Development of Workflows for OTTV and U-Value of Roof Calculation Using BIM-VPL to Assess Envelopes Thermal Performance

Fatma H. Younis[1*], Lokman Hakim Ismail[2], Izudinshah bin Abd Wahab[3] and Eman Ali Al-Awag[3]

[1]Department of Interior Design, Faculty of Art & Design, University of Tabuk, 71491, Saudi Arabia.

[2]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, Malaysia.

[3]Department of Architecture, Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, Malaysia.

*Corresponding author: fyounis@ut.edu.sa

Abstract

Envelope thermal performance has been found to have a significant effect on a building's energy performance. In Malaysia, the Overall Thermal Transfer Value (OTTV) is a mandatory metric regulated by MS 1525:2019 to limit heat gain through façades. Conventional OTTV calculation is a manual, time-consuming process prone to human error, hindering rapid design iteration. This study offers a novel methodology to automate this process by developing integrated workflows that connect Building Information Modeling (BIM) with a Visual Programming Language (VPL). The proposed system will automatically extract essential thermal and physical properties from the BIM database and compute the OTTV and roof thermal transmittance (U_r) in accordance with the MS 1525:2019 formula. The workflows were rigorously validated through a comparative analysis with traditional manual calculations, utilizing both a controlled hypothetical model and real-world case studies of residential buildings. The results demonstrate that the proposed BIM-VPL system achieves a high degree of accuracy, with deviations of less than 0.6% for OTTV and under 1% for Ur, while concurrently reducing processing time by 70–80%. Equip designers with a robust, efficient tool to rapidly assess and optimize envelope designs, enhance material selection in early project stages, ensure compliance, and drive sustainable building development.

1.0 INTRODUCTION

Energy use in construction is rising rapidly. Notably, buildings account for a large share of global energy use, and HVAC systems within them are the largest energy consumers. In 2019, for instance, buildings emitted 12 Gt CO_2, representing 21% of global greenhouse gas emissions. When broken down, 57% are indirect (originating from off-site power and heat generation), and 24% are direct (from on-site fuel combustion). The remaining 18% comes from embedded emissions in construction materials such as cement and steel (IPCC, 2022). That year, buildings also used over 43EJ of electricity, more than 18% of global electricity demand.

A report by the United Nations Environment Programme and the Yale Center for Ecosystems and Architecture stated that progress in reducing the "embodied" carbon emissions from building materials remains limited. These challenges remain significant and ongoing issues. Engaging all stakeholders throughout the lifecycle of the building sector, in both informal and formal environments, is crucial (United Nations Environment Programme, 2023). In response to this ongoing concern, many scholars, environmental advocates, and global communities have focused on advancing energy efficiency and sustainability in buildings, introducing a range of strategies and energy technologies (Niza et al., 2022).

Using construction materials with high thermal resistance reduces energy consumption, limits heat transfer, and maintains thermal comfort in buildings. In line with this, Abass et al. (2020) emphasize that building designers should carefully select materials during the design phase. In response to growing concerns about energy, regulations have been developed to address energy use since the late twentieth century. These regulations typically fall into two categories for assessing the thermal performance of building envelopes. The first, thermal insulation standards measured by U-value, gauge how well a material resists heat flow and are primarily used in colder climates. In contrast, the Overall Thermal Transfer Value (OTTV) assesses the combined effects of insulation, solar gain, and ventilation, and is primarily used in hot, humid regions, such as Southeast Asia.

Estimating the thermal performance of the envelope is typically conducted manually using an Excel spreadsheet, which can pose significant challenges for teams lacking experience. Alternatively, energy simulation software capable of executing OTTV calculations, such as VE-Navigator for LEED 4, is generally tailored to specific national standards, which may yield erroneous results in regions that use divergent OTTV equations.

Consequently, there has been a notable demand for the development of a program or tool to evaluate these regulatory frameworks among policymakers and urban planners. The multiple advantages of Building Information Modelling (BIM) have led firms and governments to develop roadmaps for adopting it across their construction industries. As highlighted by Liu et al. (2020), it is crucial to comprehensively assess additional dimensions of BIM, particularly its utility for enhancing building performance metrics, including shading mechanisms, daylighting, natural ventilation, and the external façade of structures.

Autodesk Revit is a leading Building Information Modelling (BIM) tool widely used across architectural, structural, landscape, and electrical engineering disciplines. Launched in 1997 (as Charles River Software) and acquired by Autodesk in 2002 (Kurniawan et al., 2023). Revit offers APIs that allow users to automate design tasks using computational logic and algorithms (Olofsson Hallén et al., 2023). This functionality streamlines workflows, reduces manual errors, and enhances efficiency, supporting automated energy assessment standards like OTTV and RTTV calculations.

Recent studies have used BIM to compute OTTV and RTTV at the design and conceptual stages (Changnawa, 2023; Kurniawan et al., 2023; Lim et al., 2019; Liu et al., 2020; Morakote et al., 2025; Natephra et al., 2018; Seghier et al., 2017, 2022). Most studies on BIM and VPL for thermal assessment focus on workflows developed for specific countries, such as Singapore or Thailand. Only Kurniawan et al.'s study considers Malaysia, where standard OTTV equations differ, thereby limiting the reliability of other approaches.

In Malaysia, OTTV and RTTV are computed manually (Kurniawan et al., 2023) or with the Excel-based Building Energy Intensity Tool (BEIT). BEIT was last updated in 2018 and may be outdated. Therefore, this study aims to establish automated workflows that help estimate OTTV and RTTV in line with MS1525. The study focuses on developing a BIM-based workflow for the autonomous assessment of buildings' thermal

performance on the conceptual and post-design stage. This workflow would reduce time and errors common in traditional calculations. The main contributions of this study are to introduce new workflows that can:

- Extract materials require data from the BIM database to perform OTTV calculation accuracy beyond the manual method.
- Automate and improve the accuracy of opaque roof U-value calculations, surpassing outdated methods.
- Deliver an automated workflow for OTTV and U-value calculations, real-time analysis, and data input to optimise building envelope thermal performance and enhance energy assessment efficiency.

These workflows are designed for engineers new to BIM and VPL. The approach gives a clear step-by-step OTTV calculation method for building facades. It also examines some limitations, primarily related to the semi-automated nature of the workflow and RTTV calculations on roofs with skylights, which will be addressed in future work. Calculations were manually verified for both examples and real cases. Using the most common validation method helps improve efficiency and reliability.

This section outlines the paper's structure, which is divided into six primary sections, including this introduction. Section 2 reviews relevant literature, Section 3 describes the methodology, Section 4 details the workflow and validation process, Section 5 discusses results, and Section 6 offers the conclusion and recommendations.

2.0 LITERATURE REVIEW

2.1 The Establishment of Building Energy Codes

Regulations governing the design of building envelopes specify the maximum and minimum acceptable limits for solar heat penetration through external envelopes (Natephra et al., 2018). Upgrading and improving building energy policies are being implemented in many countries to accomplish energy efficiency in various building types (Hui, 1997). There are two sets of regulations used to estimate a building envelope's thermal performance: thermal insulation standards (U-Value) and OTTV.

The implementation of energy regulations for building construction in the UK and Scandinavian countries began in the 1970s, following the oil crisis. Since then, each country has systematically revised and strengthened its requirements (i.e., indicators or criteria) for building codes. According to Allard et al. (2021), indicators are parameters used to estimate the performance of a building component (e.g., the U-value of a window) or the building energy efficiency. Criteria specify the maximum and minimum values for indicators used to regulate building energy performance, including the maximum specific energy use and the maximum U-value for windows.

On the other hand, the concept of OTTV is based on empirical formulas suggested by "The American Society of Heating, Refrigerating and Air-Conditioning Engineers "ASHRAE Standard 90A-75 for both wall and roof, and developed later by ASHRAE 90.1. The equation was given in ASHRAE 90-75 (1975), focused on three main variables: heat conduction through the opaque wall (Qwc), heat conduction through window glass (Qgc), solar heat gain through window glass (Qgs). Later, ASHRAE 90A introduced a formula for OTTVR estimation similar to the wall's equation. The roof calculation is much simpler because the amount of glazing in the roof is not significant for the skylight atrium (Lam et al., 1993).

To date, the countries that have adopted OTTV are Singapore, Hong Kong, the Philippines, Indonesia, Malaysia, Sri Lanka, Thailand, China, Bahrain, Pakistan, India, Egypt, Japan, and some Central American countries, including Jamaica and the Ivory Coast. Like some ASEAN countries, Malaysia adopted and upgraded the OTTV index since 2001, with several amendments in 2007, 2014, and 2019 to the standards. The OTTV status in Malaysia is outlined in detail in the next section.

2.2 Adoption of Energy Regulation in Malaysia

The original OTTV formula was developed by Deringer et al. in the late 1980s. It was published in a national voluntary guideline two years later. The standard was revised in 2001 and became MS 1525:2001, named "Code of Practice on Energy Conservation and the Use of Renewable Energy for Non-Residential Buildings." The version considered only two parameters of the OTTV formula: heat conduction through walls

and windows (Kannan, 2007). The total solar heat gains through windows, added in 2007, were used as a third parameter. While roofs receive direct solar exposure, enhancing their thermal resistance is a key factor in achieving the required energy efficiency. Accordingly, MS1525 introduces two formulas to assess heat penetration: RTTV for roofs with skylights and U-value for opaque roofs.

According to MS1525 Clause 5.2, the OTTV for a non-residential building with an air conditioning system and a total conditioned area not exceeding 4,000 m² is set at 50 W/m². In later versions, MS1525:2014 and 2019, the total conditioned area threshold was revised from 4,000 m² to 1,000 m², while the recommended OTTV remained at 50 W/m². For the RTTV, the MS1525 recommends that RTTV not exceed 25 W/m². U-values should range from 0.40 W/m²K (minimum) to 0.60 W/m²K (maximum), depending on whether the roof density is below or above 50 kg/m². To date, only non-residential buildings seeking green rankings are required to submit the value of OTTV and RTTV as part of the required submission. Green Real Estate (GreenRE), Green Building Index (GBI), and Green Rating Tool (GRT) are the rankings required for the OTTV and RTTV submission.

Another primary energy efficiency standard in Malaysia is MS1525 (2017). The code guides designers on design, material selection, and appliance use, promoting efficient energy use and the integration of renewable energy in new and existing residential buildings. Currently, the code cites MS1525 but does not specify a calculation method, which creates uncertainty, especially if a value below MS1525 is desired. To address this, focused research should determine if the same formula is suitable and what parameters, including total air conditioning area, are required.

2.3 Integration of BIM and VPL for Building Performance Assessment

Computer simulation software has transformed building design, making analysis more reliable and efficient. Early studies in the 1960s and 1970s focused on implementing simulation software for energy assessment. Today's tools are often integrated with BIM to analyse building systems like HVAC, lighting, and structure. As a result, simulation technology has replaced manual methods, such as the Lighting and Thermal System (LT) and CIBSE guidelines, which were previously mandated by design codes, resulting in a more integrated and streamlined design process.

BIM and VPL deliver an innovative process for assessing building performance. This process of automation, optimisation, and real-time project assessment occurs either during the design or operational phases. Recent advancements and challenges in building performance evaluation are enabled by the integration of BIM and VPL, as outlined in the following sub-sections.

2.3.1 Current State of BIM-VPL Integration

The incorporation of BIM with VPL tools has emerged as a critical enabler for automated workflows for building performance assessment (Seghier et al., 2025). The powerful capabilities of VPL tools for the parametric design and analysis process reduce the need for high-paid coding expertise (Shahsavari et al., 2021). Tools like Dynamo for Revit and Grasshopper for Rhino provide designers with simple environments to create custom assessment plugins that connect design intentions with complex data (Coskun et al., 2025). The integration of BIM and VPL addresses the limitations of traditional sustainability evaluation methods.

Recent investigations reveal that BIM and VPL workflows enhance building performance by automating data processes and improving model synchronisation (Massafra & Gulli, 2023). The proposed workflows ensure that changes to BIM models during the assessment process are automatically replicated in performance models, and that synchronisation between the design and analysis environments is preserved. As a result, organisations adopting them can achieve significant operational and sustainability improvements (Sajjad et al., 2024).

2.3.2 BIM-VPL for Energy Performance Assessment

Recent studies focus on implementing BIM-VPL to assess energy performance, reflecting the growing global emphasis on energy-efficient buildings and emissions reduction. Building on this,

Table *1* presents and compares some of these studies. The comparison highlights how these studies address key challenges in early design decision support, retrofit strategies, and compliance with energy codes,

providing a comprehensive understanding relevant to advancing BIM-VPL integration for sustainable building design and operation.

Table 1. A Summary of selected studies

Reference	Research area
(Marín Miranda et al., 2020)	Development of BIM tools to verify energy performance in the early design stage.
(González et al., 2021)	Integration of BIM and Building Energy Modelling (BEM) for assessing the energy performance of two-storey dwellings.
(Eid et al., 2022)	Implementation of VPL to automate OTTV code compliance.
(Sampaio & Araújo, 2023)	Common wall and floor materials in the modelled building were tested using the BIM model and the Green Building Studio plugin.
(Elias & Issa, 2024)	Application of Artificial Neural Networks (ANN) and VPL (Dynamo) for accurately assessing residential energy loads during the architectural design phase.
(Tsikas et al., 2025)	Energy analysis and alternative design evaluation for residential buildings were conducted using BIM and ANN.

The main challenge in building assessments today is normalising BIM-VPL workflows to realise their full potential. Standardising BIM-VPL workflows and making interfaces easier to use are crucial for increasing industry adoption. Integrating design and analysis tools, expanding automated performance measurements, and lowering technical barriers are key to maximising BIM-VPL's future benefits.

2.4 BIM - VPL Related Studies and Study Gap

Many scholars have investigated the integration of BIM into various energy regulations. The studies aim to develop a reliable and secure method for estimating the points required for Green Building rating tools in Malaysia, Thailand, and Singapore. Their findings demonstrated the capability of BIM models to estimate OTTV and ETTV values during the building evaluation, particularly during the design stage and decision-making process.

Natephra et al. (2018) incorporated BIM and VPL with OTTV indexes for Hong Kong, Singapore, and Thailand, producing a new model called "BOTTVc". This model was validated against conventional calculations and shown to provide valid results for designers and BIM users in these countries. Lim et al. (2019) built on this by developing a BIM-VPL and a Multi-Objective Optimisation (MOO) Algorithm to calculate OTTV and envelope costs during decision-making. Using Revit Architecture, Dynamo, and MATLAB, their system achieved a 44.7% reduction in OTTV.

A BIM-VPL tool was presented by Seghier et al. (2017) for evaluating envelope thermal performance using the ETTV method. The tool provides real-time feedback for green building design and automates sustainability compliance. In 2022, Seghier et al. (2022) developed a BIM-based method (RBIM) to enhance building insulation and reduce retrofit costs, in accordance with OTTV rules. The primary benefit of this method is that it simplifies and automates complex decision-making for green retrofitting by utilising BIM-VPL tools and NSGA-II multi-objective optimisation, enabling clearer comparisons of design options and facilitating easier data collection.

Liu et al. (2020) developed a cloud-based Building Information Modelling (BIM) system to calculate ETTV and Roof Thermal Transfer Value (RETV) in Singapore. The system organises semantic models of building elements and related data, enabling stakeholders to make informed decisions with immediate access

to real-time ETTV and RETV information, thereby supporting optimised thermal performance and regulatory compliance.

Addressing Malaysian energy code requirements, Kurniawan et al. (2023) introduce an automated system that leverages a BIM plugin and the Revit API to streamline building energy analysis. This system calculates OTTV and RTTV in accordance with MS1525:2014, optimising energy efficiency and simplifying sustainable building design choices. A BIM-VPL framework based on the Thailand building energy code was developed by Changnawa (2023). The system established aims to help designers optimise building elements for energy code compliance during conceptual design, providing accurate results with minor differences compared to official software.

Morakote et al. (2025) developed a BIM-based tool in Autodesk Revit using Dynamo to support the national Building Energy Code (BEC), which relies on the Overall Thermal Transfer Value (OTTV) as a key efficiency metric. This tool enables designers to calculate OTTV and estimate wall construction costs during the early design stages, reducing time requirements. The OTTV and cost calculation results were validated by benchmarking against software provided by Energy Development and Efficiency to ensure accuracy.

This study reviews research on the use of BIM-VPL to calculate ETTV, OTTV, and RTTV metrics, which are crucial for evaluating building envelope performance in accordance with regional regulations. For Malaysia specifically, these calculations are essential for compliance with the MS1525 energy efficiency standard. Notably, six studies examined these metrics after the design stage, whereas two examined them during the early design phase. However, most workflows were developed for Singapore or Thailand, and differences in building codes limit their applicability in Malaysia. Only Kurniawan et al.'s workflow utilises Malaysia's 2nd MS 1525. Table 2 summarises the metrics, design stages, and validation methods for each workflow, while

Table **3** highlights the limitations of each study and suggests avenues for future research.

Table 2. A summary of related studies and the validation technique

Reference	Country	Energy code	Stage	Validation technique
(Seghier et al., 2017)	Singapore	ETTV	Design stage	Hypothetical residential building/ ETTV guide
(Lim et al. 2019)				Real case study/ ETTV guide
(Seghier et al., 2022)				Real case study/MATLAB
(Natephra et al. 2018)	Thailand/ Singapore	OTTV/RTTV	Design stage	Hypothetical office building/ Manual calculation
Liu et al. (2020).	Singapore	ETTV	Design stage	Hypothetical building/ ETTV guide- manual calculation/
(Kurniawan et al., 2023)	Malaysia	OTTV/RTTV	Design stage	Revit-based model/ OTTV/RTTV value
(Changnawa, 2023)	Thailand	OTTV/RTTV	Conceptual stage	Hypothetical office building/ Building Energy Code (BEC) software
(Morakote et al., 2025)	Thailand	OTTV	Conceptual stage	Hypothetical building/ BEC software

Current study	Malaysia	OTTV/ U-Value for roof	Conceptual and Design stage	Hypothetical and real case study building/ Manual calculation

Table 3. Limitations of related studies

Reference	Limitation/ Future study
(Seghier et al., 2017)	The final OTTV was conducted in the designed Excel, omitting the Shading Coefficient (SC_2).
(Lim et al. 2019)	Manual verification was necessary to prevent clashes between windows and other building components resulting from changes in the window area (WWR).
(Seghier et al., 2022)	The complexity of the provided approach lies in its requirement to export data to the main program BIM and then to MATLAB for result estimation.
(Natephra et al. 2018)	To develop methods for directly obtaining (AT, SF, ESR) factors from BIM, thereby enhancing the system's holistic evaluation capabilities without requiring manual input or Python scripting.
(Liu et al., 2020)	The primary limitations lie in its focused scope, as it does not directly address the broader relationship between ETTV and overall energy efficiency, and other Green Mark assessment modules.
(Kurniawan et al., 2023)	The future work identifies the need for more extensive experimental validation, particularly regarding the nuanced effects of window dimensions to refine building energy performance further.
(Changnawa, 2023)	The future work focuses on expanding the model's geographical applicability, integrating a more comprehensive energy calculation, and improving BIM's data import capabilities to streamline the design process and reduce manual data entry.
(Morakote et al., 2025)	The study did not incorporate a shading tool in its calculation of the Solar Heat Gain Coefficient (SC) value.
Current study	Full automation of the scripts and RTTV estimation is not included.

3.0 METHODOLOGY

The Overall Thermal Transfer Value ($OTTV_R$) computational method adopted in the current study utilises BIM, an authorised tool, i.e., Revit Architecture version 2022, and Dynamo 2.12 as a Visual Programming Language (VPL). Revit Architecture facilitates the insertion of thermophysical properties for approximately all selected case study buildings, whereas Dynamo transfers and extracts the required data governing the computational process.

The proposed technique requires several primary steps, as shown in Figure 1. It begins with:

a. Developing a 3D model in BIM authoring tools (Revit Architecture), then all the thermal and physical properties of the model's façades, windows, and roof are selected from the Revit building material library.

b. A BIM model was connected through Dynamo.

c. An extraction for all the material thermal properties (U-value, absorption factor) and physical

properties (walls, windows, and roof area) assigned to the BIM model was conducted.

d. In this step, several steps were conducted; it first started with a set of mathematical functions to calculate SC, WWR, and 1-WWR. After collecting all the formula coefficients and variables, the next step was to calculate the $OTTV_R$ and the roof's thermal transfer value (U_r).

e. While the proposed system provides an instant OTTV and U_r calculations, the coefficients, parameters, and $OTTV_i$ results have been exported to an Excel spreadsheet.

f. Focuses on validating the proposed $OTTV_R$ and U_r workflows with the traditional approach. Then the proposed workflows are saved.

Section Adoption of Energy Regulation in Malaysiadescribed the implementation of OTTV and RTTV as energy codes in Malaysia. OTTV equation for an individual orientation is structured as follows:

OTTV = (Coefficient for wall) × (heat conduction through the wall) + (Coefficient for windows) × (heat conduction through windows) + (Coefficient for glass) × (solar heat gains through glass windows). In comparison, U_r estimates the thermal transmittance of the roof materials. Building on this, the study adopts the details of the equation by MS1525:2019 for individual wall types and finishes at specific orientations (i.e., south, north, west, and east), as well as the thermal transmittance of opaque roofs. These aspects are highlighted in the following sections.
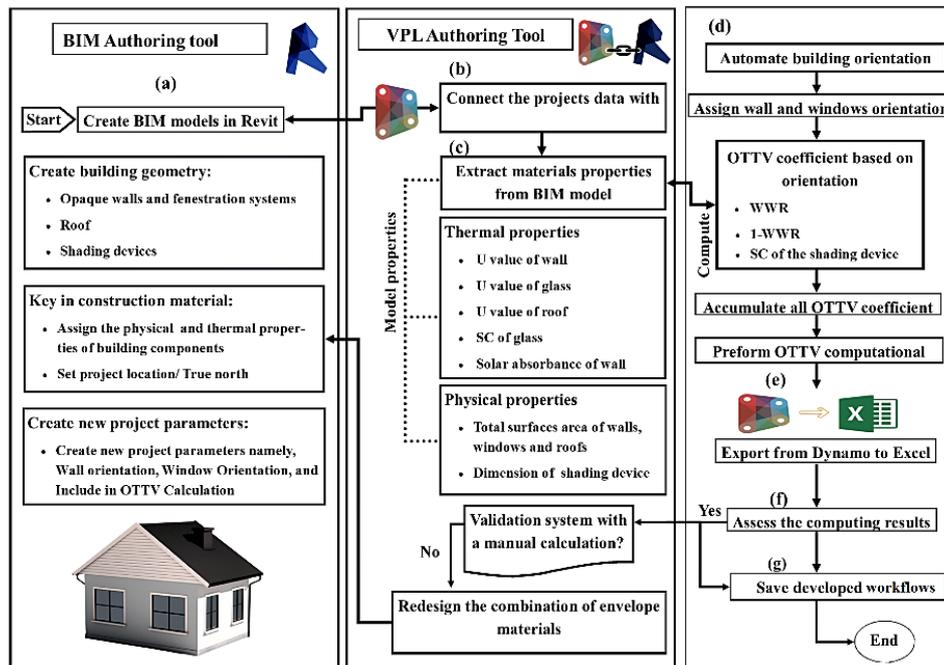

Figure 1. Outline of the proposed OTTVR and Ur workflows

3.1 Overall Thermal Transfer Value (OTTV)

In Malaysia, several formulations for calculating OTTV have been proposed in Malaysian Standard 1525 and updated in the latest version of the standard. Since the first standard MS1525:2001, the formula (Eq.1) has been revised in its latest version (MS1525, 2019) as highlighted below:

$$OTTV = 15.\alpha.(1-WWR)U_W + 6(WWR)U_F + (194.CF.WWR.SC) \qquad 1$$

Where α is the solar absorptivity of the opaque exterior wall, WWR is the Window-to-Wall area ratio, U_w is the thermal transmittance of the opaque wall, CF is the solar correction factor, and SC is the shading coefficient of the fenestration system. As noted in Eq. 1, a set of equations is required to estimate WWR, Uw, and SC values, as illustrated in Eqs. 2, 3, and 4. At the same time, Figure 2 explains the estimation process for SC.

$$\text{WWR} = \frac{\sum \text{Glazing area (m}^2)}{\sum \text{Gross exterior wall area (m}^2)} \qquad\qquad 2$$

$$U = \frac{1}{R_T} \qquad\qquad 3$$

$$SC = SC_1 \; x \; SC_2 \qquad\qquad 4$$

Where R_T is the sum of thermal resistance for all the structure layers, SC_1 is the shading coefficient of glazing, and SC_2 is the shading coefficient of the external shading device. The Shading coefficient of the external shading system (SC_2) is estimated by obtaining the ratio between the projections and the distance between the upper edge of the projection and the exposed window's length, as illustrated in Figure 2, using Eqs. 5 and 6 for horizontal and vertical shading devices.

$$R_1 = \frac{x}{y} \qquad\qquad 5$$

$$R_2 = \frac{vp}{l} \qquad\qquad 6$$
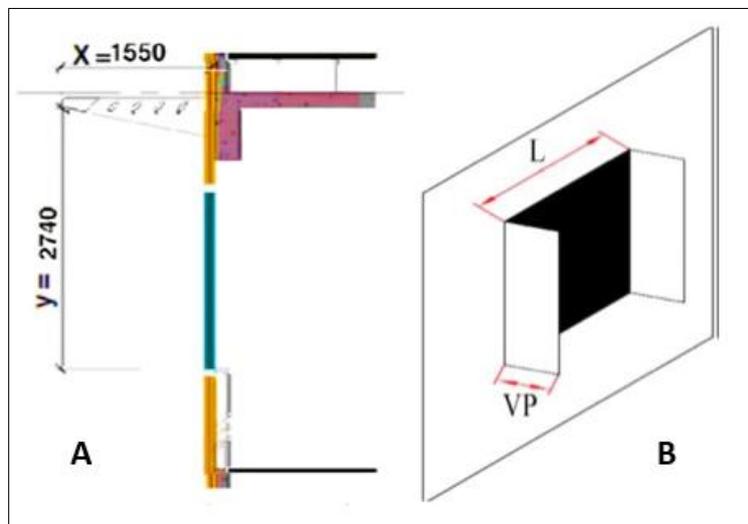
Figure 2. (A) Horizontal external shading device, (B) Vertical external shading device

Once $R_{1,2}$ is obtained, the SC_2 value can be determined from the horizontal and vertical projection shading coefficients in MS1525:2019. Regarding α and CF, they can be obtained from Table 4 and Table 5.

Table 4. Solar Orientation Factors

Orientation	OF
North	0.9
Northeast	1.09
East	1.23
Southeast	1.13
South	0.92
Southwest	0.90
West	0.94
Northwest	0.90

Table 5. Solar Absorptivity

Colour	Suggested value of α
Light	0.2 to 0.4
Medium	0.41 to 0.70
Dark	0.71 to 0.95

After calculating the OTTVi value of any given wall orientation, Eq. 7 is used to estimate the OTTV for the whole building:

$$OTTVR = \frac{A1 \times OTTV1 + A2 \times OTTV2 + \ldots\ldots + An \times OTTVn}{A1 + A2 + \ldots\ldots + An} \qquad 7$$

Where A1&n is the gross exterior wall area for orientation 1&n, and OTTV1&n is the OTTV of any given wall orientation.

3.2 Roof Thermal Resistance (U-Value)

This section explains the formula for estimating heat penetration through opaque roofs, applicable to both the hypothetical and real validation case studies, as illustrated in Eq. 8:

$$U_r = \frac{A_r 1 \times U_r 1 + A_r 2 \times U_r 2 + \ldots\ldots + A_{rn} \times U_{rn}}{A1 + A2 + \ldots\ldots + An} \qquad 8$$

Where U_r is the average thermal transmittance of the gross area, A_{ra} is the respective area of different roof sections, and U_{rn} is the respective thermal transmittance of different roof sections.

The above equations required multiple formulas to estimate OTTV and roof heat gain, making calculations complex and prone to error even when using a dedicated Excel spreadsheet. To overcome these challenges, this study developed a system for instant coefficient extraction and OTTV estimation using BIM and VPL concepts. The next section outlines these tools, followed by a description of the computational OTTV system developed in this study.

3.3 Developing a 3D BIM Model

Obtaining the correct orientation of façades and the fenestration system using BIM can be challenging. Therefore, accurately detecting walls and windows is a significant concern when selecting the correct values of (OF) and (SC) parameters, as specified by MS1525:2019. To achieve that, a 3D model with eight side polygons is designed as shown in Figure 4. Each side of the 3D model was created to represent the eight cardinal directions (North, South, East, West, Northeast, Northwest, Southeast, and Southwest). The adoption model is similar to that of Liu et al. (2020) and Chan (2017), which were developed for the same purpose, as shown in Figure 3.

Four sides of the hypothetical model, designed with different shading systems (vertical, horizontal, egg crate), to analyse the SC parameter (referred to Figure 10). The other four opaque sides feature varied wall finishes for testing data extraction scripts related to material and thermal properties, ensuring OTTV calculations in accordance with MS 1525 (3rd edition). The four types of wall finishes and thermal properties, which represent plastered brick walls, aluminium composite cladding without insulation, and aluminium composite cladding with insulation, were obtained from Leong (2018) for walls A, B, and C, respectively. In contrast, exterior brick on metal stud for wall D was obtained from the study data.
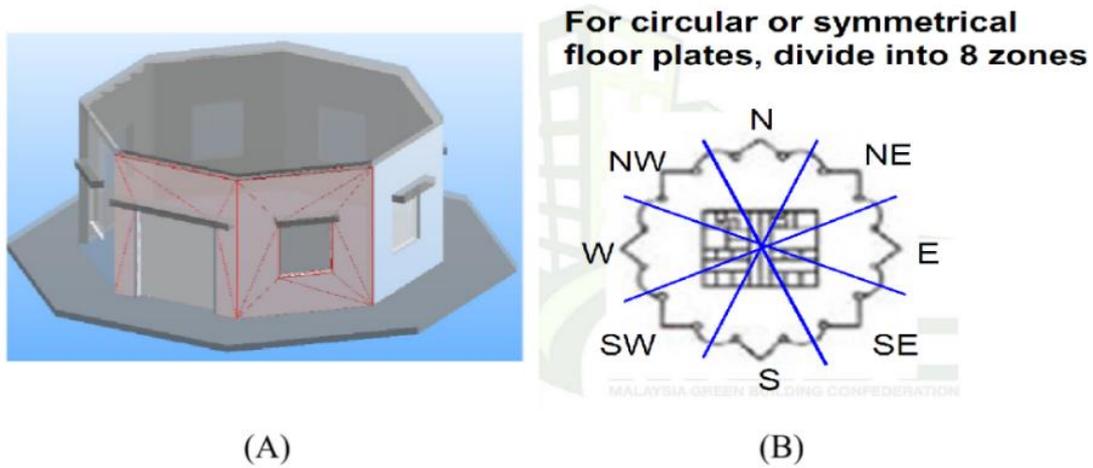
(A)   (B)

Figure 3. (A) A proposed model by Liu et al. (2020), (B) A proposed technique by Chan (2017)
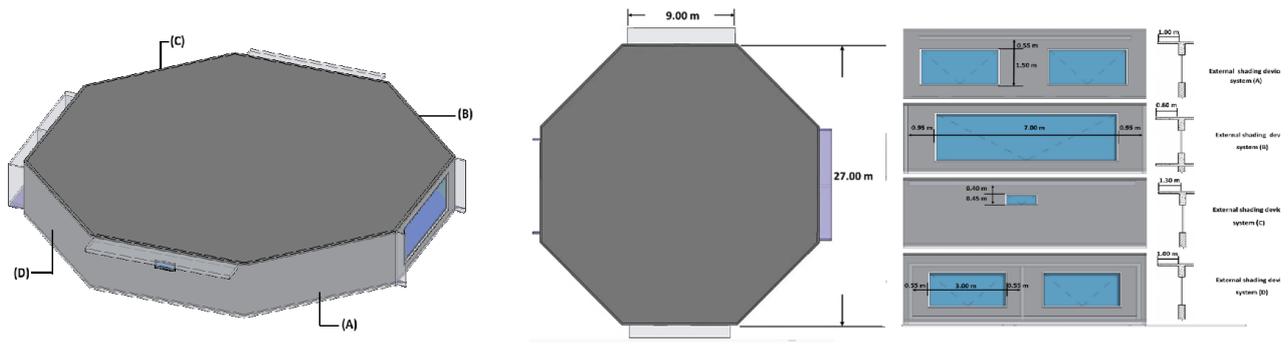

Figure 4. A proposed 3D model

3.4 Validation Methods and Case Studies

3.4.1 Validation Methods

The OTTV concept originated with ASHRAE Standard 90-75. Countries like Singapore, Malaysia, and Thailand have adopted the OTTV concept to suit their specific climates and building practices. These calculations are based on three primary sources of heat gain through the building envelope. In addition, parameters such as WWR, U-Value, and SC are the main ones in all three standards.

While the key parameters share similarities, distinct numerical coefficients are observed across the three countries. For example, Singapore and Malaysia establish constants for wall and window temperature difference (i.e., 15, 12, 6, and 4.3) and solar coefficient factor (194 and 211). In contrast, MS1525 incorporates solar absorptivity. Meanwhile, Thailand's OTTV equation employs parameters such as equivalent temperature (Teq), temperature difference (ΔT), solar heat gain coefficient (SHGC), and exterior shading reduction (ERS).

As stated in Section2.3.2 2.4, this study focuses on implementing BIM-VPL to enhance energy performance assessment, particularly for workflows tailored to MS1525:2019. Building on the foundational work of Seghier et al. (2017), Natephra et al., and Liu et al., and leveraging their validation methods, this study addresses the limitations identified in

Table **3**. Utilising BIM-VPL accelerates OTTV/RTTV calculations by treating constants and variables, promoting standardisation and practical adoption within the field.

The calculation of OTTV/RTTV in Malaysia is conducted through a traditional approach or using an outdated BEIT tool. In this study, the proposed workflows were validated using the traditional approach (manual calculation), as in Liu et al. (2020) and Natephra et al. (2018). Then, Microsoft Excel sheets were created to perform manual calculations based on OTTV and RTTV codes. The OTTV/RTTV spreadsheet template was then compared with the spreadsheets presented by Leong (2009) and Djamila et al. (2018).

3.4.2 Hypothetical Models and Case Study Buildings

Figure 5 displays the hypothetical building models used for this purpose, aligning with the approach presented in Table 2, where five of the seven studies also employed a hypothetical model. For validation, a twenty-five-story office building and a twelve-story residential building were used. The OTTV index in Malaysia primarily targets commercial buildings, particularly offices with air conditioning systems, which is why the building type in Case Study 1 was chosen. At the same time, a nonspecific code for energy management in residential buildings remains in effect, even after the publication of the "Energy efficiency and use of renewable energy for residential buildings Code of practice" (MS1525, 2017). This standard outlines the current OTTV formula and accompanying details; accordingly, Case 2 represents a residential building. It is also worth noting that both building types are consistent with those used in verification studies. Finally, Table 6 details the parameters and coefficients required for OTTV estimation in these case studies.
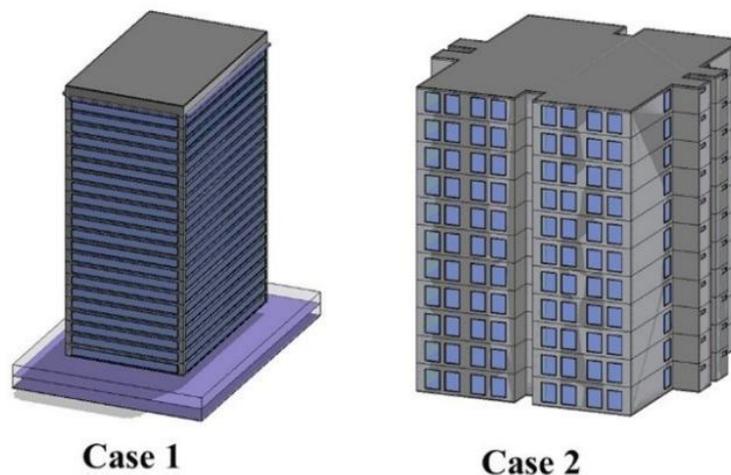

Figure 5. Hypothetical models

Table 6. Hypothetical model parameters

Model parameters	Thermal properties/ Constant
Plastered Brick wall	2.80 W/m^{2}K
Aluminium framed windows with non-coated single glazing (6mm)	2.55 W/m^{2}K
A 200 mm reinforcement concrete slab, covered with cement render	2.75 W/m^{2}K
Solar Absorption factor	0.30
Floor To Roof Height	3.00 m

This study forms part of a broader project that explores green envelope strategies to improve the thermal performance of tropical residential buildings using the OTTV code. As a second validation case within this project, three similar double-storey modern bungalows in Johor Bahru are illustrated in Figure 6. Cases A, B,

and C, with built areas of 318 m², 348 m², and 380.60 m², respectively, were selected. These houses share comparable construction materials and total built areas, ensuring accuracy of the OTTV results. After acquiring architectural drawings, their key physical and thermal properties were entered into the BIM model for analysis. Table 7 summarises the main validation parameters and coefficients.
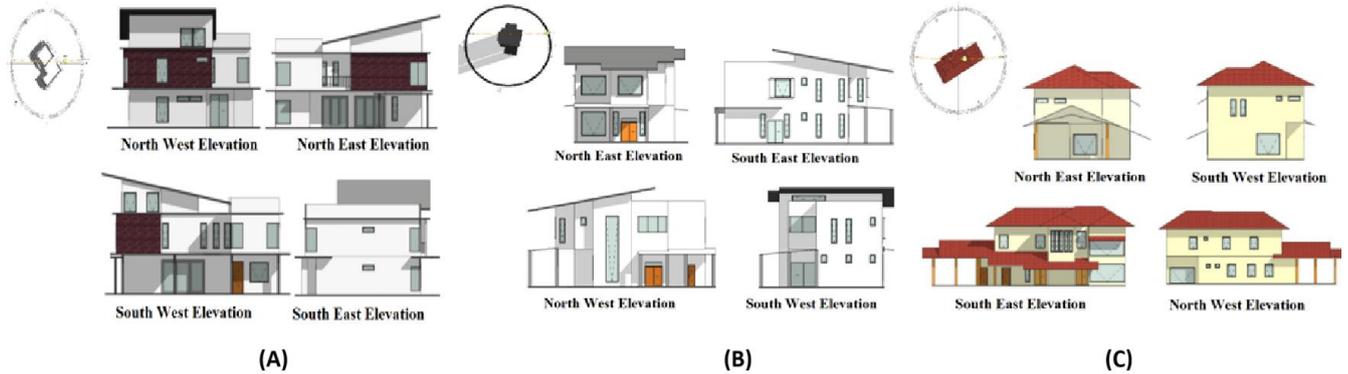

Figure 6. Exterior elevations of Case studies A, B, and C.

Table 7. Case studies model parameters

Case study	Model parameters	Thermal properties/ Constant
A, B, and C	Plastered Brick wall	2.80 W/m²K
A	Red Brick wall	4.97 W/m²K
A, B, and C	Single-glazing aluminium-framed windows	5.74 W/m²K
A and B	A 200 mm reinforcement concrete slab, covered with cement render	3.20 W/m²K
C	Slope metal roof with clay roof tiles	3.10 W/m²K
A and B	Solar Absorption factor	0.30
C	Solar Absorption factor	0.52

The next section provides a detailed overview of the proposed system's development to explore the performance of this novel concept.

3.4.3 List of Scripts

The proposed workflows are created using a set of scripts (Figure 17 and Figure 18). Each script has a set of nodes provided by VPL with BIM (Dynamo) as highlighted:

- **Select walls based on the orientation:** Categories, CodeBlock, All Elements of Category, Math / Operators [=], and elements.FilterByParameterValueAndCondition.

- **Assign window orientation:** Categories, Wall orientations, All Elements of Category, Element. Host, Element.GetParameterValueByName, Rhythm.Elements.SetParameterByNameTypeOrInstance

- **Filter of windows on the selected orientation:** CodeBlock, Elements.FilterByParameterValueAndCondition, Math / Operators [==]

- **Shading Coefficient:** Select Face, Geometry.DistanceTo, CodeBlock, Math / Operators [*], [÷]

- **Extract & Estimate OTTV, and U_r coefficients and parameters:** CodeBlock, Elements.Element.Name, Elements.Element.ID, Rhythm.Elements.GetParameterValueByNameTypeOrInstance, Elements.Element.GetParameterValueByName, Math / Operators [*], [+], [~].

- **Export to Excel:** CodeBlock, List Create, List.Transpose, List.AddItemToFront, File Path, Data.ExportToExcel.

4.0 PROPOSED OTTV AND ROOF THERMAL TRANSMITTANCE WORKFLOWS

4.1 Creating New Parameters in the Revit Template

A set of parameters named "Wall Orientation and Windows Orientation" is inserted into the model template to ease the filtration of elements according to their orientation (Seghier et al., 2017), which is shown in Figure 7. Two additional parameters, SC and OF, have been added under window elements to assign their values after the required script is executed. The new parameters were set under the "Green Building Properties" category.
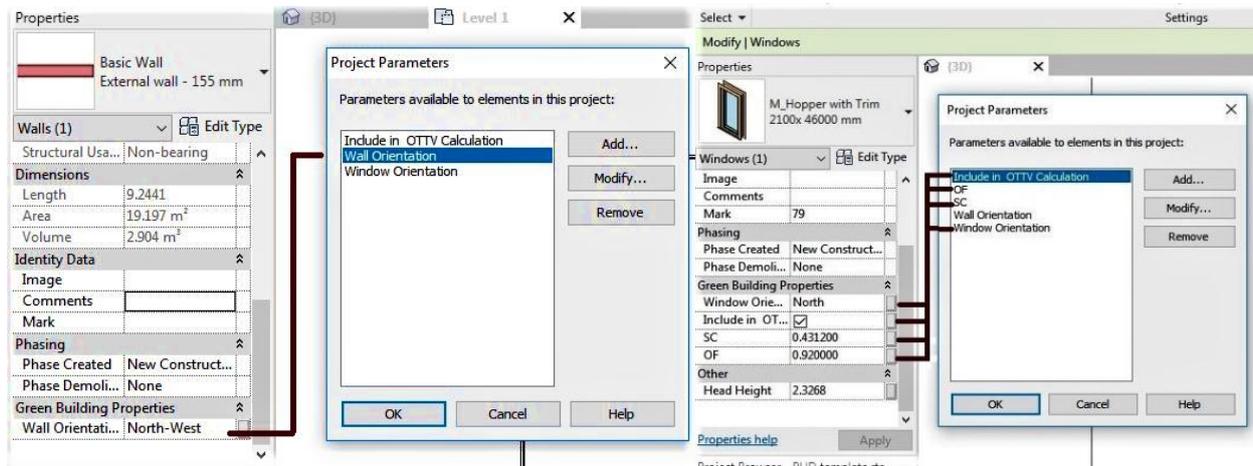

Figure 7. Create new parameters under Green Building Properties

4.2 Building's Orientation

The proposed workflow currently has a limitation that is semi-automated. In the future, we will fully automate the building orientation process. To overcome this, designers will enter each façade and window's orientation into the BIM database under "Green Building Properties." Before OTTV estimation, designers will connect three nodes corresponding to the orientation when running the script.

4.3 Assign the Window's Orientation

Figure 8 (A) presents a script designed to filter and exclude all the non-requirement windows based on the parameter "Include in OTTV Calculation," which was created to filter the non-desirable windows in the OTTV calculation (Seghier et al., 2017). Then, a mathematical function is used to match multiple elements (walls and windows) in the selected orientation, after the designer ensures that the code output is compatible with the required elements, as illustrated in Figure 8 (B).
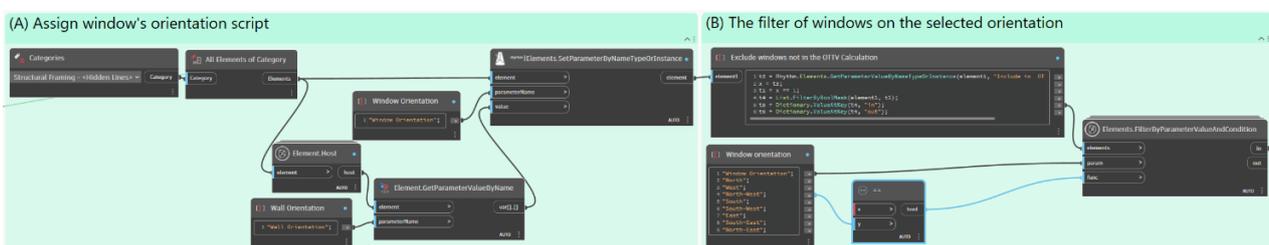
Figure 8. Process flow for filtering and assigning window orientation

4.4 Creating the Shading Coefficient (SC) Script

The shading coefficient (SC) of any glazing system is calculated by multiplying the SC of the glass (SC_1) by the SC of the external shading system (SC_2) using Eq. 4. To determine the shading coefficient of the external shading device (SC_2), Eqs. 5 and 6 are applied to estimate the ratio of the shading projection (refer to Figure 2). The ratio values are provided in the tables provided by MS1525:2019.

To achieve the stated process, a workflow is established to calculate the shading coefficient (SC). This coefficient measures the distance from the bottom of the overhang to the upper edge of the exposed window. A mathematical function then derives the ratio (R) of these measured elements. The type of shading device and the ratio's value are specified in the Code of Practice. These specify the SC_2 value. Use a mathematical formula to calculate the SC parameter based on the shading coefficient of glazing (SC_1) and the shading device (SC_2), as shown in Figure 9. Finally, assign SC's value to the project parameters created within the Revit project template. This step facilitates the extraction of coefficient values when computing OTTV using the OTTV workflow.

The developed SC workflow has a limitation: selecting the projection and window distance for each orientation. For this reason, the designer must manually select the (R). To help with this, ratios from MS1525 for each projection type are inserted into the workflow using Code Block nodes. Users do not need to get the values from the standard.
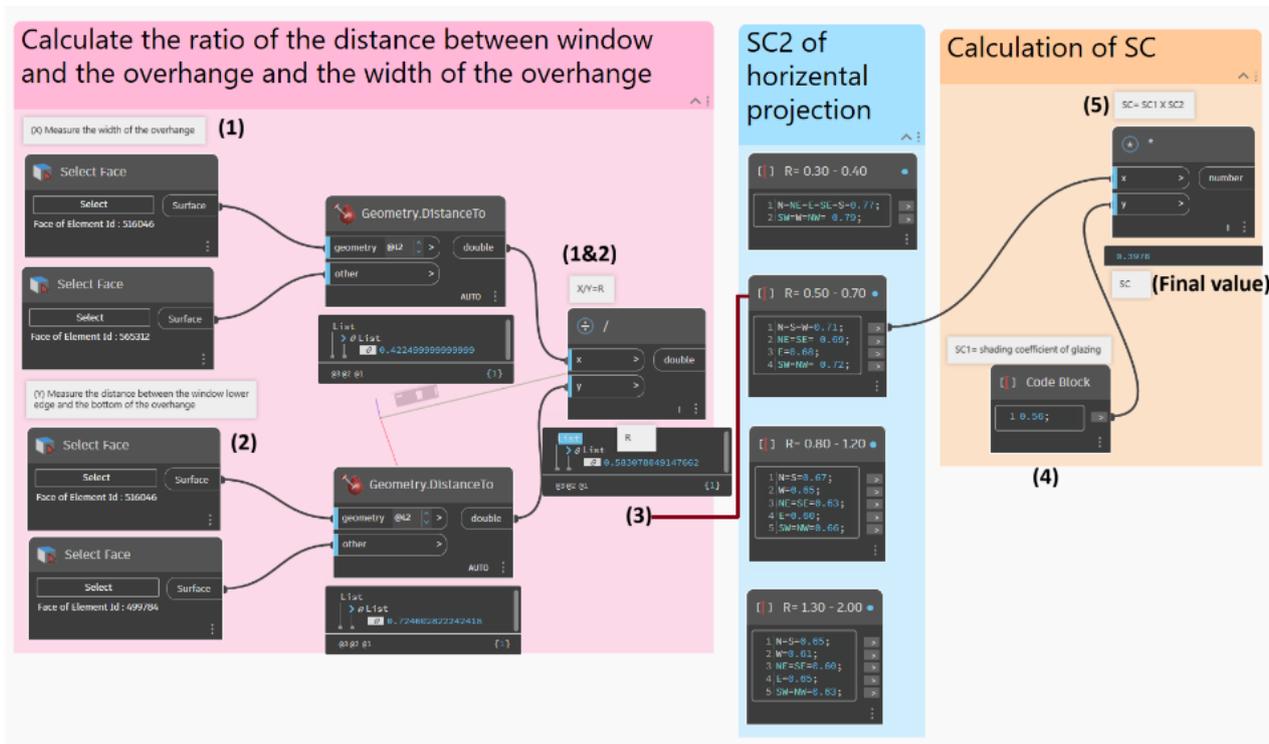

Figure 9. Process of calculating the SC coefficient using the Code Block node

4.4.1 Validation of the SC's Script

Figure 10 presents a simple model of several shading devices and windows on the North, West, South, and East orientations. This analysis step aims to obtain the SC_2 parameter; each computation is presented in Eqs. 5 and 6. To validate the proposed (SC) script, a variant design of external shading systems and windows was selected for the computational analysis presented in Figure 10. In contrast, Figure 11 and Figure *11* assessed the proposed script across various types of fenestration systems (i.e., horizontal projection, vertical projection, horizontal projection on a South orientation, and egg crate projection).
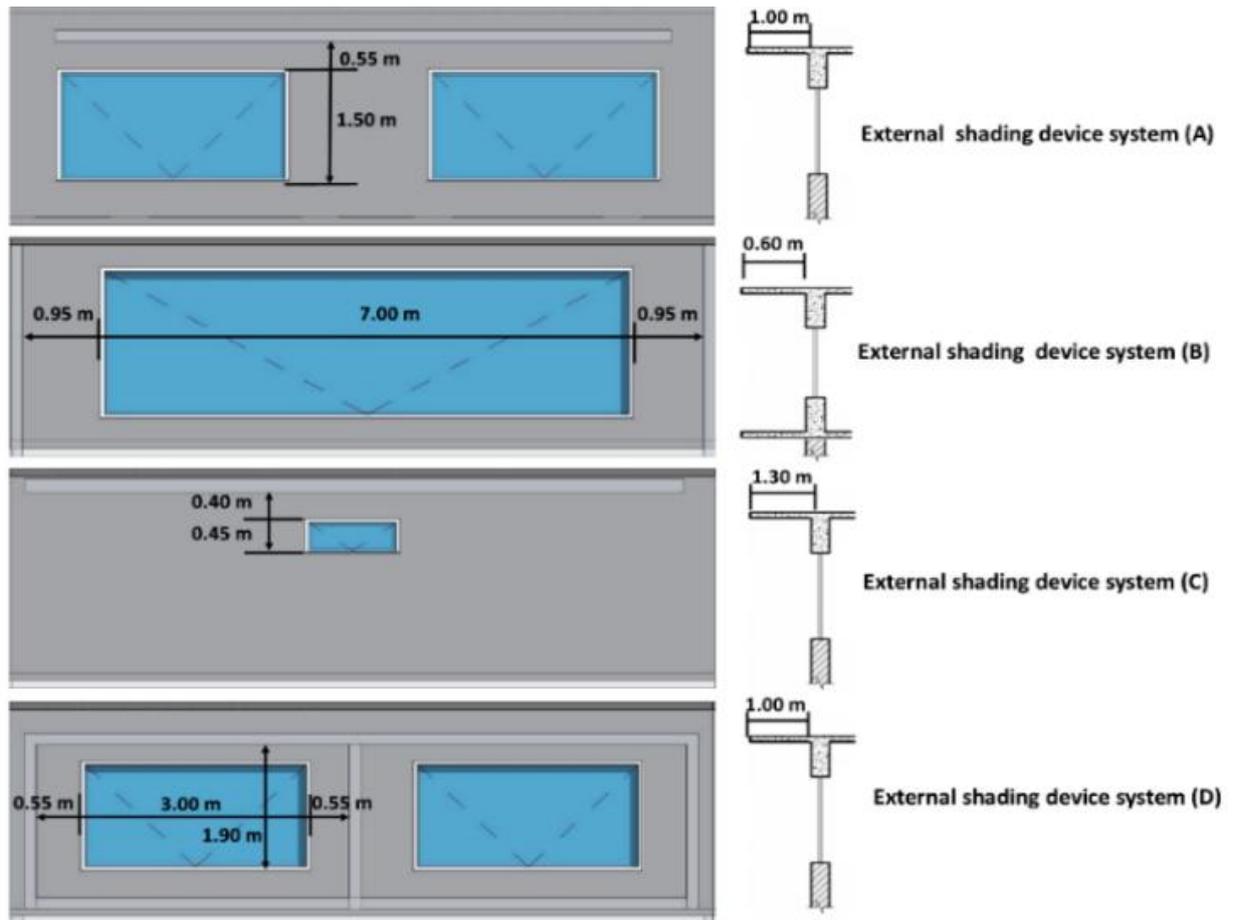
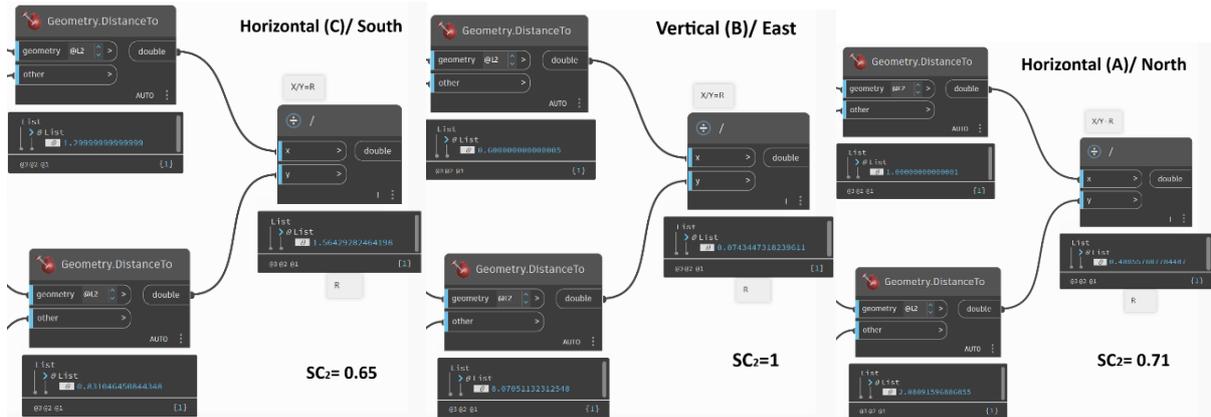**Figure 10.** Illustration of variant designs of external shading systems

Figure 11. Calculating SC$_2$ coefficient of (a) horizontal projection/ on north orientation; (b) vertical projection; (c) horizontal projection on south orientation.

Figure 12. Calculating the SC$_2$ coefficient of egg crate projection

The ratio for the external shading device (B) appears to be 0.1, which was not provided by MS1525. However, according to Nikpour et al. (2012), it could adopt the value (1) for any ratio not provided by standards.

4.5 Perform OTTV Using the Proposed Script

In this step, Eq. 2 is used to calculate the window-to-wall ratio (WWR), its complement (1-WWR), and the building's external area. Several nodes extracted the areas of opaque walls and windows at the required orientation. A mathematical function then computed the WWR, 1-WWR, and the total facade area.

After calculating the areas and ratios in the previous step, the process continues seamlessly with the extraction of other parameters, such as the thermal properties of the wall and window (U_w and U_f). The solar absorption of the wall (α), shading coefficient (SC), and orientation factor (CF) are also extracted from the BIM database. In this step, a set of Code Block nodes, such as the "Heat Transfer Coefficient" node for extracting U-value parameters of wall and window, and "Absorpance" nodes for obtaining the solar absorption factor based on wall colour, are used to extract the OTTV coefficients and parameters, as shown in Figure 13.

The extraction and calculation of data are validated using the hypothetical model in this step. As stated in Section 3.1, four opaque sides of the octagonal model are designed with varied wall materials/finishes, mainly in walls A, B, C, and D. The proposed node (Figure 13) functions by extracting the required data from the BIM 3D model and calculating the Window-to-Wall Ratio (WWR) and its inverse (1-WWR), as presented in Figure 14.
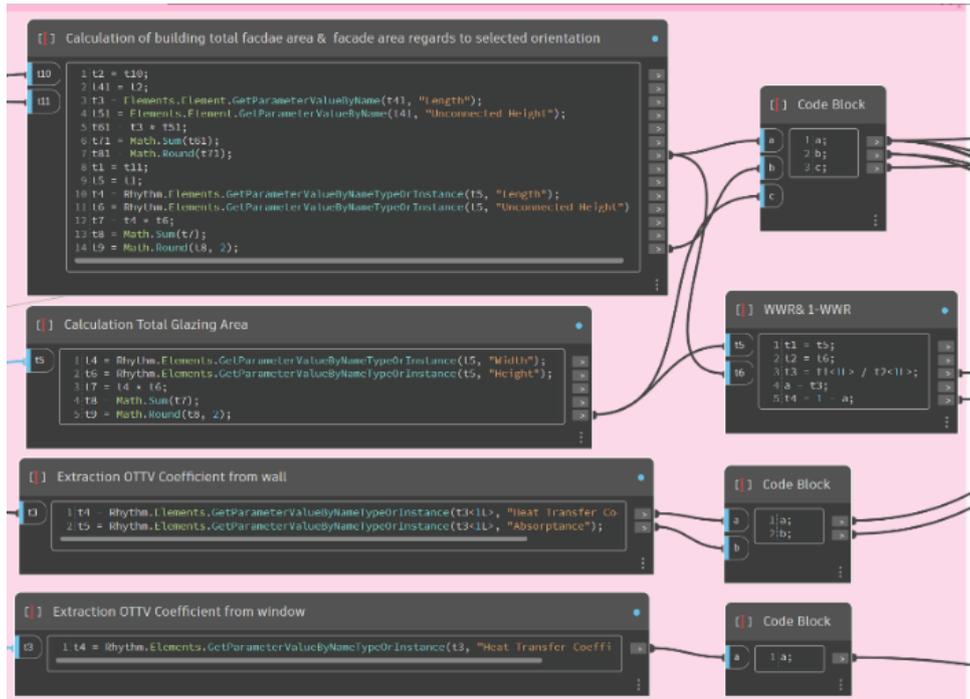
Figure 13. Set of nodes used to extract and estimate $OTTV_i$ parameters and coefficients
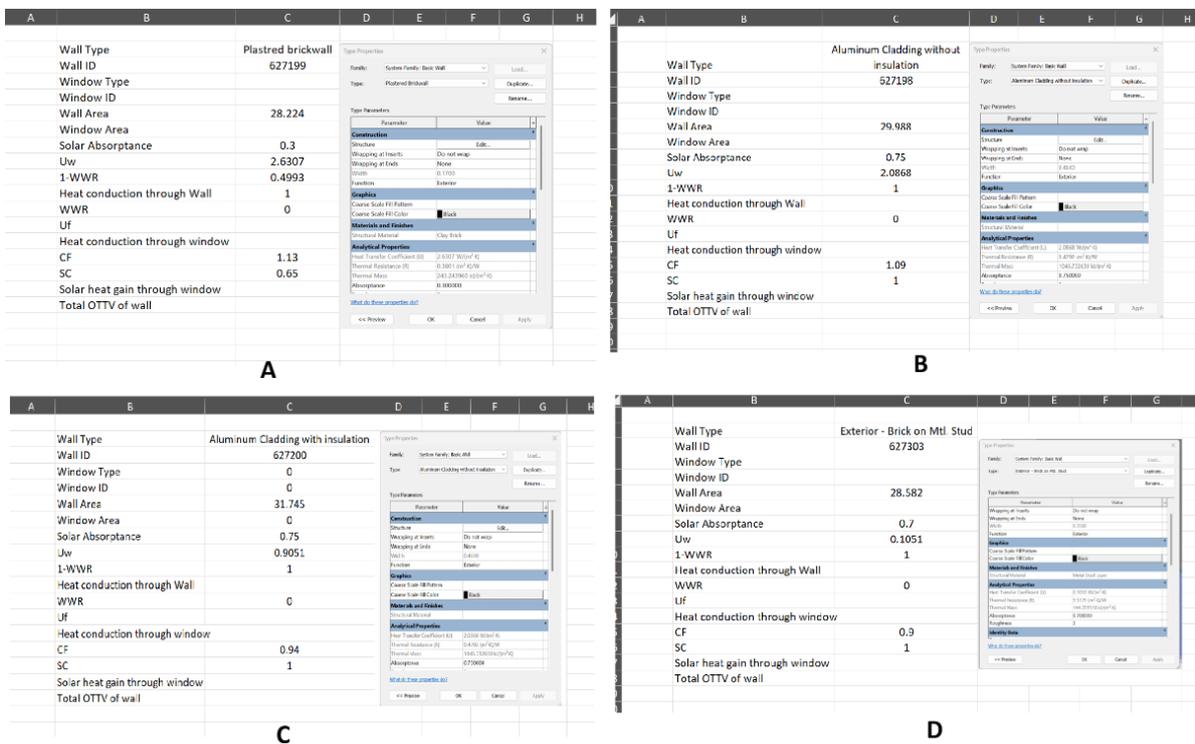

Figure 14. Data extraction and calculation from the BIM 3D model

After gathering all required coefficients and parameters, three nodes were created for each term in the OTTV formula, as shown in Eq. 7 and in Figure 15 (A). The data for thermophysical properties and coefficients needed for the OTTV calculation were organised and prepared for export to Excel using a Dynamo script, as shown in Figure 15 (B). All the scripts and nodes created to estimate OTTV are presented in Figure 17.
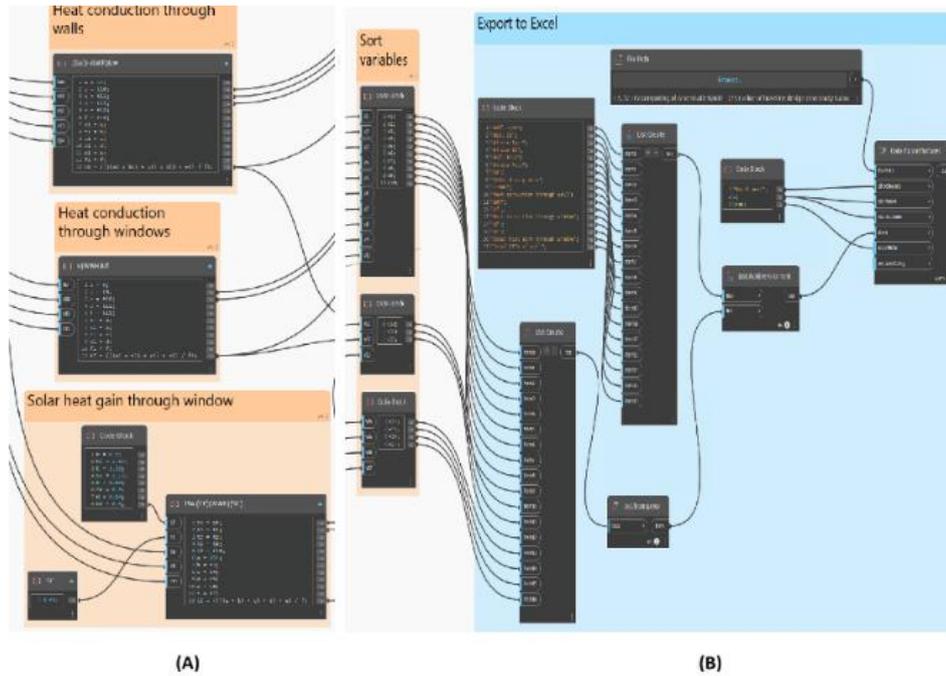
Figure 15. (A) Computational of the OTTV; (B) List of nodes used to export the final result

4.6 Proposed Workflow for Roof Thermal Transmittance (U_r) Computational

The MS1525 standard employs two methods to calculate the amount of heat that passes through roofs: one for roofs with skylights and another for roofs without. This study examines buildings without skylights and provides guidance on calculating heat loss for this roof type using Eq. 8.

The proposed U_r workflow, unlike the OTTV workflow, simplifies the process by focusing exclusively on extracting the roof's heat transfer coefficient (U-value) and total area for calculation. OTTV includes additional steps, potentially more complex, unrelated to these specific measurements. In the U_r workflow, the U-value is calculated using a Mathematical Function and then exported to an Excel spreadsheet, consistent with the OTTV export method.

The proposed script is fully automated because it focuses on estimating the roof's thermal transmittance, as shown in Eq. 8. To ease the process, a script is added to the Dynamo Player offering a straightforward method to automate manual tasks through an intuitive interface. Figure 16 shows the developed script for estimating and exporting U_r results, whereas Figure 18 shows the proposed full workflow.
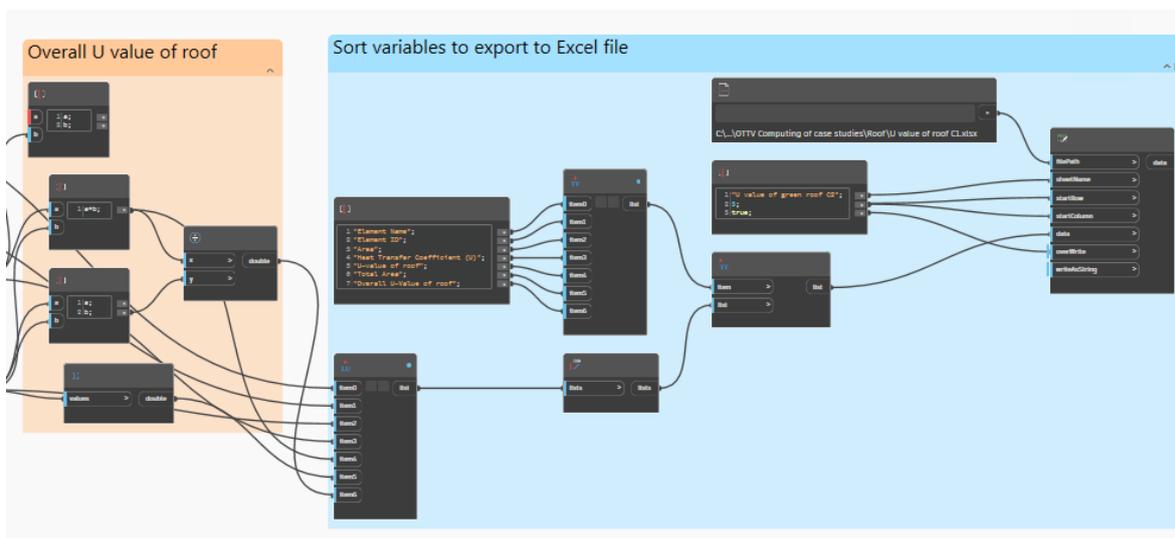

Figure 16. (A) Computation of the U_r; (B) List of nodes used to export the result

Figure 17. The proposed script to estimate OTTV

Figure 18. The proposed script to estimate the roof thermal transmittance (U$_r$)

4.7 Validation of the Proposed Workflows

This section validates the proposed OTTV and Roof thermal transmittance systems using the manual calculation method, following the methods of Liu et al. (2020) and Natephra et al. (2018). Validation utilizes three hypothetical models and three residential buildings.

4.7.1 Workflow's Validation with Hypothetical Buildings

Two validation studies are presented in Figure 5 to verify the accuracy of the computational thermal performance envelope. Results were obtained using the BIM model, and estimates were made with the proposed scripts and manual calculations.

As shown in Figure 19 and Table 8, the study comparing manual and computer calculations yielded very close results: in Case 1, OTTV differed by only 0.47% (66.09 vs. 65.62 W/m²), with the largest directional difference occurring in the south at 2.34%. Case 2 was even closer, with just a 0.06% difference (33.40 vs. 33.42 W/m²). Roof heat values were also very similar, with differences always under 1%. These results show that the BIM-VPL proposed system closely matches manual methods, providing a reliable and efficient alternative for OTTV calculations.
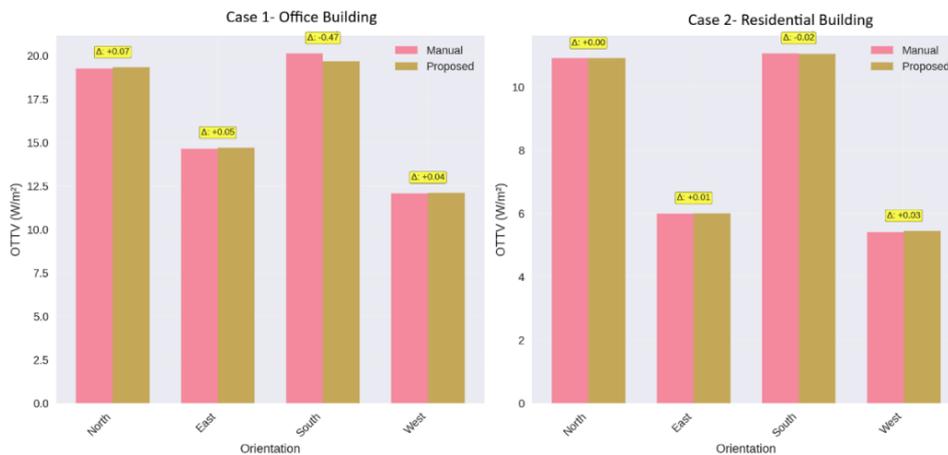

Figure 19. Workflow's validation for $OTTV_i$ assessment in hypothetical buildings

Table 8. Workflow's validation for U_r assessment in hypothetical buildings

Case 1	U_r of the proposed workflow (W/m²K)
Manual calculation	2.76
Proposed workflow	2.74
Case 2	
Manual calculation	2.74
Proposed workflow	2.75

4.7.2 System Validation with Real case Studies

The validation of the proposed systems using the traditional approach was carried out at the selected bungalow houses located in Johor Bahru State, as presented in Figure 6. The discussion of the calculation results included the OTTV and Roof thermal transmittance, summarised in Figure 20 and Table 9.

Actual building case studies empirically validated the system's strength and practical applicability. In Case A, the OTTV discrepancy was just 0.11%, with manual calculations at 35.39 W/m² and the proposed system at 35.35 W/m². In Case B, the largest deviation was 0.58%, with manual calculations at 29.32 W/m² and the system at 29.15 W/m². In Case C, the discrepancy was 0.27%, with manual calculations at 37.50 W/m² and the system at 37.40 W/m². Orientation-wise analysis evaluating discrepancies for each building façade direction

across all real building cases consistently showed deviations of under 2%, with most variations around 0.5% or less. Furthermore, from Table 9, it can be observed that the estimated value of the roof thermal transmittance using both techniques shows only a slight difference across the three cases, with the lowest deviation at 0.47% and the largest at almost 1% for cases A, B, and C, respectively.
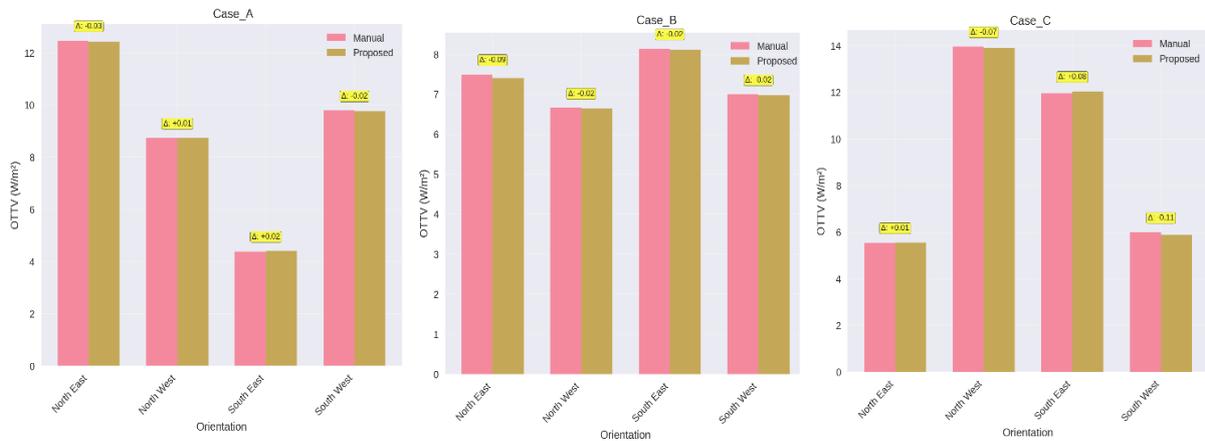

Figure 20. Workflow's validation for OTTV assessment in real case study buildings

Table 9. Workflow's validation for U_r assessment in real case study buildings

Case study buildings	Roof thermal transmittance value (W/m^{2}K)
Case A &B	
Manual calculation	3.20
Proposed system	3.28
Case C	
Manual calculation	3.10
Proposed system	3.07

4.7.3 Comparison of the Time Requirement for Manual Calculation and the Proposed System

The proposed system streamlines OTTV calculation, reducing the 53–70.25 minutes required by manual methods (as shown in Figure 21) to just 13.49–17.05 minutes using scripts. For example, in Case 1, manual calculation took 60 minutes, while the system required only 15.20 minutes; in Case C, the time dropped from 70.25 to 17.05 minutes. Overall, the system consistently reduced calculation time by about 70–80%. In terms of roof thermal transmittance (U_r), the script took only 1 minute, compared to 15 minutes with the traditional method. Due to the simplified scripts, the system detects, extracts, and estimates the thermal conductivity of the roof's materials.

Input data, such as thermal resistance values for construction materials and shading coefficients, were sourced from standards or studies with climates similar to the climate in the study area. Because the cases share similar configurations and material properties, the system further enhances efficiency by reducing the effort required for data collection and input. If designers needed to compile unfamiliar data, manual calculations would be even more time-consuming. Thus, assessing five scenarios not only highlights the workflow's reliability and accuracy for practical thermal performance evaluation but also demonstrates how the integrated process effectively connects data sourcing, system efficiency, and evaluation outcomes.

Figure 21. Comparison of the time required to perform the OTTVR between manual calculation and the proposed system

5.0 RESULTS & DISCUSSIONS

The proposed BIM-VPL workflows were reviewed through a comparative analysis with the traditional manual calculation method. This process followed the established protocols of previous studies by Natephra et al. and Liu et al. The assessment included both hypothetical building models and real-world case studies to verify the accuracy and efficiency of the automated computations of OTTV and roof thermal transmittance (U_r).

The review of the theoretical models demonstrated a strong correlation between the suggested workflows and manual calculations. Figure 19 and Table 7 summarize the findings. For Case 1, the OTTV discrepancy was minimal at 0.47% (66.09 W/m² manual vs. 65.62 W/m² proposed). The largest directional variance was observed on the south façade, at 2.34%. In Case 2, the correlation was even closer, with only a 0.06% difference (33.40 W/m² vs. 33.42 W/m²). The computed U_r values were also consistent. All deviations remained below 1% in each case, as shown in Table 8. Collectively, these results confirm this method as a reliable and accurate alternative to traditional computation methods, as firmly evidenced by subsequent practical validation.

To further demonstrate the workflows' validity, the system's practical applicability was empirically evaluated using three residential bungalows. Specifically, the results, detailed in Figure 20 and Table 9, showed consistently low discrepancies. In greater detail, for Case A, the OTTV deviation was 0.11% (35.39 W/m² vs. 35.35 W/m²). Case B exhibited the largest deviation at 0.58% (29.32 W/m² vs. 29.15 W/m²), whereas Case C showed a 0.27% difference (37.50 W/m² vs. 37.40 W/m²). Moreover, orientation-specific analysis demonstrated that deviations for each façade were consistently below 2%, with the majority near 0.5% or less. Finally, the (U_r) calculations revealed minimal variance, with deviations ranging from 0.47% to 1%.

Furthermore, these assessments indicate strong performance, with only modest differences resulting from the partial automation of specific workflow steps. For example, manually choosing parameters when calculating shading coefficients causes variation. Additionally, estimating ratios not in MS1525, as suggested by Nikpour et al. (2012), can lead to greater differences. Despite these issues, the very low, narrow error margins indicate that the proposed computational method is robust.

Regarding the study's hypothesis, the proposed BIM-VPL system is expected to accelerate processing. Manual calculations are directly compared to the proposed system. As illustrated in Figure 21, manual calculation required 53-70.25 minutes for an OTTV assessment, whereas the proposed system completed the task in 13.49-17.05 minutes, demonstrating a 70–80% time saving. In contrast, the U_r calculation was particularly efficient, taking about 1 minute rather than 15 minutes with conventional methods. This efficiency stems from automated extraction of thermal and geometric data from the BIM model, eliminating the laborious, error-prone manual data entry and lookup in traditional spreadsheets.

Fatma H. Younis, et. al

To conclude, the proposed systems address a gap identified in the literature. Unlike the platform by Liu et al., which relies on an online environment, this research utilises embedded VPL within a standard BIM authoring tool to enhance accessibility. It advances Natephra et al. by offering a validated workflow for the MS1525:2019 standard, incorporating shading coefficients and roof calculations that were previously absent in previous studies.

6.0 CONCLUSIONS

The study hypothesised that integrating Building Information Modelling (BIM) with a Visual Programming Language (VPL) could automate the calculation of the Overall Thermal Transfer Value (OTTV) and roof thermal transmittance (U_r). The study aimed to enhance the efficiency of building envelope thermal performance assessment in accordance with the MS1525:2019 standard, both during and after the design stage. To validate this, a comprehensive methodology was employed.

First, a hypothetical model with an octagonal layout was developed to ensure a rigorous and controlled testing environment and to test the system's ability to handle all eight primary orientations and various types of shading devices. Following that, practical validation included both hypothetical and real-world case studies. For the hypothetical scenario, two types of buildings (i.e., commercial and residential) were chosen to reflect real-world conditions. For real-world examples, three modern bungalows in Johor Bahru were selected for their representative construction methods and material properties, typical of regional residential buildings.

The results confirm the initial hypothesis with high precision. The system demonstrated accuracy, with discrepancies in OTTV results below 0.6% and U_r values below 1% when compared with manual calculations. More significantly, the workflow reduces the time required for performance assessment by 70–80%, mitigating the risk of human error and streamlining the design feedback loop.

BIM-VPL has been confirmed as a powerful and effective tool for assessing and analysing the thermal performance of envelopes. This study aims to provide designers without prior VPL or coding experience with a practical solution to streamline material selections, guide design decisions, and meet energy-efficiency targets during the preliminary design stages.

Future work will focus on fully automating the remaining steps, especially the assignment of shading device parameters. Development of a system to compute RTTV in accordance with MS1525:2019 is under consideration for the near future. Another direction is to assess how the system improves the thermal performance of buildings with greenery systems.

ACKNOWLEDGEMENT

7.0 REFERENCES

A Abass, F., Ismail, L. H., Wahab, I. A., & Elgadi, A. A. (2020). Development of a Model for OTTV and RTTV based on BIMVPL to Optimize the Envelope Thermal Performance. *IOP Conference Series: Materials Science and Engineering*, *713*(1), 012009. [cross ref]

Allard, I., Nair, G., & Olofsson, T. (2021). Energy performance criteria for residential buildings: A comparison of Finnish, Norwegian, Swedish, and Russian building codes. *Energy and Buildings*, *250*, 111276. [cross ref]

ASHRAE 90- 75. (1975). *Energy Conservation in New Building Design*.

Chan Seong Aun. (2017). *PAM Northern Chapter CPD UBBL BY-LAW 38A*. [cross ref]

Changnawa, T. (2023). *Integrating Building Information Modeling for Thermal Transfer Value Calculation in*

A Conceptual Design Stage (Issue May). Texas A&M University.[cross ref]

Coskun, C., Zhao, T., Lai, J., Soy, M., & Cory, C. (2025). Visual Programming Language (VPL) for Generative Architecture Design: A Literature Review. *CIB Conferences*, *1*(1). [cross ref]

Deringer, J. J., Busch, J. F., Hall, J., Kannan, K. S., Levine, M., Ayub, A. C., & Turiel, I. (1987). Energy and economic analysis in support of energy conservation standards for new commercial buildings in Malaysia. In *the ASHRAE Far East Conference on Air-conditioning in Hot Climate, Singapore*.[cross ref]

Djamila, H., Rajin, M., & Rizalman, A. N. (2018). Energy efficiency through building envelope in Malaysia and Singapore. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *46*(1), 96–105. [cross ref]

Eid, A., Aboulnaga, M. M., & Mahmoud, A. H. (2022). VPL-based Code Compliance Checking for Building Envelope Design Using OTTV Calculation. *IOP Conference Series: Earth and Environmental Science*, *1056*(1), 12033. [cross ref]

Elias, R., & Issa, R. R. A. (2024). Artificial Neural Network–Based Generative Design Optimization of the Energy Performance of Florida Single-Family Houses. *Journal of Computing in Civil Engineering*, *38*(2), 4024001. [cross ref]

González, J., Soares, C. A. P., Najjar, M. K., & Haddad, A. (2021). BIM and BEM Methodologies Integration in Energy-Efficient Buildings Using Experimental Design. *Buildings*, *11*(10), 491. [cross ref]

Hui, S. C. M. (1997). Introduction to Energy Efficient Building Design - Environmental Controls. In *Advanced on Energy*. Department of Architecture, the university of Hong Kong. [cross ref]

IPCC. (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (C. U. and N. Y. Cambridge University Press (ed.)). Cambridge University Press. [cross ref]

Kannan, K. S. (2007). Development of an Energy Rating System for Office Buildings. *Conference on Sustainable Building South East Asia*, *November*, 71–76. [cross ref]

Kurniawan, T. B., Dewi, D. A., Usman, F., & Fadly, F. (2023). Towards Energy Analysis and Efficiency for Sustainable Buildings. *Emerging Science Journal*, *7*(6), 2226–2238. [cross ref]

Lam, J., Hui, S. c., & Chan, A. L. (1993). Overall thermal transfer value control of building envelope design, part 1-OTTV limits. *Hong Kong Engineer*, *21*(8), 27–31. [cross ref]

Leong, A. V. K. (2009). MS1525:2007 Clause 5: Building Envelope. In *BGI CPD Seminar* (Issue July).[cross ref]

Leong, A. V. K. (2018). Towards Zero Carbon City A Recap of OTTV and Roof U-Values. (Issue September). [cross ref]

Lim, Y., Seghier, T. E., Harun, M. F., Ahmad, M. H., Samah, A. A., & Majid, H. A. (2019). Computational BIM for Building Envelope Sustainability Optimization. *MATEC Web of Conferences*, *278*, 04001. [cross ref]

Liu, Z., Wang, Q., Gan, V. J. L., & Peh, L. (2020). Envelope thermal performance analysis based on building information model (BIM) cloud platform - Proposed green mark collaboration environment. *Energies*, *13*(3). [cross ref]

Marín Miranda, M. J., García Dópido, I., Chorro Domínguez, F. J., Martín Castizo, M., & Campón Tovar, J. A. (2020). Verification of Energy Demand in Early Stage Design Using BIM Methodology. *Congresso Português de Building Information Modelling*, 411–419. [cross ref]

Massafra, A., & Gulli, R. (2023). Enabling bidirectional interoperability between BIM and BPS through

lightweight topological models. *ECAADE PROCEEDINGS*, *2*, 187–196.[cross ref]

Morakote, N., Rinchumphu, D., Manokeaw, S., & Khuwuthyakorn, P. (2025). BIM-based Automation for OTTV Calculation and Construction Cost Estimation in Energy-Efficient Building Design. *Proceedings of the 11th World Congress on New Technologies (NewTech'25)*, *1*, 1–8. [cross ref]

MS1525. (2017). *Malaysian Standard Energy Efficiency and Use of Renewabl Eenergy for Residential Buildings - Code of Practice*. Ministry of Science, Technology and Innovation.

MS1525. (2019). *Energy Efficiency and Use of Renewable Energy for Non Residential Buildings Code of Practice (Third revision)*.

Natephra, W., Yabuki, N., & Fukuda, T. (2018). Optimizing the evaluation of building envelope design for thermal performance using a BIM-based overall thermal transfer value calculation. *Building and Environment*, *136*(November 2017), 128–145. [cross ref]

Nikpour, M., Zin Kandar, M., Ghasemi, M., Ghomeshi, M., & Safizadeh, M. (2012). Heat transfer reduction using self shading strategy in energy commission building in malaysia. *Journal of Applied Sciences*, *12*(9), 897–901.[cross ref]

Niza, I. L., Luz, I. M. da, Bueno, A. M., & Broday, E. E. (2022). Thermal Comfort and Energy Efficiency: Challenges, Barriers, and Step towards Sustainability. In *Smart Cities* (Vol. 5, Issue 4, pp. 1721–1741). MDPI. [cross ref]

Olofsson Hallén, K., Forsman, M., & Eriksson, A. (2023). Interactions between Human, Technology and Organization in Building Information Modelling (BIM) - A scoping review of critical factors for the individual user. *International Journal of Industrial Ergonomics*, *97*, 103480. [cross ref]

Sajjad, M., Hu, A., Alshehri, A. M., Waqar, A., Khan, A. M., Bageis, A. S., Elaraki, Y. G., Shohan, A. A. A., & Benjeddou, O. (2024). BIM-driven energy simulation and optimization for net-zero tall buildings: sustainable construction management. *Frontiers in Built Environment*, *10*(February), 1–16. [cross ref]

Sampaio, A. Z., & Araújo, L. (2023). *The 6D BIM Model Applied to Evaluate the Building Energy Performance* (pp. 268–278). Springer Nature. [cross ref]

Seghier, T. E., Khosakitchalert, C., Liu, Z., Ohueri, C. C., Lim, Y. W., & Bin Zainazlan, A. F. (2025). From BIM to computational BIM: A systematic review of visual programming application in building research. *Ain Shams Engineering Journal*, *16*(1), 103173. [cross ref]

Seghier, T. E., Lim, Y. W., Ahmad, M. H., & Samuel, W. O. (2017). Building Envelope Thermal Performance Assessment Using Visual Programming and BIM, based on ETTV requirement of Green Mark and GreenRE. *International Journal of Built Environment and Sustainability*, *4*(3), 227–235. [cross ref]

Seghier, T. E., Lim, Y. W., Harun, M. F., Ahmad, M. H., Samah, A. A., & Majid, H. A. (2022). BIM-based retrofit method (RBIM) for building envelope thermal performance optimization. *Energy and Buildings*, *256*, 111693. [cross ref]

Shahsavari, F., Hart, J. D., & Yan, W. (2021). Risk Assessment for Performance Driven Building Design with BIM-Based Parametric Methods. *International Conference on Computer-Aided Architectural Design Futures*, 456–472.[cross ref]

Tsikas, P., Chassiakos, A., Papadimitropoulos, V., & Papamanolis, A. (2025). BIM-Based Machine Learning Application for Parametric Assessment of Building Energy Performance. *Energies*, *18*(1). [cross ref]

United Nations Environment Programme (2023). *Building Materials and the Climate: Constructing a New Future*. United Nations Environment Programme. [cross ref]