Analyzing and Improving Natural Daylight in Educational Buildings Using Skylights, Victoria International School of Sharjah as a Case Study

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Abstract. Due to the great importance of natural daylight in interior spaces, architects keep experimenting different techniques to achieve a good luminous environment. One of the techniques used in building design is the skylight. This study focuses on the impact of the skylight on internal spaces in schools with regards to daylight factor, glare, and cooling loads. Thirteen simulation cases, including the existing case, were simulated and analyzed using several software packages such as Revit, Ecotect and Radiance. The thirteen cases are categorized into three main groups: A, B, and C. Each category has set some fixed parameters in order to reach an optimum design compared with the existing case. After conducting the simulation and analysis, the sub-cases of Group-A failed to achieve a good luminous environment and therefore the results were rejected due to the large increment in cooling load. On the other hand, the sub-cases of Group-B showed considerable improvement in the cooling loads, but some of these cases had caused glare in the space. The sub-cases of Group-C were better than of those in Group-B. Herein, some of the results of this study were satisfactory compared with the existing case study. However, one of the cases in Group-B had the optimum case among the examined cases where all the results are within the accepted range.

1. Introduction

1.1. Research Background

The three largest uses of energy in buildings are heating, cooling and lighting. 84% of the heating and cooling loads, and most of the electricity used of artificial lighting, are generated using fossil fuels which has its large environmental impact. Thus, the importance of introducing daylight in building, while carefully considering its impact on heating and cooling loads, can have substantial effect on the building, not only in terms of environmental and economic factors, but also in its contribution to the wellbeing of the occupants [1]. The importance of natural light is seen in human visual function test, as higher visual comfort and effect is found to be obtained in natural light compared with artificial light [2]. Despite the need of daylighting in all buildings in general, daylighting in educational building particularly is of high importance. It has been demonstrated that the presence of daylight has a direct link to the performance of the students, considering the fact that human health and mental function are influenced by the light exposure’s intensity and duration throughout the day [3]. Different techniques have been used by architects to offer sufficient daylight for internal spaces; however, each climate has its own constraints and challenges. One of the greatest challenging climates, when daylight is considered, is desert climate. Challenge with this climate regarding daylight is mainly the heat gain due to the solar radiation. Natural
light usually reaches the internal spaces in three forms: direct sunlight, direct skylight, and reflected light, either sunlight or skylight, from the ground and nearby surfaces. The entering should be controlled and investigated to ensure the quality of light in the interior spaces [4]. One method of introducing natural light to interior spaces is the use of skylights. Roof skylight system is a construction technique used to allow natural light to pass through the roof and reach internal spaces. Skylights are being frequently used by modern architects as a solution to for internal spaces where sufficient daylight could not be achieved by the use of windows only. Although skylights are very favorable solution in cold climate where solar radiations through skylight help in reducing heating loads, it is challenging to use it in hot climates where this solar radiation can increase the cooling load significantly [5].

1.2. Case Study Background

Victoria International School of Sharjah (VISS) is an Australian school located in Ta’awon, Sharjah. It is designed by Taylor Oppenheim architects, a firm specialized mainly in educational facilities. The architecture design of school uses different techniques to minimize the power consumption of the school, including skylights, shading devices, and roof shading. Most of the skylights are used in corridors or interior rooms where no exterior windows are available, while few only used in classes with exterior windows. This study aims to investigate the effect of skylight on the luminous environment of internal classrooms as well as the extra cooling load caused by the presence of the skylight. A classroom located in the North-West without skylight is considered as the Case-0 (Figure 1 and 2). The field measurement of the illuminance of the class using a light-meter has indicated the reading as an average of 150 lux, which is considerably lower than other classes where some reached up to 600 lux. In this study the authors are trying to create a classroom lit naturally within a thought of no artificial light is needed during the daytime. However, visual comfort and energy consumption of cooling load would be taken into consideration.

2. Objectives of The Study:

The objectives of this study include the following:

- Analyze the natural daylight and cooling load in the existing classroom.
- Analyze the effects of different skylights with different parameters on daylight factor, glare, and cooling loads study.
- Find the best adjustment for the existing case.

3. Research Methodology

This study was conducted using Revit for 3d modelling, Ecotect for lighting and thermal analysis, and Radiance for glare study. Field study has been conducted using light meter and the results were compared with the simulated model. Thirteen cases were studied and analyzed using the mentioned software. These cases are divided into three groups; A, B and C. Each group has one or more common parameters between its cases. The groups differ from one another in terms of shape of skylight and/or type of glass used. Group A cases have one 30° skylight (Figure 4). Group B cases have one or more 90° skylight (Figure 5) with clear glass, while Group C cases have one or more 90° skylight with translucent glass. Cases within the same group differs from one another in terms of number of skylights,
orientation of skylight(s) (Figure 6), and how many faces of skylight are glazed. Table 1 indicates the simulation parameters of the 13 cases.

| Case     | Orientation of Skylight | Slope degree | Types of glass | Glazing sides | No. of skylights |
|----------|-------------------------|--------------|----------------|---------------|------------------|
| Base Case| No skylight             | -            | -              | -             | -                |
| Case A-1 | North-South 30°         | Clear        | All sides      | 1             |
| Case A-2 | East-West 30°           | Clear        | All sides      | 1             |
| Case A-3 | East-West 30°           | Translucent  | All sides      | 1             |
| Case A-4 | East-West 30°           | Clear        | Only north-facing side | 1 |
| Case B-1 | East-West 90°           | Clear        | All sides      | 1             |
| Case B-2 | East-West 90°           | Clear        | Only north-facing side | 1 |
| Case B-3 | East-West 90°           | Clear        | All sides      | 2             |
| Case B-4 | East-West 90°           | Clear        | All sides a    | 2             |
| Case C-1 | North-South 90°         | Clear        | All sides      | 2             |
| Case C-2 | East-West 90°           | Translucent  | All sides      | 1             |
| Case C-3 | North-South 90°         | Translucent  | All sides      | 2             |

a South side with horizontal shading

All the simulated data used the following fixed parameters:
- Weather data file: Abu Dhabi, UAE
- Design sky illuminance: 11,000 lux
- Visible transmittance (0-1): Clear glass: 0.611 and Translucent glass: 0.658
- U-Value (W/m²K): Walls: 1.72, Floor: 0.88, Clear glass: 2.41, Translucent glass: 1.40
- Room area: 93.6 m²

4. Simulation Analysis

4.1 Base case – Existing

It can be observed, by both field measurement and virtual analytical model, that the natural daylight in the existing case is not satisfactory. Average daylight factor is 1.67% which is considerably low. Illuminance in the center is around 120 lux. The field measurement showed an average of 150 lux at
the center which is very similar to the calculated value. This similarity validates the accuracy of the model. The cooling load was also simulated for the comparison with the later cases.

4.2 Group A - Skylights with 30º angle

All cases in Group-A have significant increment in terms of daylight factor compared to the existing case. Glare was not avoided in case A-1 and A-2. All cases are rejected due to the considerably higher cooling loads comparing to the existing case study (Charts 1 and 2). Changing the orientation of the skylights from North-East, case A-1 (Figure 8), to East-West, case A-2 (Figure 9), has increased the cooling loads insignificantly and thus it is neglected. Replacing the clear glazed with translucent, case A-3 (Figure 10), has reduced the cooling loads by 5%. The same results of case A-4 (Figure 11) in terms of cooling load were achieved. Although cases 3 and 4 were similar in cooling loads and in reducing glare in the space, case A-4 with only north-facing clear glazed showed better results in terms of daylight factor for using translucent panel. Since all Group-A was failed, the original shape of the 30º-slopped-skylight in Group-A has been switched to Group-B, 90º angle skylight with clear glazing panels. This proposal is expected to reduce the cooling loads which were the common problem in all Group-A cases as well as to reduce glare in the space.

4.3 Case B - Skylights with 90º angle skylight with clear glass

In Group-B the cooling loads area considerably lower than those of Group-A due to the skylight’s 90º inclination rather than the 30º. Daylight factor is less than Group-A but it is still accepted in most of the cases and it is greater than existing. Case B-1 is significantly better than those of Group A in terms of cooling loads (only 30% greater than existing case). However, small amount of glare is caused, and visual comfort is not achieved. (Figure 12). Light was more evenly distributed in Case B-2 (Figure 13) where south side is blocked; however, daylight factor was not sufficient. Glare was caused in Case B-3 (Figure 14) and Case B-5 (Figure 16). Blocking the skylight from the south resulted in obvious decrement in glare. Changing the orientation of the skylight from east-west to south-north increased the amount of glare in the space. By adding more skylights with all sides clear glazed and adding shading horizontal device instead of blocking the south-facing side of skylight, better results are obtained, and the resulted case is considered satisfactory. Cooling load is also reduced, compare to Group A, and the new cooling load is acceptable in all cases except Case B-5, which suggested adding three skylights to increase the amount of daylight in the space since; although daylight factor reached very good levels, glare was caused, and cooling load was increased rapidly. Better results can be achieved by multiple trial and error experiments but Case B-4 (Figure 15) is a good start for future development (Chart 1 – 2).

4.4 Case C - Skylights with 90º with translucent glass:

Clear glass was replaced with translucent panel in Group C. This was an attempt to create space with diffused light that will prevent the glare. Although it has small effect in minimizing cooling load, the problem of glare was not resolved (Figure 17, Figure 18 and Figure 19) the results were not as expected (Chart 1-2).

5. Analysis and Discussion

All cases with skylight increased the cooling loads of the existing case but with different amounts. Initially, the authors added 30º slopped skylight (Group A) similar to the skylights used in other parts of the school. The results of adding slopped skylight with 30º was not satisfactory in all cases. Cooling loads were increased significantly; it reached almost to triple the existing case in most scenarios. Visual comfort was not obtained either; most scenarios caused glare and failed to give uniform light distributions in the space.

Due to the results of Group A, the authors offered another design of skylight with 90º angle (Group B), which is a monitor design. This design has given better results regarding the cooling loads which were gradually developed to reach the optimum scenario.
Although some of the previous scenarios were satisfactory regarding the amount of heat gain and the increment in daylight factor, most of them failed to obtain visual comfort. Glare was the main problem in the previous cases; thus, the clear glass used in Group B was replaced with translucent panels in Group C. However, the glare was not solved, and the results were rejected.

For a better understanding, Chart 1 compares the thirteen cases in terms of energy consumption due to cooling loads where Group A is the highest. Chart 2 compares the daylight levels of all cases. Among all the thirteen cases, Case B-2 has the lowest increment in daylight factor which is the main purpose of this research and thus rejected.
Below are charts showing all the studied cases in terms of energy consumption due to cooling loads as well as in terms of daylight levels.

**Chart 1:** Comparisons between all the studied cases in terms of energy consumption due to cooling loads. The percentage of increment compared to the existing case is indicated on each bar.

**Chart 2:** Comparisons between all the studied cases in terms of energy consumption due to cooling loads. The percentage of increment compared to the existing case is indicated on each bar.
6. Conclusion
The following conclusion can be drawn:

- Group A failed to offer good alternative for the existing case as the cooling loads were not accepted.
- Changing the geometry of skylight had great impact on cooling loads without compromising the amount of daylight entering the space.
- Replacing clear glass with translucent panels minimized the cooling load, decreased the glare; however, daylight factor was decreased as well. Tested scenarios were not satisfactory but further study could lead to better results.
- Case B-4 is the optimum case among the examined cases where all the results are within the accepted range.
- The possibility of integrating a skylight into classes could be an option if the cooling loads were studied carefully.

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