

Energy performance of an adaptive façade system

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ABSTRACT:

The objective of this study was to determine the influence of an adaptive façade system on the energy performance of a hypothetical office building located in a cold climate. The design of a nine-story office building was selected from an advanced design studio taught by the authors, and used as a case study to carry out a whole building energy simulation. The energy simulation was run by a state-of-the-art simulation tool, DesignBuilder, using EnergyPlus weather data in Minneapolis, MN and Houston, TX. An adaptive façade system was developed, consisting of a typical curtainwall system and an operable shading system. The energy performance of the adaptive façade system was numerically verified using Lawrence Berkeley National Laboratory (LBNL) software, and was used as input variables in DesignBuilder. The results of the analysis revealed the adaptive façade system consumes less heating energy compared to its static façade counterpart. The study addresses the importance of adaptive façade systems that contribute to aesthetics, technical innovation and building sustainability.

CONFERENCE THEME: Applied research

KEYWORDS: Adaptive façade system, energy performance, building energy simulation

INTRODUCTION

Buildings worldwide, more than rapid transit and other urban infrastructure are responsible for about 40% of CO₂ emissions, the US being the largest culprit by far (DOE 2010). CO₂ emissions in the US in 2008 were 14% higher than they were in 1990. In effect, a reduction in building energy consumption is a design imperative. As construction expands in countries such as China and India, absolute emissions figures are on the rise. Innovative design strategies to reduce energy consumption are essential in tackling future climate change and energy use.

It is well understood that climate is fundamental and highly effective in implementing sustainable building design by manipulating building mass and plan layout as a first step to reduce the use of natural resources and energy consumption. Building design must account for different urban settings and different climate conditions.

Achieving an energy efficient building is a complex process, influenced by various factors such as building envelope performance, occupant behaviours, operational schedules, HVAC efficiency, and environmental building performance, to name a few. The primary problem of the contemporary building envelope is its “static” nature in relation to its “dynamic” environment. Such a condition is not optimal for building energy conservation. Further, the energy performance of glazing systems is increasingly more important as contemporary buildings pursue higher window-to-wall ratios. In addition, energy performance is directly affected by heat transmission (U-factor), solar heat gain coefficient (SHGC), visible light transmittance (VLT) as well as air infiltration through quality workmanship. Therefore, in order to maximize energy efficiency, more in-depth research on high performance façade systems should be developed and applied in different climate zones.

This paper investigates how effectively and sensitively an adaptive building facade system affects the energy performance of an office building compared to a static façade system and which climate has greater environmental benefits from an adaptive façade system. The analysis of an adaptive façade system is applied to a studio project taught by the authors and demonstrates the benefits and challenges of an adaptive façade system. The study has developed the concept of using a shading system to create an adaptive façade to improve the energy performance of a building. An external shading device has been widely implemented across the building to address both of architectural and functional issues.

As an initial approach toward an adaptive façade system, an operative shading system was developed and its energy performance was numerically investigated. Two climate zones were considered in accordance with the ASRHAE climate zone definition: 1. Cold and humid (climate zone 6A) and 2. Hot and humid (climate zone 2A). Figure 1 highlights two cities used in this paper.

The primary objective of this paper is to conduct a comparative study of energy consumption of a building façade that utilizes an adaptive façade system in accordance with seasonal changes. A hypothetical 9-story office building located in Minneapolis, MN, and Houston, TX respectively served as the case study. The study focuses on demonstrating the energy efficiency of an adaptive façade system in two different climate zones compared to a static façade system. The study finally concludes with recommendations for developing a high-performance building envelope.

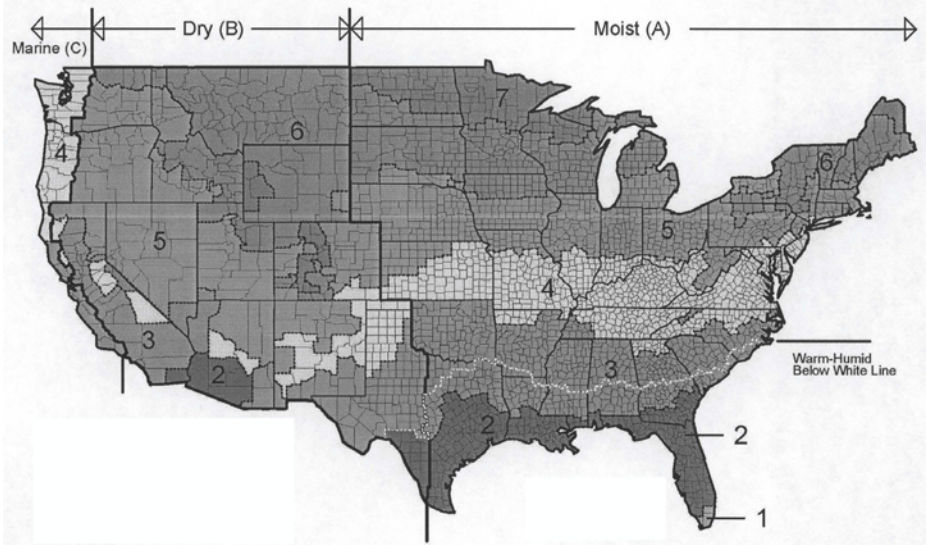


Figure 1: USA Climate zones and case study cities

I. MATERIAL AND METHOD

I.1 OUTLINE OF SIMULATIONS

The simulation of energy consumption of the case study building was performed using DesignBuilder, a whole building energy analysis software program that utilizes EnergyPlus simulation engine (DesignBuilder version 2.3). DesignBuilder is a building thermal performance simulation program performed on hourly-recorded weather data mainly consisting of sub-hourly weather data and illumination data. The simulation specifically focuses on calculating energy performance of a building façade system by changing its energy performance values while keeping other input parameters in DesignBuilder constant in each simulation run.

The nine-story office building study comprises a total of 14,000 m² gross floor area, which includes 12,000 m² for working spaces and 2,000 m² for service cores. The building mass incorporates outdoor spaces for recreational and green garden purposes. All internal spaces in the building were modelled as one thermal zone that maintains uniform indoor temperature and relative humidity.

The designed operation schedules were used as a typical office schedule set forth in DesignBuilder. The interior set point is 22 °C and 24 °C for winter and summer respectively with steady relative humidity of 30% across the year. The use of lighting and office appliances were also simulated with 24-hour schedules and a target lighting level of 50 lux. The opaque wall assembly made of batt insulation and spandrel glass set to provide an assembly U-factor of 0.363 W/m²-K. The roof and floors, constructed with metal deck and concrete, offers an effective U-factor of U-0.215 W/m²-K. These U-factors are also in accordance with ASHRAE 90-1 building envelope requirements. The

shading system is assumed to cover 50% of the entire building façade in addressing aesthetic and energy efficiency measures.

The simulation was carried out for two seasonal periods: 1. Summer mode from April 1 - when the cooling season starts - to September 30 when the cooling season ends; and 2. Winter mode from October 1 - when winter season starts - to March 31 when the heating season ends. The adaptive features of the building facade in summer and winter modes were simulated using simple performance values in DesignBuilder by changing its heat transmission (U-factor), solar heat gain coefficient (SHGC), and visible light transmittance (VLT). Figure 2 visualizes architectural characteristics of the case study building.

Table 1 summarizes the input parameters used in the DesignBuilder simulation. Input variables for the comparative study are highlighted in green in the table.

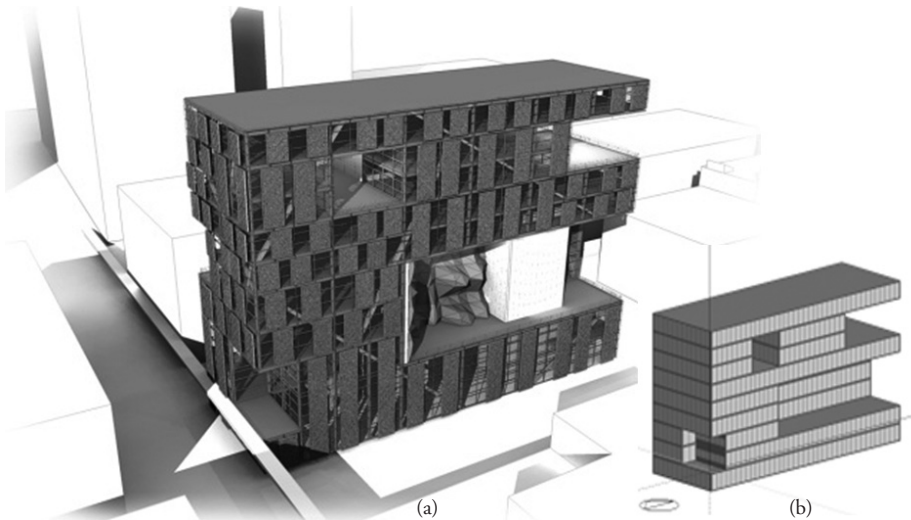


Figure 2: A rendered view (a) and DesignBuilder set-up (b) of a case study building

Category	Descriptions	Reference Values
Activity	A typical office working schedule and activities	Schedules set up in DesignBuilder
Environmental Control	Heating	22 °C
	Cooling	24 °C
	Lighting	500 lux
	Relative Humidity	30%
Construction	Roof and floor construction; cast concrete construction	U- 0.215
	Opaque wall lightweight construction; rigid insulation with spandrel glass	U-0.363

Table 1: Summary of input parameters in DesignBuilder

Fenestration	Window to wall ratio	70%	
	Double IGU with low-e coating on surface #2 + PV integrated laminated glass shading device	Baseline system	Adaptive system
		U-2.8 SHGC-0.2 VLT-0.34	U-1.9 SHGC-0.2 VLT-0.34
	Air exchange per hour	0.7ACH	

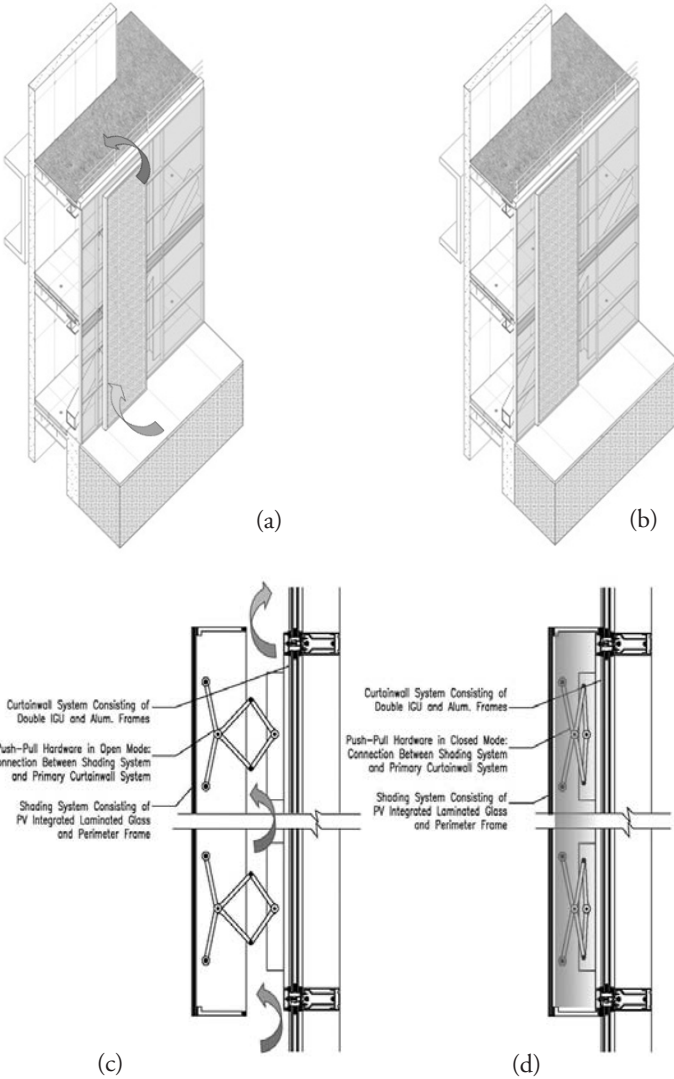


Figure 3: Axonometric views of an adaptive façade assembly in summer (a) and winter (b); sectional details in summer (c) and winter (d)

The fenestration system in this study consists of a typical curtainwall system with an integral external shading system. The curtainwall system consists of a low-e coated insulated glass unit (IGU) and thermally broken aluminium frames. The shading system is comprised of photovoltaic (PV) thin film laminated glass and an aluminium frame along the edges of a PV panel. The shading system is hung off from the curtainwall frames using operable brackets, providing a ventilated cavity in warmer seasons and a closed cavity in cooler seasons. For comparative purposes, a baseline façade system with an integral static shading system was also simulated in DesignBuilder. Sectional details of the adaptive façade system are illustrated in Figure 3.

1.2 CALCULATIONS OF ENERGY PERFORMANCE VALUES OF AN ADAPTIVE FAÇADE SYSTEM

The energy performance of a façade system is typically characterized by U-factor, SHGC, VLT, and air infiltration rate. The U-factor of an adaptive façade system was determined in accordance with NFRC 100 using Therm 5 (Therm version 5). Therm 5 is temperature-driven heat transfer 2D software that determines the heat transmission of a façade assembly, including material conductivity, radiation, and convective effects. SHGC and VLT of the adaptive façade system assembly were determined in accordance with NFRC 200 and NFRC 300 using Window 5 (Window version 5). The low-e coating simulated in this study is a spectrally selective soft coat that offers the best U-factor, SHGC and VLT available in current market. The PV laminated glass unit is simulated with metal-coated glass that offers similar SHGC and VLT to that of the thin PV film panel. The simulation here does not incorporate computational fluid dynamic (CFD) simulating thermal gains through solar radiation in the closed cavity during winter seasons. Figure 4 shows the overall heat transmission of an adaptive façade system resulting in the effective U-factor of 1.9 W/m²-K.

The effective energy performance values of the baseline and adaptive façade system used in both climate zones are summarized in Table 2. The calculation of these values took into consideration 50% of the façade area being covered with a shading system. It is observed that the major difference between the baseline and adaptive façade system is its U-factor and air exchange rate. The adaptive façade system results in an enhanced U-factor due to the insulative attributes of the closed cavity

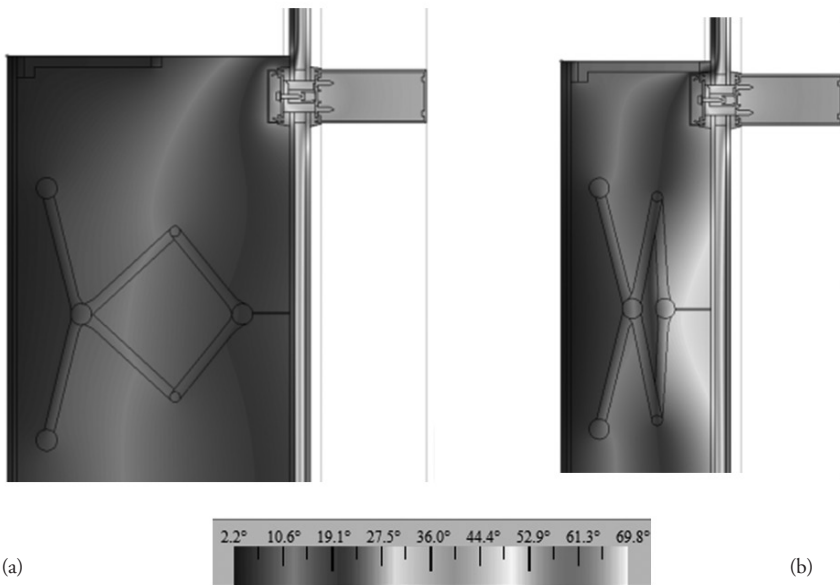


Figure 4: U-factor verification in accordance with NFRC100; façade assembly with ventilated cavity (a) closed cavity (b)

	Baseline façade system	Adaptive facade system
Effective U-factor	2.8 W/m ² -K	1.9 W/m ² -K
Effective SHGC	0.2	0.2
Effective VLT	0.34	0.34
Effective air infiltration rate	0.7ACH	0.5ACH

Table 2: Summary of energy performance of baseline and adaptive façade system

during winter months. The closed cavity also improves the air exchange rate, thus further contributing to energy conservation. In the absence of a simulation tool to estimate the air exchange rate, the air exchange rate of the adaptive system was assumed to be reduced by 30% compared to the baseline façade system, resulting in 0.5ACH. The values in Table 2 are the input variables in DesignBuilder for annual energy loss/gain calculations through the façade systems.

2. RESULTS AND DISCUSSION

The results of energy consumption of a 9-story office building located in Minneapolis, MN (cold/humid) and Houston, TX (hot/humid) are presented in this section. An annual energy simulation was carried out to assess the energy influence of an adaptive facade compared to a static façade system. The analysis revealed that the adaptive façade system consumes less energy than the static façade system. The same study showed that the adaptive façade system in cold climates offers greater energy saving than hot climates. Sensitivity analysis indicated that further energy saving can be achieved through strategically incorporating external louvers and fins into the adaptive façade system in both climates.

2.1 COMPARATIVE ANALYSIS RESULTS

The cooling and heating energy load of the building with the baseline façade system in Minneapolis MN was measured to be approximately 6,700MBtu (consisting of 2100MBtu/yr of the cooling load and 4600MBtu/yr of the heating load) whereas the building with the adaptive façade system in Minneapolis MN consumed 5,100MBtu/yr (consisting of 2300MBtu/yr of the cooling load and 2800MBtu/yr of the heating load). The adaptive façade system in Minneapolis provided approximately 1,800MBtu of energy reduction equating to \$20,000/yr operational cost saving compared to the baseline façade system. It was observed that both façade systems yields a similar cooling load consumption for summer months while the adaptive façade system consumes less heating load than the baseline system. This is due to the fact that U-factor and air exchange rates normally constitute a small percentage of the total heat gain of the building in summer seasons but they are major contributors for the heat loss during winter seasons. Figure 5 shows the monthly energy usage pattern and the energy consumption comparison between the baseline and adaptive façade systems.

For the hot climate where the cooling energy is dominant (Figure 5 (b)), the annual energy consumption of the baseline and adaptive façade system was measured to be 5700MBtu and 5100MBtu respectively. Although the heating energy is reduced by 50%, the total energy saving from this specific adaptive façade system is marginal because insulative facades are rarely beneficial and the solar control is more of a priority for such hot climates. Therefore, further research on the solar control attributes should be incorporated into the studied adaptive façade system focusing on geometry, dimension and materiality in relation to façade orientations and solar path. Figure 5 illustrates the comparison of the total heating energy between the baseline and adaptive façade system.

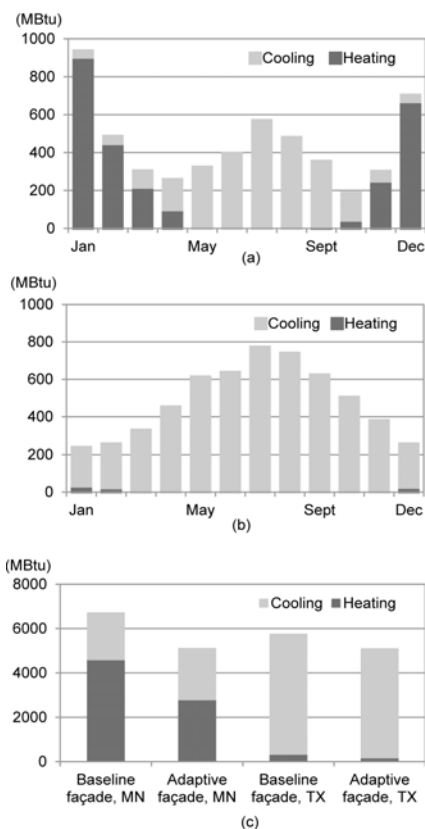


Figure 5: Monthly energy usage pattern in Minneapolis MN (a) and in Houston TX (b). Annual energy consumption comparison between baseline and adaptive façade systems in two climate zones (c)

CONCLUSION

This paper focuses on two objectives: first, to develop an understanding of how effectively and sensitively an adaptive building façade system affects the energy performance of a building compared to a static façade system and to analyse its energy performance in cold and hot climate zones.

The adaptive façade system consists of an exterior adjustable shading system installed adjacent to a curtainwall system, which produces an open cavity in the summer and a closed cavity in the winter to enhance energy performance.

A case study building located in a cold climate region was investigated and a whole building energy simulation was run. The result of the analysis revealed that the adaptive façade system substantially decreased heating loads compared to a baseline façade system. The adaptive façade system discussed in this paper works better in a cold climate than a hot climate zone, and therefore, additional study will be carried out to develop other adaptable façade systems that are suitable for hot and temperate climate regions. Further, the adaptive facade system will be experimentally tested to verify the simulated energy performance data against empirical data.

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