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# EFFECT OF ADJACENT SHADING ON BUILDING ENVELOPE HEAT GAIN IN TROPICAL CLIMATE

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## Abstract

*In tropical regions, approximately 60% of building energy is consumed by cooling systems, with heat gain through the building envelope being a major contributor. The Overall Thermal Transfer Value (OTTV) is a metric used to quantify average heat gain in air-conditioned buildings. However, the standard OTTV calculation does not account for shading from adjacent buildings—an increasingly common feature in high-density urban areas. This paper presents an empirical study on the thermal performance of building envelopes considering adjacent shading in tropical climates. Dynamic simulations of annual heat gain were conducted for buildings with and without adjacent shading for comparative analysis. The results highlight the significant impact of adjacent structures on heat gain performance and offer supplementary data to improve the current OTTV calculation method, especially for multi-block developments.*

**Keywords:**

Interblock Shading, Solar Radiation, Thermal Performance, Overall Thermal Transfer Value

# 1. Introduction

The building sector accounts for nearly 40% of global energy consumption, with a substantial portion of this attributed to electricity used for maintaining indoor thermal comfort. In the United States, for example, heating, ventilation, and air-conditioning (HVAC) systems consume approximately 37% of the total energy used within the building industry (US DOE, 2012). Similarly, commercial buildings in Japan and Hong Kong report HVAC-related energy consumption ranging from 25% to 30%. In tropical regions such as Malaysia, cooling systems alone contribute around 60% of the energy demand in office buildings (BSEEP, 2013). A significant source of this cooling load is the heat gain through the building’s exterior envelope. Consequently, developing reliable methods to evaluate the thermal performance of the building envelope is critical for enhancing energy efficiency.

## 1.1 Building Envelope Heat Gain

The building envelope plays a pivotal role in determining a building's energy performance and is widely regarded as one of the most critical components influencing energy efficiency (Egwunatum et al., 2016). Numerous studies have highlighted how the thermal properties of envelope materials directly affect operational energy usage, particularly for cooling and heating systems (Yuan et al., 2016; Jalaei & Jrade, 2014). As such, the envelope’s thermal performance is a key criterion in achieving green building certifications. To ensure indoor thermal comfort, the envelope must function as an effective thermal barrier, minimizing heat gain and loss.

In Southeast Asia, the Overall Thermal Transfer Value (OTTV) is a widely used metric for quantifying the average rate of heat transfer through a building envelope. Many countries in this region have adopted OTTV regulations as part of mandatory energy efficiency standards for new building developments.

## 1.2 Overall Thermal Transfer Value (OTTV)

The concept of OTTV originates from the energy conservation standards of ASHRAE Standard 90-75, which was later adopted in many countries and subsequently revised based on respective weather conditions and energy requirements (Bhanware et al., 2019). OTTV is a measure of heat transfer into mechanically cooled buildings through its envelope. Hence it acts as an index for assessing the thermal performance of commercial buildings. The concept of

OTTV generally assumes that the envelope of a building is completely enclosed and based on three major components including:

a) Conduction through opaque walls
b) Conduction through window or transparent elements
c) Solar radiation through transparent elements

According to Malaysian Standard (MS) 1525 (MS, 2019), the OTTV equation is as below:

$$OTTV = 15\alpha\,(1 - WWR)\,U_w + 6\,(WWR)\,U_f + (194 \times OF \times WWR \times SC)$$

Under the current OTTV guidelines in MS1525, buildings are assumed to be free-standing—meaning the shading effects of adjacent structures are excluded from the calculations. However, in densely populated urban environments, it is common for buildings to be closely spaced, with neighbouring structures casting shadows on one another. These inter-building shading effects can significantly reduce solar heat gain through the façade and, therefore, should not be neglected in thermal performance assessments. In response to this gap, the present study investigates the impact of adjacent building shading on envelope heat gain, with the aim of enhancing the accuracy and applicability of OTTV assessments for high-density urban contexts.

## 2. Method

### 2.1 Dynamic Simulation

To meet the research objectives, an experimental modelling approach was adopted. A representative building model was developed based on typical architectural design practices, operational characteristics of commercial buildings, and relevant Malaysian standards. This study specifically focused on assessing heat gain through the building envelope in air-conditioned, non-residential buildings located within multi-block developments in a tropical climate.

Dynamic computer simulation was used to analyse the thermal performance of the building envelope under varying urban conditions. By simulating different distances and height ratios between adjacent blocks, the study explored how inter-building shading affects heat gain, providing a comprehensive understanding of its implications on energy efficiency.

### 2.2 Selection of Simulation Tool

Numerous building performance simulation tools are available in the industry, each with varying capabilities. The selection of an appropriate tool depends on several factors including user proficiency, interface usability, simulation detail, cost, availability of technical data, and support resources. To achieve accurate and reliable results, considerable effort must be devoted to defining the building's geometry, internal loads, HVAC systems, material specifications, and operational parameters (Yezioro et al., 2008).

This study utilised eQUEST as the simulation platform due to its robust energy modelling capabilities and widespread recognition in research and practice (Hosseini et al., 2021; Elnabawi, 2020; Adrian et al., 2013). Key performance criteria for the software included its ability to accommodate detailed architectural inputs, incorporate local weather data, define simulation schedules, and generate hourly performance outputs for in-depth analysis. eQUEST offers a user-friendly interface and integrates features such as energy cost estimation, lighting and daylighting analysis, and automated implementation of energy conservation measures (Rallapalli, 2010).

### 2.3 Model Development

The simulation model featured a high-rise, open-plan office building with a central core configuration. A double-tower development was created, consisting of two primary buildings: Building A (the subject of analysis) and Building B (the adjacent shading structure). The analysis focused on the impact of Building B's placement and massing on Building A's envelope heat gain performance. Building A was modelled as a 25-storey commercial office tower, subdivided into four air-conditioned zones based on cardinal orientations—north, east, south, and west (see Figure 1). The design allowed for a detailed analysis of how varying the distance and height of Building B affected the solar heat gain experienced by Building A's façade.

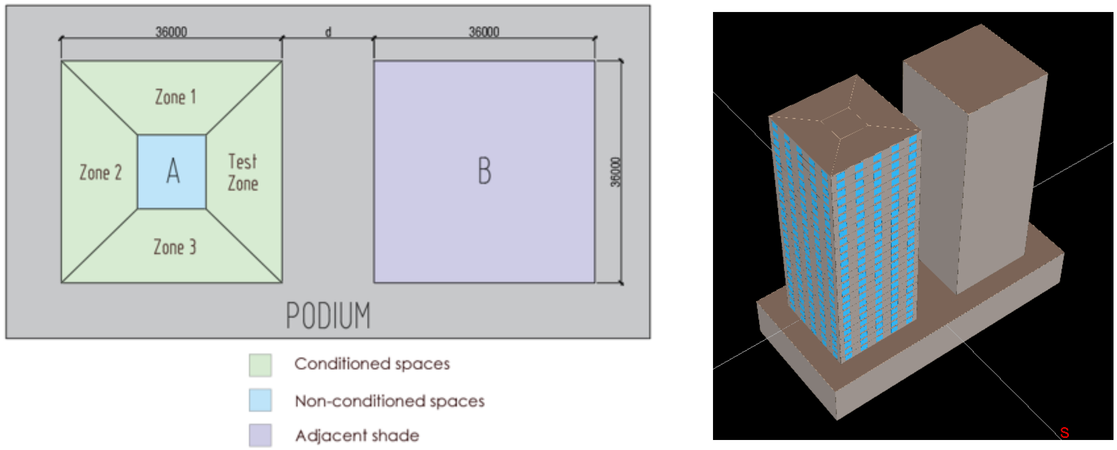


**Figure 1:** *Plan and 3D View of the building model*

The model was tested across eight orientations—north, northeast, east, southeast, south, southwest, west, and northwest—with heat gain performance evaluated for each component, including conduction through opaque walls, conduction through glazing, and solar radiation through transparent elements. A standard distance of 20 metres (D) was used to reflect typical multi-block development scenarios in Malaysia. Adjacent building heights were varied in 20 metre increments, ranging from 0 m to 100 m, to produce different shading ratios as outlined in Table 1. These configurations represent shading ratios of 1:0, 1:1, 1:2, 1:3, 1:4, and 1:5—where the ratio denotes the relationship between the setback distance (D) and the height of the adjacent shading mass.

**Table 1** *Simulation variables*

| Ratio (D:H) | Distance, D (m) | Height, H (m) |
|---|---|---|
| 1:1 | 20 | 20 |
| 1:2 | 20 | 40 |
| 1:3 | 20 | 60 |
| 1:4 | 20 | 80 |
| 1:5 | 20 | 100 |

## 2.4 Criteria of Analysis

The analysis was based on two main criteria. First, the reduction in individual heat gain components—wall conduction, window conduction, and solar radiation through glazing—was examined to determine how varying setback distances and adjacent building height ratios influenced thermal loads. This assessment provided insights into the relationship between external obstructions and the thermal performance of the building envelope. Second, the overall heat gain was evaluated to quantify the cumulative shading effect of adjacent blocks. Since the OTTV represents the average thermal transfer across the envelope, a reduction in total heat gain reflects enhanced OTTV performance and a corresponding decrease in cooling energy demand.

## 3. Result and Discussion

### 3.1 Solar Radiation and Conduction Heat Gain

The total heat gain from window solar radiation, wall conduction, and window conduction was analysed across all building orientations. The results for the west orientation are presented in Figure 2 as a representative example.

In the 1:0 scenario—where no adjacent shading is present—heat gain is highest from wall conduction and window solar radiation, with relatively lower contribution from window conduction. Conversely, in the 1:5 scenario—where adjacent shading fully obstructs direct sunlight—the lowest values of wall and solar heat gain are observed, while window conduction slightly increases, likely due to heat reflected or trapped within the dense multiblock environment.

As expected, unshaded facades (1:0) experience significantly higher solar exposure, especially in tropical climates where prolonged sunlight exacerbates internal temperature rise. The introduction of adjacent shading significantly reduces solar radiation and wall conduction heat gain, with a consistent reduction trend across the ratios from 1:0 to 1:5. Notably, while wall and solar heat gains decrease with increased shading, window conduction exhibits a subtle increase, likely due to accumulated radiant heat and reduced convective dissipation in shaded zones. This trend was consistent across all orientations, with only minor variations.

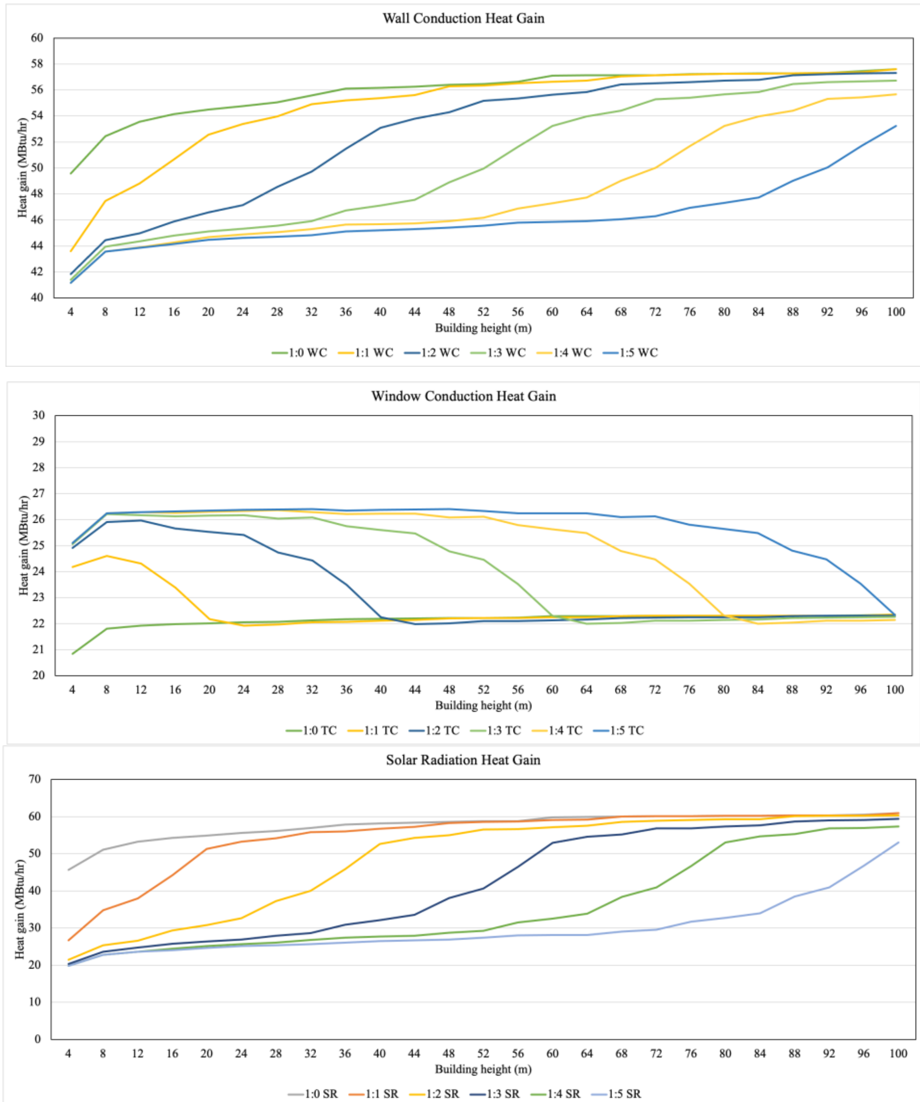


**Figure 2:** *Building envelope heat gain for west orientation*

### 3.2 Building Envelope Total Heat Gain

Examples of adjacent block shading effect is illustrated in Figure 3-6 for north, south, east and west orientations. Figure 7 presents the total heat gain profiles for all orientations. A general trend is observed where heat gain increases with building height, plateauing at higher floors (~90m). For the unshaded case (1:0), heat gain begins at approximately 116 MBtu/hr at the ground level, peaking at 140 MBtu/hr by 60m height. In shaded scenarios (1:1 to 1:5), initial heat gains are lower—below 90 MBtu/hr—rising to maximum values between 110 and 130 MBtu/hr depending on the shading ratio.

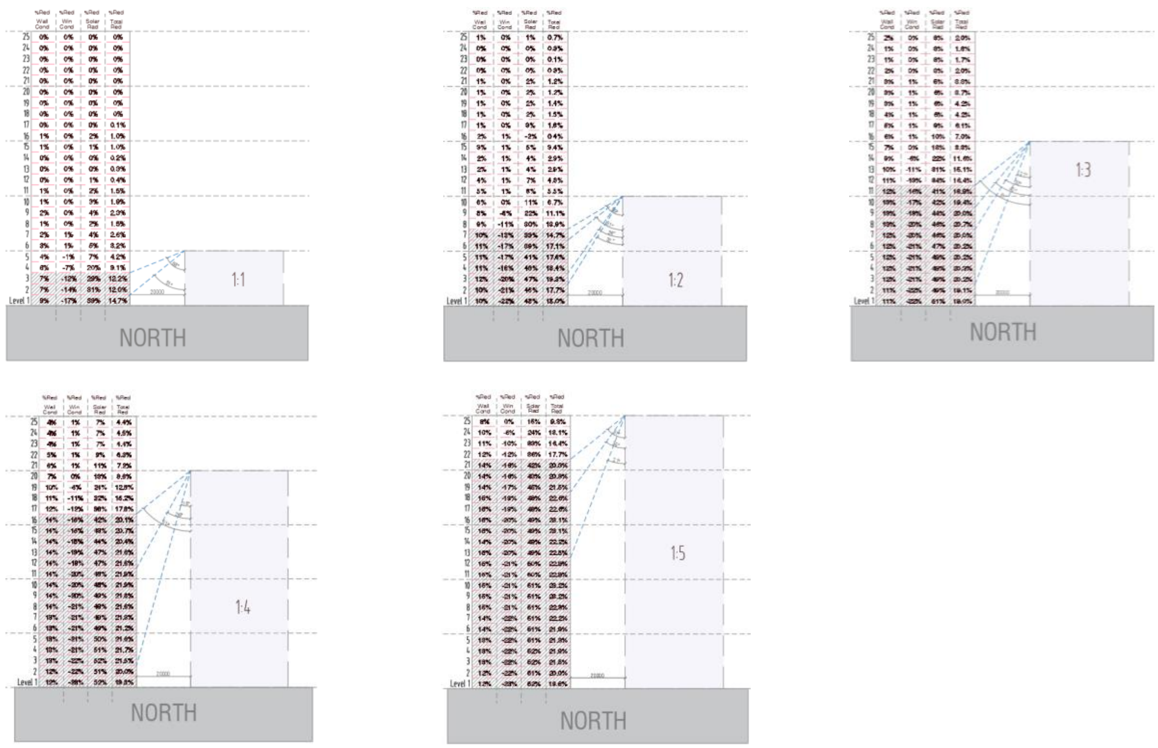


**Figure 3:** *Impact of adjacent shading (ratio 1:1, 1:2, 1:3, 1:4, 1:5) for north orientation*

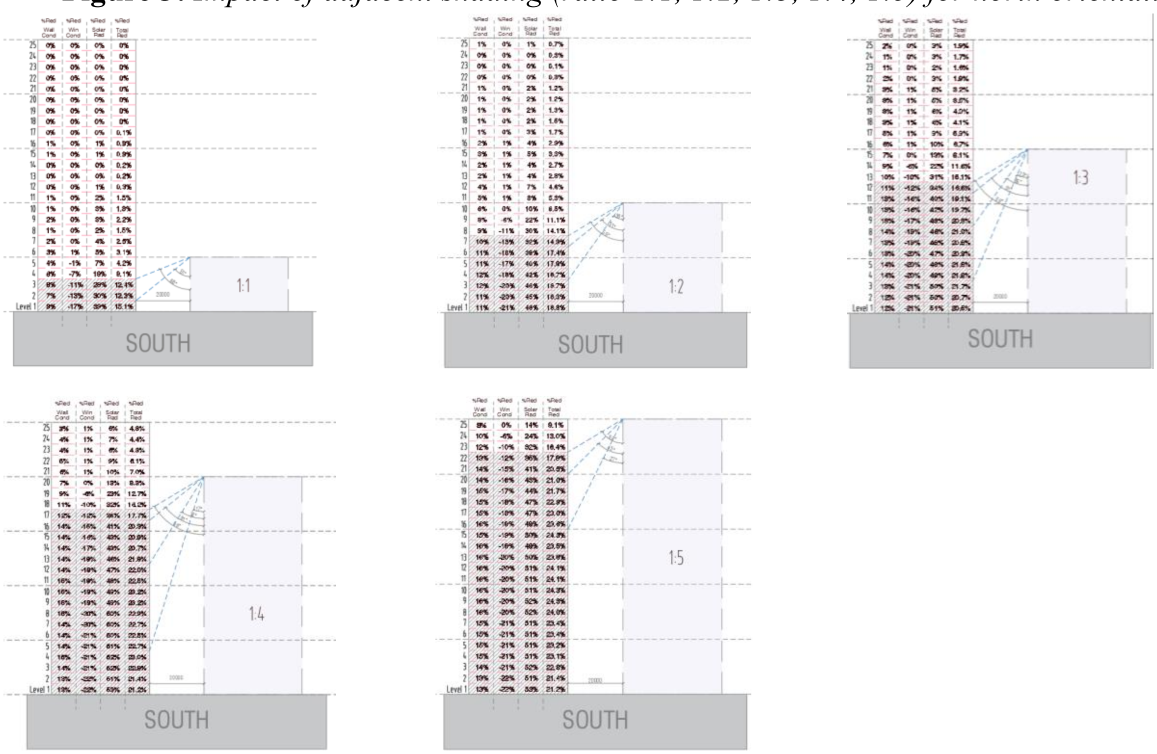


**Figure 4:** *Impact of adjacent shading (ratio 1:1, 1:2, 1:3, 1:4, 1:5) for south orientation*

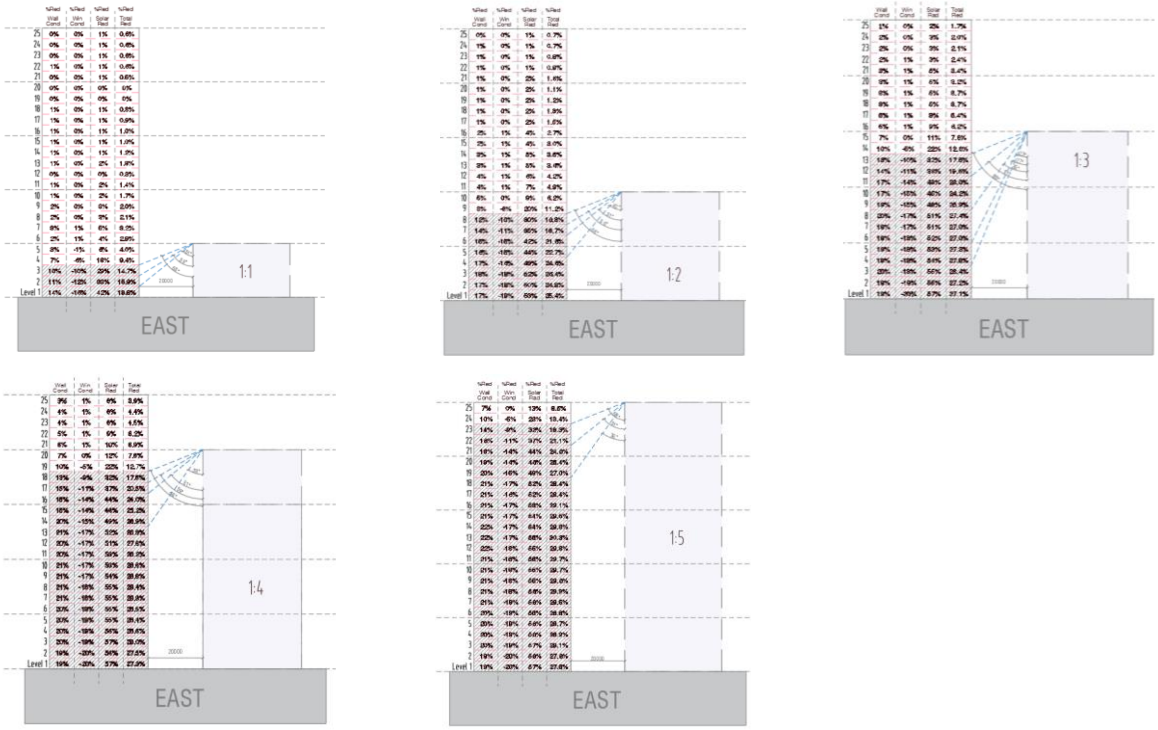


**Figure 5:** *Impact of adjacent shading (ratio 1:1, 1:2, 1:3, 1:4, 1:5) for east orientation*

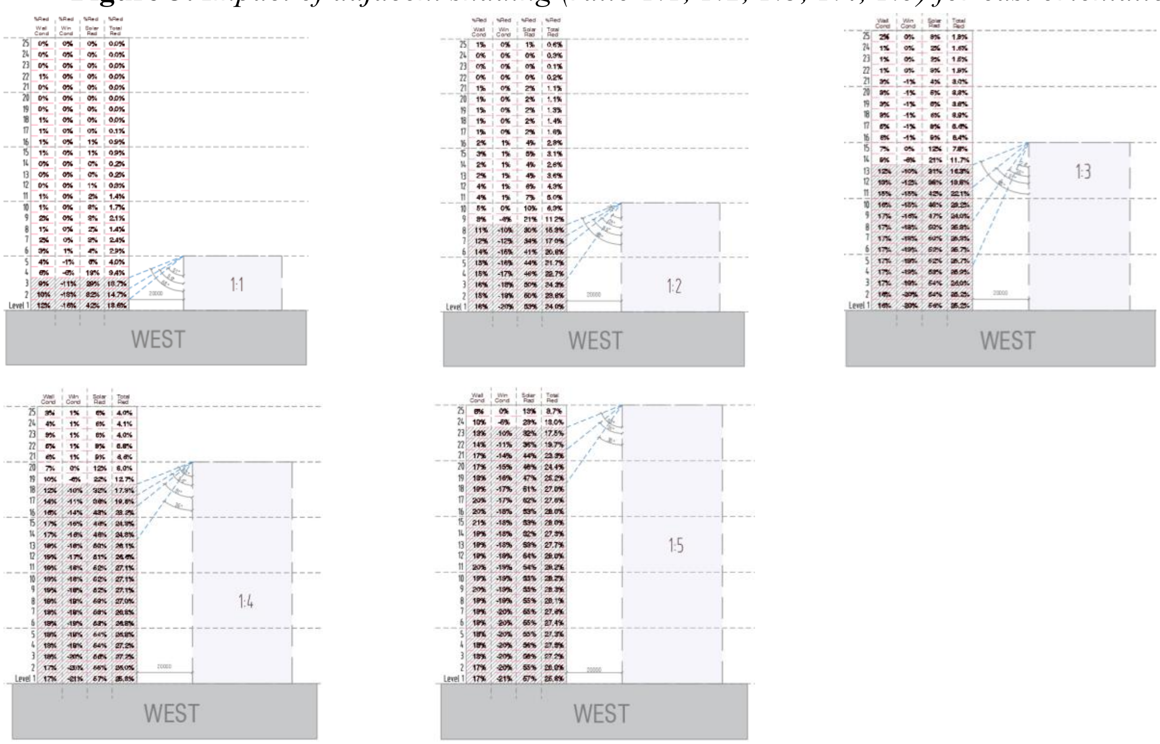


**Figure 6:** *Impact of adjacent shading (ratio 1:1, 1:2, 1:3, 1:4, 1:5) for west orientation*

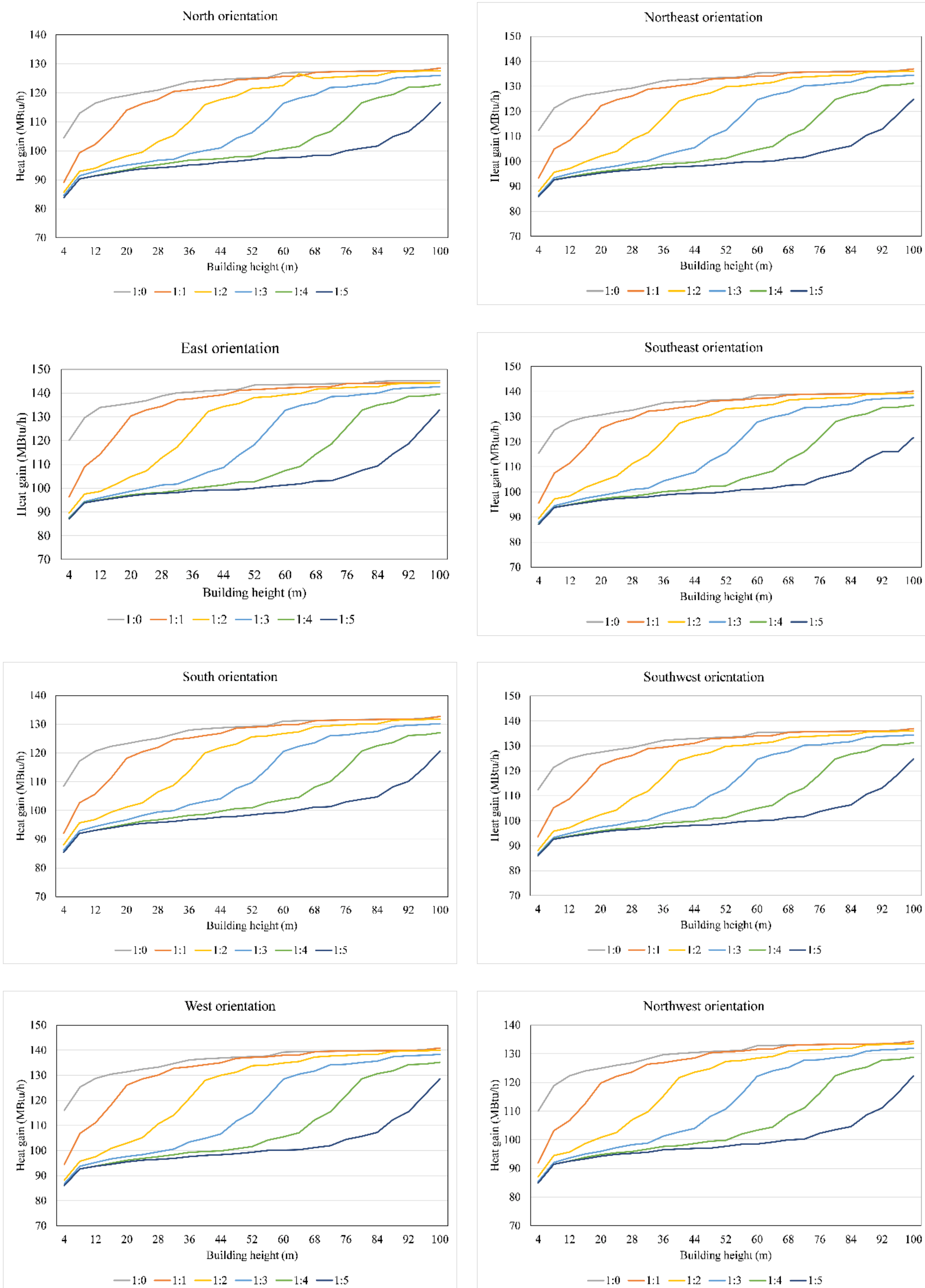


**Figure 7:** *Building envelope total heat gain*

The results as shown in Figure 4 clearly demonstrate the moderating effect of adjacent shading, with the most pronounced differences occurring at building heights beyond the reach of shading elements. This effect is especially evident in the east-facing façade, where the highest heat gain values are recorded, reaching up to 150 MBtu/hr in the unshaded scenario. This orientation receives intense morning solar radiation, consistent with Malaysia's equatorial location, making it critical for passive solar design strategies.

Among all heat gain components, solar radiation through glazing remains the dominant contributor to overall envelope heat gain. Therefore, strategic placement of shading elements and facade orientation are essential considerations for thermal performance optimisation in dense urban developments.

## 4. Conclusion

This simulation study aimed to evaluate the impact of adjacent shading on the heat gain performance of building envelopes. The results demonstrate that adjacent structures significantly influence thermal efficiency, with shading effects varying progressively across different building orientations. A key finding is that using absolute values for adjacent shading coefficients in OTTV assessments may lead to inaccurate estimations of a building's thermal performance. Instead, the analysis reveals that obstruction angles between buildings—and not merely distance-to-height ratios—are critical in determining the extent of solar heat gain reduction. The study further suggests that the relationship between shading geometry and thermal performance is not strictly linear. Therefore, incorporating orientation-specific correction factors is essential for achieving accurate OTTV evaluations in dense urban settings.

As the findings are based entirely on simulation data, further research should include experimental validation through field measurements. Real-world testing of various distance-to-height ratios across diverse climates would enhance the reliability and applicability of these results. Additionally, expanding the study to include a wider range of urban configurations and adjacent building typologies would support the development of more robust design guidelines. Such efforts will be instrumental in improving passive design strategies and promoting energy-efficient urban development.

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# References

Adrian, C. Z. M., Hien, W. N., Marcel, I., & Kardinal, J. S. (2013). Predicting the envelope performance of commercial office buildings in Singapore. Energy and buildings, 66, 66-76.

Bhanware, P. K., Jaboyedoff, P., Maithel, S., Lall, A., Chetia, S., Kapoor, V. P., Rana, S., Mohan, S., Diddi, S., Siddiqui, A.N., Singh, A. & Shukla, A. (2019). Development of RETV (Residential Envelope Transmittance Value) Formula for Cooling Dominated Climates of India for the Eco-Niwas Samhita 2018, 16th IBPSA Conference, 2-4 September, Rome, Italy.

BSEEP (2013). Building energy efficiency technical guideline for passive design. Building Sector Energy Efficiency Project (BSEEP), Malaysia.

Egwunatum, S., Joseph-Akwara, E., & Akaigwe, R. (2016). Optimizing energy consumption in building designs using building information model (BIM). Slovak Journal of Civil Engineering, 24(3), 19.

Elnabawi, M. H. (2020). Building information modeling-based building energy modeling: Investigation of interoperability and simulation results. Frontiers in Built Environment, 6, 573971.

Hosseini, S. M., Shirmohammadi, R., Kasaeian, A., & Pourfayaz, F. (2021). Dynamic thermal simulation based on building information modeling: A review. International Journal of Energy Research, 45(10), 14221-14244.

Jalaei, F., & Jrade, A. (2014). An automated BIM model to conceptually design, analyze, simulate, and assess sustainable building projects. Journal of Construction Engineering, 2014(4), 1-21.

Malaysian Standards: (MS) 1525:2019. Energy efficiency and use of renewable energy for non-residential buildings.

Rallapalli, H.S. (2010). A Comparison of EnergyPlus and eQUEST Whole Building Energy Simulation Results for a Medium Sized Office Building. Thesis. Arizona State University.

U.S. Department of Energy, Buildings Energy Data Book, 2012. Retrieved from, http://buildingsdatabook.eren.doe.gov/DataBooks.aspx. (Accessed 15 May 2019)

Yezioro, A., B. Dong, and F. Leite. 2008. “An Applied Artificial Intelligence Approach Towards Assessing Building Performance Simulation Tools.” Energy and Buildings 40 (4): 612–620.

Yuan, L., Ruan, Y., Yang, G., Feng, F., & Li, Z. (2016). Analysis of factors influencing the energy consumption of government office buildings in Qingdao. Energy Procedia, 104, 263-268.