Integrated Facades for Building Energy Conservation

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***Abstract*—The increasing necessity of sustainability in built environments has reinforced the role of climate responsive design in contemporary practice. Building facades - a boundary layer between indoor and outdoor environments, in turn, have transformed to fulfill adapted roles of high performance integration. The façade is no longer a mere static element that offers a shelter for users. Instead, it is an active, restorative, and generative building system that maximizes the use of natural resources – light, heat, rain, and wind and engages occupants often as a visual stimulator.**

This paper explores an integrated façade system as a sustainable façade alternative to a contemporary curtainwall glazing system. The façade was designed for a multi-story office building in Charlotte NC with a south facing façade to maximize daylighting year around, reduce solar heat gain during cooling seasons, and increase solar heat gain during heating seasons. Comparative analysis was carried out to understand energy efficiency of an integrated façade system compared to a baseline building in accordance with ASHRAE 90.1. Advanced performance analysis was based on EnergyPlus and Radiance simulation. Results were compared to a baseline façade system to explore the impact of integrated façade systems on building energy consumption and daylighting efficiency.

Keywords-integrated façade; sustainable façade alternative; ASHRAE 90.1.

I. INTRODUCTION

Building sustainability has gained more attention and importance in architecture due to climate change and increased energy demand in the built environment. It is of the utmost important to design buildings that lessen the environmental impact and use of non-renewable resources. Building sustainability begins with a climate responsive design with a passive approach to maximize the use of natural resources – light, heat, rain, and wind. One way that buildings can respond to the environments is to integrate a kinetic façade system that reacts to dynamic outdoor environments providing daylighting and solar protection, and in some cases energy generation and environmental cleaning.

Recent examples of integrated façade systems include works such as Al-Bahr Towers in Abu Dhabi UAE, whose facade systems was initially inspired by the Mashrabiya of local geometric pattern, and dynamically responds to sun's movement with open-close motions in order to maximize daylighting and minimize direct solar gain. The "smoke eating" façade in Mexico City is another integrated façade example whose façade is coated with titanium oxide (TiO_2) in order to convert harmful smog pollutants in the city into harmless CO_2 and water in conjunction with UV radiation. The algae bio-reactor integrated façade in Hamburg, Germany has the potential to generate renewable energy sources while enhancing building energy consumption and user experience. These examples, along with many others, have actively employed the façade as a design strategy that radically transforms interior spaces through maximized daylighting, control solar heat gain, generative energy, and restorative air quality.

II. INTEGRATED FAÇADE DESIGN

An integrated facade serves as a mediator between the exterior environment and conditioned interior spaces. It acts as a barrier to unwanted elements like extremes of heat and cold, rain, harsh winds, and noise. The integrated façade acts as a filter of light, sound, and weather, which can be passive design strategies for integrated façade design. The façade can also be a stimulator to building users or urban dwellers by exciting, especially their visual sense from ever-changing aesthetics of building facades, and often allowing them to interact with integrated facades. Finally, the facade can serve as a generator which helps to store and generate energy (e.g. solar or wind) and clean air pollutants by breaking them down into less harmful compounds. Figure 1 shows four levels of integrated façade roles. Advanced technologies are required as the integrated façade pursues the upper level of its roles.

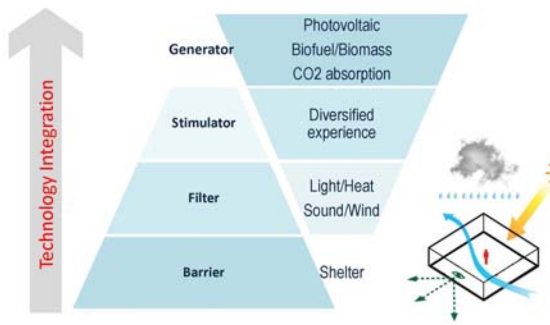

Figure 1. Four levels of integrated façade function

The design concept of integrated facades is often inspired by nature which is often called biomimicry. Biomimicry provides a wide source of inspiration for enhancing façade design and performance. Nature informs façade design through adoption of material efficiency or geometric efficiency. Examples include the golden ratio, the structure of exoskeletons, and a surface structure that is based on soap bubble geometry. Biological processes from nature can inspire sustainability performance of a façade. Examples include photosynthesis, the hydrophobic effect, and photocatalysis, which were reflected and developed as a photovoltaic façade, self-cleaning façade, and pollutant removal façade, respectively. After integrated façade design concept is set, iterative modelling and performance evaluation processes should be incorporated, allowing designers to rapidly set up design alternatives and evaluate sustainability performance through different performance criteria. This process can lead to the development of system details for visual or performance mock-up. Figure 2 demonstrates a design process of integrated façade system.

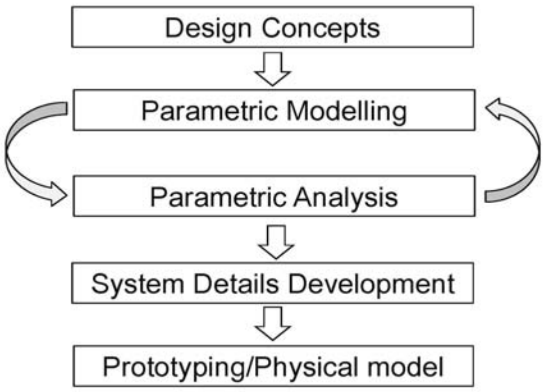

Figure 2. Design process of integrated façades

III. Performance Evaluation of an Integrated Facade

A. System description

The integrated facade investigated in this paper consists of a primary façade skin, which acts as a barrier, and a performative skin, which acts as both a filter and a stimulator. The primary skin is a unitized curtainwall system, which is composed of IGU and thermally broken aluminium frames. The performative skin was initially inspired by the Chinese art form origami. The simple folding of panels for the performative skin allows the integrated façade to transform daily and seasonally to optimize diffused light and minimize unwanted heat gain. The transforming nature of the integrated façade similarly activates the façade as a stimulator. Four aluminium panels of the performative skin fold and unfold across the building façade as they track the sun's movement throughout the day. Each panel is 1.5m wide by 5m tall with gradient density of perforation across the panel – maximum perforation toward the center of a panel at eye level - to provide daylight and view out. The typology of the perforation was further developed through a parametric design investigation. Perforations in the folding panel were arranged across each panel, allowing the most unobstructed view at eye level. These perforations seek to stimulate the occupant visually, engaging with the surrounding view and casting shadows across the interior space as the panels' positions change throughout the day.

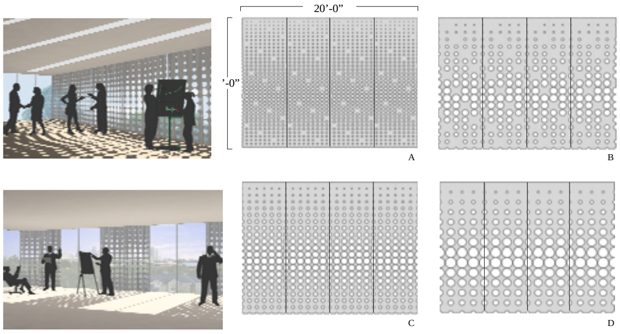

Figure 3. Integrated façade system overview

B. Whole energy simulation set-up

In order to understand the energy benefit from the integrated façade compared to the baseline building, a whole building energy simulation was carried out using DesignBuilder, whose simulation engine is based on Energy Plus. The baseline building is assumed to be a medium-rise office building with 30m x 30m footprint, located in the city of Charlotte, NC. Table 1 summarizes the input parameters in DesignBuilder. To highlight, the energy performance value of the curtainwall system for the baseline building satisfied ASHRAE90.1 requirements using an IGU (insulted glass unit) with high performance soft low-e coating. The curtainwall frame is thermally broken aluminium extrusion, and the spandrel panel consists of an IGU with mineral wool insulation to meet opaque wall's thermal requirements in accordance with ASHRAE90.1. While the window to wall ratio (WWR) for the baseline is set to be 40%, the integrated façade building has 80% of WWR to maximize passive design strategies. In order to comprise heat loss and heat gain through an enlarged window area of the integrated façade building, the integrated façade utilizes an IGU with argon gas infill and soft low-e coating. The curtainwall system is a unitized aluminium system with thermal break, and its spandrel consists of an IGU and back mineral wool insulation. Folding shading panels are hung off of curtainwall frames in order to regulate unwanted solar gain and maximize daylighting by opening and closing its assembly depending on the sun's movements. Airtightness for both buildings was set to be 0.7AC/h which represents good industrial practice in accordance with the ASHRAE Fundamental Handbook. The daylighting control was assumed to be installed in the integrated façade after running the daylighting analysis, as shown in Figure 4.

TABLE I. INPUT PERIMETERS IN DESIGN BUILDER SIMULATION

	Baseline	Integrated façade
Program	Office	Office
WWR	40%	80%
Glazing	IGU with PPG SB70XL	IGU with PPG SB70XL and argon infill cavity
Curtainwall frame	Thermally broken aluminum system	Thermally broken aluminum system
Shading device	NO	Automatic control
Spandrel	Mineral wool batt insulation	Mineral wool batt insulation
Airtightness	0.7AC/h	0.7AC/h
Daylighting Control	No	Yes

C. *Energy simulation results*

The results of the analysis show that the integrated façade results in energy usage intensity (EUI) of 91kWh/m^2 for cooling, 13kWh/m^2 for lighting load, and 48kWh/m^2 for heating respectively, totalling 138 kWh/m^2 annually. The baseline building was estimated to consume the total EUI of 222kWh/m^2 consisting of 121kWh/m^2 for cooling, 63kWh/m^2 for lighting, and 38kWh/m^2 for heating. The total energy consumption of the integrated façade was less than the baseline building by 30%, which was primarily attributed to the daylighting benefit from the higher WWR of the integrated façade and its ability to control unwanted heat gain throughout cooling seasons.

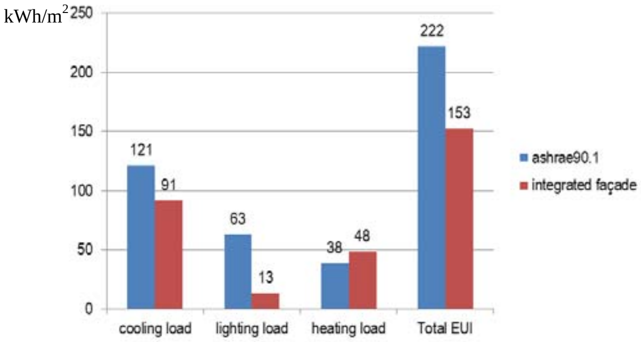

Figure 4. EUI comparison between the integrated façade and the baseline façade

The heating load from the integrated façade was higher than the baseline building due to the heat transfer through the large window area. This can be further improved through enhancing the U-factor of its primary façade. Figure 4 compares energy consumption between the two buildings.

Further, the exterior and interior surface temperatures of the integrated façade were estimated to be lower than that of the baseline façade in the summer, which means that the integrated façade offers better thermal comfort to users at the perimeter zone. This is attributed to a performative façade that acts as a shading device in the summer and a wind-breaker during the winter. As shown in Figure 5, the daylit perimeter zone from the integrated façade building is greater than the baseline facade, contributing to energy reduction in lighting and cooling loads.

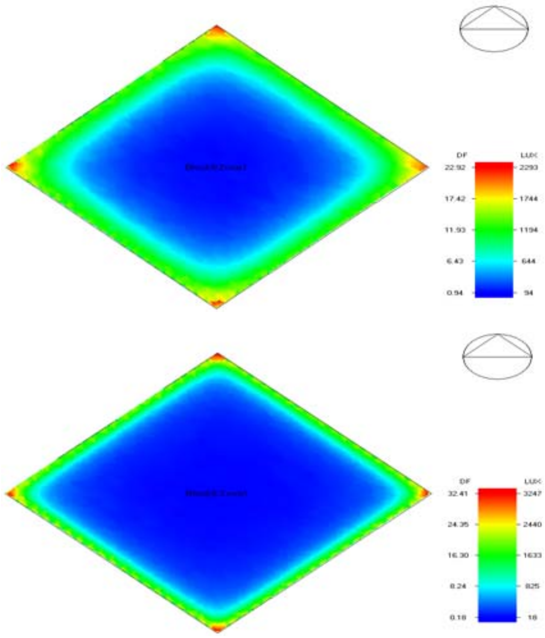

Figure 5. Daylighting simulation for integrated façade (a) and the baseline façade (b)

IV. CONCLUSIONS

In order to respond to climate change and resource depletion in the built environment, an integrated façade can contribute by reducing environmental impacts and building energy consumption. This paper investigated the development of an integrated façade system and carried out a comparative analysis through whole building energy simulation. The integrated façade analysed allows achieving energy saving in cooling and lighting, and provides more thermal comfort for users. The primary energy demand was reduced by approximately 30% in comparison to the baseline ASHRAE90.1 building. An evaluation of pay-back period of the integrated façade system will be the topic of further works of the author in future.

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