3 is the room with two big windows- highest GR.

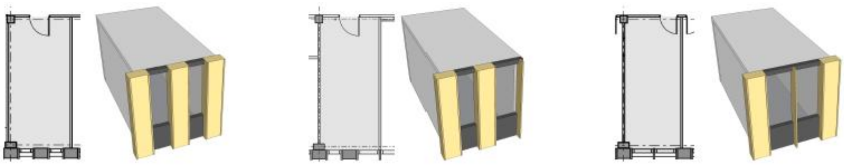


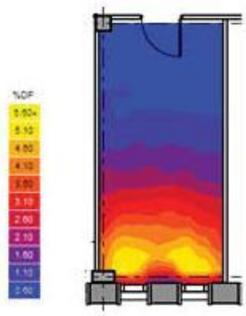
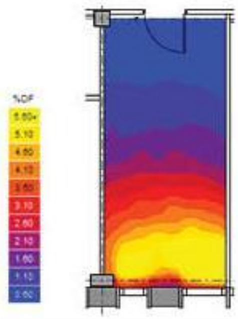
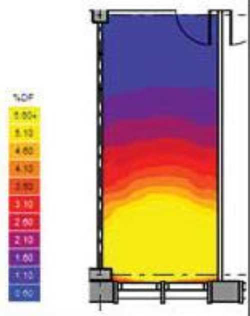
Figure 2: Cellular room1, Cellular room 2, and Cellular room3

3.1. Day-lighting performance

The building's light strategies are using high windows for deeper light penetrations. GR is higher in the North and lower in the South for maximize diffuse light and minimize direct sunlight.

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 1 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% (RENNIE, 1998), these results show poor luminous indoor environments in all rooms. Even all rooms were provided with high windows, they are too deep creating a poor day lighting environment; as the result, 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 light may be needed in these rooms almost the time in the year to achieve required luminous environment. In sunny sky condition, the rooms might become brighter; however, glare problems started to appear.

Table 1: Lighting calculation summary of three cellular rooms

CELLULAR ROOM 1 Glazing ratio: 32.5% Room depth: 6.9m Room width: 3.2m Room height: 3.4m 	**Average daylight factor:** 2.17% **Uniformity ratio:** High value: 5.56% Low value: 0.74% Uniformity ratio = 0.74/5.56 = 0.13 **Limiting depth rule** $\frac{6.9}{3.2} + \frac{6.9}{3.4} \le \frac{2}{(1-0.5)}$ 4.18 ≤ 4 (not satisfied) --> the room is too dark at the back	
CELLULAR ROOM 2 Glazing ratio: 39.1% Room depth: 6.9m Room width: 3.2m Room height: 3.4m 	**Average daylight factor**: 2.62% **Uniformity ratio:** High value: 7.19% Low value: 0.87% Uniformity ratio = 0.87/7.19= 0.12 **Limiting depth rule** $\frac{6.9}{3.2} + \frac{6.9}{3.4} \le \frac{2}{(1-0.5)}$ 4.18 ≤ 4 (not satisfied) --> the room is too dark at the back	
CELLULAR ROOM 3 Glazing ratio: 45.5% Room depth: 6.9m Room width: 3.2m Room height: 3.4m 	**Average daylight factor**: 3.62% **Uniformity ratio:** High value: 10.9% Low value: 1.18% Uniformity ratio = 1.18/10.9= 0.1 **Limiting depth rule** $\frac{6.9}{3.2} + \frac{6.9}{3.4} \le \frac{2}{(1-0.5)}$ 4.18 ≤ 4 (not satisfied) --> the room is too dark at the back	

3.2. 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. 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. Because the thermal simulations aimed at evaluating passive thermal performance, the internal conditions were selected without active heating or cooling strategies. The infiltration rate is assumed as 0.30ach.

Condition 1: Unoccupied building, no internal gains, no nature ventilation. In Figure 3, 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. This is proved in Figure 4 which shows temperature of all zones in midseason time; the zone 1 temperature line is the most stable line.

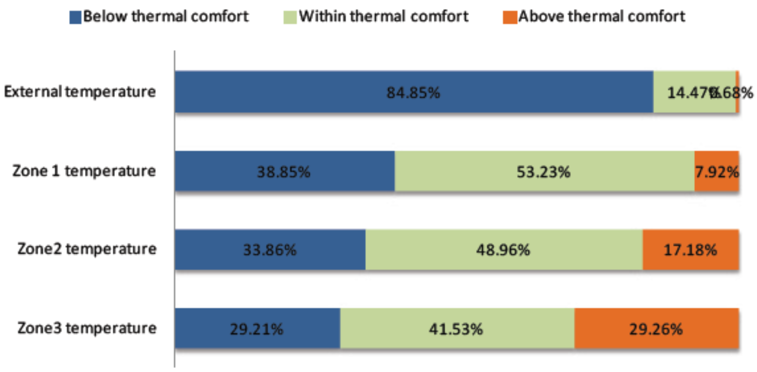


Figure 3: Annual percentage of hours below, within and above thermal comfort of internal condition 1

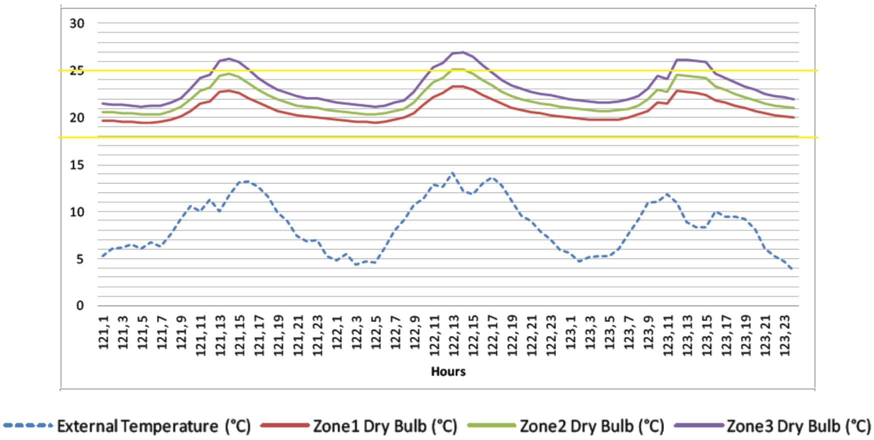


Figure 4: Temperature of three zones in three mid season days (internal condition 1)

Condition 2: Occupied and smaller opening for nature ventilation. In Figure 5, all rooms have equal percentage of time within thermal comfort. In Figure 6 the temperature line of zone 1 is still the highest and closest to thermal comfort temperature.

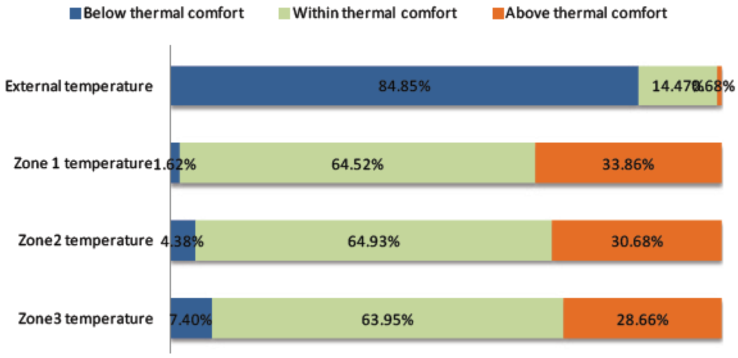


Figure 5: Annual percentage of hours below, within and above thermal comfort of internal condition 1

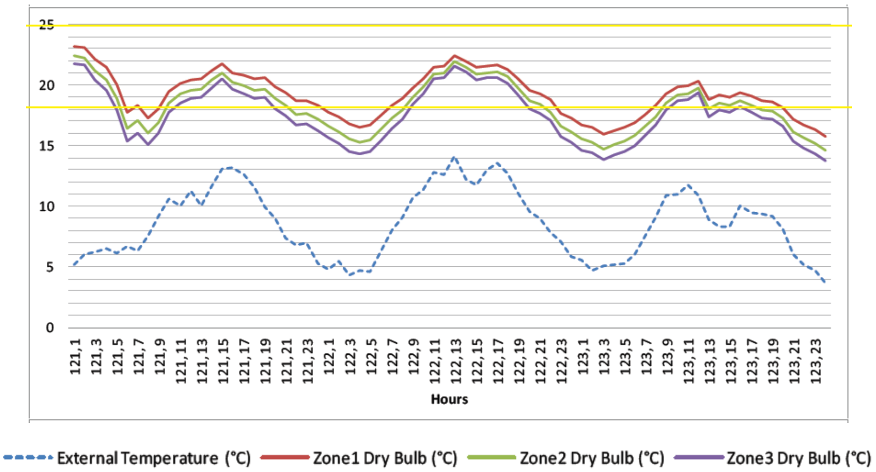


Figure 6: Temperature of three zones in three mid season days (internal condition 1)

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.

4. CONCLUSION

In conclusion, through studying the Gateway building, numbers of interesting information could be learnt. In the detailed study on internal spaces of the Gateway building, the lighting performances of cellular rooms are poor due to the room's configurations and window type. The room 3 which has highest GR apparently is the room with best daylight performance; however, this room still cannot achieve satisfactory luminous working environment. By studying thermal performance, the room 1 with lowest GR appeared to have the best thermal performance in the 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 the rooms with the same use of material, same dimensions, in the same conditions and slightly different façade, thermal performance will not be affected so much. Compare with daylight performance, the change of the façade leads to significant change in luminous environment and the lighting energy consumption could fluctuate dramatically.

In office building with highly insulated envelope, due to internal gains and office characteristics, thermal performance could be ensured in good level. 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 designing process, it is inefficient if the designers are more careful in thermal performance than day lighting issue or reverse. Both of these aspects should be considered in the same time to come up the best strategies. If the light and thermal relationship is understood carefully, the Balance is not difficult to achieve to reach efficient office building as well as internal comfort.

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