Reaching Design Solutions Using Building Technology Simulation: New Thai Parliament Design Competition

Jatuwat Varodompun*
Faculty of Architecture and Planning, Thammasat University, Pathumthani 12121, Thailand

Abstract

Under the current environmental and energy concerns, architects are forced to design better buildings which are both energy efficient and environmental friendly. Green ideas and concepts presented by designers are typically sketches and simple design diagrams which come from past design experiences and expertise. Design solutions derived by such process are skeptical because it lacks the measurable outcomes. To solve this problem, one of the solutions is to utilize computer which increasingly plays significant roles in building simulations. Many progresses were made for better users' interfaces, accuracy, and computation speed. This article will demonstrate the emerging simulation technology that could aid the design decision making process based on simulated data including air temperature, solar radiation, wind speed, daylighting level, and others. One of the five finalists in Thai parliament design competition is the case study for demonstrating this design with computer simulation process. Using well recognized and state-of-the-art software including ANSYS CFX and eCOTECT, major components of this parliament were selected and simulated under specific design inquiries involving atrium design, shading device, and skylight design. In this study, CFD (Computational Fluid Dynamics) data from ANSYS CFX helps designers select proper atrium ventilation and fenestration systems. At the same time, radiation and daylighting data can optimize shading device, façade, and skylight design. Enhanced by this process and measurable outcomes, the designers can be confident in their final design solution which could improve both energy and environmental performances. For any future projects, this article is an example of how building technology simulation and architectural design could play hand-in-hand and, in turn, came up with the better design solutions as well as effective design process.

Keywords: Simulation, Sustainable design, Energy and environment, Design, Building technology, Parliament

* Corresponding author.
E-mail: vjatuwat@umich.edu

1. Introduction

As designers have been challenged to design the buildings that the efficiency are improved and, at the same time, become more environmental friendly, many designers are still struggling of adjusting themselves toward these criteria. Normally, designers assume the environmental and energy concepts by simple method such as graphical diagram and simple direct calculation. These methods are convenient, low-cost, and sometimes persuasive to the client. However, these graphical diagrams came from unproven assumption which is based on personal experiences and expertises. This means that there will be many circumstances that things could behave beyond designers' expectation and became the false required responsibility. In other words, what designers tend to do is educational guess which could never happen or happen much differently. Once the building is built, the cost of fixing problems could be very high for modification. Sometimes, cost of mistakes are energy cost such as higher HVAC (Heating Ventilating and Air-Conditioning) energy cost, lighting energy cost, and additional investment cost such as replacing glazing system, or additional insulation, etc. For instance, inefficient glazing system could increase energy cost throughout the building life.

In Thailand, buildings of both commercial and residential sectors consume 45% of electricity (EPPO/MOE, 2008). Most of building electricity goes for two prime consumers, HVAC and lighting. Effective building design could reduce both energy types significantly. Though range of energy saving highly varies among building types and investment, data shows significant energy saving could be possible from good architectural design. An energy efficient office could consumed less than 100 kWH/m^2 per year, while typical office could consume up to 250 kWH/m^2 per year.

To tackle the energy consumption issue, building simulation using computer software has been developed rapidly. Nowadays, simulation software became feasible and affordable. Many softwares for simulating building energy, ventilation, radiation, daylighting, and acoustics are available for implementation. The list of more than 100 softwares can be found in Building Energy Software Tools Directory within U.S. DOE Energy Efficiency and Renewable Energy (EERE) website (EERE, 2010). Utilizing these simulation softwares along with proper simulation techniques, designer could predict the energy and environmental performance in advance and with better accuracy.

To demonstrate how building technology could aid design process, one of the five finalists of Thai parliament design competition was selected to be a case study. This design was proposed by one of leading design firm namely D103 international. Figure 1 is the illustration of the exterior perspective of this building. After the following section which will discuss objectives and methodology. After that, overview of

Figure 1. Exterior perspective of a Thai parliament finalist by D103 International.

the case study will be introduced. Then, the following discussions will demonstrate how building tech simulation could help designer obtain design solution of building atrium, building façade, and main auditoriums.

2. Objectives and methodology

Being supported by research while designing, architects and researchers shares new experience from close collaboration. Results from this process could illustrate a new way of architectural practices. Along the integration between design and research, this study aims at accomplishing the following objectives.

1) To improve the performance of selected building using building technology research.

2) To demonstrate how building technology research could assist and went along with the design process under actual circumstances.

3) To demonstrate simulation tools which could solve different design problems.

4) To address some effective building technology applications which readers could utilize for enhancing performance of their projects.

To succeed these four objectives, design process and research methods should be synchronized. Since designing with research support is new, there is no formal code of conduct of such activities being addressed. Accordingly, method presented in Figure 2 is proposed. In each preliminary design stage, there is possible research question addressed by both architects and researchers. If the questions can be answered by using team's expertise, architects could carry on working on the design. On the contrary, if the questions can not be answered in this stage, they must be answered by using research process. The process begins with selecting the research tools (energy, lighting, airflow, etc.). Then, parametric cases should be setup and the results must be, in turn, analyzed. Finally, the results were translated to graphical format for communication purposes. This process is continued as the preliminary design progress toward the detailed design stage.

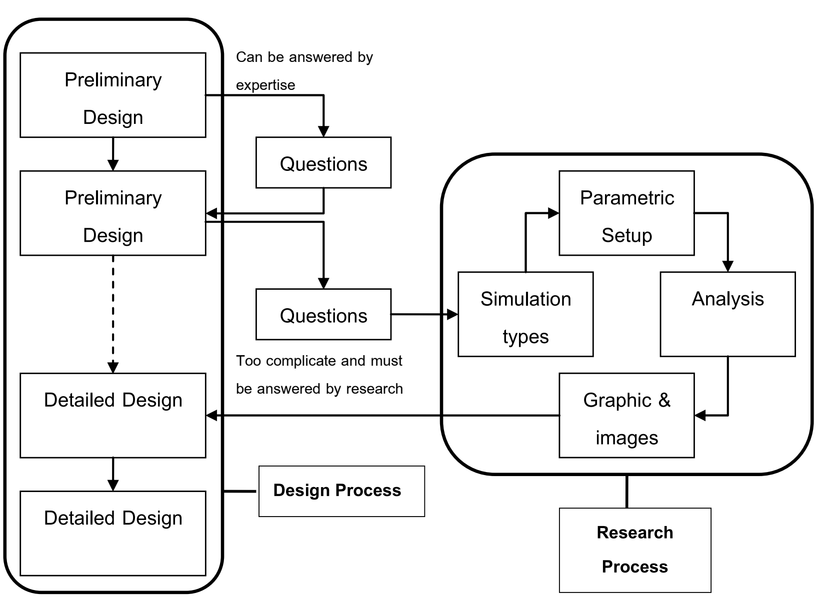


Figure 2. Proposed design and building tech research integration.

3. Project overview

The site of this project is located in Bangkok near the Ratanokosin Island, and adjacent to Chao Praya River. With the construction budget of 12,000 million baht, this building gross area is almost 250,000 sq.m on the site area of 190,400 sq.m. Thai government set the design competition which is opened for all architects across the country. More than 100 individuals and design firms involved in this major event. There are many round took place prior to select the five finalists which were then asked to proposed the design and concepts in detail. As one of the five finalists, D103 wanted to rigorously implement the building simulation to guide their design toward sustainability goals.

D103 proposed their building to be symmetrical and compact by stacking five above ground floors over two underground floors. As shown in Figure 3, the simplified diagram indicates overall placement of major functions. Two main council auditoriums are located in the circular shape building 4th floor and can be accessed by all functions

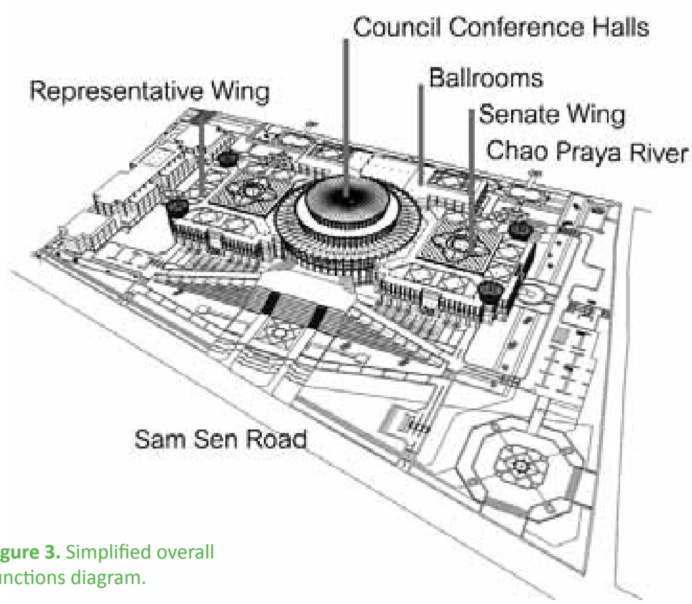


Figure 3. Simplified overall functions diagram.

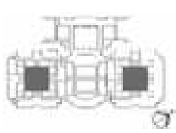
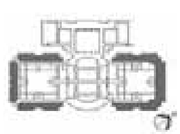
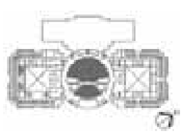
	Spaces	Ventilation	Solar Radiation	lighting Atrium
	Atrium	Thermal comfort of occupants in spaces using CFD	Will be tested with CFD	Appropriate daylighting illuminance of occupants and vegetation in spaces
	Office Façade	Not applicable for testing	Shading device to minimize direct irradiance penetrating into spaces	Adequate illuminance for occupants for installation of shading devices
	Council Auditoriums	To be tested in the funture	To be tested in the funture	Adequate illuminance for occupants when using top window

Table 1. Components of parliament building and environmental parameters to be studied.

surrounding them. Two rectangular buildings with large open courts interlocking this circular shape are the office and support functions. The building on the left is representative wing, while the building on the right is senate wing. The ballrooms and functioning spaces are located facing Chao Praya River.

After discussing the energy and environmental concepts, the design team decided to deeply investigate the major components including atriums, office façades, and conference halls. Table 1 shows the matrix of these spaces against the related environmental parameters such as ventilation, solar radiation, and daylighting. The simulation set up and results of these major components will be discussed in the following sections.

4. Atrium ventilation

Instead of having utility core at the building center, D103 decided to place two identical square atriums at the center of two building wings. Both atriums suppose to allow daylight and ventilation for the occupant access. Thus, natural ventilated atrium is preferred more than the air-conditioning one. The big challenge for designing this passive atrium is thermal comfort of occupants because of Thailand hot-humid condition. After mapping Bangkok weather data in psychometric chart, there is small amount of hourly temperature and RH (Relative Humidity) that are within the comfort zone (Boonyatikarn, 2002). To maximize thermal comfort, passive strategies including natural ventilation, mixed-mode mechanical ventilation, and vegetation utilization, were implemented and investigated. In addition, this atrium will be the first atrium in Thailand to used ETFE (Ethylene tetrafluoroethylene) which is lighter than glass almost 1,000 times. With this light weight property, the support structure could be minimized and long span space could be built by much cheaper cost. Although the nature of ETFE is transparent, solar radiation could be reduced by screening reflective pattern on the surface. In other words, this could reduce SHGC (Solar Heat Gain Coefficient) of ETFE significantly. The following analysis will also focus on the best implementation of this new material to improve the occupants' thermal comfort and heat transfer of both atriums.

In order to study complex thermal scenario, CFD (Computational Fluid Dynamic) simulation must be used. ASHRAE (American Society of Heating Refrigerating and Air Conditioning Engineers) RP 1133 was referred to validate the CFD simulation process such as grid independency (Chen & Srebric, 2001). After

Affected Component Diagram

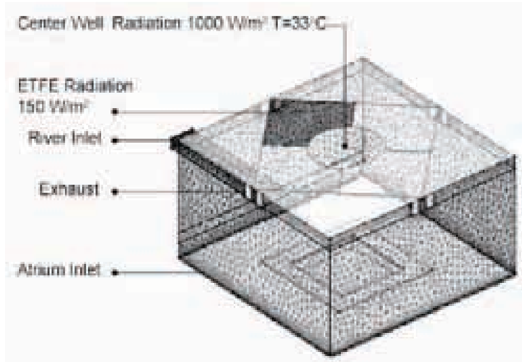


Table 2. Atrium CFD simulation scenarios.

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
River Inlet	Close	Open 33°C	Open 33°C	Open 33°C
Exhaust fan	Close	Close	Open 1m/s 29°C	Open 1m/s 29°C
Atrium Inlet	Close	Close	Open 0.1 m/s	Open 0.2 m/s
Vegetation	None	None	None	Surface temp 28°C

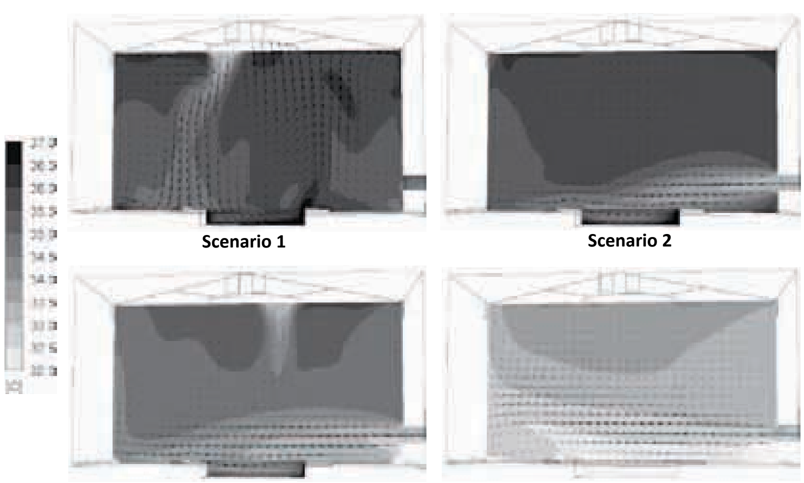


Figure 4. CFD temperature and air current vector of parliament atrium.

meshing, CFD model contain 1,000,000 grids and each simulation scenario takes 150 iterations. Affected component diagram and simulation scenarios are presented in Table 2.

Given these simulation scenarios, the CFD air temperature data and air current vector are presented in Figure 4.

4.1 Discussion of atrium's comfort condition

If there is none of any support system, the atrium will become a very hot place. Scenario 1 shows that outdoor air can ventilate the space only through the top well and, as a result, air temperature at the occupied zone could reach 35°C or higher than the outdoor air temperature by 2°C. Though the solar radiation is blocked by low SHGC ETFE, the remaining radiation still heats up the floors' surface. High surface temperature increases the air above and causes the war air to float upward. After that, the warm air floats out of the space by using the same top well that the outdoor air coming in. The remaining hot air traps below the ceiling and increase the air temperature to 36.5°C which is warmer than outdoor by 3.5°C. Temperature of outdoor incoming air is warm up by floating warm air which shares the same opening. The temperature of incoming air is increased by crossing warm air and, in turn, it can not cool down the radiated space effectively.

Since the solar radiated space is usually warmer than outdoor air, the outdoor air should be introduced into the space effectively. The riverside ventilation intake was operated in Scenario 2. At the same time, the top exhaust fan was activated to remove the trapped heat near ceiling. Simulated results indicate that the occupied zone can de effectively cooled down by the high velocity incoming river air current. This current is purely driven the buoyancy effect which is generated by rising warm air from the heated floor. Moreover, this river air intake turns the top well become purely outlet. Thus, rise warmer air does not mixing with the incoming cooler air down below. Exhaust fans also help stratification process by inducing the air upward. However, they are still not adequate to remove trapped warm air below the ETFE.

The challenge to maximize comfort of this atrium is to reduce the air temperature below the outdoor air. Thus, the cool air left over from the building ventilation system is utilized. This air is the exhausted air from the air conditioning space as required by

ASHRAE Standard 62.1 2004 (ASHRAE, 2004). Though the exhausted air is cool, it is polluted and can not directly supply to the atrium. Heat recovery system utilizes low exhausted air temperature to reduce clean incoming hot air. It was estimated that the temperature could be reduce to 29°C. In scenario 3, air volume of 6 m^3/s (12,500 cfm) is supplied into the space through air slot around the atrium parameter. At the same time, the top exhaust fans were activated with double capacity of the previous case. Results show that the occupied zone temperature uniformly close to the outdoor air. Only the area near bottom inlet remains lower than the outdoor. CFD data also shows that there was air flowing in from the top well and disrupts the uniform stratified flow pattern. Thus, the further adjustment is needed to create uniform stratification which could improve IAQ (Indoor Air Quality). Such stratification help pollutants to float only upward and help the air in the occupied zone remain clean.

To further reduce the air temperature and create uniform stratification, the cool air volume must be increased to create higher positive pressure. Such pressure will push air outward and convert the top well to be only exhaust. Not only increase the pressure, the double air volume of 12 m^3/s (25,000 cfm) should successfully drop the air temperature below the outdoor. Fixed surface temp of 28°C at center represents the indoor vegetation which should provide constant cooler surface temp due to evaporation. Results show that both cooled air supply and indoor plants could substantially reduce the occupied zone temperature to 31°C which is lower than the out door by 2°C. Outdoor river air-flow could turn to be negative impact since its temperature is warmer than the indoor condition. However, this intake should be maintained because it could be utilized to remove excessive indoor moisture and pollutants. To achieve both air quality and comfort purposes, this riverside air intake should be controllable. The automatic damper should be programmed to be activated by temperature set point. In winter or in the morning when the outdoor air is not too hot, this channel should be opened. In the peak summer month when the temperature could reach 40°C in the afternoon, the river intake should remain closed to keep the cool air in the occupied zone.

4.2 Atrium design solutions for thermal comfort enhancement

Besides the atrium ventilation system, the results also suggest the proper use of ETFE and green wall system. In all cases, results show that it is rarely to have the trapped air below ETFE to be lower than the outdoor air. In other words, the heat is always flowing out through ETFE during daytime. This clearly indicates that the material should have high U-value that can conduct the heat out effectively. Based on these findings, designer can use cheap regular single layer ETFE instead of expensive double pressurized ETFE. Briefly, this construction reduces the construction cost significantly. Another characteristic of ETFE that must be strictly complied is SHGC. ETFE must be minimized the penetrated radiation down to 15%. To achieve this characteristic, ETFE must be printed with highly reflective pattern. Highly reflective pattern can maintain the surface temperature close to outdoor temperature within only 1-2°C increment. Given this condition, the heat of trapped hot air near ceiling still flows outward and the penetrating solar radiation remains minimal.

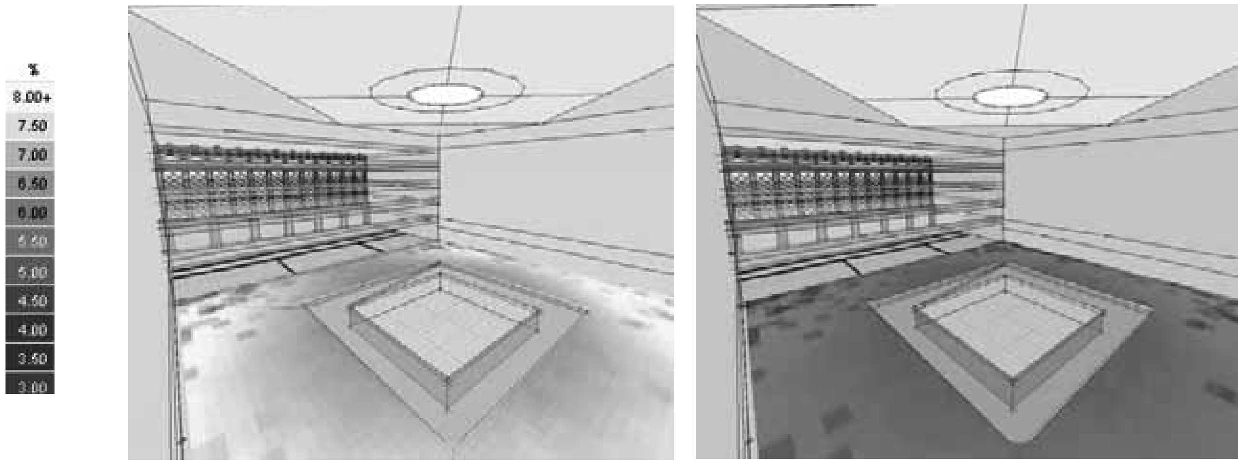
In scenario 4, it was proven that vegetation could reduce indoor air temperature. To maximize vegetation surface, the designer decided to use green wall for all side walls. These green walls are not only lower the air temperature but also create large field of exposure to occupants. Occupants' body will expose to the cooler surface temperature the surrounding green wall and feel cooler. In other word, green wall can reduce MRT (Mean Radiant Temperature) of an occupant (ASHRAE, 2005).

5. Atrium daylighting

After studying the thermal comfort, daylighting utilization is also a major concern of this atrium. When using this space, occupants should expose to adequate daylighing level. IESNA handbook (Illuminating Engineer Society of North America) sets the minimum recommended DF (Daylight Factor) for general space at 2.5-5% (Rea, 2000). Two major parameters that significantly impact DF are the LT (Light Transmittance) of glazing (in this case ETFE) and the interior reflectance. Since low SHGC of given ETFE is achieved by fritted pattern (not the translucency), the LT of this ETFE is assumed to be the same as that of the SHGC. For the interior reflectance, the designers concern the impact of typical bright wall and vegetated wall which is normally darker. To answer this design inquiry, eCOTECT was used to perform daylighting analysis. Overcast sky of 14,500 lux is used for DF calculation. LT of ETFE is fixed at 0.15 and the interior reflectance of 0.8 (white wall) and 0.3 (light wall) were simulated.

5.1 Discussion of atrium's daylighting

In Figure 5 , simulated results show distinct different of DF at horizontal plane 0.75m above the atrium floor. Overall DF of Ref-0.8 scenario or wall reflectance of 0.8 is higher than that of Ref-0.3 scenario or green wall reflectance of 0.3. Average DF of the former reaches 7.09, while DF of the latter drops to 5.12. Based on this finding, it can be



Ref-0.8 Scenario

Ref-0.3 Scenario

Figure 5. Daylight factor comparison of typical bright wall and green wall.

concluded that by changing wall reflectance by 0.5, the daylight factor could decrease by 2%.

5.2 Atrium design solutions for daylighting enhancement

In general, glazed skylight of any given atrium should be small to minimize solar radiation. ASHRAE 90.1 2007 suggests that the glazed skylight with SHGC of 0.19 should not go beyond 5% of roof area (ASHRAE/IESNA, 2007). In this case, when green wall or vegetation is the majority of the atrium's interior surface, illuminance from daylight could drop, significantly. Data shows that DF of 5.12 is right at the threshold of minimum DF of general daylit space. This finding directly correlates to the size of area and LT of ETFE. Unlike any conventional atrium, this atrium requires large ETFE area to maintain appropriate DF. However, it should be remarked that this statement hold true if LT of ETFE is low (in this case, 0.15). Also, since the location of ETFE is far above the human visual field and the ETFE LT is only 0.15, problems related to visual discomfort should be minimized. This conclusion allows the designer to maintain the size and shape of original ETFE design which must fit the green wall in the space down below.

Aside from proper daylighting for human, designers should extend the concern toward plants survivability. Appropriate illuminance level does not only enhance well-being of occupants but also support the growth of the trees and vegetation planted within an atrium. Figure 6 is the illustration of final atrium design with green walls in all sides and trees in the middle.

6. Façade solar protection

Façade is one of the major components that strongly impacts building energy performance. Under intense solar radiation of this region, shading device is almost mandatory in glazed buildings. The main function of shading device is to protect direct solar radiation to hit the external surface of the glass. At the same time, it should still

Figure 6. Parliament atrium perspective.

allow occupants to access outdoor view and daylight. As one of the major building in Thailand, façade system of this parliament building should perform excellently under both criteria. Initially, designers proposed automatically movable shading system which can perfectly optimize both solar and daylight. However, many experts criticized its high cost, practicality, and durability. As a result, the fixed external shade became more realistic solution for this project. Among many fixed shade patterns such as horizontal, vertical, and others, performance of shading device varies from one façade orientation to another. To obtain the best shading solution, façades with different shading systems were tested with eCOTECT as shown in Figure 7. The base case is window without any shading device. First proposed alternative is to set the windows back behind the extruded column role. Shading is expected purely by extrusion length which is 0.6 and 1.2 m. The extrusion of 1.2 m is maintained throughout the rest of design alternatives which ranging from vertical, horizontal, diagonal, tilted diagonal, and triple horizontal.

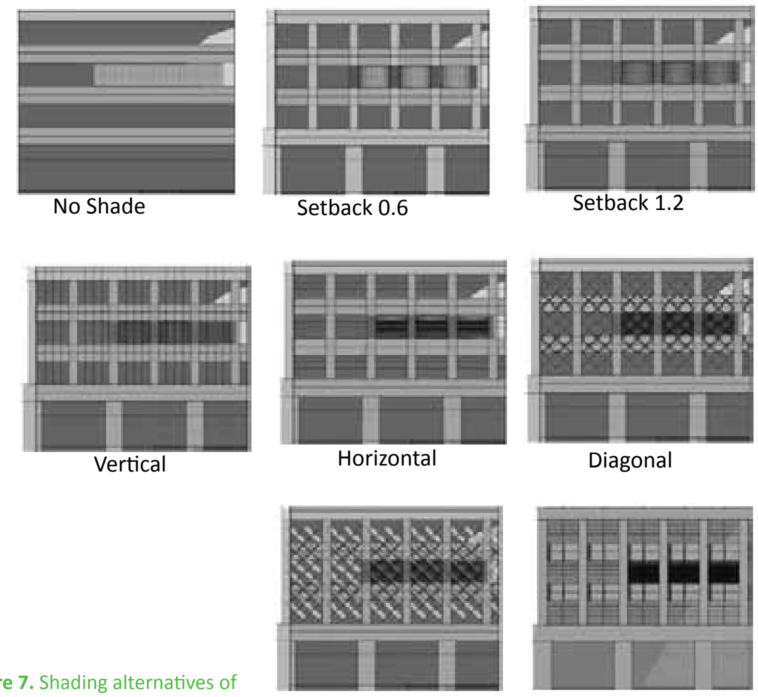
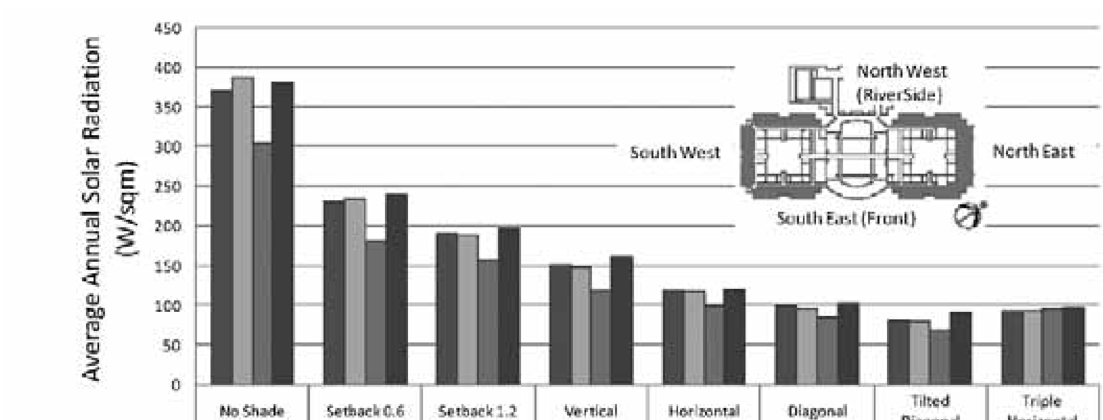


Figure 7. Shading alternatives of Parliament façade.

6.1 Discussion of façade solar shading

Irradiance simulation which is unique feature to eCOTECT software is used to demonstrate shading performance of eight design alternatives by TMY2 (Typical Meteorological Year version 2) 1.2 m, th Bangkok weather file from USDOE (US Department Of Energy) & NREL (National Renewable Energy Laboratory) (Hirsch, 2004). Average solar radiation from 8:00 to 17:00 on glass surface of four faced orientations is plotted in Figure 8. Results of all façade orientations indicate the same



	No Shade	Setback 0.6	Setback 1.2	Vertical	Horizontal	Diagonal	Tilted Diagonal	Triple Horizontal
South East (Front)	370	231	190.71	150.95	118.83	98.68	81.81	93.17
South West	387.02	233.5	189	147.77	117.05	96.4	79.81	92.35
North West (Riverside)	303	181	156.64	119.11	99.68	85.22	68.36	96.52
North East	380	238	196.65	161.37	120.75	102.09	90.59	97.12

Figure 8. Average annual solar radiation of four façade orientations.

tendency. Average irradiance significantly reduces if the designers add more shading components. By setting back the window back by 1.2 m irradiance drops by almost half in all façades. After that, shading components does reduce the solar radiation but the impact is not strong as the previous does. In general, northwest façade tends to expose to lower solar radiation, while the rest exposes to the same level of intensity. Highest effective shading pattern is tilted diagonal which is cross pattern with one array of diagonal fins cover almost all glass exposure. Compared to no shaded glass, tilted diagonal fins could reduce solar radiation down to 20-25%. In addition, results show that horizontal shading device performs better than that of the vertical in all orientations. Adding more horizontal fins to be three instead of two also improves shading performance by reducing solar radiation by 5-25 W/m^2.

6.2 Shading device solutions for solar radiation protection

Given the simulated data, it is clear that the shading device must be installed in all façades. Although the tilted diagonal and diagonal are the best two solutions, they might not be the best for occupants in adjacent spaces. Designers aware that it might be not easy to access the outdoor view and might generate high contrast pattern which might be glary for the viewers. To maximize both visual comfort and solar radiation protection, "triple horizontal" shading device become the best solution. Tough it slightly increases the incident solar radiation by 3-8 W/m^2 as compared to that of tilted diagonal; it allows occupants to access the view with less visual discomfort. Since the glazing area of this building is less than 40% of wall area, solar radiation from glass might be not severe as much as in other fully glazed building. Along with this shading solution, double low-e glass and interior sunscreen are highly recommended to maximize both thermal and visual comfort. The close-up exterior perspective of building façade with the recommended design solution is shown in Figure 9.

Figure 9. Close-up exterior perspective of building façade.

Figure 10 is the comparison of hourly incident solar radiation of south east façade without shading device against that of triple shading device. Triple horizontal fins which provide long shading depth can prevent most of direct solar radiation except the low angle beam in the morning. With this design, it is no need for occupants to use sun screen almost year round except during the early hours of winter.

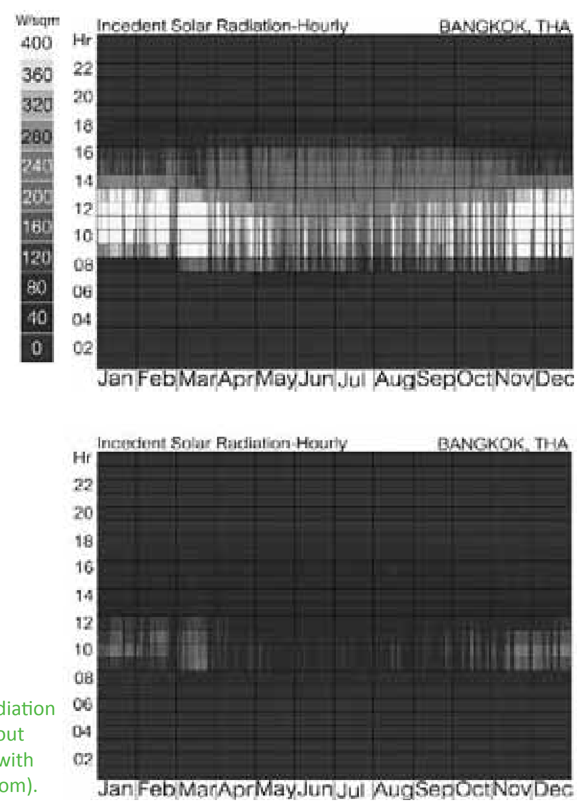


Figure 10. Hourly solar radiation of south east façade without shading device (Top) and with triple horizontal fins (Bottom).

7. Office daylighting

Although shading device can effectively reduce the impact from direct solar radiation, it could also reduce daylight penetrating into the space. Since the shading device of the building façade can effectively protect the direct solar radiation, the penalty of blocking daylight should be investigated. Analogous to the previous analysis, eight shading devices were tested with eCOTECT. In stead of solar radiation, daylight factor in the office area at the task height of 0.75 m was investigated. Dayligthing simulation feature in eCOTECT allows users to simulate both overcast and clear sky condition. Since the designers want to ensure an actual daylighting performance, the worst case scenario of overcast sky with sky luminance at 14,500 lux was used. Average daylight factor of the studied grid with the depth of 4 m away from window were used to justify the daylighting performance of each shading solution. Normally, glass with high Light Transmittance (LT) could maximize and deepen the daylight level within any space. However, low SHGC glass typically has limited range of LT. In this case, SHGC of 0.2-0.3 is recommended to minimize the solar load. Therefore, LT of such glass rarely goes beyond 0.5. In additional, extremely high LT possibly causes glare problem if it is not properly designed. Given these concerns, glass of appropriate LT of 0.45 was implemented.

7.1 Discussion of office daylighting condition

Figure 11 presents the daylight factor distribution of the work plane. It is obvious the DF is the highest when measured near the glass. After that, it drastically decreases along the room depth. When the building has no shading device, daylight could penetrate deeper and at the same time brighter. However, the daylight factor only goes as high as 5% near the window. Accordingly, it is impossible to get the DF of 5% which is the highest recommended threshold of workspace for the rest of the design alternatives. DF could significantly drop by just setting the window back and having the shading projection from columns. Not only had the daylight factor near window drops to 3-4 %, but the daylight factor in the deeper zone drop even greater. Similar to solar radiation, adding additional element could decrease daylight level further. Vertical fins allow daylight level to access the space better than that of the horizontal. In the last three alternatives, daylight factor is almost identical. Though daylight factor close to window area noticeably drops, the daylight still penetrates to maintain daylight factor of 2.5-3 % throughout the room (depth 4m) (room full depth varies from 4-16m). This level is still satisfied the lower threshold of daylight factor recommended by IESNA for general work area.

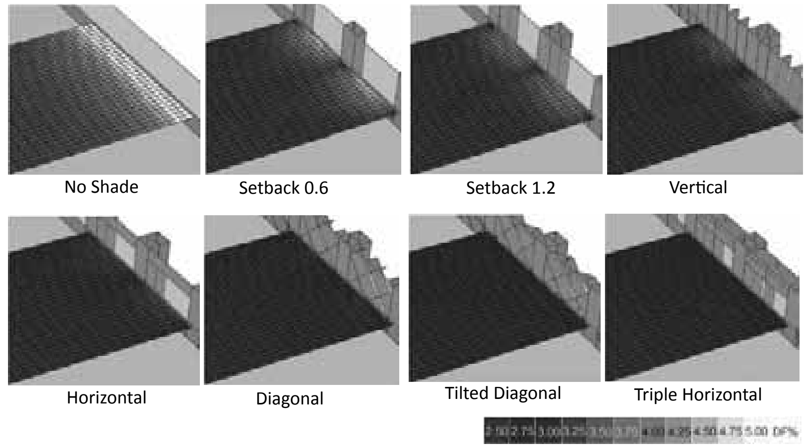


Figure 11. Daylight factor of each shading device alternatives.

Average DF data in Figure 12 gives the clearer picture of daylighting performance of each shading design. DF of no-shaded

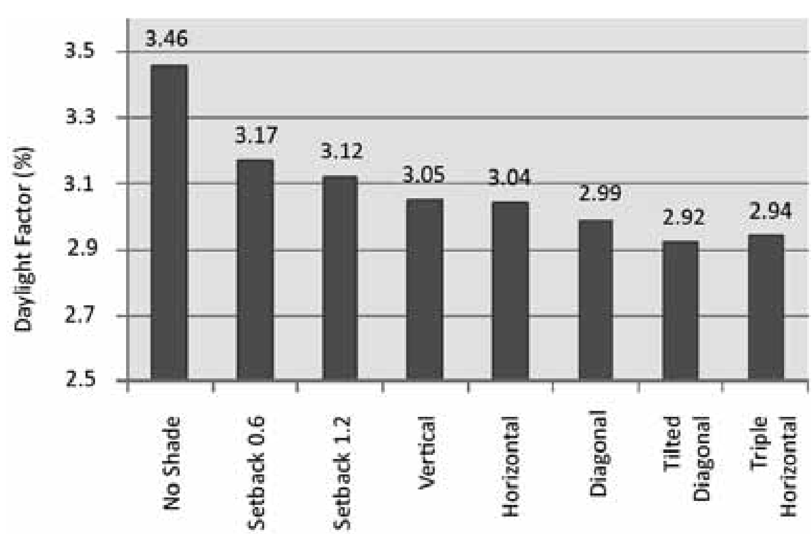


Figure 12. Average daylight factor in an office space of different shading devices.

façade is not as high as expected. This means that the high DF of 5% is only maintained near the window area. Once the shading is installed, DF only drop 0.3-0.5%. Triple horizontal fins maintain DF of 3% which is closed to that diagonal shades.

7.2 Shading device and daylighting impacts

The main benefit of shading device is to protect solar radiation from directly hitting the glass but the daylight reduction is always the major concern. Based on the simulated data, the daylight reduction penalty is not worse as much as projected. Triple horizontal fins maintain the same DF level as that of tilted diagonal fins but the former does not obstruct the outdoor view. In other words, it performs best when the designers want to optimize three major factors including solar protection, daylight maintaining, and view access. As a result, the design team was able to confirm that the triple horizontal is the best design solution for the parliament façade. The unique feature of this design is light shelf which allows daylight access deeper. See Figure 13 for the light shelf concept and the office interior with this shading design. The top fin not only shades the glass below but also helps bouncing toward the ceiling. The bright ceiling increases daylight level of workplace and at the same time reduce glare from viewing through windows. The two lower fins reduce the needed fins' length of a single fin, while they still maintain shading projected area which is very important to minimize cooling load from glass.

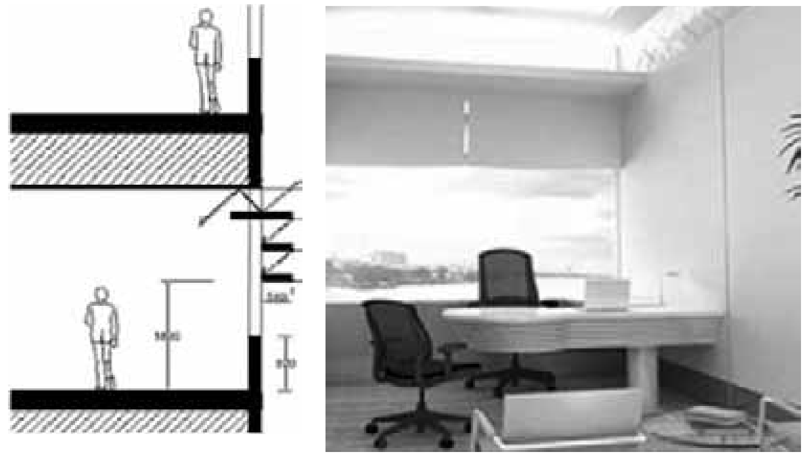
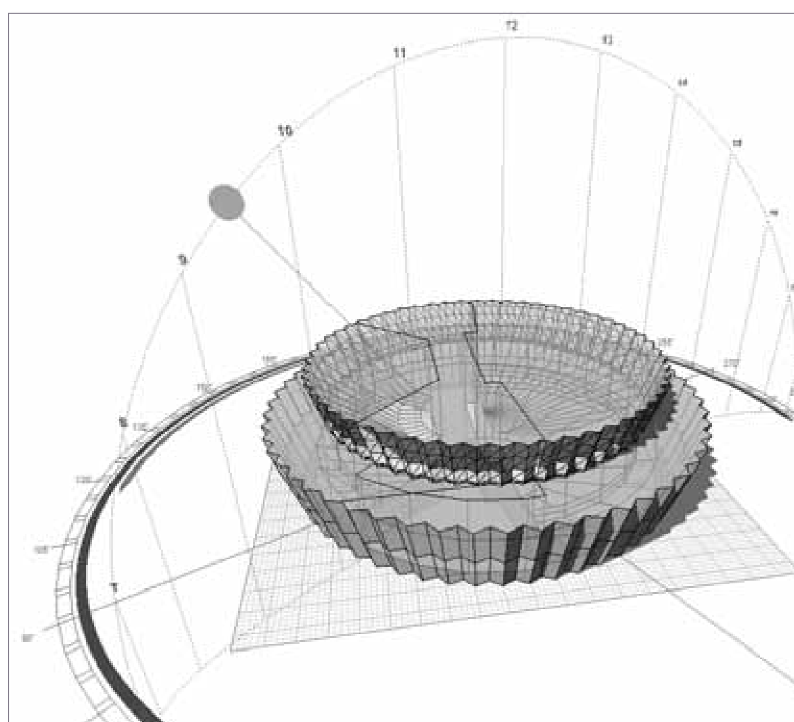


Figure 13. Light shelf concept of triple horizontal fins for office façade.

8. Main auditoriums daylighting

In this parliament project, one of the most important features is two main auditoriums which are located on the forth and fifth floors. The larger room is for representatives, while the smaller is for senates. Both rooms were placed at the building center where they can be most easily accessed from all supportive units. Senates and representatives can conveniently enter both rooms from their offices and riverside banquet halls. Since both rooms are on top of the building, it is possible to implement the skylights for introducing daylight into the space. The designers decided to utilize top clear-story to bring the daylight into both rooms. However, the dayligthing performances of this design needs to be investigated. To prove that this idea works, both auditoriums and related components were modeled and tested by using eCOTECT as shown in Figure 14.

Figure 14. eCOTECT model of auditoriums for daylight performance studies.



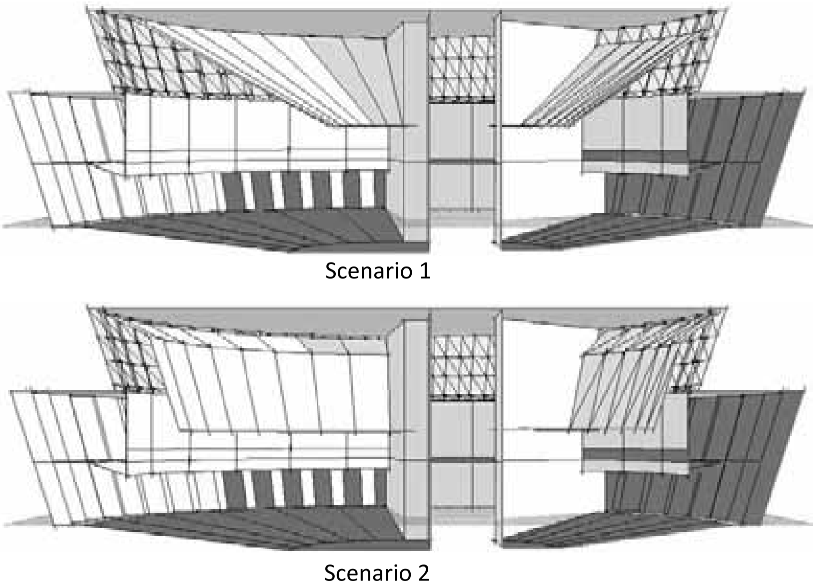


Figure 15. Auditoriums with two ceiling designs for daylighting simulation.

Once the daylight enters the space, it needs to be properly distributed. Since the light comes from top windows, ceiling shape and geometry are important for maximize the daylight level down below. Thus, the ceiling design will be studied along with the top windows. As shown in Figure 15, two distinctive ceiling designs will be simulated. The first scenario aims to maximize daylight level by sloping the ceiling down and allows the light to access most of the space. The second scenario aims to reflect the light back of the room where the daylight can reach with difficulty. To fairly compare both systems, similar glass of LT 0.75 and ceiling reflectance of 0.8 are used. The DF at the work plane of 0.75 m height from the floor will be compared and discussed in the following sections.

8.1 Discussion of auditorium daylighting condition

Plotted DF on work plane in Figure 16 clearly differentiates daylight performance of both design solutions. The DF of first scenario is higher than that of the second. Majority of daylight illuminates the front part of the room which DF can go as high as 3%. On the contrary, the back of the room remain dark and DF can be as low as zero. To increase light level at the back of the room, the ceiling was tilted vertically for bouncing the daylight toward the back of the rooms. In scenario 2, this concept was implemented. However, the result does not come out as good as estimated. Daylight only illuminates the middle part of the room and DF only goes as high as 0.9. Not only DF of the front part decreases, but also DF of the back part does not increase as well. For the average DF, the first scenario is 0.97%, while DF of the second drops to 0.27%. This means that the first scenario is almost quadruple DF of the second. However, both scenarios could not maintain the average DF close to 2.5% level.

8.2 Skylight solution of parliament auditoriums

Since the first solution provides higher DF on the work plane, the designers decided to apply this design solution for both auditoriums. As shown in Figure 17 the interior perspectives of both auditoriums show how the skylight and ceiling design after decorating with Thai contemporary style. The eCOTECT results indicate the possibility that the direct sun could reach the seats down below. This might cause major visual comfort problem for both representatives and senates during the meeting. To prevent this problem from happening, Movable fabric shading

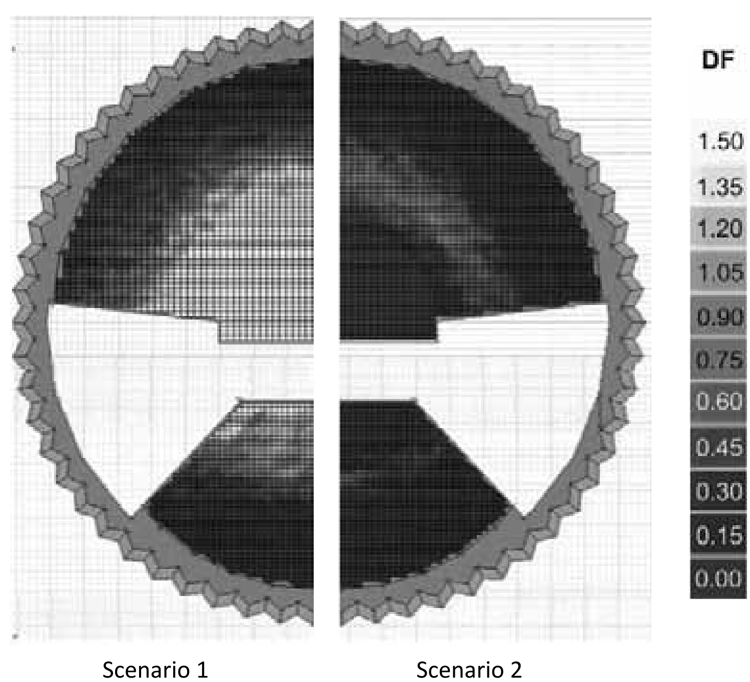


Figure 16. Daylight factor of parliament auditoriums.

Figure 17. Interior perspective of representatives' auditorium (Top). Interior perspective of senates' auditorium (Bottom).

device is installed for all windows. These sun screens could be programmed and control to synchronize with solar orbit. Only solar impacted window will be shaded by an automatic sun screen, while the rest could still allow the sky light to illuminate the rooms.

9. Limitations

When simulation tools were used, the issue is always validation. In general, there are needs to have full scale experiment to confirm the simulated results, particularly CFD simulation. However, the unique aspect of this study is to support the design decision making process. In the design process, designers need fast results to make critical decision. The results from this study are the trend to see the difference among design alternatives. In other words, precise accuracy is not the main priority here. It should be cautioned that validation might be highly important in other types of research. For instance, CFD used for studying stack effectusing solar chimney must be validated against acceptable means such as full scale experiment. For the readers who want to learn more about simulation software used in this study, please review Appendix.

10. Conclusion

Four objectives using proposed method in Figure 2 are accomplished. First, it is certain that this parliament building could be much different from its current appearance if there are no supportive data from building technology studies. Second, the designers might make a wrong decision based on academic guess which might impacts comfort and energy toward negative directions. Though the weakness of validity simulation is also the major concern of the design team, it is the economic and convenient solution to at least convince the designer toward the greener design solutions. Third, various tools use in this study were proved to be effective for solving design problems. Fourth, this study demonstrates some applications which could be applied to other project with similar criteria. ETFE roof and light shelf are good examples of such technology. To sum up, this article should be a good example of how the simulation techniques could support the design decision making process. Based on the positive feedback for D103, the author of the article believes that this integrative process could improve not only the quality of designs but also the design process itself.

Acknowledgement

Although this design only qualifies for the final five of this competition, the authors would like to thank the designers of D103 who support this design and research process from the beginning to the end. In addition, the author would like to thank Mr. Chanon Ampornsirisin and Mr. Chavanat Rattana-mahavong for all the graphic and modeling works used in this study.

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Appendix: Simulation software overview

ANSYS CFX is the software for CFD simulation. CFD simulation allows users to visualized airflow from the numerous data points with in CFD model. This data was calculated based on highly complex Navier-Stoke Equation. Generally, the software numerically computes parameters at each data point (node) by balancing mass, momentum, and energy. Like other CFD software, it allows users to setup simplified scenarios and solve fluid dynamics problems by different turbulent models such k-e, RNG k-e, k-omega, and others. After multiple iteration of solving, the results could be visualized. Users could view temperature, humidity, velocity, radiation, and other variables, if required. The advantage of ANSYS CFX is capability to handle complex geometry and advanced turbulent models. This makes ANSYS CFX perfect for architectural airflow simulation. The process of CFD simulation using ANSYS CFX begins with 3D modeling exported from any 3D software. This model was created from typical 3D model transferred to meshing software such as ANSYS ICEM. Once the model is meshed, it can be imported to CFX Pre where users can setup the airflow scenarios. After setup, CFX-Solver solves the specific problem using Navier-Stoke Equation. Then, results can be visualized and even animated by using CFX-Post.

ECOTECT is the software for comprehensive environmental design. It can simulate thermal performances, water usage, solar radiation, daylighting, shades and shadows, and acoustic. With exceptional visualization features, the software is aimed for architects to use in design decision making process. It allows typical 2D or 3D models to be imported and simulated associated environmental concerns and design questions. In this study, ECOTECT was mainly used for solar radiation and daylighting studies. ECOTECT allows users to import given weather file which contains local climatic data such as temperature, RH, radiation, wind, etc. Based on given weather file, ECOTECT can effectively study effect of solar radiation on building skins. ECOTECT uses INSOLATION equation to calculate the amount of energy actually falling on a surface of any complex building form by using both direct and diffuse radiation. For daylighting, ECOTECT uses The Building Research Establishment (BRE) Split-Flux method which is a widely recognized and very useful technique for calculating daylight factors. This method calculates Daylight factor of overcast sky condition using three components including sky, external reflected, and internal reflected components.