Comparative Performance Evaluation of a Multi-story Double Skin Façade Building in Humid Continental Climate

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ABSTRACT: This paper focuses on investigation of a multi-story double skin façade system in the humid continental climate of Michigan. The double-skin façade is an architectural phenomenon driven by the aesthetic desire for an all-glass façade which aslo reduce building energy consumption. In this paper building envelope performance is investigated by modeling energy performance of different design scenarios of a commercial building with double skin façade and compare it with the actual energy consumption. The primary goal of this research is to clarify the state-of-the-art performance of DSFs in hot continental climate, so that designers can assess the value of these building concepts in meeting the design goals for thermal comfort, ventilation, energy efficiency and sustainability. This investigation adopts an analytical approach using dynamic simulation software (Energy Plus/Designbuilder), to understand the performance of single skin façade in comparison with a double skin façade. The results proved that the multi-story façade in humid continental climate had a major impact on enhancing performance and as a result, a reduction in energy usage.

KEYWORDS: multi-story double skin façade, energy performance, building envelope,

INTRODUCTION

The building facade plays an important role in achieving energy conservation. Due to technological advances, transparency and the use of glass has become an attractive envelope option in architectural design. Designing buildings with all glass facades provide external views and potential for an excellent level of natural light as well and natural ventilation.

However, with the use of glass, heat loss during the winter and solar gain during the summer will increase energy loads. In central Europe, which has moderate-to-cold climates, new concepts were tested that used outdoor conditions in creating climatic-responsive buildings (Givoni, 1998; Szokolay, 1980; Wigginton, 1996). Advanced facade technologies were developed for the high-end office building sector, in particular (Wigginton, 2002), and designers tried to integrate more building services into the facade system.

Transparency and the use of glass has also become an attractive envelope option primarily in buildings. The challenge is to improve building performance while providing a more comfortable and healthier place for users. Fortunately, there are numerous methods and techniques that can be employed to achieve these goals.

The concept of DSF is not new and dates back to many years ago where in central Europe; many houses utilized box-type windows to increase thermal insulation (Oesterle, 2000). Many authors claim that the double skin façade system can improve energy performance of the building due to the greater insulation provided by the outer skin. Design strategies need to consider the climatic conditions and local characteristics such as temperature, solar radiation, wind velocity and temperature in order to results in energy consumption reduction. The potential of using a double façade of the building in climates other than Europe has not been fully studied though. A number of interesting investigations and findings are reported in the literature pertaining to passive ventilation in buildings with double skin facades.

New enclosures that can substantially reduce energy usage by allowing natural ventilation is a promising development. Aesthetics aside, a double-skin facade (DSF) is believed to reduce cooling loads, allow for more or better natural ventilation, and provide natural ventilation in high-rise buildings. The aim of this study is to propose an effective way to reduce energy consumption in a building during cold and hot seasons in humid continental climate-of Michigan. Therefore, it will focus on how DSF works in such climates. The primary goal of this study is to clarify the state-of-the-art performance of DSFs, so that designers can assess the value of these building concepts in meeting design goals for energy efficiency, ventilation, productivity, and sustainability.

1.0 METHODOLOGY

One major goal of this study is to do a Building Performance Verification to compare the simulation result with the actual building energy consumption data provided in the unversity of Michigan webstie; and in doing that also checking the simulation tool capabilities. As suggested by Ternoey et al. (1985), the easiest way to evaluate energy improvements in building design is to appraise energy use patterns with a base case. For this purpose, the building has been simulated with single skin as a base case.

Then a parametric study was carried out focusing on energy use. The base-case scenario with double low-E pane windows was simulated to calculate the energy demand during the occupation stage. Then the same building with the DSF was simulated. Moreover, parameters such as different types of glazing, and cavity depth were varied to study the impact of energy use. This study is divided into three main parts:

- Development and simulation of the reference single-skin building
- Simulations of the DSF in terms of energy performance
- Simulation and analysis of the alternatives.

1.1. Base Case- model description

The five-story, 593,727 square foot, Biomedical laboratory of University of Michigan Ann Arbor integrates sustainable design features with innovative mechanical systems to reduce the building's energy consumption. Although the initial construction cost for the double skin façade buildings are higher than conventional, energy efficiency measures allow for lower operating costs and a greater long-term rate of return.

Nestled in the University of Michigan main campus in Ann Arbor, the Biomedical laboratory have 2 laboratory Blocks, Office ribbon towards south double-skin facade, Separated from the laboratory spaces by the Atrium, 300-seat Auditorium, and Vivarium.

Figure 1. Double Skin Façade Biomedical laboratory (image: Mona Azarbayjani)

The specifications of the project are:

-Double glass façade for full length of office ribbon. This passive façade includes a three ft wide space that provides a seasonal heating and cooling benefit to the building. During winter, dampers at the top of the double wall are closed. Heat from sunlight hitting the double wall is captured within this void, effectively reducing the heat load on the south face of the building. During summer, dampers at the top of the double wall are opened. Heat from sunlight hitting the double wall is flushed out via the stack effect, effectively reducing the cooling load on the south face of the building. And while the double glass façade is a cost-effective environmental design feature, it also produces a striking visual statement about the use of technology in a highly technical building.

-Multi-story thermal flux: the greater height improves natural convection and makes the heat capture and exhaust more efficient.

-Exhaust air energy recovery,
-Use of specialized fan-coils in linear equipment corridors where equipment that generates a great deal of heat is located,

-Use of special sensors that automatically increase the volume of supply air when higher-than-desired levels of carbon dioxide are measured in returned air (non-lab areas only, since all lab air is exhausted

-Extensive use of sensors and remotely-monitored control systems

Some of the building features are as follows:

- A Unique High-Performance Facade:

• The double-skin facade (two surfaces of glass, creating an insulated airspace) is a multi-story (full height), full depth (3'), thermal flue. The facade allows for complete transparency while ensuring protection from excessive heat gain, heat loss, and glare:

- Natural Light:

• The facade brings a significant amount of balanced natural light into the library, carefully controlled by fixed and movable sunshades.

- Natural Ventilation:

• Operable windows in the facade allow for fresh air throughout the year (even in winter). In the winter, spring and fall, the windows allow heat from the cavity to be brought into the building. During the summer month the cavity is ventilated to the outside as a external air curtain.

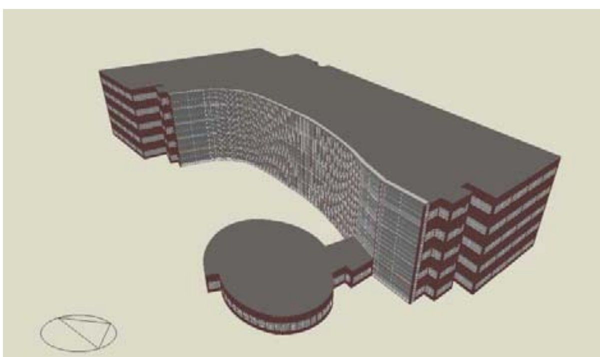
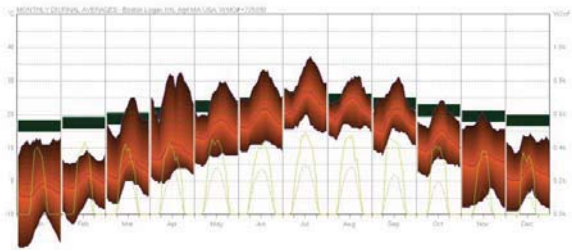
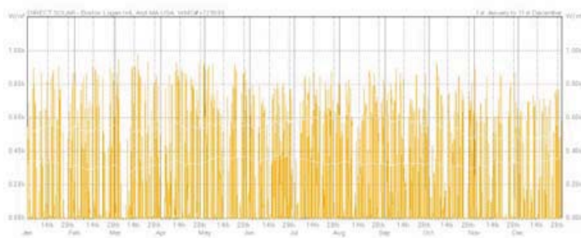


Figure 2. Model of the double skin façade building created in DesignBuilder

After obtaining basic building and weather data, a simulation of the building's energy performance was undertaken. This was the base case simulation for a single skin facade system. The simulation software used for this research was Design Builder with EnergyPlus as an engine.
Since the behavior of double skin facades is highly dependent on the type of climate, following sections outline a process for selecting the type, analyzing characteristics and properties and selecting strategies preferable for a specific context.

Components of the studied double skin included internal layer, composed of 6 mm clear glass pane, 20 mm argon filled gap and 6 mm internal low-e glass and aluminum frame with thermal breaks. External layer consisted of 6 mm clear glass. Components of the single skin were similar, with double glazing composed of 6 mm external clear glass, 20 mm argon filled gap, internal 6 mm low-e glass and aluminum thermal brake frame. Both cases included shading blinds, where in the case of double skin they were placed in the cavity, and for double glazing on the interior of the building.





The building will not only conserve significant amounts of energy, but it will also create a highly conducive environment for study and research while ushering in a new era of campus architecture focused on resource conservation.

Figure 3. Climate analysis, average temperature and solar insolation

The Michigan, Ann Arbor climate is classified as a humid continental climate (Koppen Dfb with areas of Dfa). Summers are typically warm, rainy, and humid, while winters are cold, windy, and snowy. Spring and fall are usually mild, but conditions are widely varied, depending on wind direction and jet stream positioning. The hottest month is July, with a mean temperature of 73.9 °F (23.3 °C). The coldest month is January, with a mean of 29.3 °F (−1.5 °C). The city averages 42.5 inches (1,080 mm) of precipitation a year, with 41.8 inches (106 cm) of snowfall a year. Most snowfall occurs from December through March. There is usually little or no snow in April and November, and snow is rare in May and October. Prevailing wind directions throughout the year are South-West and North-West.

1.2. Zoning

The plan was divided into multiple zones according to geometry, proximity, and use. Each zone was then assigned an activity template (indicated by color in images) which associate that zone with different energy profiles and schedules. As shown in figure 4, the zoning and schedules are often repeated floor to floor. The atrium is treated as one single zone inside DesignBuilder, with openings in the floor and ceiling of the corresponding floors connecting them. The building has 3 floors and a basement, and the zones are divided by the use of each one. We have 8 different zones, hall/lecture/assembly area, circulation area, display and public area, generic office area, reception, toilet, workshop-small scale, light plant room.

1.3. Model parameters and inputs for DSF

Please note the R-Value unit is h·ft²·°F/Btu and the U-value unit is BTU/(h °F ft²)

Equipment Gain: Open Labs = 10 W/sqft
[Diagonestic Imaging]
- Typical Alcoves = 20 W/sqft
- Tissue Culture Alcoves (65 total) = 30 W/sqft
- Entrance Alcoves = 10 W/sqft
- Procedure Rooms = 20 W/sqft

Linear Equipment Corridor = 30 W/sqft [zone 12, 19]
Office areas: 6 W/sqft
Lighting Energy: 0.050 W/sf/foot-candle
Display and Task Lighting: 2 W/sf

Widow area: 100% on the South facade, 30% over all

Glazing Type:
Exterior: Double Clear 3mm/6mm Air [U-Value: 0.568]
Interior: Double Clear 6mm/13mm Arg [U-Value: 0.449]

Construction Template: Medium Weight

External Walls: R-16
Roof: R-22
Ground Floor: R-16
Infiltration: 0.5 ac/h

HVAC Template:
VAV with fan-assisted terminal reheat, Ventilation: 6 ac/h
Heating CoP: 0.60
Cooling CoP: 1.30
Fuel: Electricity for Heating and Cooling

The default schedules for the laboratory activity templates were based on a 9 hr/day, 6 days/week operational schedule. Outside this time plug, lighting, heating, cooling and DHW loads would shut off.
However, being a collegiate facility, the Center maintains significantly longer hours. For this model the schedule was simplified to 14hr/day (8 am – 10 p.m.) 7 days/weeks. While this schedule does not reflect daily variation in office hours, it averages to the same number of operational hours per week. Modified schedules were implemented for public spaces, office spaces, and assembly spaces.

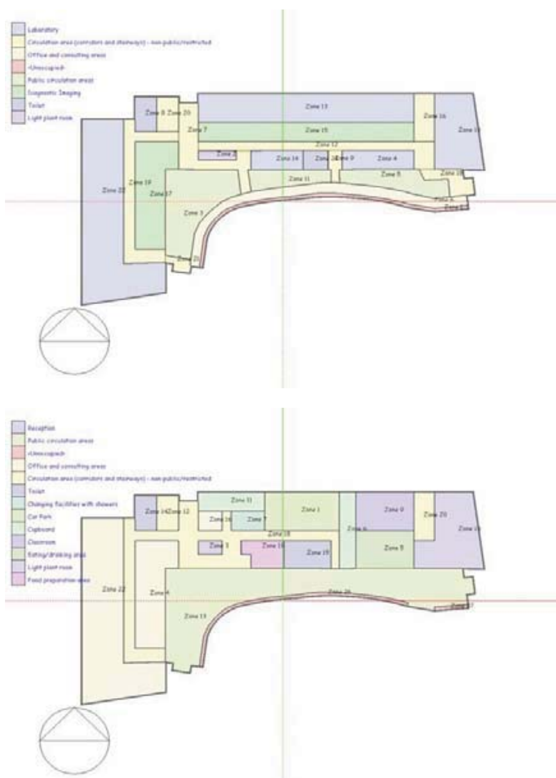


Figure 4. Zoning, model created in DesignBuilder

The hourly energy simulation shows the daily variation in system loads since insolation, air temperature and internal gains vary throughout the day. The cavity has been considered as a separate zone and it can be seen that the building systems are performing reasonably. The cavity, which is not heated or cooled, shows large temperature swings, high solar gains (up to ~1,500Kbtu/ hr) and high natural ventilation rates (up to 70 ac/hr) when the temperature rises above the set point. The interior zones, which are heated and cooled, have more stable temperature profiles, lower solar gains (~300 Kbtu/hr) and moderate ventilation rates (~ 2ac/hr). It can also be seen that internal gains follow the 8:00am – 10:00pm occupation schedule.

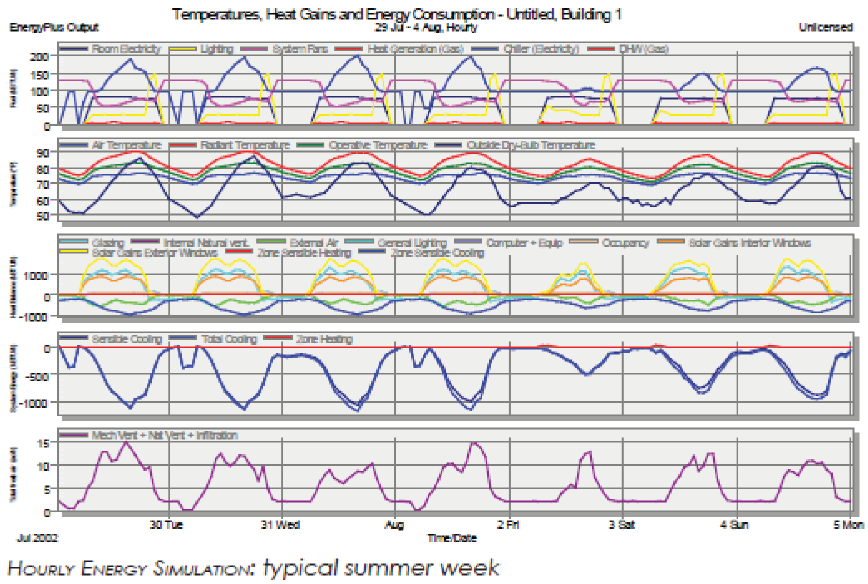


Figure 5. Hourly data on a typical summer week

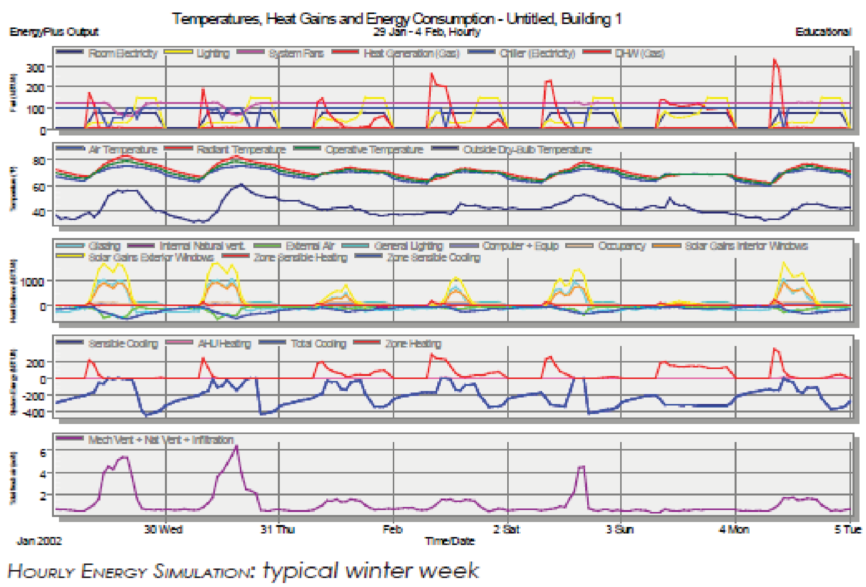


Figure 6. Hourly simulate data on a typical winter week

1.4. Results: Building performance and its consumption

Monthly energy results average the daily variation and shows how energy loads respond to season variations. It can be seen that lighting loads are reduced during the summer, as the days are longer and day lighting can meet a larger portion of the lighting need. There is also a reduced fan load during the summer month. However these savings are offset by a roughly 40% increase in cooling loads during the summer months and total electric load remain fairly constant throughout the year.

Figure 7. Double skin façade energy simulation results (Left side) Single skin façade energy simulation results (Right side)

The benefit of the double façade becomes apparent comparing heating loads.
The annual energy consumption of the double skin has been compared with single skin as illustrated above. It was discovered that in total double skin façade consumes 5 percent less energy than single skin façade.

One major goal of this study is to do a Building Performance Verification to compare the simulation result with the actual building energy consumption data. As illustrated below the modeled energy consumption and actual energy performance are within 10 percent range which is pretty accurate.

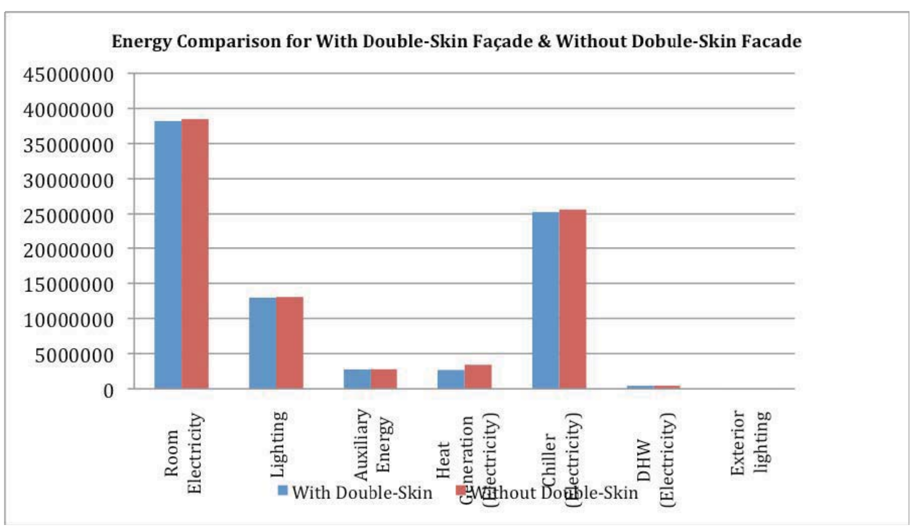


Figure 9. Total energy consumption comparison

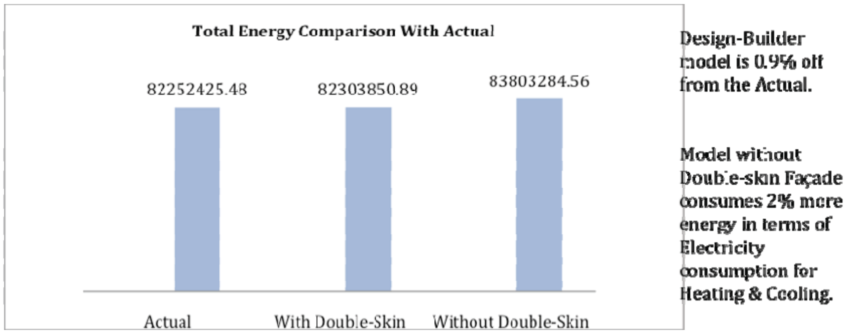


Figure 10. Annual energy breakdown comparisons [KBtus]

As illustrated in figure 10, Energy consumption can be reduced by about 5.4 percent after implementing double skin façade system.

CONCLUSION

In general, energy consumption in buildings is determined by function, climate, building components, construction, control, and settings. The climate and the ambiance are considered as-boundary conditions in energy simulation. Building function also has an important impact on energy use. Building components and construction both provide great potential for improvement of energy demand in such areas as adequate thermal insulation, a key component of energy consumption. A careful choice of windows and shading devices should help to avoid additional solar gains. Incorporating efficient HVAC equipment and heat recovery techniques may also reduce the energy use. Designing a high-performance facade system will make a tremendous impact in minimizing energy consumption and optimizing the thermal condition.

One major goal of this study is to do a Building Performance Verification to compare the simulation result with the actual building energy consumption data. Second, is to change building envelope properties in the simulation tool with keeping all the other input parameters as it is and check the effect of that for control of microclimates within this type of environment. These strategies include preferential glazing to admit or block insulation, appropriate location and orientation of spaces to introduce air currents within inhabited spaces, employment of passive strategies (ducts, wind towers and shafts) to promote circulation as well as heat extraction.

Energy savings are not so much but other aspects can justify the recourse to the double skin facade other than energy efficiency and that is thermal comfort in all glass façade building which is not in the scope of this paper.

For this climate, the main advantage is improved thermal insulation. During the winter months, exterior skin increases external heat transfer resistance, therefore utilizing interior air for preheating air cavity is advantageous. During the summer, air must be extracted in order not to cause overheating, by natural, hybrid or mechanical modes.

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