Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Energy Performance Evaluation of Double Skin Facades for Office Buildings in Warm Temperate Climates

Archana Bajracharya [a], Sanjaya Uprety [b]

[a, b] *Department of Architecture and Urban Planning, Pulchowk Campus, IOE, TU, Nepal*
Corresponding Email: [a] baj.archana@gmail.com, [b] suprety@ioe.edu.np

Abstract

The contemporary architectural and corporate trends seem to have embraced glazed glass facades as ultimate design elements. In the present scenario, energy concerns are growing in order to reduce the Green House Gas emissions and designers as well as developers are urged to build energy efficient structures. The main energy consuming activities in an office building are lighting, operation of equipment, heating and cooling. The building façade is responsible for effecting lighting, heating and cooling loads. Double Skin Façade (DSF), usually constructed in European countries is taken as energy efficient. This research has been carried out for testing the suitability of DSF in Kathmandu. An instance of office building is selected and surveyed for thermal, lighting and acoustic comfort near the glazed façade. As the result, the comfort level was found to be unsatisfactory in terms of thermal comfort. Hence DSF system was introduced in the building on the street side and checked for improvements regarding thermal comfort through energy modeling and simulation. Energy Plus along with Open Studio application and Open Studio plug-in for Sketchup were used. Through rigorous simulations with varied parameters, it was found that south oriented DSF façade, with optimized parameters and configurations performed better than similar north oriented DSF façade in terms of thermal energy consumption. It was concluded that a naturally ventilated DSF cavity of 900 mm with double glazing in the inner skin, single glazing in the outer skin and horizontal blinds within the cavity with specific configurations can save heating and cooling loads by 10%.

Keywords

Double skin facade, Glazed facade, Heating load, Cooling load, Office building

1. Introduction

There has been increasing global interest in reducing energy consumption by building sector. The building as a system along with its embodied energy, can contribute to carbon emission in operational phase. To take control on these attributes of the buildings, the building typologies and their characteristic architectural features need to be explored for better energy performance. Among passive design strategies for control of natural ventilation, daylighting and solar heat gain into the transparent and glass fabric of a building, Double Skin Façade (DSF) is a popular concept. It is acclaimed as an environmentally responsible design strategy with major predicted savings in energy and life cycle costs. The double-skin façade essentially refers to a pair of glass skins separated by an air-corridor. The air space between the two skins acts as insulation against temperature extremes, wind and sound and may also have shading devices, which may be controlled [1]. In the present scenario, established organizations, companies and corporate businesses follow a trend showcasing their presence and standing in the market through glazed building façade. While the building owner has an ambitious façade as his priority, it is the designers' responsibility to take into account the effects of local weather, energy consumption and indoor comfort along with symbolism of concepts and innovation in the design process. As the façade of the building can considerably affect the heating and cooling needs in the indoor spaces, maintenance work load, day lighting requirements and other factors, energy performance of the façade element should be studied and it is envisaged that passive strategies like double skin system can ultimately benefit the owner in monetary terms.

Since the highly appreciated double skin façade system has not come to practice in most of Asian cities, the energy performance evaluation of the system for office buildings in a particular climatic context shall be a great aid to the architects and designers. The research was done with and objective to evaluate the energy performance of a typical single skin glazed building façade system, compare the energy performances of the single skin glazed façade and double skin glazed façade with its variable parameters for a typical office in warm temperate climate and conclude with inferences on suitability of use of DSF in warm temperate climatic condition.

2. Literature Review

2.1 Emergence of Double Skin Facades

The first instance of a Double Skin Curtain Wall appeared in 1903 in the Steiff Factory in Giengen, Germany [2]. Later instances are communal housing blocks of Narkomfin building (1928) by Moisei and Centrosoyus in Moscow by Le Corbusier in the concept of 'respiration exacte' with a double skin glazed façade. Figure 1 shows the Centrosoyus building in Moscow. He also designed Cite de Refuge (1929) and the Immeuble Clarte (1930) in Paris with the same concepts for the facades.

After the 90s the implementation of double skin facades was influenced by increasing environmental concerns both from a technical standpoint and political influence that made "green building" a good image for corporate architecture.

Figure 1: Centrosoyuz at Moscow, Russia[2]

2.2 Double Skin Facades (DSF)

Double Skin Facade is an assembly of a pair of glass skins separated by an air corridor, cavity or intermediate space ranging in width from 20 cm to several meters[3]. Figure 2 shows a cavity of Double skin facade. The glass skins may stretch over an entire structure or a portion of it depending on the type of DSF. The main layer of glass, usually insulating, serves as part of a conventional structural wall or a curtain wall, while the additional layer, usually single glazing, and is placed either in front of or behind the main glazing. The layers make the air space between them work to the building's advantage primarily as insulation against temperature extremes and sound and as an air corridor for ventilation. Solar control devices might be placed in the cavity between these two skins. DSF also protects from air pollution, a factor of particular importance in office buildings situated in the vicinity of busy roads.

Figure 2: View of cavity space of Double Skin Facade of Intesa St. Paulo building, Italy[4]

Design parameters of DSF are the aspects which affect the quality, design and performance of DSF. They can be briefly listed as follows:

1. Design and type of the façade
2. Structural design of the façade
3. Geometry of the cavity
4. Type of cavity ventilation
5. Type of glazing, shading and lighting devices
6. Material choice for panes and shading
7. Positioning of shading devices

There are four types of DSF according to the type of geometry [3] as shown in figure 3.

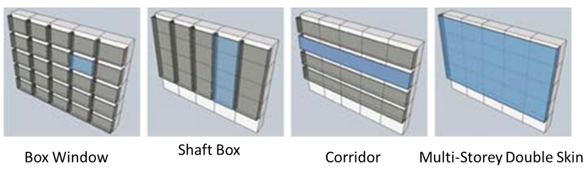

Figure 3: Types of DSF[5]

Box window type double-skin façades are room wise ventilated façades with horizontal and vertical partitions on each window. A shaft box type façade consists of a double skin façade with building-high cavities whose widths are restricted to the width of window. The full-height cavity forms a central vertical shaft for exhaust air. The corridor type double-skin façades consists of air channels separated horizontally at each intermediate floor. Multi storey double-skin façade is the one with the cavity not separated at each storey but extending over the whole height of the building. In this kind of DSF, the air that accumulates at the top of the air space between the two layers is likely to get hot on sunny days. The warm air siphons out through openings in the outer skin at the roof edge while cooler replacement air is drawn from near the base of the building.

DSF enhances energy savings and reduces environmental impacts as it provides low solar factor and smaller U value than single skin walls, reducing the heating or cooling requirements of the perimeter spaces within the building [6]. The higher temperatures inside the cavity during heating periods lead to increased temperatures close to the windows, and as a result improved thermal comfort for the occupants. When air movement is enabled within the façade system, the use of mechanical ventilation can be reduced or eliminated. As the solar radiation is being absorbed by the shading devices the temperature inside the cavity is likely to be increased. Due to the stack effect approximately 25% of this heat can be removed by natural air circulation.

2.3 Past research on DSF

In a study of DSF in moderate and humid climate of Phnom Penh, Cambodia, it was found that the optimum parameters of DSF were 500 mm cavity depth, bronze laminated glass for the internal, and external layers of DSF, and external blind louvre. The combination of all optimum parameters could potentially reduce about 34% of the annual energy demand [7].In another study carried out the following year by [5], two driving forces-wind and stack effect (buoyancy forces) were investigated to study the possibility of providing comfort in the building. Mainly ventilation strategies were focused by taking the advantage of wind patterns, buoyancy and stack effect. The results showed that DSF provides internal comfort by natural ventilation strategy. Same result was found by [8]. [9] examined the effect of DSF on energy consumption, thermal comfort and condensation for a typical office building in Singapore. DSF with a purely stack effect was found good enough to extract solar heat gain inside the cavity, however, adding ventilation did not result in greater energy savings due to maintenance costs. [10] studied the performance of DSF in moderate and humid climate of Rasht, Iran and concluded that DSF-shaft box type with 75 cm cavity width is more suitable for the climate. Although double-skin façades have already been implemented in several locations, however, the benefits and performance of ventilating façades are still widely debated. The most important outcome of the various researches is that the façades must be customized for each individual case and climate to maximize efficiency [11]. In a recent study for hot climate of Riyadh, Saudi Arabia, simulation analysis clearly rejected any hypothesis that DSF can be useful in hot arid climates as there was a minimal 2-5% reduction in baseline energy usage [12]. Hence it has been a subject of research to explore the performance of DSF in any specific context.

3. Methodology

The research was carried out first through a survey of comfort among the employees in the selected office building having a single skin glazed façade. The quantitative data collected through structured questionnaire provided the results to evaluate energy performance of the building. The envelope composition, occupancy, and equipment of use, working hours, orientation and data essential for energy modeling were collected during field visit. These data were used to build the Base Case energy model. DSF models were created in multiple scenarios adding DSF cavity to Base Case model, with various parameters in order to compare single skin glazed façade and double skin glazed façade. Climatic data for the selected locality was collected and analyzed, which is very essential for energy modeling. The simulation results were analysed and discussed to conclude with inferences on use of DSF in warm temperate climatic condition.

3.1 Selection of the building

The context of research is taken as Kathmandu city. The couple of criteria for selection of the building for analysis were created so that a larger number of buildings can benefit from the outcome of this research. The first criterion was that the chosen instance of office building needed to represent the façade systems of a majority of office buildings being constructed, used and likely to be constructed. Most of the office buildings in Kathmandu fall under the category of glazed façade designed and built with regardless of energy performance. The next criterion was that the building should contain office spaces next to the glazed façade and the office needed to have operated for at least a whole year.

3.2 Climatic data

The climate of Kathmandu is warm temperate characterized by warm days. Winter ranges from November to February. Rest of the months is warm.The analysis of weather data of ten years from 2007 to 2016, recorded by the Department of Hydrology and Meteorology Nepal showed that the lowest monthly mean minimum temperature reaches up to 3.17°C. During summer the highest maximum temperature reaches up to 30.24°C. The humidity ranges from 95.16% in the morning to 52.04 % during the day. Monsoon rain is observed during July. The prevailing wind direction in the Kathmandu valley is westerly ranging from 0.95 m/s to 13.4 m/s.

3.3 Building Specification

The seven storied CE Construction building at Tripureshwor, Kathmandu was selected. The selected building is shown in figure 4.

Figure 4: Selected Building

The lowest storey is semi basement. A typical floor size is 20 metres long and 14 metres wide with the floor height of 3 meters. The front road side façade of the building is north oriented with 80% of glazed area. The glazed façade is of 6 mm thick bronze tinted glass in aluminum framing. All other sides have 230 mm thick brick masonry envelope. East and west faces do not have fenestrations while the south face has 26% window wall ratio. CE Construction building is occupied from ground to fifth floors as open office space running nine hours a day and six days a week. The total electrical energy consumed from April 2018 to March 2019 is 1, 65,000 KWhr. This covers the energy used for lighting, office equipment, operation of electrical heaters, fans, split AC units and other electrical appliances and machinery.

4. Energy Modeling

Energy model and simulation of the selected building was carried out using EnergyPlus™, a widely used whole building energy simulation program useful to model both energy consumption for heating, cooling, ventilation, lighting and plug and process loads and water use in buildings. The OpenStudio SketchUp Plug-in was used to create geometry and the OpenStudio Application, a graphical interface was used to assign envelope, loads, schedules, and HVAC. The CE construction building was simulated with some simplification in model. For clarity in understanding of results regarding the effect of DSF, semi basement and top floors were not included in the model. The base case model prepared in openstudio is shown in figure 5.

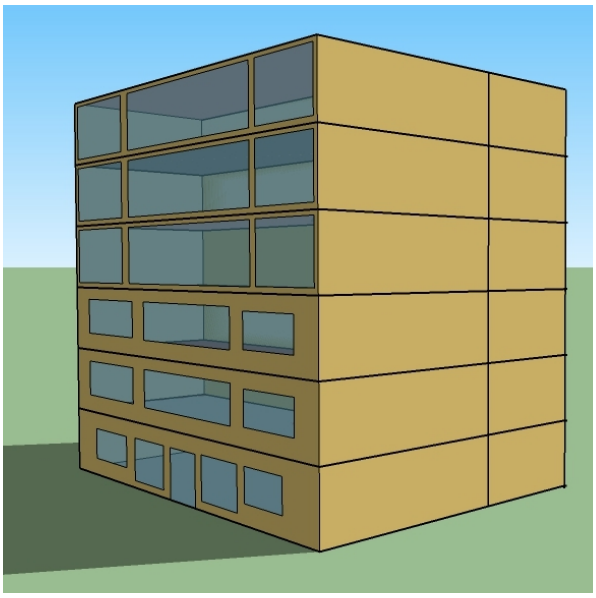

Figure 5: Base case Model prepared in openstudio

The existing building components, parameters and properties were used for Base Case model. In addition to these, essential component for DSF, which is double glazing in the inner skin [6], was integrated in the Base Case Model. Other scenarios were created for use of DSF. Several researches [7], [5], [13] concluded that among various types of DSF, multistorey type is the most beneficial for energy saving. Hence a multistorey type DSF was added to the glazed street side on all floors except the ground. DSF model having cavity width of 900 mm is shown in figure 6.

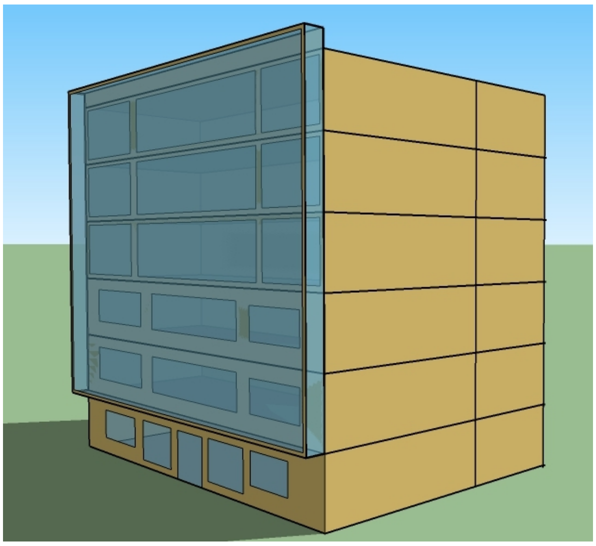

Figure 6: DSF Model prepared in openstudio

Applying different variables to DSF components, in base cases of two orientations, there were altogether 11 scenarios. They are summarized as follows:

Table 1: Simulation Scenario Parameters

Components	Variables
DSF oriented to North: Ventilation type Cavity width	 sealed cavity/ Naturally ventilated 300mm,600mm,900mm, 1200mm
DSF oriented to South: Sun shading device Blind position Slat tilt angle	 With/without internal blinds 300 mm and 700 mm from outer glass 45 degree and 90 degree

5. Findings and Discussion

5.1 Comfort and Satisfaction Survey

The warm temperate climate of Kathmandu has maximum daytime temperature ranges mostly around the comfort range (16°C-20°C) during winter but exceeds the comfort range (20°C-24°C) during summer. Hence summer is meant to be more uncomfortable than winter, which was verified by comfort and satisfaction survey carried out among 32 employees working in the CE Construction Building. The results showed that more than two-third of the occupants do not use heating appliances during winter, which lasts merely four months (Nov-Feb). During summer, use of fans and AC is consistent. Also the tinted glazed facade has reduced daylight penetration, increasing the use of artificial lighting.

5.2 Base Case Model

Simulations of base cases were done for north and south oriented buildings. Total heating and cooling loads for each month for north and south oriented buildings are depicted in figure 7 and figure 8. Results showed that cooling load contributed to 90% of total thermal loads. Thus only reduction in cooling load can reduce thermal loads.

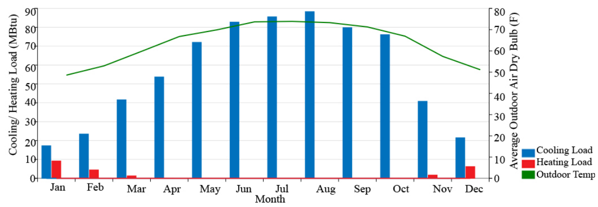

Figure 7: Thermal loading results of north oriented Base case Model

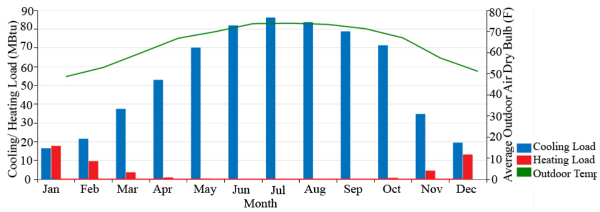

Figure 8: Thermal loading results of south oriented Base case Model

5.3 DSF Model

For reducing cooling loads, multistory DSF with 300mm wide cavity was simulated in sealed (N300 Seal) and naturally ventilated (N300 NatV) scenarios for building oriented to north. 6mm single glazed bronze tinted glass was used for DSF skin. Both strategies reduced total energy consumption. The latter scenario performed better than former by 1.15% as shown in figure 9.

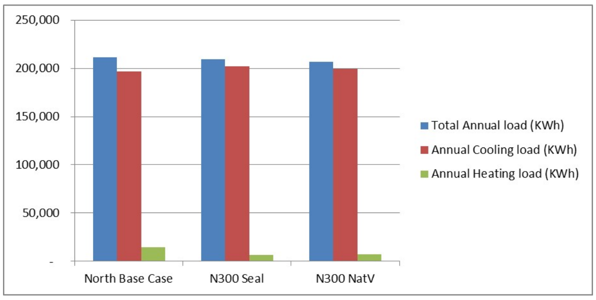

Figure 9: Thermal loading results of DSF model with sealed/ naturally ventilated cavity

Thus natural ventilation was adopted to test cavity widths of 600mm, 900mm and 1200mm. The results of simulation in figure 10 showed 50% reduction in heating load but around 1.5% increase in cooling, with minimal (2-2.5%) reduction of total energy consumption along with increase in cavity width. A multistory DSF cavity acts as the buffer and increases the temperature of window's outer surface. Thus the heating load is drastically reduced benefiting winter conditions. But the cooling effect of natural ventilation did not work as use the north face of the building does not receive direct solar radiation and the wind velocity is not consistent.

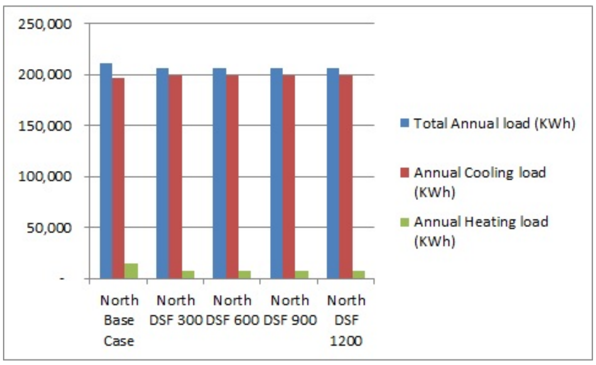

Figure 10: Thermal loading results of DSF model with north orientation

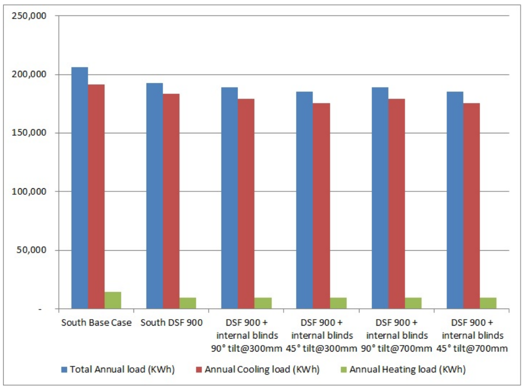

Figure 11: Thermal loading results of DSF model with south orientation

As use of DSF in north oriented facade showed much benefit in winter but drawbacks in summer, scenarios were created to test for the performance of DSF in south oriented façade. Among the cavity widths tested in north case, 900mm was the most effective and reasonable. 1200 mm had negligible benefits over 900mm cavity width. Thus for south case, 900mm cavity width was adopted with natural ventilation. This configuration reduced energy consumption up to 6.36%. In the next scenarios, internal blinds were added within the cavity for shading control at distances of 300mm and 700mm from external skin, each at slat tilt of 90° and 45°. 700mm scenario with slat tilt of 45º ranked higher in energy saving. This last configuration yielded 8.36% reduction in cooling load and 33% reduction in heating load resulting to an overall reduction of 10.1%. The simulation shows an annual energy saving of 20,807 KWh. The summary of the results is shown in figure 11. Thus in the south oriented cases it was found that the cooling load is decreased and naturally ventilated DSF is more effective with wider cavity width. Shading device at 45º tilt further decreases the surface temperature of façade by reflection of solar radiation.

6. Conclusion

The research conducted for evaluation of a multistorey type DSF in The warm temperate climate of Kathmandu yielded some results that enabled some conclusions to immerse. A typical single skin glazed façade contributes unsatisfactorily to the comfort of occupants. Summer is more uncomfortable than winter, increasing the cooling energy load. The tint essential for glare and privacy control in turn increases the use of indoor lighting in most of the daytime. To maintain comfort conditions in the workspace near a single skin conventional glazed facade, heating and cooling loads should contribute to around 60% of total energy consumption. Cooling load is around 85% of total thermal load and hence more interventions in design of façade should enhance cooling performance of the building.

The use of double glazing in the inner façade, appropriate cavity size and shading control are inevitable to reap the benefits of DSF. When compared to single skin double glazed façade in warm temperate climate, a 6mm glazed naturally ventilated multistorey type DSF used on the south face with internal blinds building a reduction of energy consumption can be achieved by around 10%. But the same does not hold true for all orientations. Addition of multistorey DSF in north façade brings negligible energy saving and thus is not recommended.

In warm temperate climate, a naturally ventilated DSF cannot be a building envelope solution to enhance the indoor thermal comfort in all orientations. DSF is immensely beneficial to reduce heating load but in a warm climate, natural ventilation in DSF works only in specific orientations. This research finds that naturally ventilated multistorey DSF can be adopted for south oriented facades with benefits in summer. The essential components of DSF that need to be applied for better energy performance in the south façade are use of double glazing in the inner skin, minimum cavity width of 900mm, and use of internal blind shading within the cavity with 45º tilt of slats. Around 10% saving in thermal energy consumption can be achieved with this configuration.

Further research can be done to evaluate the effectiveness of DSF in the context of warm temperate climate. The energy performance can be further evaluated for east and west orientations, use of mechanically ventilated cavity and alteration of many more DSF components.

References

[1] Meyer T Boake and K Harrison. The tectonics of the environmental skin. 2003.

[2] A.M.L. Crespo. *History of the Double Skin Façades*.

[3] S Uuttu. *Study of Current Structures in Double-Skin Facades.MSc thesis in Structural Engineering and Building Physics*. Addison-Wesley Professional, 2001.

[4] Scanferla Marco. *Energy efficient glazed office building envelope solutions for different European climates*. 2017.

[5] Mona Azarbayjani. Climatic based consideration of double skin facade system: Natural ventilation performance of a case study with doubleskin façade in mediterranean climate. 2013.

[6] Harris Poirazis. *Double skin facades for office buildings; a literature review*. 2004.

[7] Yonghuort Lim and Mohd Rodzi Ismail. Efficacy of double skin façade on energy consumption in office buildings in phnom penh city. 2012.

[8] Hali Zafer Alibaba and Mesut B Ozdeniz. Energy performance and thermal comfort of double-skin and single-skin facades in warm-climate offices. 2016.

[9] N. W. Hien. Effects of double glazed façade on energy consumption, thermal comfort and condensation for a typical office building in singapore. 2005.

[10] N Rezazadeha and H Medib. Thermal behavior of double skin facade in terms of energy consumption in the climate of north of iran-rasht. 2017.

[11] Kate M. DuMez. *Analysis of Energy Efficient Curtain Wall Design*. 2017.

[12] Naif Altahlawi. *Integrated Thermal and Daylight Performance Comparison of Single and Double Glass Skin Façade for Hot Climate Conditions*. 2019.

[13] Sabrina Barbosa. Double skin facades for naturally ventilated office buildings in brazil. 2014.