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Design Assessment for High-Performance Building Façades towards Integrated Towers

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Abstract— **The primary objective of this paper is to address the challenges of quantifying the sustainability of contemporary building façade systems and to establish performance assessment methods. The analysis work is based on the case study of high-rise integrated towers located in two different climate zones in accordance with ASHRAE 90.1. One of the case study buildings is Aurora Tower in Kuala Lumpur, Malaysia located in Climate Zone 1A, and the other building is New York Times building in New York City located in Climate Zone 4A. The research utilized the integration of BIM (building information modeling) and energy simulation tool to facilitate workflow of 3D modeling and energy performance verification of building facades. The analysis focused on three areas: heat gain, daylighting control benefits and solar energy potentials from building facades. The analysis results reveal that shading devices of both integrated towers contribute to reducing heat gains by approximately 50% compared to the building without shading devices. Integrating daylighting control along the building perimeters reduces artificial lighting load by 80% compared to the building without daylighting control. Photovoltaic (PV) integrated shading devices can provide the solar energy potential of 1%~5% of total electricity usages depending on climate zones. Integration of BIM and energy simulation tool provides timely efficient energy verification and offers a powerful framework toward solving many problems in contemporary building's sustainability.**

Keywords—**building façade, performance assessment, energy sustainability, integrated tower, building information modeling**

I. Introduction

The building's use phase accounts for 90% of its total life cycle energy consumption, and an intelligently designed building envelope can significantly enhance its sustainability. Building envelopes are closely interdependent with other building service systems such as HVAC (heating, ventilation and air conditioning) and artificial lighting systems and can further reduce building energy consumption by 7% to 20% depending on building types and sizes (Kim, 2011). As contemporary buildings use more glass in their building facades, challenges exist in economic viability (i.e., management of heat loss and gain) as well as in environmental stewardship (i.e., carbon-neutral building).

As contemporary buildings tend to implement high window-to-wall ratio (WWR), energy savings from building envelopes becomes a primary concern by reducing heat gain and maximizing daylighting through windows. Some building facade technologies, such as low-e coatings, tinted glass, ceramic frit, colored interlayer and shading devices, serve to improve energy performance of a façade system. Despite their wide applications in contemporary buildings, the actual energy performance of these technologies is not well understood or quantified in the building industry, mainly because design teams focus on code-complying building façade constructions. Building energy codes enforce thermal performance requirements (i.e. U-factor and solar heat gain coefficient (SHGC)) without taking into consideration of site-specific climate conditions and building orientations.

Further, daylighting can provide around 10% energy savings for office buildings in temperate climates (Zain-Ahmed et al., 2002), but the quantification of daylighting performance during the design process is often ignored due to its voluntary compliance. In other words, despite benefits of daylighting controls, life cycle cost justification between upfront costs for installing daylighting controls and use-phase lighting energy saving from daylighting controls are not well carried out during design process, preventing it from wide implementation. It has long been a challenge to balance between solar heat gain control and daylighting maximization through a façade system during the early design process and to understand their ecological-economic implications.

The primary goal of this paper is therefore to address the challenges of quantifying the sustainability of contemporary building façade systems and to establish performance verification of a façade system in integrated towers using parametric building information modeling (BIM) and an energy simulation tool. One of the case study buildings is Aurora Tower in Kuala Lumpur, Malaysia designed by Buro Ole Sheeren, located in Climate Zone 1A in accordance with ASHRAE90.1-2007. The other case study building is New York Times Building in New York, USA designed by Renzo Piano Building Workshop and Fox & Fowel Architects, located in Climate Zone 4A. The following sections present parametric modeling and building energy simulation using integrated BIM process. Energy performances of building facades include solar heat gain, daylighting and solar energy generation potential.

This investigation will also provide design alternatives and guidelines that could enhance sustainability of building envelopes.

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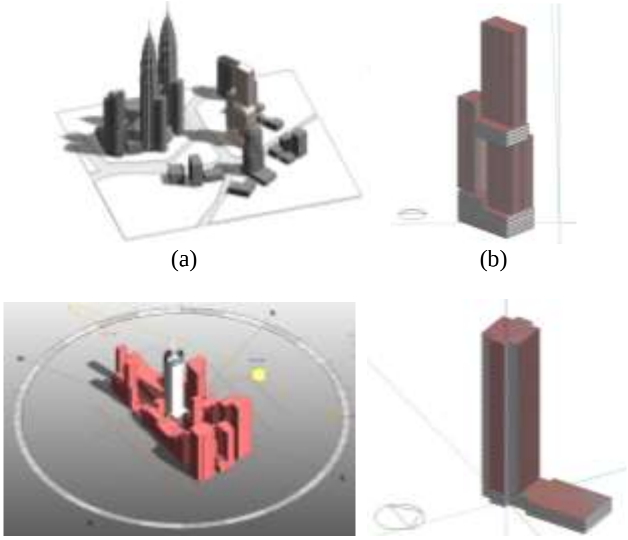
II. Analysis Targets and Methods

A. Integration of BIM and Building Energy Simulation

The building mass and external shades were built in the Revit Massing platform. 3D Revit modeling allows carrying out parametric energy consumption analysis by changing WWR, façade constructions, air tightness and perimeter zone depth. 3D Revit models of the case study buildings were exported as Green Building xml (gbxml) into DesignBuilder. The gbxml contains information about building mass, external shades, WWR and thermal and perimeter zones. DesignBuilder is a building thermal performance simulation program performed using hourly-recorded weather data and illumination data. The simulation specifically focuses on calculating solar gain and daylighting performance through a vision curtain wall system while keeping other input parameters in DesignBuilder constant in each simulation run.

In DesignBuilder, construction specifications (U-factor, solar heat gain coefficient (SHGC), visible light transmittance (VLT)) of a vision and spandrel curtain wall were assigned based on the façade section details and actual low-e coatings of a curtain wall system, conforming to ASHRAE 90-12007 building envelope requirements. The perimeter zone depth was set at 15ft deep for both case study buildings based on the horizontal transom height of a vision curtain wall system. The building operation schedule that was used was a typical office schedule set forth in DesignBuilder. The use of artificial lighting was also simulated, with 8:00-18:00 schedules per day and a target lighting level of 500 lux. An average lighting power of 11 W/m2 was used for the lighting energy calculation. The construction air tightness was assumed to be 0.25 ACH.


(a) (b)

(c) (d)

Figure 1. BIM (a, c) and energy analysis setups (b, d) of Auroral Tower (top) and The New York Times Building (bottom)

B. Configurations of Building Envelopes

Building envelopes fulfill many functions: structure, climate control, energy savings and generation, aesthetics, psychological well-being, and occupant comfort. Building envelopes are closely interdependent to building service systems and can further reduce building energy consumption by 7 to 20% depending on building type and size. As contemporary buildings often specify high quantities of glazing in the building envelope, challenges exist in not only economic viability but also energy code compliance and environmental stewardship. A highly glazed building requires performance-based design, employing an integrative design and comprehensive whole building performance verification process.

That is why it is important to address the challenges of quantifying the sustainability of contemporary building envelopes and to establish performance assessment methods and sustainability matrix.

III. Analysis Results

A. Solar Gain

Aurora Tower is located in Climate Zone 1A, which is hot and dry. It is a mixed use high rise tower consisting of office, residential, retail/amenities, mechanical and parking spaces. The curtain wall is composed of laminated glass with triple silver low-e coating and shading devices in front of the curtain wall facade. The spandrel curtain wall assembly is made of batt insulation and spandrel glass set to provide an assembly U-factor of 0.87 W/m^2-K. The vision curtain wall was set to provide an assembly U-factor of 5.45 W/m^2-K, SGHC-0.28 and VLT-0.58. Figure 2 shows Aurora Tower's configuration and curtain wall assembly.

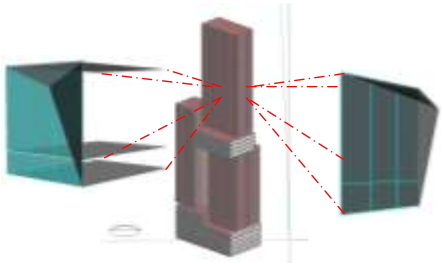
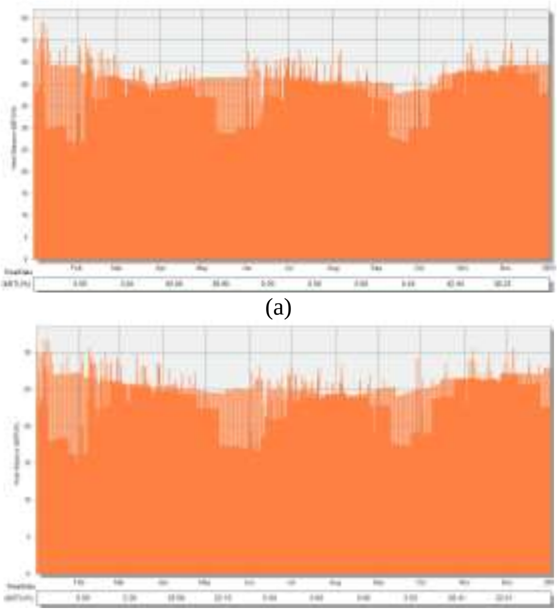


Figure 2. Aurora Tower massing and shading device configuration

The New York Times Building is located in Climate Zone 4, which is mixed and humid. The building is mixed-use, primarily consisting of commercial and office spaces. The building integrates many sustainable features that reduce energy consumption. The ceramic-coated rods in front of the curtain wall blocks unwanted sun while maximizing daylighting performance. The ceramic rods, made of 41mm diameter aluminum tubes with 50mm spacing, are evenly covered across the façade areas except at viewing zones. The spandrel curtain wall assembly is made of batt insulation and spandrel glass set to provide an assembly U-factor of 0.363 W/m2-K. The vision curtain wall was set to provide an assembly U-factor of 2.56 W/m2-K, SGHC-0.31 and VLT-0.56. These values are calculated based on a double silver low-e coating. Figure 3 shows The New York Times Building and curtain wall assembly.

Figure 3. The New York Times Building and curtainwall assembly

Blocking solar gain through a vision curtain wall is important in that contributes to internal heat gain and reduces the interior cooling load. In order to understand the shading effect of the shading devices used in Aurora Tower and the ceramic rods in The New York Times Building, the building energy simulation was carried out for each building without shading devices and ceramic rods and with shading devices and ceramic rods, and solar gains (kBtu/hr) through vision curtain wall for each scenario were measured. The analysis reveals that in Climate Zone 1A, the shading device of Aurora Tower reduces the maximum solar gain through vision curtain wall (26.4kBtu/hr) by 35% compared to the building without shading devices (42.4kBtu/hr). Figure 4 shows the analysis output data of solar gains through vision curtain wall.



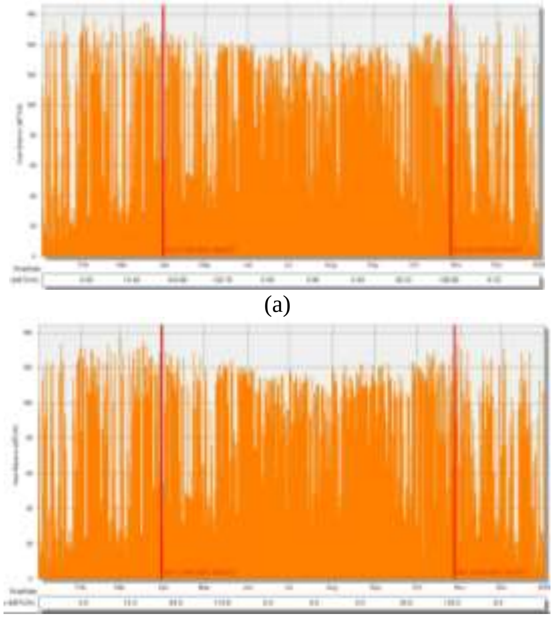
(a)

(b)

Figure 4. Hourly solar gain of Aurora Tower without shading devices (a) and with shading devices (b)

In Climate Zone 4A, the ceramic rods in The New York Times Building reduce the maximum solar gain through vision curtain wall (122.2kBtu/hr) by 11% compared to the calculations of solar gain without the ceramic rods (138.7kBtu/hr). Figure 5 shows the hourly heat gain value through the vision curtain wall of the New York Times Building without ceramic rods and with ceramic rods.

The geometric configuration of the shading devices in Aurora Tower is more efficient at blocking solar heat gain compared to the screen device in The New York Times Building.



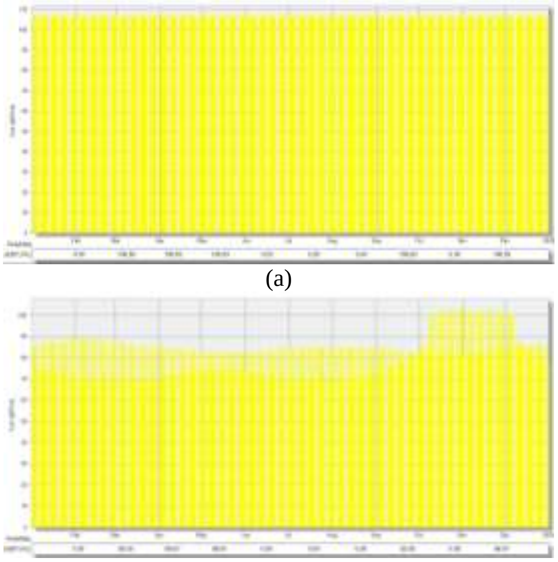
(a)

(b)

Figure 5. Hourly solar gain of the New York Times Building without ceramic rods (a) and with ceramic rods (b)

B. *Daylighting Control Benefit*

Daylighting benefits were measured by applying the daylighting control function along the buildings' perimeters in DesignBuilder. Daylighting performance is affected by the visible light transmittance (VLT) level of vision curtain wall as well as the presence of shading devices. Heat gain and daylighting performance act against each other, so it is important to find a balance between heat gain mitigation and daylighting maximization. In order to calculate the benefits of daylighting control, the daylighting liner control was applied with an allowable glare index of 22 in DesignBuilder. The analysis reveals that the daylighting control in Aurora Tower can reduce the artificial lighting load by 17%, from 106.6kBtu/hr to 88.4kBtu/hr. Figure 6 presents the lighting consumption of Aurora Tower without and with the implementation of the daylighting control.

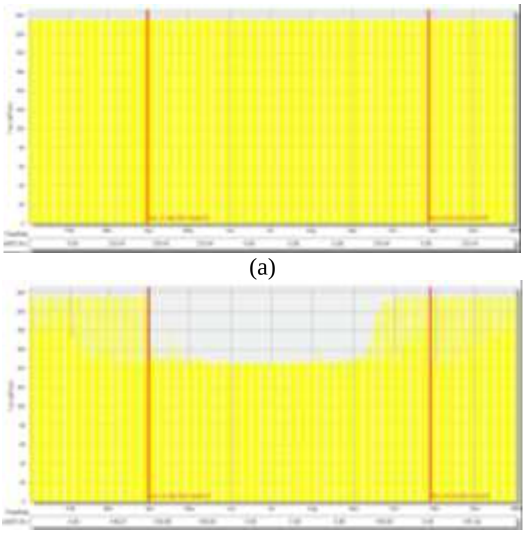


(a)

(b)

Figure 6. Hourly artificial lighting load of Aurora Tower without daylighting control (a) and with daylighting control (b)

Daylighting control for The New York Times Building can reduce the artificial lighting load by 25%, from 215.4kBtu/hr to 161.5kBtu/hr. It is interesting to note that compared to The New York Times Building, Aurora Tower consumes less artificial lighting load due to Kuala Lumpur, Malaysia having a higher sunlight intensity than New York City. Figure 7 presents the lighting consumption of The New York Times Building without and with the implementation of the daylighting control.



(a)

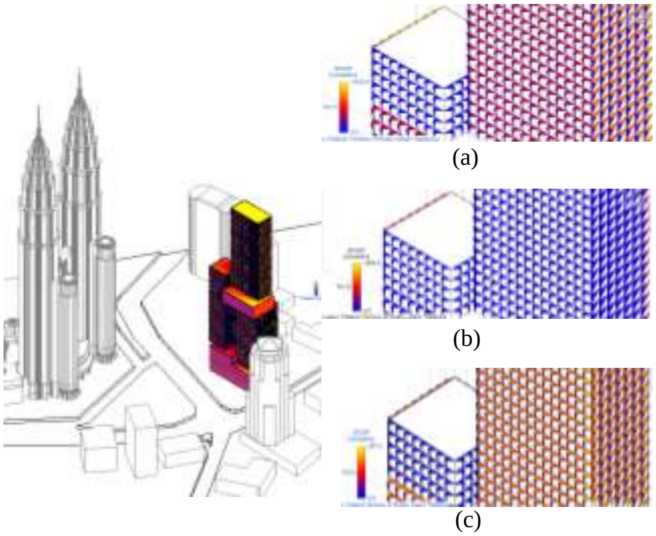
(b)

Figure 7. Hourly artificial lighting load of The New York Times Building without daylighting control (a) and with daylighting control (b)

C. *Solar Energy Potential*

To enhance the buildings' sustainability, the shading devices of Aurora Tower and ceramic rods of The New York Times Building were assumed to utilize thin film photovoltaic(PV) systems for electricity generation. Solar energy potentials were calculated in Vasari (a Revit-based energy simulation tool), taking the surrounding buildings into consideration.

An accumulative electricity generation potential for a year in Aurora Tower is approximately 226,000kWh based on 5% efficiency of a PV system, which equates to ~$22,600/yr. Figure 8 illustrates the level of insolation intensity reaching the shading devices of Aurora Tower in different seasons.



(a)

(b)

(c)

Figure 8. Annual accumulative insolation of shading devices of Aurora Tower in equinox (a), summer (b) and winter (c)

TABLE I. SOLAR ENERGY POTENTIALS OF AURORA TOWER

	Spring	**Summer**	**Fall**	**Winter**	**TOTAL**
Solar Energy Potential (kWh/yr)	64,200	63,800	48,900	49,100	226,000
Electricity Saving ($/yr)	assuming $0.1/kWh				22,600

For The New York Times building, the annual solar energy potentials from the ceramic rods were estimated to be 156,400kWh based on a 5% electricity efficiency from a thin film photovoltaic system. Winter months demonstrate the least amount of solar energy potential, and equinox seasons and summer show similar accumulative insolation levels. This equates to an annual electricity savings of ~$15,600. Figure 9 and Table 1 show insolation analysis images and the solar energy potential. Table 2 shows seasonal and annual the solar energy potential of The New York Times Building.

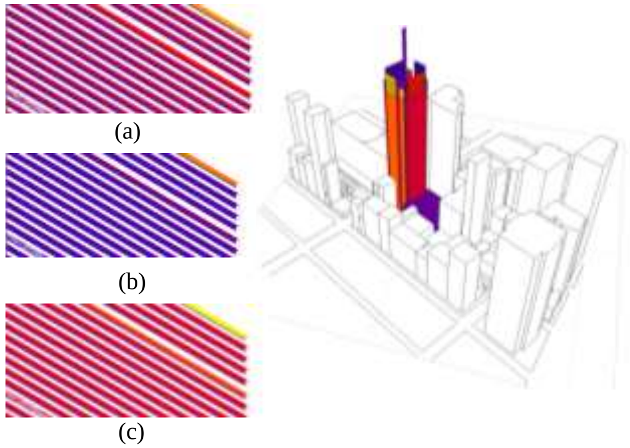


Figure 9. Annual accumulative insolation of the ceramic rods of The New York Times Building in equinox (a), summer (b) and winter (c)

TABLE II. SOLAR ENERGY POTENTIALS OF THE NEW YORK TIMES BUILDING

	Spring	Summer	Fall	Winter	TOTAL
Solar Energy Potential (kWh/yr)	43,000	43,200	43,200	27,000	156,400
Electricity Saving ($/yr)	assuming $0.1/kWh				15,600

IV. Conclusions

This paper examines two case study buildings undertaken as part of a research focus on verifying the sustainability performance of building façades. Our aims with the analysis work presented in this paper are to investigate the sustainability indicators in the areas of solar gain, daylighting benefits and the solar energy potential of building envelopes and to explore how climate zones affect the sustainability indicators of building envelopes in different climate zones. We used a parametric modeling and analysis tool to facilitate design-analysis workflow, creating different typologies of external shading devices in Autodesk Revit and analyzing the sustainability performance in DesignBuilder.

The analysis' results reveal that the external shading devices contribute to the reduction of solar gain through vision curtain wall by ~11%~35%, depending on the shading devices' typologies and site locations. Further, daylighting control can reduce the artificial lighting load by 17%~25%. Finally, PV-integrated shading devices in a high-rise building can offer $15,000~$22,000 in electricity cost savings.

The geometric configuration of the shading devices in Aurora Tower is more efficient in blocking solar heat gain compared to the screen type of The New York Times Building. It is also interesting to note that, compared to The New York Times Building, Aurora Tower consumes a smaller artificial lighting load due to the higher sunlight intensity in Kuala Lumpur, Malaysia. The integration of BIM and energy simulation methods provide a timely, efficient energy assessment of different façade system alternatives and sustainability performance of building envelope systems.

Acknowledgment

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