

DESIGN GUIDELINES FOR THE UTILIZATION OF TILTED FAÇADES TO ENHANCE BUILDING ENERGY PERFORMANCE

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ABSTRACT

Intense solar radiation is one of the key design problems for buildings in tropical regions. The recommended practice is to install shading devices, particularly to protect glazing systems. However, many design factors do not allow shading devices to be implemented in all cases; shading devices may not be appropriate to particular design concepts. To serve the designers' preference, alternative solutions should be provided. This study aims at investigating the performance of a new design alternative—the tilted façade. By simply tilting a wall downward, solar radiation can be minimized in the same way as a shading device. The state-of-the-art energy software, eQUEST, was used to simulate energy performance of buildings in Bangkok, Thailand. At the same time, simulated results were confirmed by using experimental data monitoring from specially customized test cells. A wide range of WWR (Window to Wall Ratio) was tested against different façade orientations, glazing types, and shading devices with similar projected lengths. Tilted façades can be most effective for all orientations except for the north. Also, tilted façades allow designers to use more glass without any additional energy consumption. Based on these results, a set of design guidelines for using tilted facades are proposed. Designers can not only utilize these guidelines to effectively adjust façade angle but also optimize the glazing size for the best energy performance.

KEYWORDS

tilt, incline, façade, glass, glazing, energy, performance, fenestration, simulation

1. INTRODUCTION

Today energy efficiency in building design is almost mandatory for all designers since energy consumption of buildings is responsible for more than 40% of electricity production in Thailand [1]. To handle the high cooling load in this tropical region, HVAC (Heating Ventilating and Air Conditioning) systems demand large amounts of energy compared to electric lighting and appliances. The prime source of cooling load usually comes from intense solar radiation penetrating through glass and opaque portions of the building façade. In Thailand,

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peak radiation on southern glass walls can be as high as 600 W/sq.m during December and January. Architectural design features such as building form, orientation, Window to Wall Ratio (WWR), etc, can play a major role in reducing the cooling load and enhancing building energy performance [2].

Shading devices are a common practice recommended for protection from direct solar radiation. However, many designers do not always implement this effective feature for many reasons. Some architects want to express their design concept through a lean building form with large continuous glazing areas where shading devices might not be a suitable feature. As a result, architects might choose to neglect the use of shading devices for solar protection purposes despite the additional cooling load compared to a building with effective shading design. To reduce such high cooling loads, designers rely on expensive glazing systems or large chiller plants to deliver thermal comfort for the building occupants. Since such solutions are usually expensive, initial building cost can skyrocket and becomes an unavoidable burden to the owners. Recently, the new idea of using tilted façades was proposed as an alternative to shading device systems. By simply tilting the wall downward, intense solar radiation can be reduced and, in turn, energy demand for cooling decreases. Reflected solar rays from tilted façades can be managed through proper landscape design. Such ideas were already recognized by some architects in Thailand and have already been used in some actual projects. As shown in **Figure 1**, Bangkok University Landmark Complex designed by A49 was using tilted façades to express the architectural concept. Government Complex designed by GCDC is another example which rigorously applies tilted façade systems as the main building feature. See **Figure 2**.

Studies related to tilted facades are limited. Thus, this research aims at studying tilted façade performance comprehensively by investigating:

1. Four major design variables which highly impact building energy consumption. These variables includes:
 - WWR (Window to Wall Ratio)
 - Façade orientation
 - Tilting angle
 - SHGC (Solar Heat Gain Coefficient) and SC (Shading Coefficient)
2. Energy performance of tilted facades will be compared against that of horizontal shading systems using both energy simulations and full scale experiments.

FIGURE 1. Bangkok University Landmark Complex in Pratumthani.



FIGURE 2. Government Complex in Bangkok.



Results from this study will allow the designer to improve energy performance by systematically utilizing tilted facades. By offering an alternative to the more common use of shading devices, this study of tilted facade performance could be a major contribution to architectural design practices.

2. LITERATURE REVIEW

To understand how the tilted façade works, a number of theories should be discussed. The most important theory, which directly links to façade tilting angle, is Lambert's cosine law, as written in **Equation 1**. Since use of a tilted façade directly relates to building form and geometry, Lambert's cosine law is useful to describe the impact of solar incident angle on tilted surfaces. Users can apply Lambert's cosine law to predict the irradiance of any given surface affected by the sun at a given incident angle. The normalized radiation on a surface (I_α) can be determined as the product of incident solar radiation (I_o) and the cosine of the incident angle (α). Tilting the wall downward tends to increase incident angle which, in turn, reduces the normal radiation on the tilted surface.

$$I_\alpha = I_o \cos \alpha \quad (1)$$

Based on these theories, the cooling load of a glazing system can be calculated by using **Equation 2**. Cooling load (Q in Watts) can be determined by multiplying the glass area (A in sq.m), Cooling Load Factor (CLF), Solar Heat Gain Coefficient (SHGC), and Solar Heat Gain Factor (SHGF in W/sq.m) [3]. It is a straight forward rule that larger glass areas generate higher cooling loads. More complicated variables like CLF depend on building thermal mass which can delay and alternate the peak cooling load. $SHGC_\theta$ is the glass transmittance property depending on the incident angle, θ . This variation represents Lambert's cosine law as discussed earlier and shown in **Equation 1**. Sometimes, SHGC of a glass panel is described with another term, SC (Shading Coefficient). SC can be determined by dividing SHGC at a 90° incident angle of a given glass and a reference glass which is a 3mm clear glass ($SHGC_{ref}$), see **Equation 3**. To calculate cooling load regionally, the recorded solar radiation at given site latitude must be included. This last variable is SHGF.

$$Q = A \times CLF \times SHGC_{\theta} \times SHGF \quad (2)$$

$$SC = \frac{SHGC_{90}}{SHGC_{ref}} \quad (3)$$

The cooling load of a building does not come only from glass but also from other sources including walls, roofs, infiltration, ventilation, appliances, and occupants. Current methods for calculating cooling loads can be found in ASHRAE fundamental [3]. After summing up all cooling load components, HVAC energy demand at a given hour in watts can be determined using **Equation 4**. Coefficient Of Performance (COP) is the HVAC system performance which indicates the rate of power (E in Watts) needed to remove cooling load (Q in Btu/h) at a given scenario. Annual HVAC energy usage can then be calculated by adding hourly energy use of the operating period.

$$E = \frac{Q}{3.412 \times COP} \quad (4)$$

Calculating cooling load is not a simple task and it is a very tedious and time-consuming process. Today hand calculation is almost completely replaced by computer simulation. Therefore, eQUEST which is a well-recognized energy simulation software will be utilized in this study. Further details can be found in *eQUEST Quick energy Simulaton Tool* [4].

3. EXPERIMENT AND SIMULATION SETUP

In this study, there will be the combination of both full scale experiment and computer simulation.

3.1 Full scale experiment

To demonstrate and validate the performance of the tilted facade, full scale test cells were built for HVAC energy comparison. The first cell represents a building with or without a shading device, while the second cell represents the building with a tilted façade at 120°. See **Figure 3** for the actual test cells setup. **Figure 4** is a simplified diagram of the second test cell. It indicates the tested components, glazing system, HVAC, and cell construction.

FIGURE 3. Test cells of shading system (left) and tilted façade system (right).



FIGURE 4. Simplified diagram of tilted façade test cell.

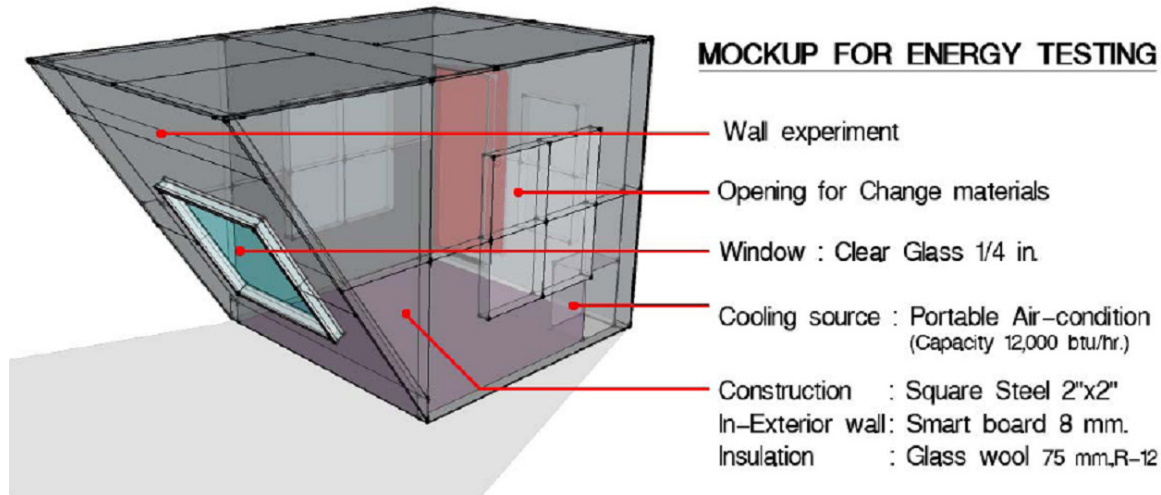


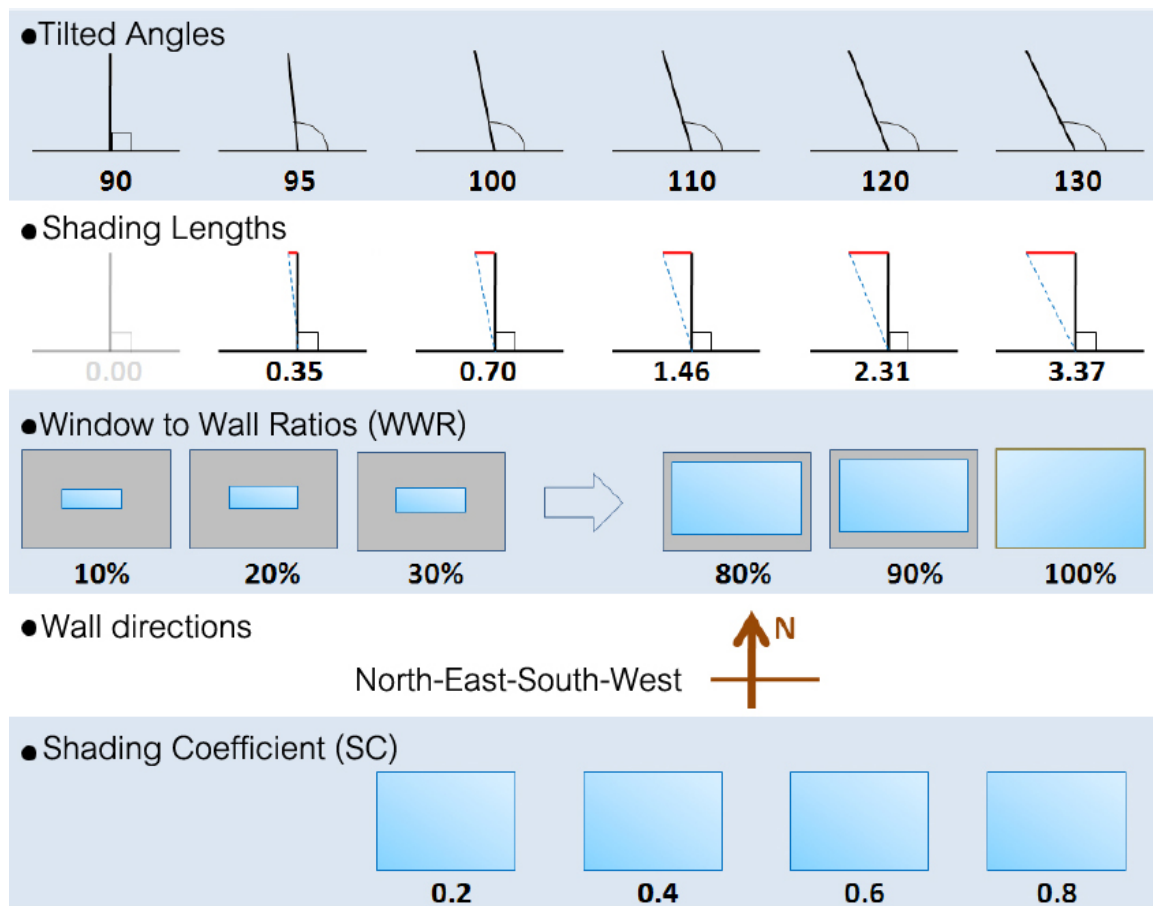
TABLE 1. Test cells materials and construction.

Type	Materials	Resistance (ft ² F h/Btu)	Resistance (m ² C/W)
Structure	Square Steel 2"x2"	—	—
Exterior wall	Smart board, T-8 mm.	0.095	0.017
Insulation	Stay Cool, T-75 mm.	11.54	2.03
Interior wall	Smart board, T-8 mm.	0.095	0.017
Glazing	Single Clear 1/4 in (6 mm.)	—	—
Shading device	Smart board, T-8 mm.	0.095	0.017

Except for the tilting angle of the two façades, all variables of both cells were identical. Typical 6 mm glass was used, while all roofs and walls were insulated. **Table 1** summarizes all envelope components of both cells for reference. Two identical 12,000 Btu/h air-conditioning units were installed and their electrical consumption monitored during the test period. Since both cells were exposed to the same outdoor climatic conditions, calibrated energy data can be compared.

3.2 Energy simulation

The energy program used in this study was eQUEST 3.6. This software is capable of simulating the energy consumption of a building by using the latest cooling load model [3]. Parameters which were varied to study the performance of tilted façades include façade orientation, glass SC, and WWR. To compare the performance of tilted façades and shading devices, additional variables, tilted angles, were tested against a series of shading lengths. **Figure 5** and **Table 2** summarize all parametric studies—up to 1,760 simulated cases. In the case of both tilted façade and shading device, light sensors were set at 500 lux to incorporate the benefit of daylighting for energy saving. Room reflectance was fixed at 0.4 for the ceiling, wall, and floor. All others variables were not only identical but also followed the recommended parameters for an office building in ASHRAE standard 90.1 2007 [5].

FIGURE 5. Variables for parametric studies.**TABLE 2.** Summary of parametric studies for eQUEST simulation.

Variable	Detail	Case	Parametric Runs	Total Parametric Runs
Tilted facade				1,760 cases
1. Tilted wall	90, 95, 100, 110, 120, 130 degree	6	6 cases	
2. WWR	10, 20, 30, 40, 50, 60, 70, 80, 90, 100%	10	60 cases	
3. SC	0.2, 0.4, 0.6, 0.8	4	240 cases	
4. Orientation	North, East, South, West	4	960 cases	
Shading device				
5. Shading device	0.35, 0.70, 1.46, 2.31, 3.37 m.	5	5 cases	
6. WWR	10, 20, 30, 40, 50, 60, 70, 80, 90, 100%	10	50 cases	
7. SC	0.2, 0.4, 0.6, 0.8	4	200 cases	
8. Orientation	North, East, South, West	4	800 cases	

4. RESULTS

The energy impact of four variables including orientations, tilting angles, glass SC, and shading devices will be summarized here. For the convenience of readers, simulated results of the 1,760 cases are presented in the **appendix** at the end of this article. For further discussion, only selected results are presented as follows.

4.1 Façade orientations

In **Figure 6**, the energy consumption of different façade orientations is plotted against a wide range of WWR (10–100%). Only low WWR of 10–20% shows energy reduction, while the higher WWR indicates larger energy consumption. The energy reduction at low WWR is possible because of the optimization between glass area and daylighting access. Within this WWR range, daylight sensors can effectively cut down the electricity consumed by the lighting system, while the cooling load remains low. When WWR increases more than 20%, the energy required by all façade orientations increases due to the higher cooling load coming from a larger glass area. Facing the façade to the east makes the building HVAC energy demand the most, but it is not distinctively more than those of South and West façades. On the other hand, a north façade shows the least energy increment when WWR increases. This can be explained according to electricity consumption plotted in **Figure 7**. An east facade tends to maintain high cooling in the morning, which comes from early solar exposure, while the cooling load of the afternoon is maintained by thermal mass and doesn't drop as much as expected. In contrast, a north façade interferes least with direct solar radiation; the cooling load of this orientation remains low and uniform all day.

FIGURE 6. Energy consumption of façade with different orientations and WWR (tilted 90 and SC 0.8).

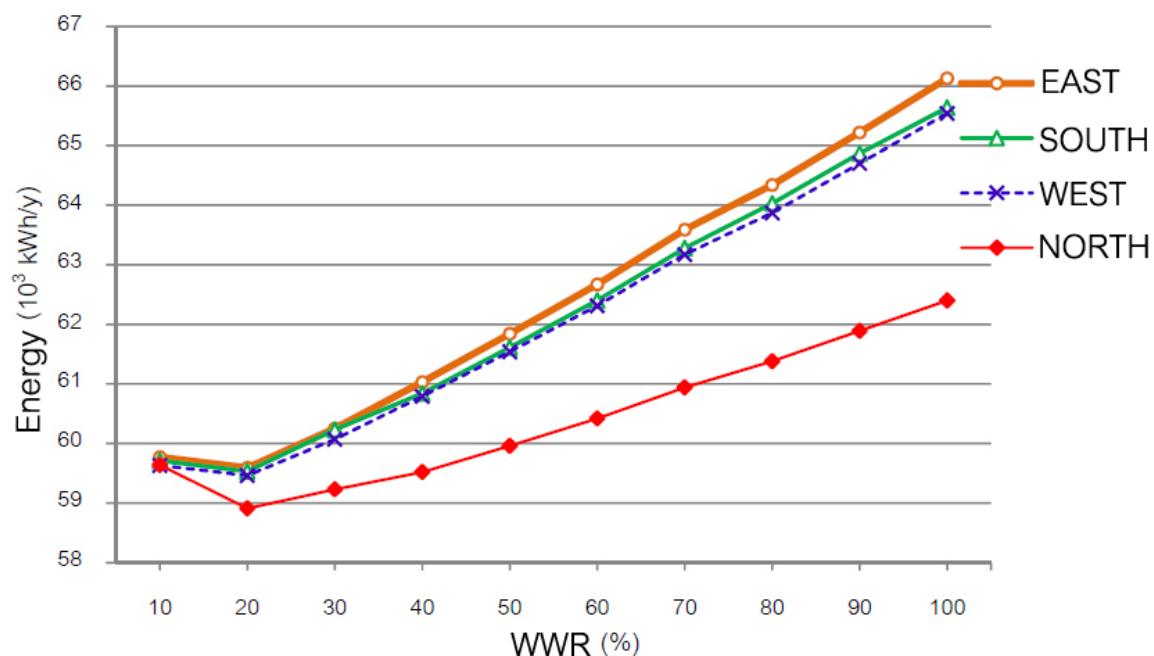
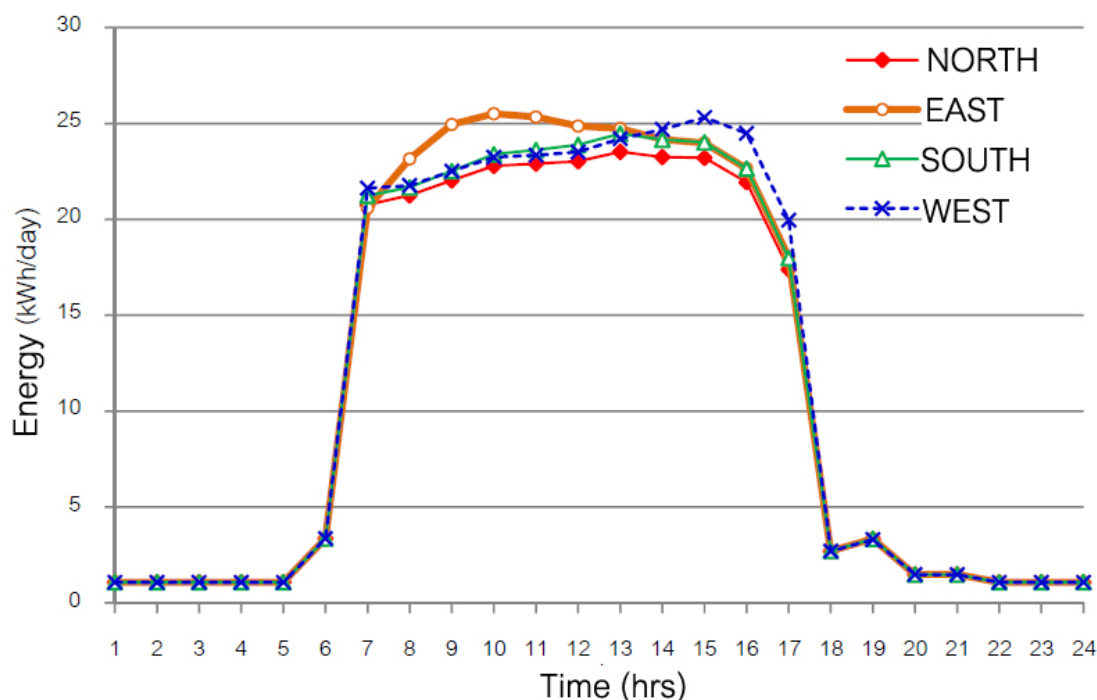


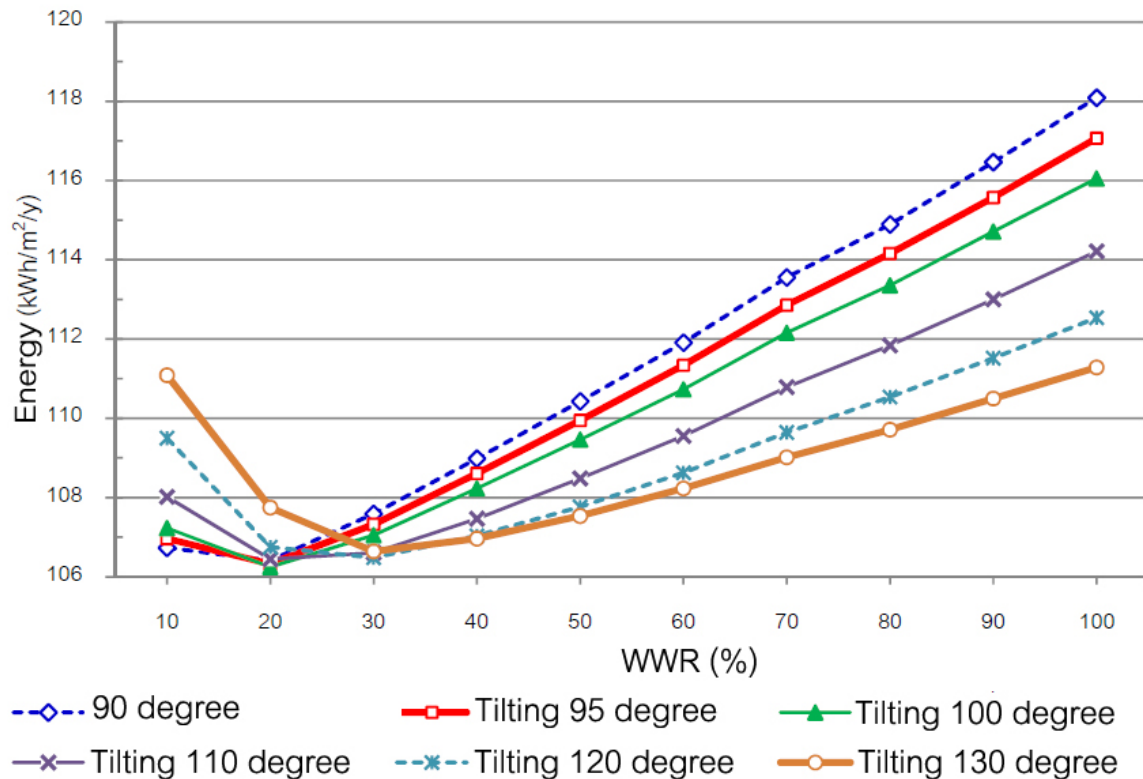
FIGURE 7. Hourly energy consumption of different façade orientation and WWR of April 6th.

4.2 Tilting angles

Based on the previous results, the east façade, which consumes the most energy, was selected to demonstrate the impact of tilted angles. See **Figure 8**. When WWR is less than 30%, tilting seems to increase the building energy consumption because it substantially reduces daylight levels. Additional energy is required by the lighting system to maintain illuminance of 500 lux [6]. Energy consumption reaches the minimum when WWR ranges 20–30% depending on tilting angle. Only tilting more than 120° can extend the optimized WWR from 20% to 30%. Tilting can not only shift the minimum energy consumption toward higher WWR, but can also slow the energy demand when WWR increases. This proves that cooling energy reduction due to inclining walls has a stronger impact than the increased electric lighting energy needed because of the reduction in daylight. In this case study, every 10° of tilting increment can reduces energy up to 1–2 kWh/sq m per year (at WWR 60–100%).

Data monitored from the test cells confirmed the simulated results. **Figure 9** shows the energy recorded from both test cells when HVAC systems were operated from 8:00 to 17:00. The first cell represents a typical building which has a 90° façade. This cell has no shading system and faces east. The second cell was built to be identical with the first cell but the glazed façade was tilted 120° towards the floor. After comparing energy profiles of both cells, data shows that the energy profile is similar and the peak consumption occurs at 14:00 for both cells. However, energy demand from the second cell is lower than the first cell all day with an offset of roughly 100 W most of the time. The tests were conducted during April, which is the hottest month in Thailand. The impact from direct solar radiation clearly increases the cooling load of the first cell and, in turn, wastes more cooling energy. In **Figure 10**, areas of solar beams projection onto the cells' interiors are shown. Tilted façades can reduce cooling by reducing the size of solar beam area penetrating through the glass.

FIGURE 8. Energy consumption of facades with different tilting angles and WWR (EAST and SC 0.8).



4.3 Glass properties

In this test, only the SC of glass will be studied. LT (Light Transmittance) of all glazing systems was fixed at 0.85. **Figure 11** shows the energy impact on four SC ranging from 0.2-0.8 which was plotted against various WWR. The data shows that once SC increase, the impact of WWR becomes stronger on energy consumption. The range of energy demand from WWR 20% to WWR 100% is 12 kWh/sq m per year. On the contrary, the impact of low SC allows the energy profile to swing only 1.5 kWh/sq m per year. It is interesting that if SC is roughly 0.4, the energy demand of WWR 10% and 40% can be equal. At WWR 10%, energy is used for lighting, while at WWR 40%, energy is utilized for cooling. If SC goes even lower to 0.2, it is possible that energy consumption of WWR 10% and 90% can be the same.

4.4 Shading devices

Similar to the impact of tilting angles, longer shading devices can reduce energy demand as presented in **Figure 12**. Energy consumption of a building with shading devices can increase if WWR is less than 20%. Low WWR and long shading devices can increase lighting energy demand and, consequently, raise overall energy consumption. The lowest energy consumption of all shading lengths can be found at WWR 20%. This indicates that the lighting and cooling energy are optimized. Once WWR goes over 20%; energy consumption of all shading lengths increases. Longer shading devices can slow down the incremental rate of energy consumption. At WWR 100%, a 3.37m long shading device can save over 7.5 kWh/sq.m of energy per year compared to glass without any shading device.

FIGURE 9. Energy demand of two test cell recorded on April 21st.

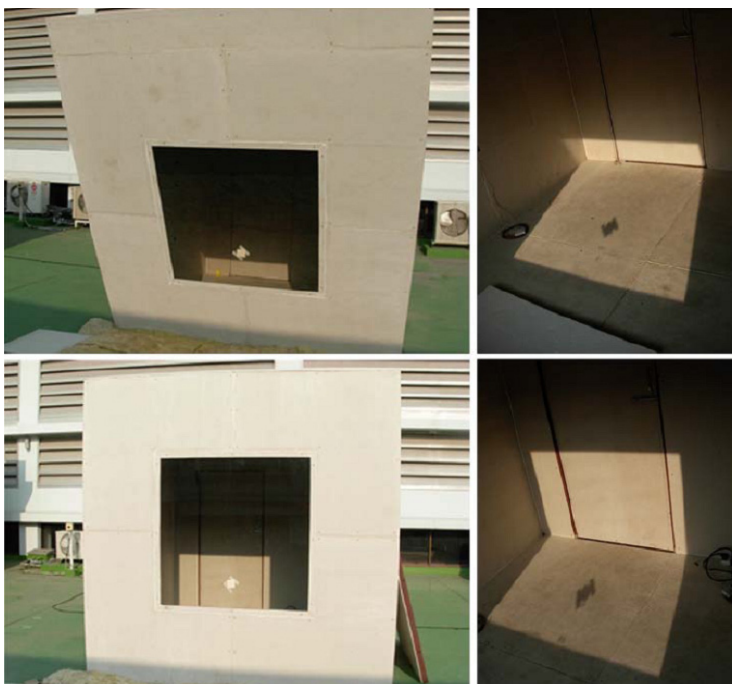
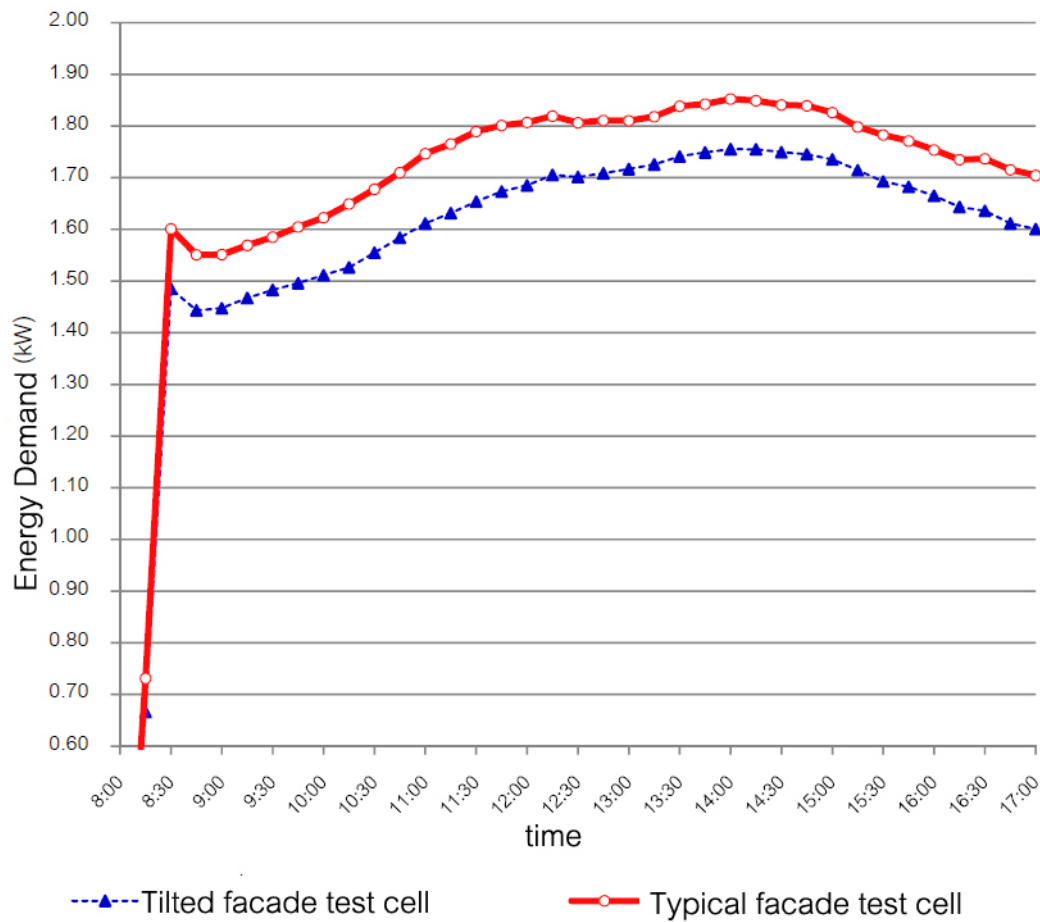


FIGURE 10. Impact of direct solar beam on both test cells.

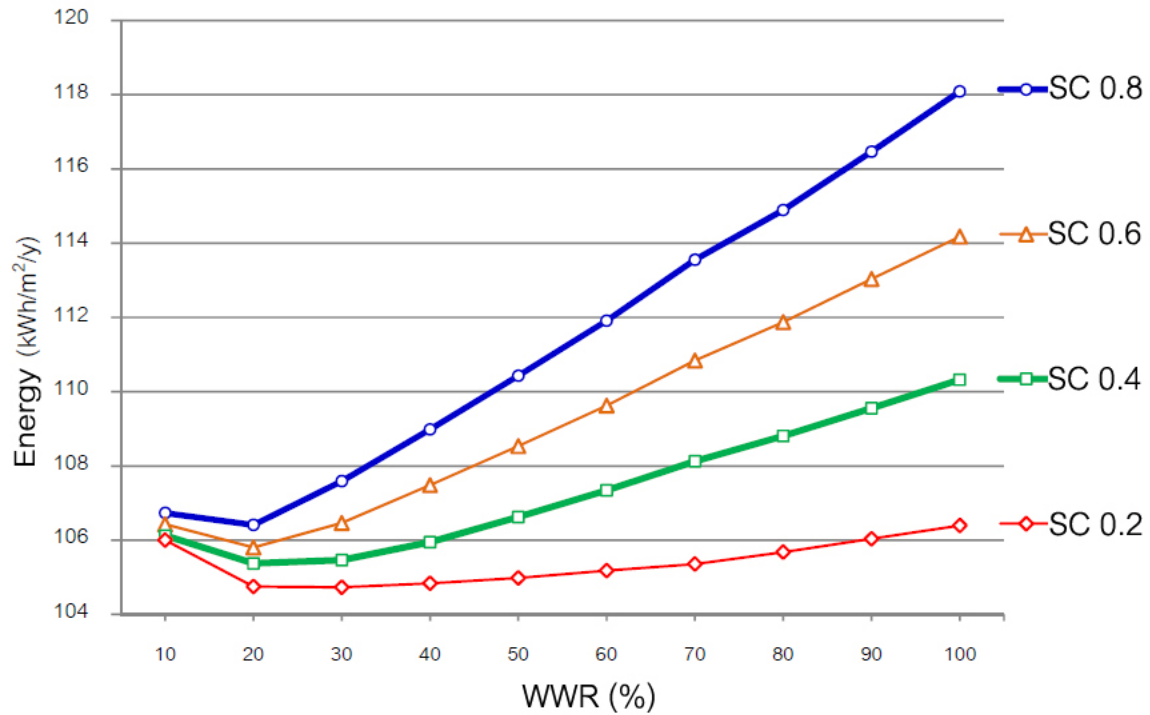
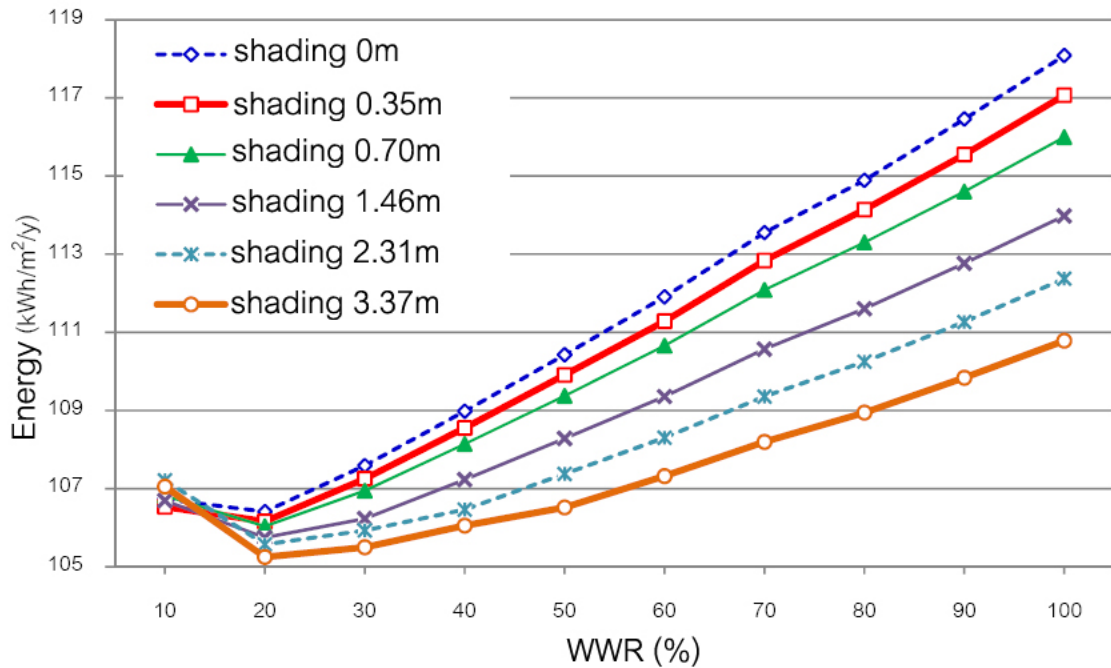
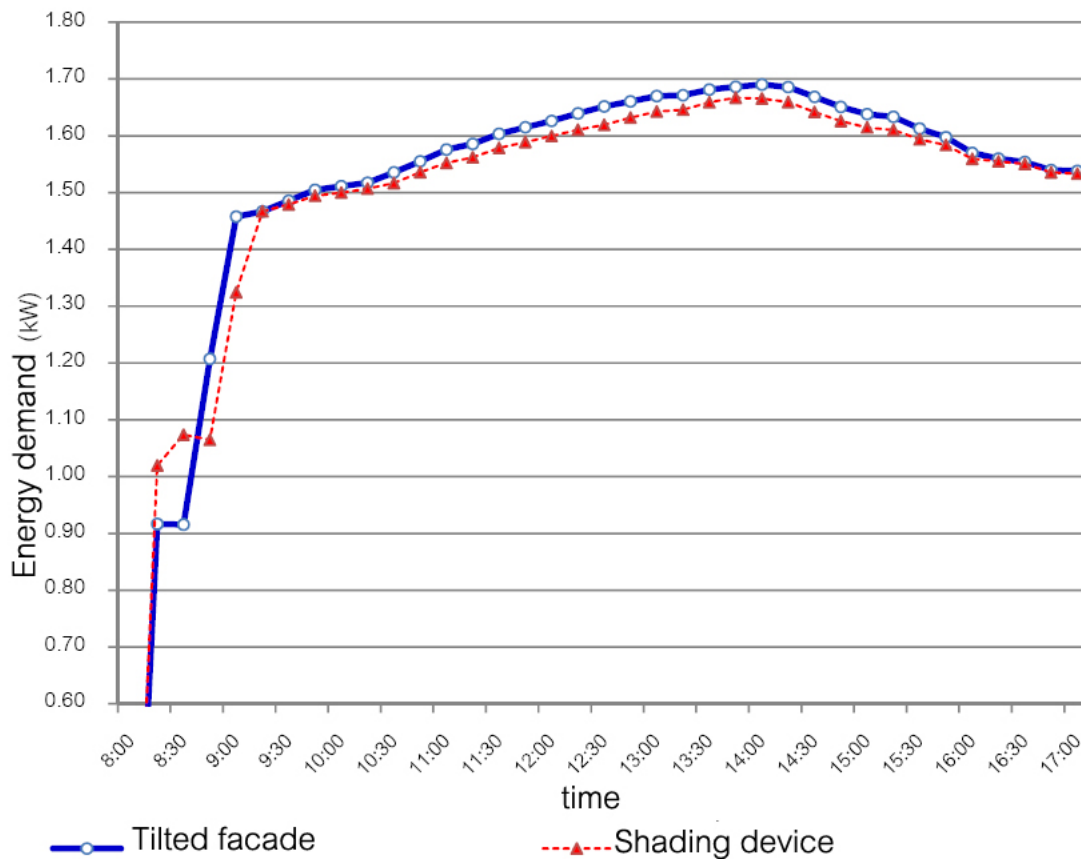
FIGURE 11. Energy consumption of facades with different SC and WWR (EAST and tilted 90°).**FIGURE 12.** Energy consumption of facades with different shading lengths and WWR (EAST-facing and SC 0.8).

FIGURE 13. Energy demand of two test cell recorded on April 11th.



After installing shading devices of 1.5 m, which is equal to a tilting angle of 120° on the first test cell, the energy consumption of both test cells can be compared. Both cells face east and were air-conditioned from 8:00 to 17:00. The plotted data in **Figure 13** shows the similar energy profiles. The peak energy demand of both shaded and tilted facades occurs at 14:00. Overall, use of a shading device tends to consume slightly less energy than that of a tilted façade, particularly during peak cooling load. Peak discrepancy was at 0.25 kW during the test day (11th of April). This means that a shadow cast on the glass is more effective than avoiding solar radiation by tilting of a wall downward. However, energy consumption in the early hours of operation shows a difference. Energy-use of the test cell with a shading device was slightly higher than that of the cell with a tilted façade. During this hour (8:00), the incident angle of the direct sun was very low. Therefore, the shading device could not effectively perform, while a tilted glass wall can slightly begin to reduce the impact at this low sun angle.

5. DISCUSSION

This section will discuss the application of the tilted façade summarized from both simulated and monitored data as shown previously.

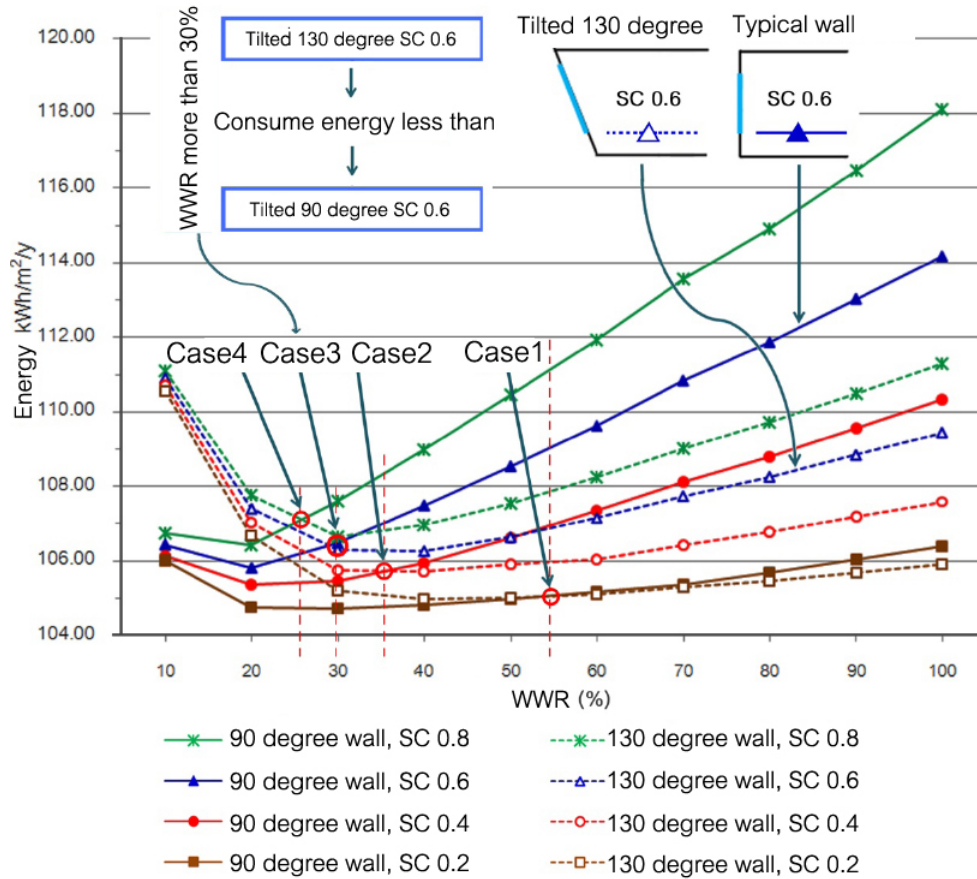
5.1 Applications of the tilted façade for architectural design

- **Orientation of the tilted façade:** after reviewing the energy consumption of a building with a tilted façade, the east wall should be considered first for tilting since this orientation tends to consume the most energy. Then, the south and west façades should also be tilted if energy conservation is a high priority. Energy consumption of both these orientations came second and third consecutively. For the north façade, tilting should not be applied. Energy saving is not as high as expected, while levels of daylight decreases undesirably.
- a. **Window to Wall Ratio:** if the building walls are mostly opaque and have WWR less than 10%, a tilted façade might not help reduce energy demand as much as expected. On the contrary, it might reduce daylight and waste more energy in a building with daylight dimming controls. For WWR 20%, the energy consumption of a building with a tilted facade seems to balance with that typical of a building without tilting. At this WWR, a tilted façade can offset additional energy demand from lighting with the saving from cooling energy. Since additional first cost is required for daylight dimming systems, buildings with WWR 20% are not recommended for tilted façades. The full benefit of a tilted facade can be achieved when WWR is more than 30%. After this point, a larger area of glass can bring in adequate daylight, while the saving of cooling energy can be maximized with the tilted facade. This means that architects are allowed to use a larger area of glass while simultaneously maintaining energy conservation.
- b. **Glass SC:** Glass properties, particularly SC, play a major role in cooling reduction which, in turn, affects energy consumption of a building. When a tilted façade is in place, low glass SC can further reduce building energy consumption. Once overlays both tilted façade of 130° and typical 90° wall on the same chart, the energy performance of the same SC can be compared. See **Figure 14** and **Figure 15**.

Using **Figure 14**, architects can make design decisions regarding tilted façade and increase glass WWR. In case 1, for glass SC 0.2, tilted façades consume increasingly less energy than a typical 90° wall once WWR is more than 55%. In other words, If WWR increases to not more than 55%, a tilted façade will always perform less well than a typical vertical façade. For glass SC 0.2, once WWR goes over 55%, a tilted wall should be used. When poorer SC is used, suitable WWR for applying tilted façades decreases. As shown in case 2 and 3, once SC increases to 0.4 and 0.6, WWR allowance reduces to 35–30%, respectively. Case 4 indicates that the highest SC, up to 0.8, reduces the WWR allowance to as low as 25%. All in all, using low SC glass can incrementally increase the impact of tilted façades when WWR increases.

Another consideration about glass SC is shown in **Figure 15**. It is possible to save energy with higher SC glass if two key factors are applied. Tilted walls must be used with certain WWR. In case 1, a 130° tilted wall with glass SC 0.8 can out perform a typical wall of SC 0.6 if WWR is over 33%. In case 2, if the SC of a tilted facade goes lower than 0.6 and WWR is more than 55%, it can perform better than a typical wall with SC 0.4. **Figure 15** also shows that it is impossible to beat a typical wall of SC 0.2 with higher SC glass in a tilted façade across the entire range of WWR.

In summary, low SC glass can increase the performance of tilted façades and enables design preferences using larger glazing areas without giving up building energy performance. Thus, the first priority is to use glass with low SC as much as

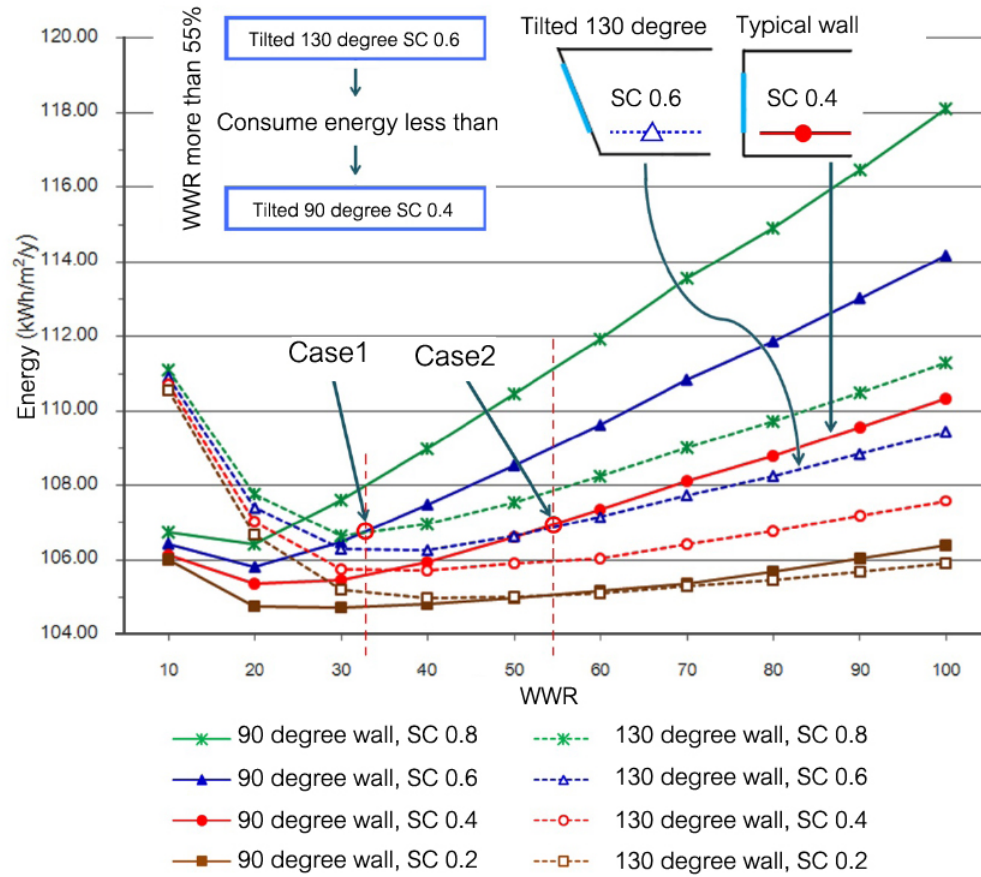
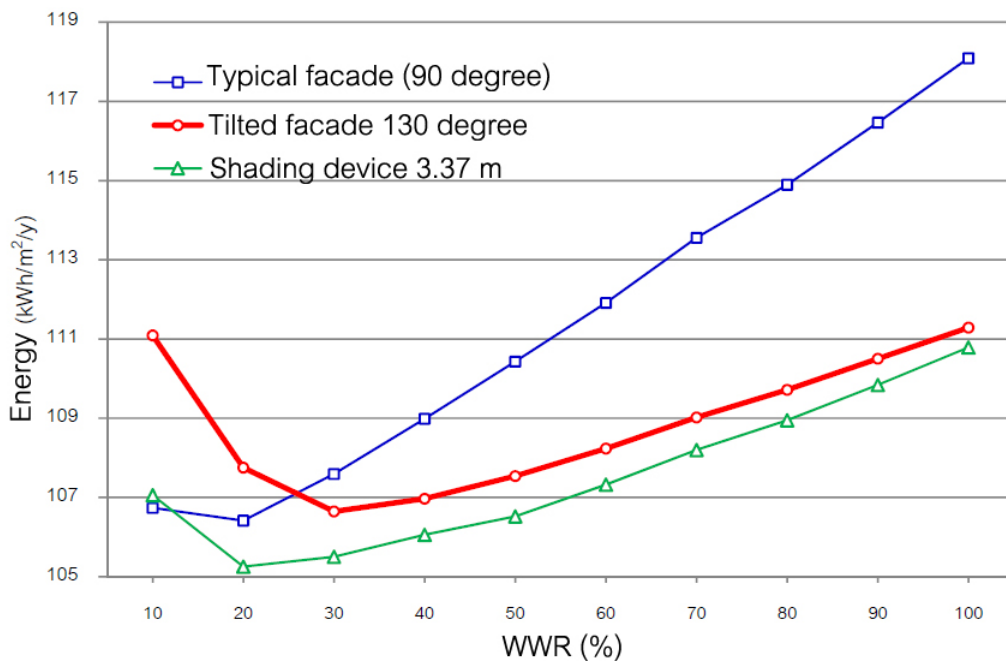
FIGURE 14. Overlay of energy consumption of tilted and typical walls #1.

possible. However, if the use of high SC glass is unavoidable, a tilted façade is an effective solution. It can reduce the energy demand across wide WWR range which goes as low as 25%.

- c. Shading device comparison:** the data in **Figure 16** shows that shading devices can perform better than tilted façades for all WWR. A shading length of 3.37 m is more energy efficient than a façade with a 130° tilting angle which have similar projection factors, particularly in a low WWR range. Buildings with WWR of 10% allow the shading device to save up to 2 kWh/sq m of energy per year as compared to a tilted façade. The saving reduces to 1 kWh/sq m per year once WWR surpasses 30%. Though the data suggests that a shading device might be a better option for protection from direct sun light, construction of a long shading device of 3.37m might be either impractical or expensive. Splitting the shading device into smaller sizes while having similar projection factors might be an alternative. However, designers need to consider both potential view obstruction and the difficulty of construction details.

5.2 Case studies of design implementation

The followings are guidelines for implementing tilted façades. Architects can use the data to determine the size of additional glass which can be incorporated into the design when using

FIGURE 15. Overlay of energy consumption of tilted and typical walls #2.**FIGURE 16.** Comparison of buildings with a shading device of 3.37 m and a 130° tilted façade.

tilted facades. Otherwise, the additional energy saving can be calculated for various tilting angles if WWR is similar to that of a typical façade.

- Increased glass area:** under particular design circumstances, glass area needs to be enlarged. Though such over-sizing can increase daylight levels and improve the outdoor view, it can worsen energy consumption. In this case, use of a tilted façade allows architects to increase glazing size without creating the additional energy demand. **Figure 17** demonstrates how a tilted façade could assist designers to use larger glass sizes. The horizontal dash line indicates the level of energy consumption which crosses both typical 90° walls and 130° tilted façade lines. Based on both crossing points in **Figure 17**, WWR of both facades can be read. Given the same energy demand of a 90° façade with WWR at 40%, a 130° tilted façade can increase WWR to 70%. In this case, the tilted façade allows glass size to be enlarged by 30%.
- Enhanced energy performance:** a direct benefit of the tilted façade is energy conservation. If architects decide not to increase the glazing area, tilted façade with similar WWR to a 90° wall could significantly reduce energy consumption of a glazed building. **Figure 18** demonstrates how to estimate energy reduction of a tilted façade. At given WWR, the energy saving of the tilted façade can be determined. The red dashed line which is drawn vertically indicates the energy consumption of WWR of 100%. This line crossed two points in this chart which indicates the energy consumption of both typical 90 and 130° tilts. The amount of energy consumption in both cases can be read. At the same WWR, a tilted wall can save up to 6.8 W/sq.m per year or roughly 5.76 % of overall building energy consumption.

FIGURE 17. Applications of tilted façade for increasing WWR.

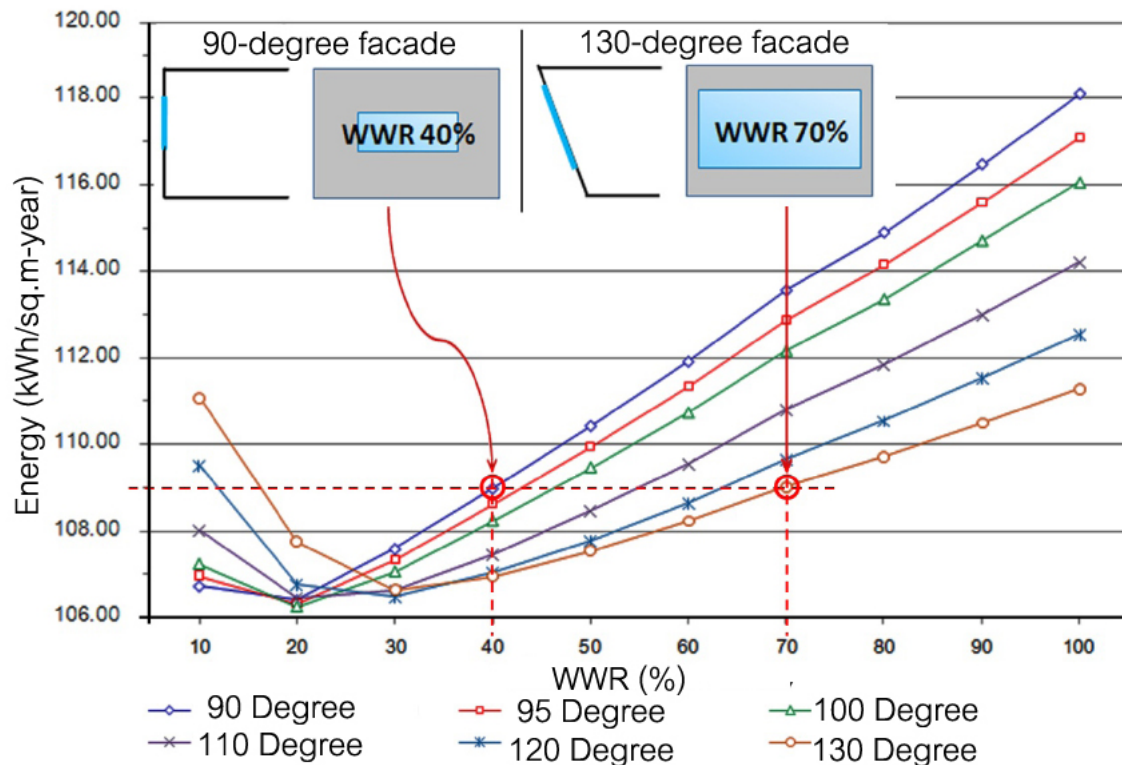
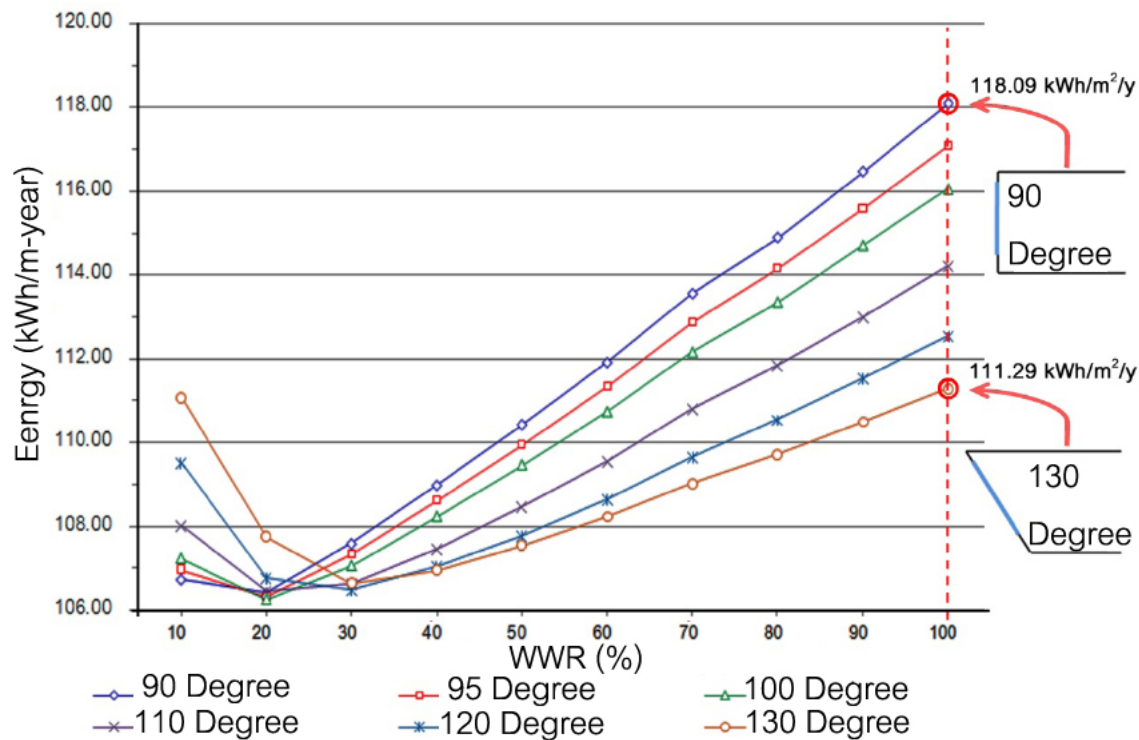


FIGURE 18. Applications of tilted façade for enhancing energy performance.



6. CONCLUSION AND RECOMMENDATIONS

With the current global energy threats, applications for enhancing building performance are extremely important. Established solutions such as shading devices still work feasibly and effectively. However, sometimes this approach may conflict with the architects' design concept. Using tilted façades is one promising alternative that can offer almost similar energy performance. This study explored many aspects of using tilted façades; it looks at the impact of a range of variables such as WWR, façade orientations, and SC, and also made comparisons with the use of shading devices. Readers can easily use the data shown in Appendix and method presented in this article to estimate appropriate tilted angles and match the estimated energy saving. To properly implement tilted façades, here are some recommendations:

6.1 The tilted façade and building forms

The Tilted façade is the application which is directly related to building geometry. This emphasizes the importance of architects who take full responsibility for creating buildings' form and determine buildings' configuration. Results from this paper do not offer one possible design solution for enhancing building performance but also challenge designers to implement such solutions with independent creativity. An obvious application of tilted façade is low and mid-rise buildings since the height of the building does not make the top floor over extend the base. However, there is one building that indicates the possibility of applying tilted façade on a high-rise building. Taipei 101 or Taipei World Financial Center which was designed by C.Y.LEE is the best example. This former tallest building of the world utilized tilted façade in all orientations. As shown in **Figure 19**, building façades are tilted downward for every eight floors.

6.2 The tilted façade in various locations

The tilted façade is not just applicable for tropical regions like Thailand. One of the best examples is London City Hall designed by Norman Foster. The building is tilted southward as shown in **Figure 20**. This exposes the north façade to expose to the sky and makes the south self-shaded. The upward tilt of the north façade allows the northern skylight to penetrate the building deeper. The south façade is tilted downward and so minimizes the effect of direct solar radiation which usually comes from the south. This configuration should substantially reduce the building cooling load and, in turn, minimizes the HVAC energy demand. Though tilted façade seems to be applicable in other locations in different latitudes (rather than Bangkok 14°N), it requires further in-depth investigation. Based on the solar geometry of different sun charts [7], upper latitudes tend to shift the solar band toward the south. As a result, lower solar altitude causes stronger radiation impact on the south facade, while higher solar altitude reduces radiation impact on the north façade. Given this fact, south façades might need to be tilted more steeply downward to handle the low angle sun. It is even possible that north façades at upper latitudes might need to be tilted upward to gain more daylight. The impact can be reversed for locations closer to the equator. North and south façades might need to be tilted downward equally since the solar impact is almost the same in both orientations. For the locations in the southern hemisphere, tilted façades should be applied to the north orientation rather than the south.

FIGURE 19. TAIPEI 101 designed by C.Y.LEE.



6.3 Tilted façade and green building trends

One of the drawbacks of using tilted façades becomes apparent when owners decides to submit their buildings for LEED (Leadership in Energy and Environmental Design), a most well-recognized green building rating system. Since tilted façades directly link to energy performance, it would seem that their use would support Credit EA1 Optimized Energy Performance [8]. Unfortunately, this isn't the case. This credit refers to ASHRAE 90.1 Appendix G which calls for an energy cost comparison between the baseline and proposed models. The rules in Appendix G were formulated to create fair comparison between models which will lead to realistic estimation of savings based on the computer simulations. This method promotes the use of good orientation, glazing, shading devices, daylighting, advanced HVAC systems, etc, but it overlooks the impact of a building's geometrical factors. Since appendix G indicates that the building geometry of the baseline and proposed models must be identical, a feature related to building geometry such as a tilted façade would create no additional benefit. This is

FIGURE 20. London City Hall designed by Norman Foster.



the major challenge to the modification and revision of this standard, specifically; Appendix G should incorporate a fair simulation method for a tilted façade to gain energy saving benefits.

7. ACKNOWLEDGEMENT

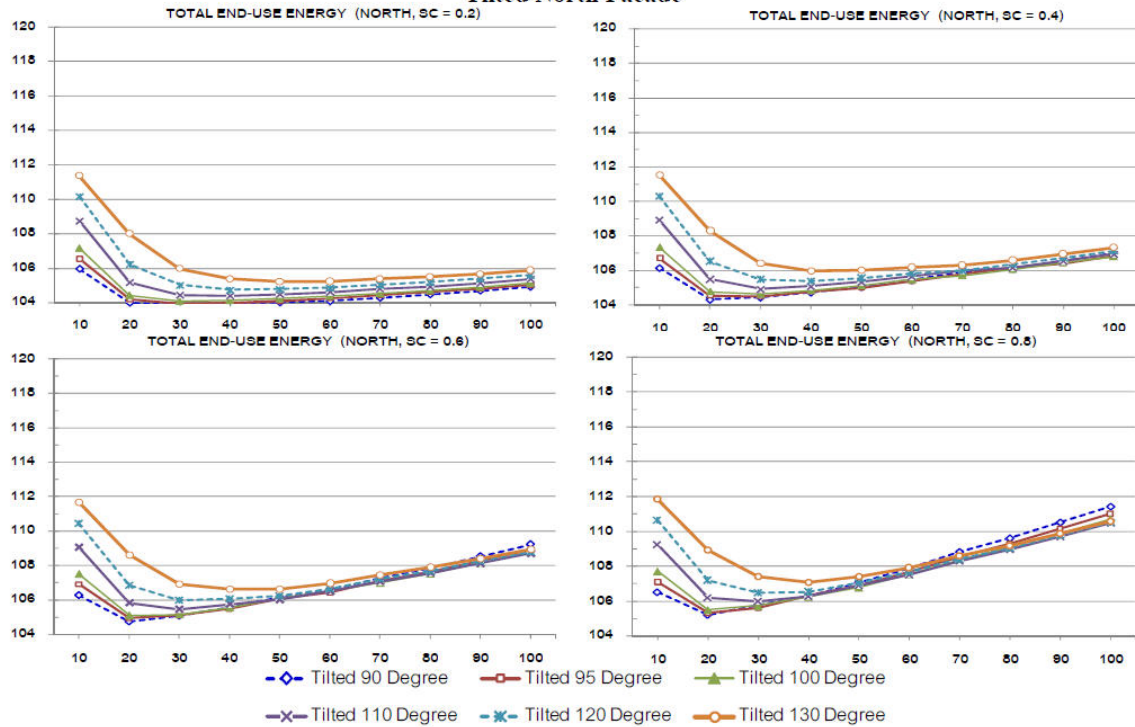
Special thanks for the grant from TGIST (Thailand Graduate Institute of Science and Technology) and XCEP (eXcellent Center for Eco-Product Development) for supporting the research activities. Also, the authors would like to thank MTEC (National Metal and Materials Technology Center) for funding the test cells and providing the facilities for the research experiments.

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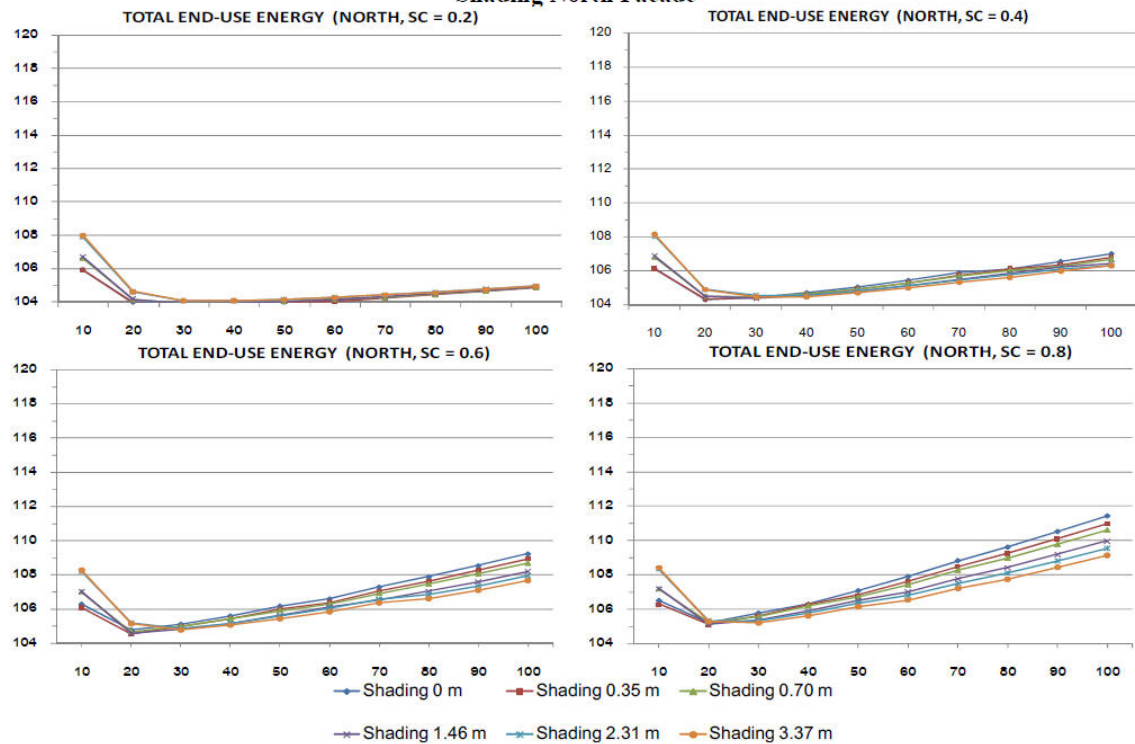
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APPENDIX

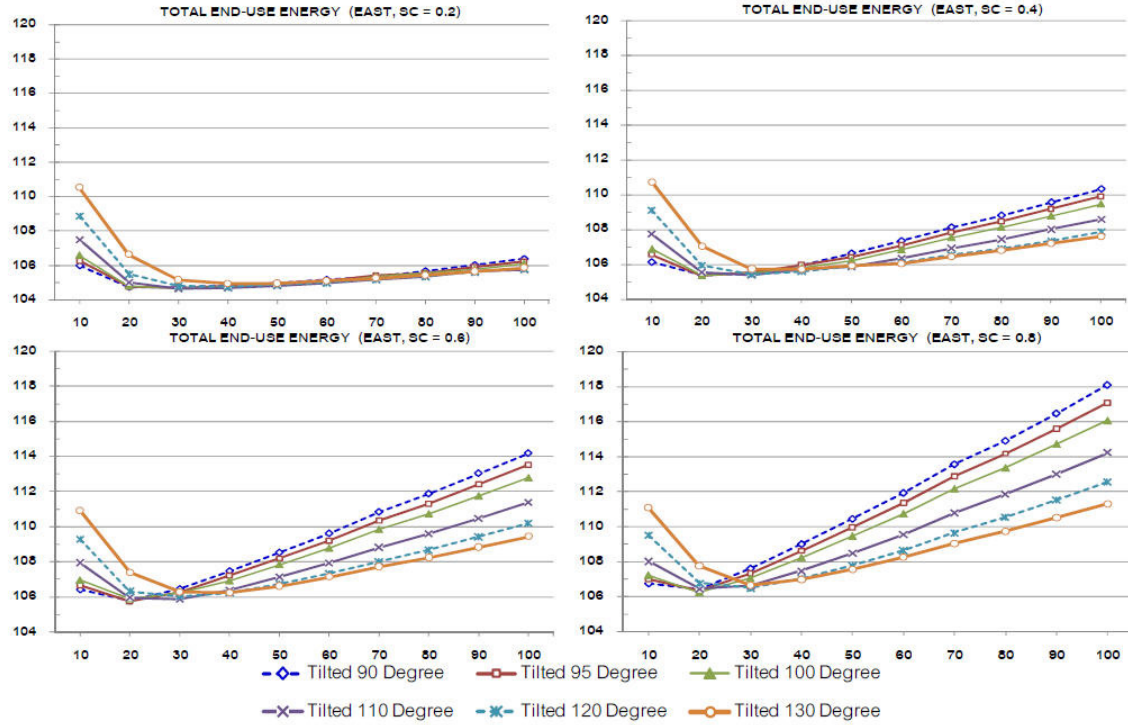
Tilted North Facade



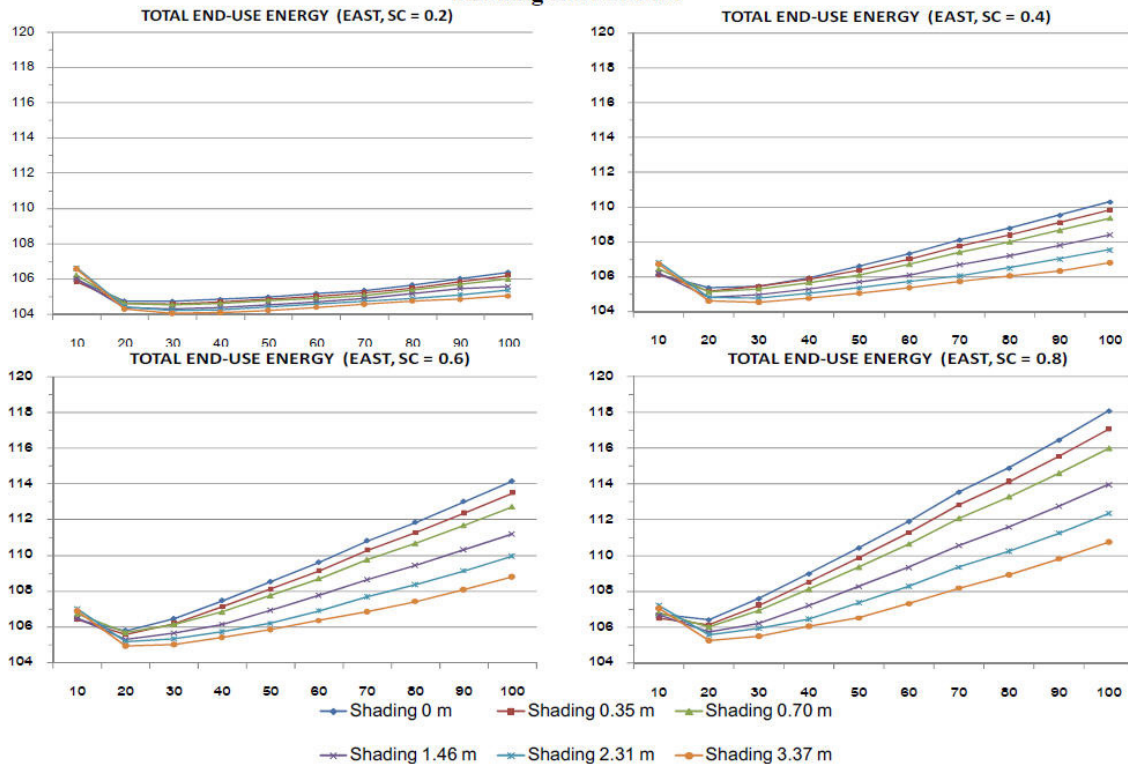
Shading North Facade



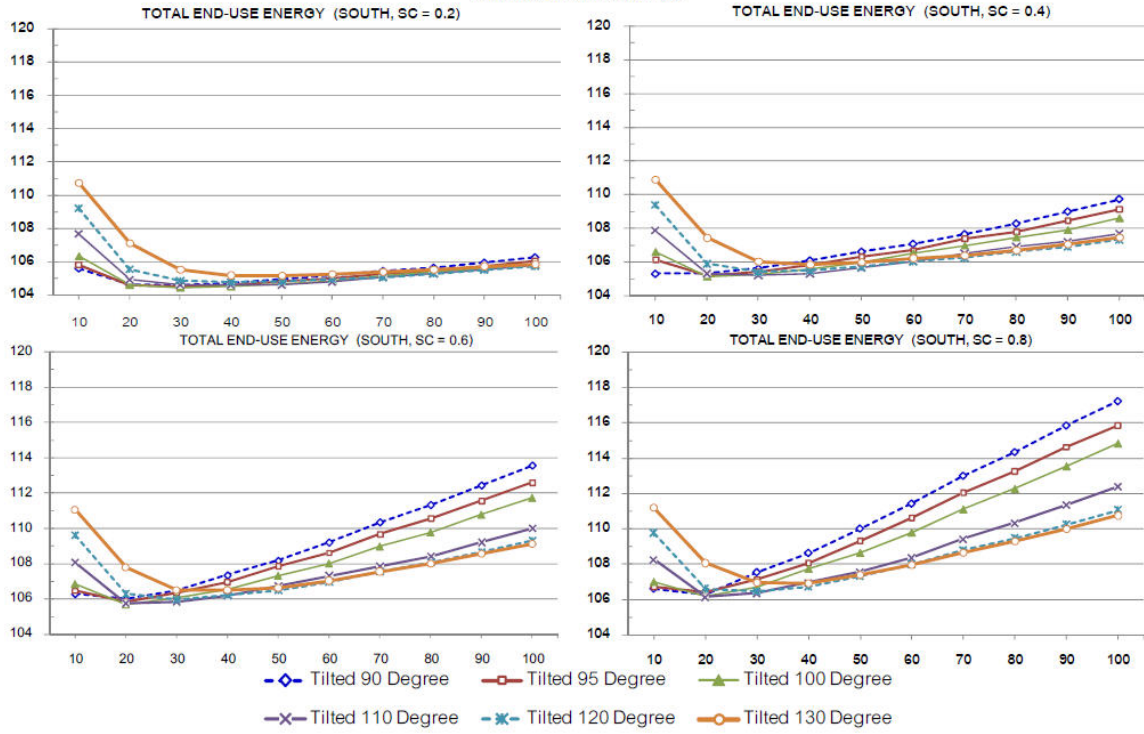
Tilted East Facade



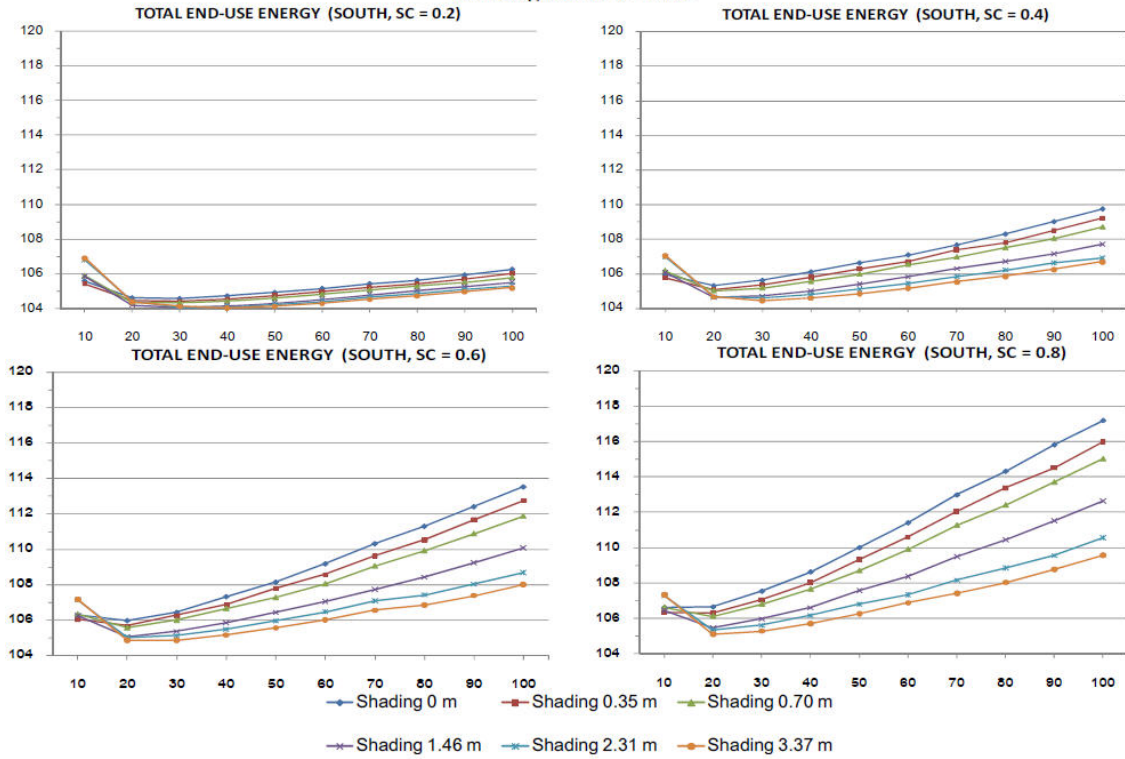
Shading East Facade



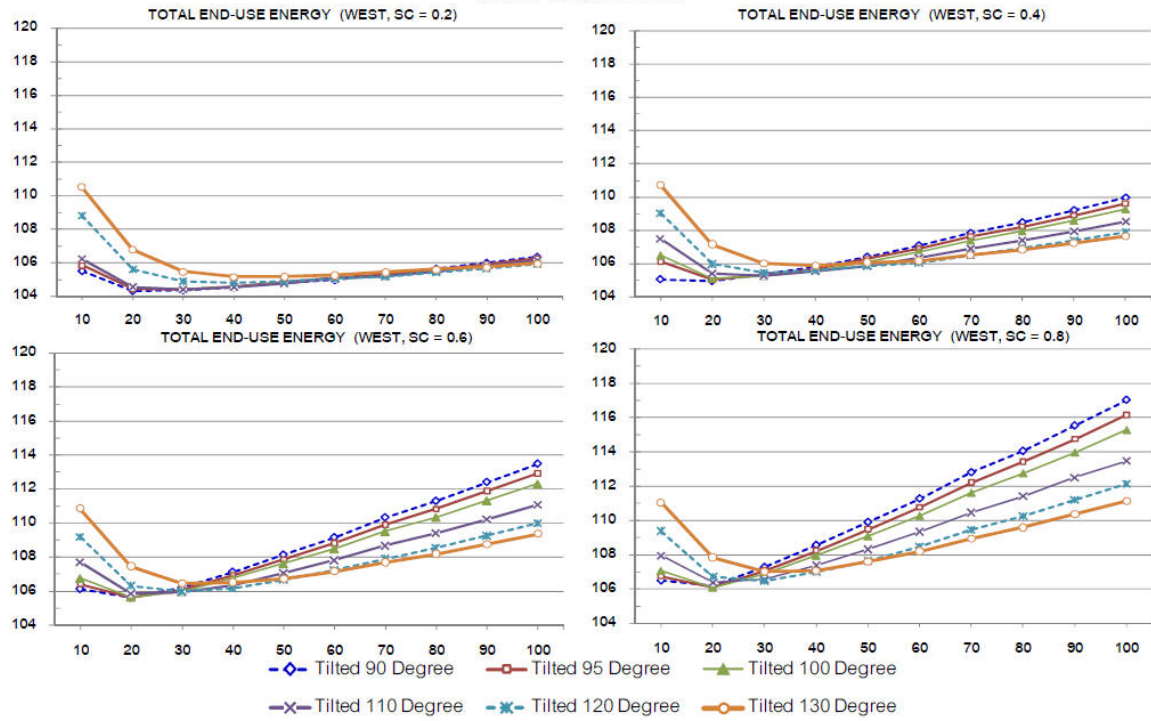
Tilted South Facade



Shading South Facade



Tilted West Facade



Shading West Facade

