OPTIMIZATION BUILDING PERFORMANCE IN EARLY DESIGN STAGE USING INTEGRATED DYNAMIC MODEL

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Abstract

Considering the magnitude of energy loss in building, development of energy saving methods appears to be essential. Daylight plays a significant role in designing energy efficient buildings and improving visual comfort for the occupants. Many daylight analysis methods have been developed in this area. Most of these methods focus on opening maximization. These methods unfortunately might reduce comfort since it causes direct solar glare. There is a need for a reliable lighting simulation model to control the lighting strategy in early stage design. This study proposes a strategy for visualizing daylight analysis of buildings by using Integrated Dynamic Model (IDM). IDM is a combination of design tools used during the conceptual phase for holistic classroom that considers the building's energy usage, daylight distribution, and thermal indoor environment. The optimization focus is related maximize the performance of the building envelope design. The purpose of this paper are; firstly, providing a new strategy for visualizing the predicting daylight while respecting architectural integrity. The second purpose is to facilitate the designer for choosing window and envelope design alternatives during early stages. The third is to maximize the positive impacts of daylight. Lastly, hopefully IDM could present a simplified simulation and analyze method with the timely, accurate and efficient process.

***Keywords**: Integrated Dynamic Model (IDM); parametric design; daylight; energy saving; early design stage*

INTRODUCTION

It is clear that global warming is increasing rapidly and raise the challenge to design low-energy buildings. Comfort and energy demand for cooling and lighting are influenced by the facade. With this in mind, early design stage is necessary especially for energy consumption analysis. As a consequence, building performance simulations are increasingly used to design buildings. Especially since lighting strategy using daylight is important to control the energy consumption. Daylight plays a significant role in designing energy efficient buildings and improving visual comfort for the occupants. Daylight is an important aspect for making architectural decision, such as building shape, opening, envelope design and orientation. Daylight is affected by seasons, latitude and elevation, location and time. Wherefore, design parametric can provide daylight analysis faster with some alternative designs.

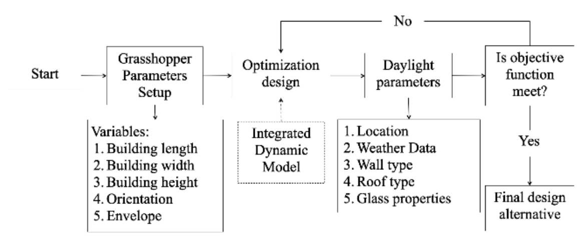


Figure 1. Flow chart of the proposed workflow methodology

Many energy saving methods have been developed in this area. One of the method is energy consumption evaluation in existing buildings (Sari et al, 2019; Hummel et al, 2020). It is a process of revision and identification of the strengths and weaknesses to improve the condition of existing buildings for future designs. The evaluation of buildings in real conditions of use or post-occupancy evaluation is time-consuming and expensive. There is a need to develop a new method that is faster in managing building performance. Commonly, designers focused on increasing daylight by creating a large window. Daylighting from the large window brings one critical issue, glare. Users tend to use blind to block the glare. The result indicates that blind system only reduces the glare but it does not decrease the energy consumption. Therefore, a new strategy is needed to provide integrated software which can ease the design decision, modeling and solve the problem.

This study proposed a strategy for visualized energy analysis of buildings using Integrated Dynamic Model (IDM) which focusing on human comfort. This new method is using a computer simulation to make the model of the building with parameters that can easily be changed and edited. Building simulations are an important part for investigating building performance. IDM is a combination of design tools used during the conceptual design phase for performance optimization. The concept of IDM is changing building design into a faster and more detailed one; while reducing global warming impact, and having a flexible process with multiple design alternatives. Fig. 1 illustrates the flow of the proposed workflow methodology. Our case study is using one classroom in National Taiwan University of Science and Technology (NTUST) to investigate conceptually whether IDM method could measure the discomfort glare. IDM is used for daylight distribution and thermal indoor environment. The optimization focus is related to building envelope design. The shape and exterior structure of a building play major roles in determining its energy efficiency. To do this, we designed the opening and compared with actual condition. Also, the proposed workflow overcomes the interoperability problem by integrating the parametric modelling in one platform using Rhinoceros and its packages tools. The approach facilitates and allows designers to figure out the building performance during early design stages.

This paper is structured as follows: Section 2 is a literature review from previous research. Section 3 describes design process integration form different simulation tools (site analysis, thermal comfort, opening type, daylight analysis and glare probability analysis). The proposed workflow is using Rhinoceros /Grasshopper and its packages tools. This section also discusses methodology and simulation results. Section 4 discusses the conclusion.

LITERATURE REVIEW

Currently, there have been new ways to integrate design tools with building energy simulation tools. These methods are faster and more accurate. Kristoffer Negendahl introduced IDM to create better performing building. These models can provide fast and nearly instantaneous results.

Ma Qingsong and Hiroatsu Fukuda carried out Rhinoceros, Grasshopper, Ladybug, and Honeybee as a simplified tool for building thermal evaluation to minimize the energy consumption and maximize the daylight. Grasshopper is a plug-in for Rhino that utilizes a graphical algorithm editor so that the designers do not need any proper scripting experience to generate parametric models quickly. Ladybug allows the designer to import standard EnergyPlus Weather files (*epw) into Grasshopper and provides a variety of 3D interactive graphics/metrics, including Sun-path, wind-rose, radiation-roses, radiation analysis, shadow studies, and view analysis.

Emad Elbeltagi et al. presents a workflow for developing a strategy to visualize parametric energy analysis of residential building by using parametric analysis and energy modelling based on thermal comfort analysis. Their research used Rhino, Grasshopper, EnergyPlus, and DIVA to demonstrated possible method of combining design and energy simulation. DIVA allows users to conduct glare analysis of daylit spaces in time. They reported that the parametric energy analysis promises improved accuracy in the energy analysis process during the early design stage.

Design Process Integration

Figure 2 represents the steps for IDM of the early design energy analysis process. The design process was conducted by linking parametric software was known as Climate Consultant, Rhino/Grasshopper, Honeybee, Ladybug, and DIVA

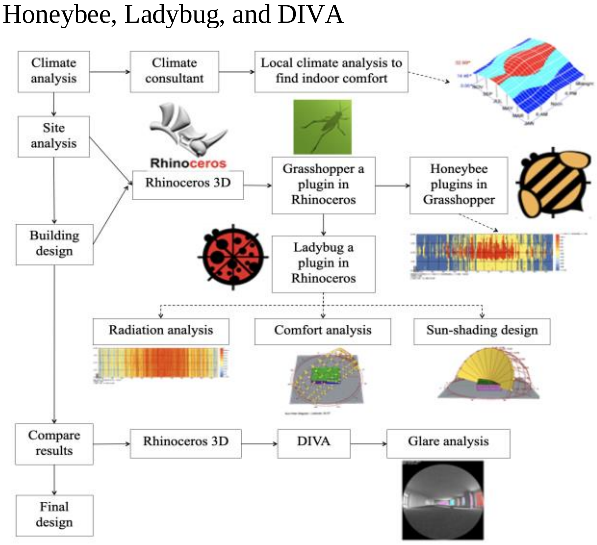


Figure 2. Integrated dynamic model between Climate Consultant, Rhinoceros, Grasshopper, Honeybee, Ladybug and eQuest

ANALYSIS AND RESULTS

Step 1: Site analysis using climate consultant

Studies conducted within one classroom in National Taiwan University of Science and Technology (NTUST), Taipei, Taiwan with latitude 25.01506 and longitude 121.54277. Additionally, Climate Consultant program will provide us will all data concerning to understanding the local climate. Climate Consultant is a computer program that translate outdoor conditions to indoor comfort which uses generalized assumptions about building design (Milne, 2016). This program uses annual 8760-hour EPW format climate data and translates this raw data into graphics displays. During the summer season, the daily outdoor temperature reaches 32°C and winter season reaches 0°C. January is the coldest month, representing winter while July is the hottest month, representing summer. As shown in **Figure 3**, during the summer season the daily outdoor temperature reaches 32°C and winter season reaches 0 °C.

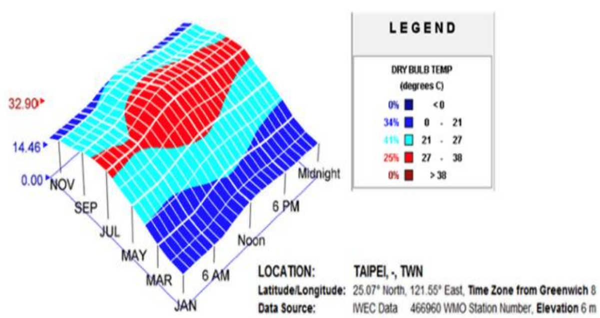


Figure 3. Psychometric chart for Taipei, Taiwan from Climate Consultant program displays January is the coldest month and July is the hottest month

Step 2: Environment analysis

The second issue is designing opening and facade. General environment analysis use Rhino/Grasshopper and Honeybee. The work process of environmental analysis in Honeybee is shown in **Figure 4**. The simulation presents Thermal comfort and dry bulb temperature. Thermal comfort is one of the primary elements which determines the quality of indoor environment in naturally ventilated buildings. Therefore, this can be used to control heating and cooling sensor of the building by combining its cooling system and natural ventilation. Reduced cooling load might happen when the outdoor temperature similar to indoor temperature so it could lower the heat loss and reduce the cooling power consumption. **Figure 5** shows the site analysis result from Honeybee plug-in program. According to the graph, -1 means cold, 0 means comfortable and 1 means hot. Taipei adaptive thermal comfort around 12 AM to 9 AM and 6 PM to 11 PM.

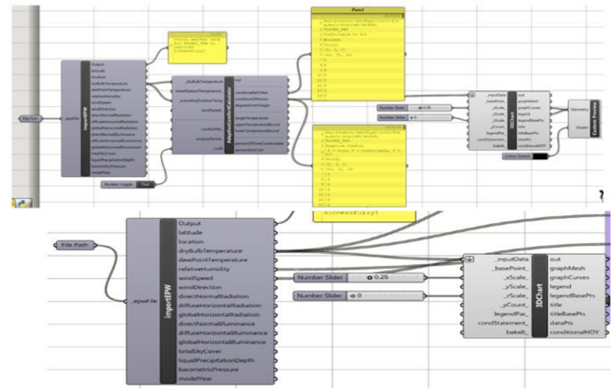


Figure 4. Work process of thermal comfort and dry bulb temperature in Grasshopper and Honeybee.

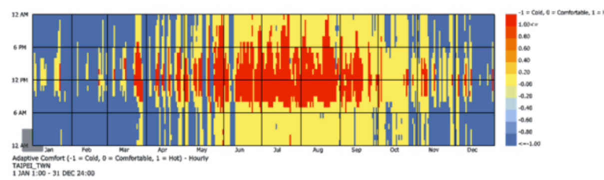


Figure 5. The adaptive thermal comfort in Taipei, Taiwan around 12 AM to 9 AM and 6 PM to 11 PM.

Designing openings in a Subtropical climate like Taiwan is challenging. The weather in Taiwan from May to September each year is typically hot and humid. (**Figure 6**). Humidity can compromise classroom occupant's health and comfort. To prevent the internal humidity and energy saving, passive ventilation by opening windows for cross ventilation is applied for the classroom.

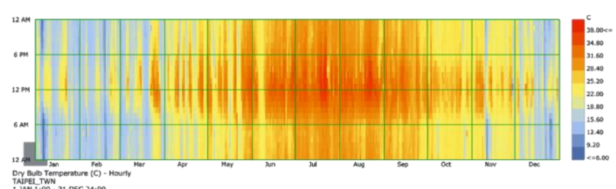


Figure 6. Dry bulb temperature in Taipei Taiwan, represent the humidity of the classroom

Step 3: Modeling of building geometry

Rhino is a basic program to modelling the classroom. **Figure 7** summarize the detailed information about the classroom. The classroom is a 10.95 m wide and 16.95 m deep rectangular space, with 3.00 m clear height. It assumed to have an 88 mm single pane glazed window with varieties size. The main facade of the building is southwest oriented. Lighting and ventilation are essential factors in the design. With balcony and large windows located at southeast and window located in the northwest, daylight can naturally flow into every corner.

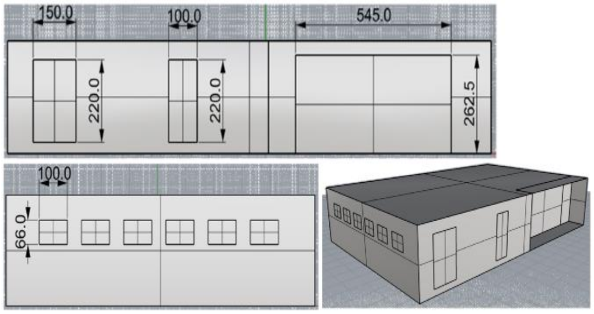


Figure 7. Envelope and opening design for classroom.

Step 4: Daylight control analysis

After creating building geometry using Rhinoceros, we generated parametric geometry using Grasshopper. Hence, the classroom uses a large window for facade designs. Glare control is important to create user comfort. Furthermore, Grasshopper/Ladybug could anticipate the optimum solutions for the building design. **Figure 8** presents a set of Grasshopper definitions used to design daylight in the classroom by using sun path diagram and sun shading analysis.

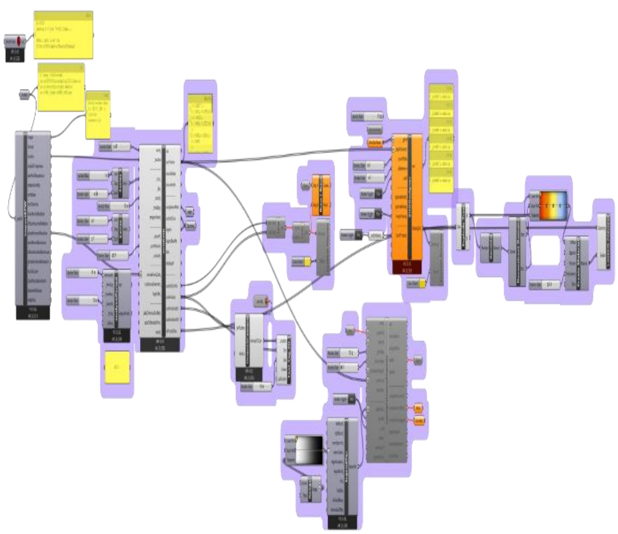
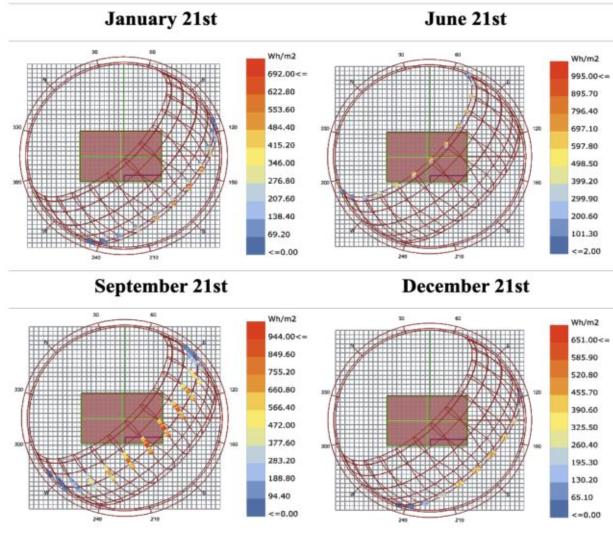


Figure 8. Grasshopper definition for daylight control analysis.

The modelling experiment is conducted for 4 cases in January 21st, June 21st, September 21st and December 21st, which are representing maximum and minimum sunlight availability over the years. Sun path diagram was a graphic that describes how the sun will impact the site and building throughout the year. Sun Path diagram provides a solar position that helps the architect to predict the shading. The designer can select the best window shading based on the optimal performance. It can be noticed in **Table 1** that as the altitude rises, the solar radiation performances in Southwest orientation becomes higher. The aim of creating shading for the building was to avoid visual comfort (glare) for the student and maintain a uniform distribution of daylight. Sun shading devices highly needed for the southwest view.

Table 1. Annual global horizontal radiation on January 21st, June 21st, September 21st and December 21st.

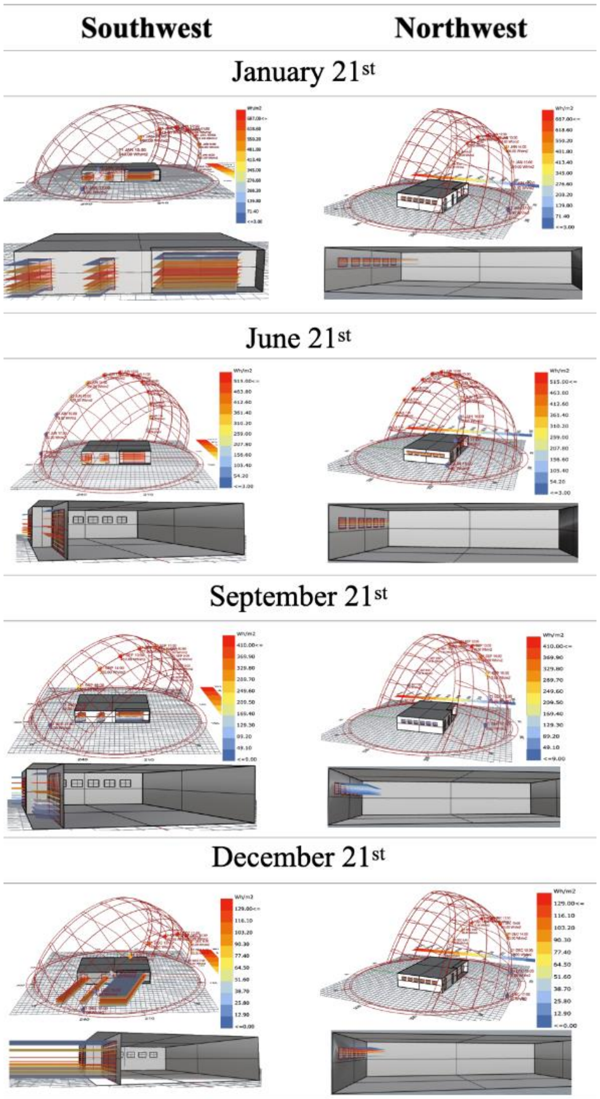


The parametric software created the main model for the classroom louver which can be controlled and changed parametrically. Therefore, the horizontal state louver is considered the best static way to utilize daylight. **Table 2** shows that the highest solar radiation is in the middle of the horizontal louver around 687 w.h/m^2 and the lowest solar radiation is near the ceiling (6 w.h/m^2). On January, June, and September, the reflected light looks steadier. The simulation program suggested louvers distances from the window (L) from 0.50 to 3.00 (**Table 2, Table 3**).

Table 3. A Comparison showing the best louver design result

Louver parameters (m)	21st January	21st June	21st September	21st December
Distance from window (L)	3.00	0.50	0.75	10.00
Distance between louvers (D)	0.37	0.37	0.37	0.37
Number of louvers	7	7	7	7

Table 2. Louver design for January 21st, June 21st, September 21st and December 21st.



Step 5: Comparison

From the previous conditions, we found some design alternatives. As an architect, envelope design is an integrated design technology and aesthetic. **Figure 9** is showing the best performance and succeed to reflect and prevent glare. However, a comparison experiment conducted between classroom design without louvers and classroom design with louvers. Therefore, to validate the result, the design classroom is simulated using Diva for Rhino. Diva for Rhino is a highly sophisticated daylighting and energy modeling software (Solemma. 2016). It was developed at Graduate School of Design at Harvard University under Prof. Christoph Reinhart. Diva for Rhino allows users to predict glare.

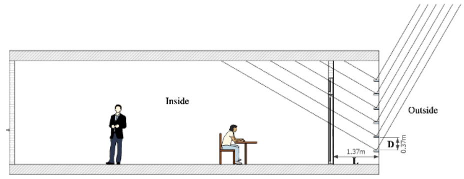
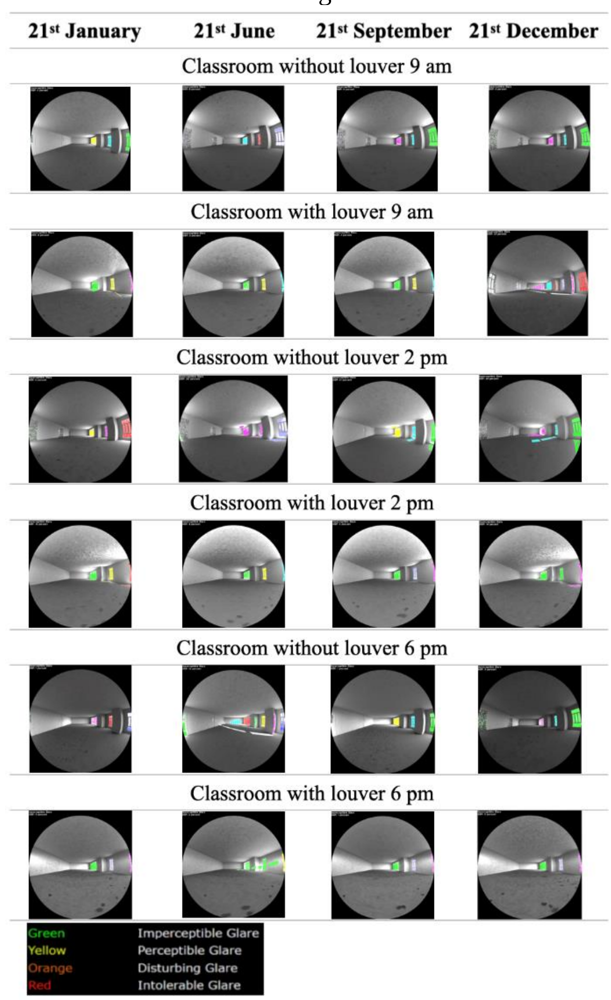


Figure 9. Louver final design; L is distance from window and D is distance between louvers

A comparison conducted between the classroom with and without horizontal louvers. This data uses the sun direction and sun path at January 21st, June 21st, September 21st and December 21st (Table 4). Table 4 shows a Daylight Glare Probability (GDP) from selected months. DGP is a metric to predict the appearance of discomfort glare in daylit spaces proposed in 2006 by Jan Wienold and Jens Christoffersen.

Table 4. DGP is comprising with and without louvers design



There are four different colors from the simulation result; green means imperceptible glare, yellow means perceptible glare, orange means disturbing glare and red means intolerable glare. On Table 4, horizontal louvers design is showing good performance at 9 am 2 pm and 6 pm. Except on December 21st at 9 am, near the northwest window, there is insufficient glare in the classroom. At January, June, and September, sunlight is reflected and prevented successfully (Table 4).

CONCLUSION

Currently, there have been new ways to integrate design tools with building energy simulation tools. These methods are faster and more accurate. IDM can provide fast and nearly instantaneous results. It was used as a simple method to predict the daylight in Taipei, Taiwan. The classroom was designed parametrically to achieve best building performance. Simulation research has been carried out with programs for Rhinoceros including Climate Consultant, DIVA, Grasshopper, Ladybug, and Honeybee.

The simulation occurred at four different times of the year, January 21st, June 21st, September 21st, and December 21st. From this simulation, we found that the concentration on horizontal louver shading is suitable for the subtropical climate. In this case, the horizontal louver will block solar radiation efficiently before it penetrates through the window glazing. Horizontal louver design shows the best performance in reducing the glare. However, on December 21st at 9 am, the horizontal louvers are still insufficient. It prevented direct sunlight.

In conclusion, IDM could be applied to visualize and predict daylight in the classroom. This new strategy is facilitating the process of envelope design alternatives during early stages. The conventional methods were time-consuming and costly. IDM is presenting a simplified simulation and analysis.

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