Climate Adaptive Kinetic Façade Design: Optimization of Daylighting and Energy Efficiency towards the Net Zero Energy Building

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Abstract

Energy consumption in buildings is increasing rapidly due to solar heat gain and glare. Again, buildings are affected by different climatic and natural factors which are dynamic in nature and change with time. Therefore, there is a need for buildings to adapt to changing weather conditions while retaining adequate daylighting and energy efficiency. Research showed that compared to static facades, climate adaptive kinetic facades offer potential opportunities for adequate daylighting and energy efficiency by adapting to changing outdoor conditions. Most of the research in this field has been conducted for temperate and seasonal climates where little information is available on the application of climate adaptive kinetic facades for tropical climates. Only a few research attempted simultaneous analysis of adequate daylighting and energy savings by reducing direct solar heat gain. Moreover, less attention is provided in the context of Dhaka city where office buildings face more energy demands due to glass facades, excessive heat gain and use of air conditioners. So, the study aims to find out the optimized configurations of climate adaptive kinetic facades of office buildings by the optimization of daylighting and energy performance towards the path to net zero energy building in the context of Dhaka. Literature review and case study analysis are conducted to explore the effects of this façade system. Field survey and data collection are conducted to select a case office building in Dhaka. Further 3D modeling and several simulation analysis are conducted to find out the optimized angle and depth result for twelve months of a year. The result of multi-objective optimization showed that these facades have a significant positive impact on daylighting and energy performance particularly on the south façade in Dhaka. The result showed 12 different depths and angles throughout the year where the angle varied from 1^{o} to 29^{o} and depth varied from 0.83 meter to 1.00 meter. The study has the potential to be useful for future façade designs for office buildings in tropical cities particularly in Dhaka city using climate adaptive kinetic facades.

Keywords: Kinetic Facades, Heat Gain, Daylighting, Energy Efficiency, Office Buildings

1. Introduction

The energy consumption in buildings accounts for approximately one-third of the total energy demand in the world and is expected to grow by 2.1 % per year by 2040 (Bui et al., 2020; Dhavalep & Mhetras, 2022; Mahmoud et al., 2022). Among diverse types of buildings, office buildings have the maximum energy concerns due to the use of glass facades, air conditioners and solar heat gain and glare. So, energy efficiency measures for office buildings are urgently required (Aun, 2009; Al-Masrani et al., 2018).

Moreover, the weather pattern is shifting continuously and pronounced seasonal variations are noticed. Again, daylighting and energy requirements are changing with the comfort needs of the occupants which is an ever-changing factor. So it can be argued that static passive building designs are not always effective for daylighting, energy efficiency and occupants' comfort in a consistent manner (Rodriguez & D'Alessandro, 2014; Ahmad & Alibaba, 2019). Rather passive strategies and active technologies need to be integrated to reduce energy consumption and ensure adequate daylighting of office buildings. (Hosseini et al., 2019; Navarro et al., 2020; Dhavalep & Mhetras, 2022).

1.1 Problem Statement

Building facades are affected by different climatic factors including solar radiation, wind, etc. which are dynamic in nature. Again, for the high temperature and humidity, the use of glass façades traps the heat and increases the energy demand for cooling in tropical cities (Tabadkani et al., 2020). In Bangladesh, the increased use of glass facades results in creating air-conditioned office spaces with artificial lighting for ensuring occupants' comfort (Bari, 2020). Which in turn results in maximum energy usage and increasing energy demand. And all these induce the energy crisis in the country and create frequent power disruptions in Dhaka. So Energy efficiency measures with optimized daylighting are urgently required (Rana et al. 2020).

1.2 Aim and Objectives

The aim of the study is to find out the optimized configurations of the climate adaptive kinetic facades by the optimization of daylighting and energy performance of office buildings from a Dhaka perspective. Objectives of the study are:

- To explore the effects of climate adaptive kinetic facades
- To find out the optimized configuration (angle and depth) for the south façade of a case office building in Dhaka City.

2. Literature Review

A kinetic façade is a transformative and automatic element that can change its shape, size, form, orientation, or opening. Whereas climate adaptive facades refer to the façade that can adapt according to the outdoor environment and consist of intelligent frames and systems (Nashaat and Waseef, 2018, Ahmad and Alibaba, 2019). So the climate adaptive kinetic façades of buildings need to be in motion due to visual means and comfort and control the indoor environment by reducing solar heat gain and glare (Ayyappan & Kumari, 2018).

2.1 Static Façade in Daylighting and Energy Efficiency

Studies showed that in tropical climates there are varying sky conditions and different solar angles. So conventional static solar shading systems have limitations to control the diversified quality and quantity of solar heat gain throughout the year and thus are less effective in energy efficiency (Rodriguez & D'Alessandro, 2014; Al-Masrani et al., 2018).

2.2 Climate Adaptive Kinetic Façade in Daylighting and Energy Efficiency

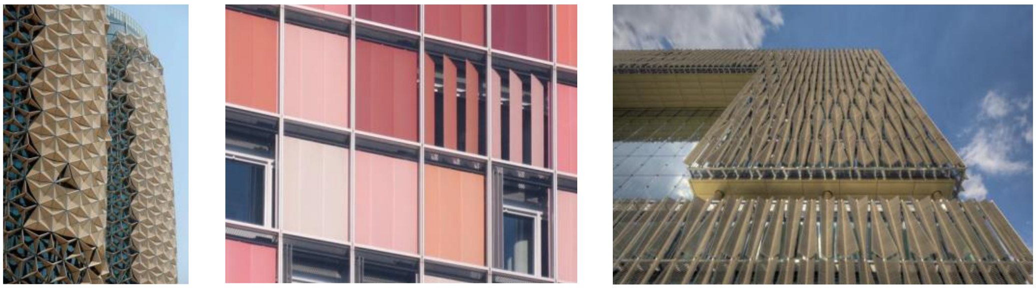
Studies showed that climate adaptive kinetic facades can save energy use by 20-30% for commercial buildings (Grobman et al., 2017). Again the kinetic photocells track the sun's position and can produce 30-40% more energy than a similar type of fixed photocell (Ramzy & Fayed, 2011).

Research in Melbourne, under temperate climate, showed that climate adaptive facades can reduce energy consumption by 14.2% to 29% for office buildings. Computational optimization was done by EnergyPlus and Eppy to analyze the comparative energy consumption (Bui et al., 2020). Another research in Tehran, under arid climate, showed the simultaneous optimization of visual and thermal comfort achieved by adaptive facades for a hypothetical space. The parametric simulation and multi-objective optimization were done by Rhinoceros, Grasshopper, Ladybug, Honeybee and Octopus (Rizi & Eltaweel, 2021).

2.3 Case Study Analysis

Al Bahar Tower's (Fig 1(L)) external kinetic façade is used to improve daylighting and reduce glare. It can reduce solar heat gain by 50%, achieve electricity load savings by 20% and reduce cooling costs by 15% (Moam.info, 2018). The climate adaptive façade of GSW Headquarter (Fig 1(M)) controls heat gain, daylight and airflow. It can reduce energy consumption by 40%. Again the climate adaptive kinetic façade of Q1 Thyssen Krupp Headquarter (Fig 1(R)) can reduce glare and heat gain, and improve daylight performance. Thus it can maximize energy efficiency (Edupuganti, 2013).

Figure 1: Façade of Al Bahar Tower (L), GSW Headquarter (M) & Q1 Thyssen Krupp Headquarter (R)



Source: Moam.info (2018) and Edupuganti (2013)

Therefore, it is evident that several research has already been conducted on the use of climate-adaptive kinetic facades in the context of temperate and seasonal climates. Also, there are multiple examples in those regions. But only a little research information is available for tropical climates, particularly for Dhaka City. Hence, the knowledge of the effects of these facades in tropical climates remains incomplete. Consequently, research on the application of this façade system for Dhaka city is urgently required.

3. Methodology

The field survey is used for the selection of case building and data collection. Further simulation analysis is incorporated for data analysis. Simulation methodology is used by the Rhinoceros (version 7) and its plugins (Grasshopper, ClimateStudio, Octopus, Wallecei). Multi-objective optimization of daylighting and energy performance simulation is done by the plugins and Design Explorer software is used to find out the optimized configuration. Rhinoceros and its plugins are validated successfully for energy simulation (Cachat & Goia, 2020). The simulation procedure has been conducted by using the weather data of Dhaka, available in the EnergyPlus weather format.

3.1 Selection of Case Building

The study case building is selected by purposive sampling as the building has an exterior shading system on the curtain glass façade on its south side. It is the NCC Bank Head office, Motijheel, Dhaka (Fig. 2).

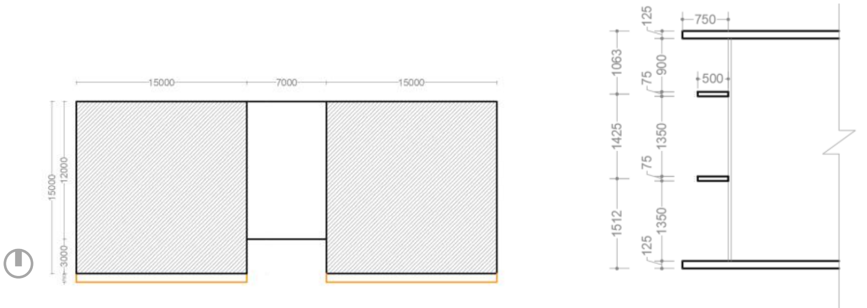
Figure 2: Google Map Location (L), South Elevation of NCC Bank (M & R)

Source: (Google Map, 2019)

3.2 Field Survey and Data Collection

From the field survey, data about the geometry and dimension of the shading device is collected as below (Fig. 3). The office room has been found in 15 x 15 meter grid (Fig. 3 (L)). Two intermediate shading devices are added outside the glass façade with extended floor planes. The dimensions are shown in the section (Fig.3 (R)).

Figure 3: Typical Floor Plan (L) and Typical Façade Section (R) of NCC Bank Head Office

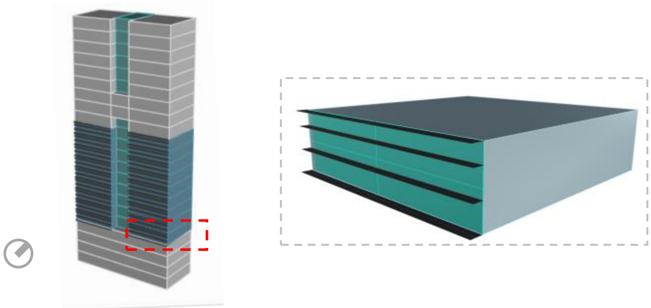


Source: Field Survey

3.3 3D Model Making

A 3D model is generated according to the collected data using Grasshopper and Rhinoceros (Fig. 4). It is a 22 storied building where only the 4th to 14th floors have shading devices. The multi-objective simulation procedure is conducted for the south façade of one room on the 4th floor of the building. The office room dimension is 15m x 15m and considered as an open-plan office. On the south façade, four shading devices are considered outside the curtain glass façade. All the other three facades are considered to be closed.

Figure 4: Full Building Model Created in Rhinoceros (L) and Room Module of 4th Floor (R) of NCC Bank



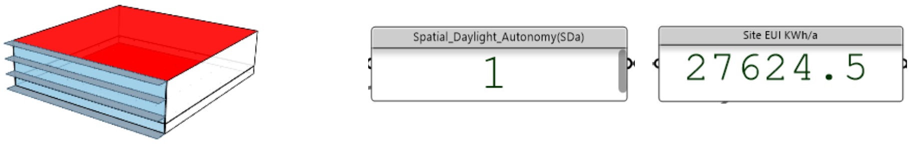
Source: 3D Model in Rhinoceros

3.4 Grasshopper Simulation and Outputs

In the simulation, the shading device is considered to be static and kinetic. The angle and depth are considered for the kinetic façade system. Angle is limited to -30° to 30° and depth is limited to 0.3m to 1.0m.

Rhinoceros (version 7.0) and Grasshopper is used to create the daylight model and energy model (Fig.5 (L)). ClimateStudio is used to input the weather data file and daylight and energy simulation. Daylight Simulation provides the result of Spatial Daylight Autonomy (sDA) and Energy Simulation provides the result of Energy Use Intensity (EUI) (Fig.5 (R)). Octopus is used for multi-objective optimization considering maximum sDA and minimum EUI.

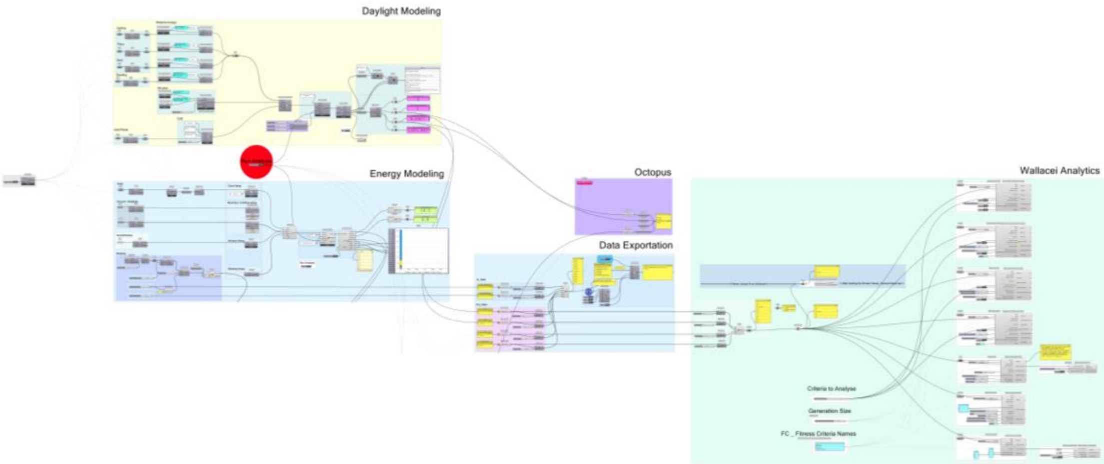
Figure 5: Daylight and Energy Model in Grasshopper (L), Daylight and Energy Simulation Outputs (R)



Source: Grasshopper Analysis

The full script is shown in Fig. 6.

Figure 5: Grasshopper Script for Modelling, Simulation and Optimization



Source: Grasshopper Interface

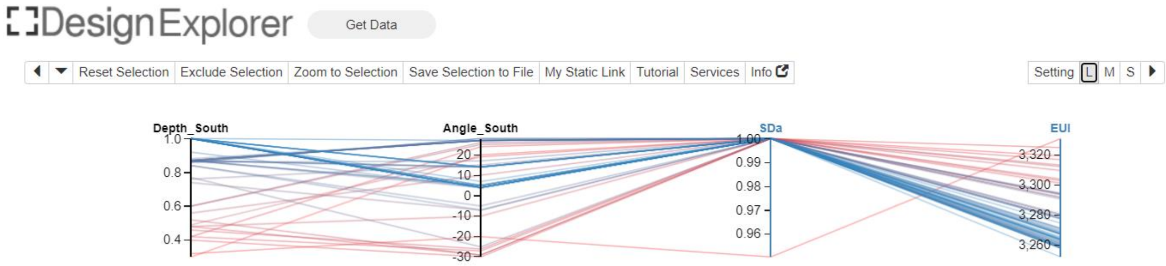
The output data of Octopus is generated as an excel file (Fig. 7). Finally the output data is analyzed in Design Explorer (Fig. 8). The simulation process is conducted 12 times to find out the optimized configuration for 12 months of a year.

Figure 7: Excel File Created by Octopus and Wallecei

1	**in**:Depth_South	**in**:Angle_South	**out**:SDa	**out**:EUI
2	1	23	1	2567.4
3	0.84	-20	1	2615.9
4	0.39	6	1	2770.8
5	0.69	-14	1	2647.4
6	0.47	-24	1	2695.8
7	0.91	-14	1	2551.5
8	0.9	23	1	2529.6

Source: Octopus Analysis

Figure 8: Design Explorer Analysis Using the Excel File

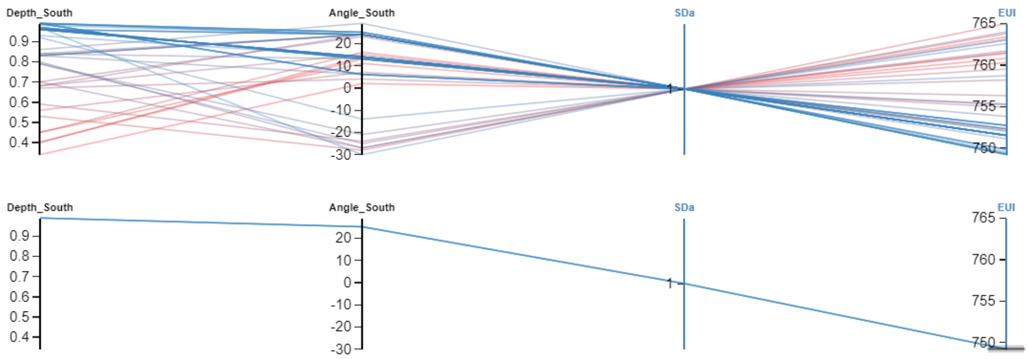


Source: Design Explorer Interface

4. Result Analysis

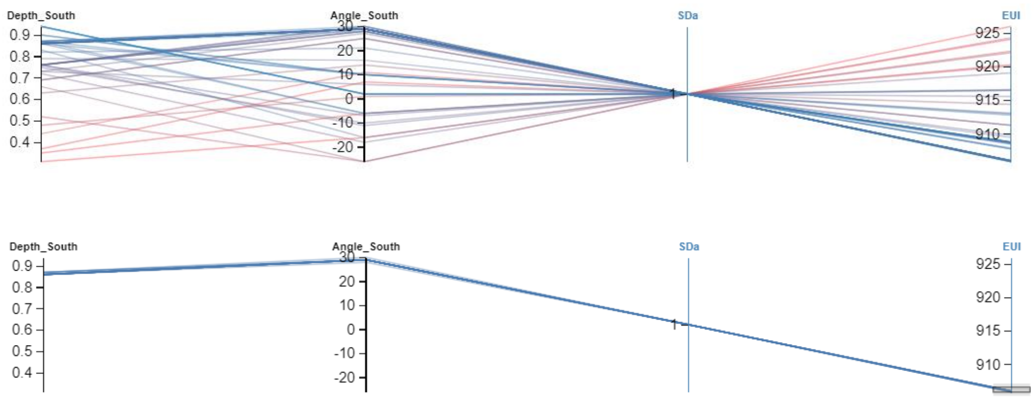
When the façade is considered as kinetic and rotating and scaling every month of a year, multi-objective analysis differs from one to another. For example, the Design Explorer Analysis of January (Fig. 9) and February (Fig. 10) are as below:

Figure 9: Design Explorer Analysis for January



Source: Design Explorer Interface

Figure 10: Design Explorer Analysis for February



Source: Design Explorer Interface

The optimization analyzed 50 iterations. Among them, considering maximum sDA and minimum EUI, the result of January showed the optimum depth of 0.99m and optimum angle of 25° for the shading device. Whereas, for the month of February, the optimum depth is 0.87m and optimum angle is 29°. Here, even for continuous two months, the optimized depth and angle varied from 0.99m to 0.87m and 25° to 29°.

The same simulation procedure has been followed for all 12 months of a year. The summarized results for all 12 months are as below:

Table 1: Optimum depth and angle for shading device with corresponding sDA and EUI

	Depth (m)	**Angle (º)**	**Optimized sDA (% area)**	**Optimized EUI (kWh)**
January	0.99	25	1	749.2
February	0.87	29	1	905.9
March	0.83	28	1	1698.2
April	0.99	21	1	2303.6
May	0.88	10	1	2558.1
June	1.00	14	1	3259.8
July	0.99	12	1	3106.4
August	1.00	19	1	3466.4
September	0.99	1	1	3007.6
October	1.00	28	1	2473.2
November	1.00	25	1	1407.8
December	0.93	24	1	860.8

Source: Design Explorer Analysis

The results showed that after the optimization of daylighting and energy performance, the optimized depth and angle differ from month to month.

5. Discussion

The literature review and simulation analysis provides a comprehensive view of the effectiveness of the use of climate adaptive kinetic facades for daylighting and energy performance. Further, the optimized configurations of this façade system for the south façade of office building is analyzed from the Dhaka perspective. Results provide the insights of different shading angles and depths required for different months to reduce the energy requirement while maintaining adequate daylight. So, the static shading device cannot make the best use of daylighting and energy consumption throughout the year. Thus an optimum solution is essential for every month and even days and hours to achieve a net zero energy building. Hence, it is obvious to shift from static shading devices to climate adaptive kinetic facades that can rotate and change their dimension according to the current weather conditions. So, the successful application of climate adaptive kinetic façade is important for adequate daylighting and energy efficiency.

6. Conclusion

The necessity to consider the climate adaptive kinetic façade system as an alternative to the traditional static shading systems has been acknowledged throughout the study. Different studies showed that office buildings are rapidly growing with glass facades along with artificial lighting and air conditioners, and resulting in high energy demand in tropical climates such as Dhaka city. So, this study will help the architects and create the opportunity for future façade designs of office buildings. Hence, this study can be the base for further research on the use, implementation and configuration of climate adaptive kinetic facades for different types of buildings particularly office buildings in Tropical Climate. Future research can be conducted by including several optimization options like, energy harvest, LEED credit, etc. and increasing the variables such as material, rotation axis, aesthetic and technical requirements, etc.

Acknowledgment

This paper is based on the research work done in the M.Arch course ‘Daylighting’, under the supervision of Prof. Dr. Md. Ashikur Rahman Joarder of the Department of Architecture, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. The authors gratefully acknowledge the support provided by BUET.

References

Ahmad, J., & Alibaba, H. Z. (2019). Kinetic façade as a tool for energy efficiency. International Journal of Engineering Research and Reviews. Vol. 7, pp. 1-7.

Al-Masrani, S. M., Al-Obaidi, K. M., Zalin, N. A., & Isma, M. I. A. (2018). Design optimization of solar shading systems for tropical office buildings: Challenges and future trends. *Solar Energy*, 170, 849–872.

Aun, C. S. (2018, March 28). GREEN BUILDING INDEX – MS1525 Applying MS1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential [Online]. Available: https://fdocuments.net/document/green-building-index-gbi-ms1525green-building-index-ms1525-applying.html?page=1 [Accessed 13 April 2023]

Ayyappan, K. L. & Kumari, M. (2018). A Review On The Application Of Kinetic Architecture In Building Facades. *International Research Journal of Engineering and Technology*, 5(8), 1726-1743.

Bari, N. (2020). The Impact Of Building Facade On Cooling Efficiency And Related Thermal Comfort For West Oriented Offices In Dhaka City. Thesis (M.Arch). BUET

Bui, D.-K., Nguyen, T. N., Ghazlan, A., Ngo, N.-T., & Ngo, T. D. (2020). Enhancing building energy efficiency by adaptive façade: A computational optimization approach. *Applied Energy*, 265(3), 114797.

Cachat, E. T., & Goia, F. (2020). Co-simulation and validation of the performance of a highly flexible parametric model of an external shading system. *Building and Environment*, 182, 107111.

Dhavalep, A., & Mhetras, A. (2022). Comparison of Energy Performance of Commercial Buildings With and Without Kinetic Facades. *International Journal of Innovative Science, Engineering & Technology*, vol. 09, pp. 60-68

Edupuganti, S. R. (2013). Dynamic Shading: An Analysis. Thesis (M.Arch). University of Washington

Google Maps. (2019). Google Maps. [Online]. Available: https://shorturl.at/fuGIU

Grobman, J., & Yekutiel, T. (2013). Autonomous Movement of Kinetic Cladding Components in Building Facades. *International Conference on Research into Design.* Madras, Chennai.

Hosseini, M., Mohammadi, M., Rosemann, A., Schröder, T., & Lichtenberg, J. (2019). A morphological approach for kinetic façade design process to improve visual and thermal comfort: Review. *Building and Environment*, 153,186-204.

Mahmoud, A. H., Dewidar, Mohamed, & Ahmed, S. (2022). The role of intelligent facades in energy conservation. *International Conference on Sustainbility and the Future*. Cairo, Egypt.

Moam.info. (2018). Case Studies. Moam.info. [Online]. Available: https://moam.info/case-studies_5c2388b1097c47db218b45a5.html

Nashaat, B., & Waseef, A. (2018). Kinetic Architecture: Concept, History and Applications. *International Journal of Science and Research.* ISSN [Online]: 2319-7064, pp. 750-758

Navarro, A. L., Loonen, R., Juaristi, M., Barrio, A. M., Attia, S., & Overend, M. (2020). Occupant-Facade interaction: a review and classification scheme. *Building and Environment*, 177.

Ramzy, N., & Fayed, H. (2011). Kinetic systems in architecture: New approach for environmental control systems and context-sensitive buildings. *Sustainable Cities and Society*, *1*(3), 170–177.

Rana, J., Hasan, R., Sobuz, H. R., & Tam, V. (2020). Impact assessment of window to wall ratio on energy consumption of an office building of subtropical monsoon climatic country Bangladesh. *International Journal of Construction Management*, 22(3), 1-26.

Rizi, R. A., & Eltaweel, A. (2021). A user detective adaptive facade towards improving visual and thermal comfort. *Journal of Building Engineering*, 33, 101554.

Rodriguez, C. S., & D'Alessandro, M. (2014). Climate and Context Adaptive Building Skins for Tropical Climates: a review centered on the context of Colombia. *Advanced Building Skins*. Bresssanone, Italy

Tabadkani, A., Tsangrassoulis, A., Roetzel, A., & Li, H. X. (2020). Innovative control approaches to assess energy implications of adaptive facades based on simulation using EnergyPlus. *Solar Energy*, 206, 256–268.