Development of a Model for OTTV and RTTV based on BIM-VPL to Optimize the Envelope Thermal Performance

F Abass 1, L H Ismail 1, I A Wahab 1 and A A Elgadi 1

1 Department of Architecture, Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
Corresponding author: fatmaelbeltagy@gmail.com

Abstract. The thermal performance of a building has a profound effect on sustaining the conditions of indoor environments, and it is critical in obtaining any energy-efficient design. Choosing an appropriate construction material is one of the most effective methods to prevent excessive energy consumption in the building, to minimize heat flows, and sustain a comfortable temperature for occupants. The majority of the existing buildings in Malaysia are mostly constructed using bricks for their outer walls; many studies nominated these materials as the producer of heat. This study is focusing on evaluating the thermal performance of construction materials in a tropical climate, with the involvement of manual calculation methods for Overall Thermal Transfer Value (OTTV) of walls and roof. Therefore, this study proposes integrating Building Information Model (BIM) and visual programming language (VPL) for supporting the calculation of OTTV based on MS1525:2014. The expected result of the proposed system will support designers on calculating OTTV coefficient comparable with the manual calculation, which is considered promising in minimizing time-consuming and human error when optimizing envelope performance during building design. This study proposed a model to access and extract construction materials properties from BIM library using VPL to estimate OTTV value using a real-time calculation tool.

1. Introduction
There is continually growing for energy, especially in the building sector, where approximately 40% of the overall global energy consumption is consumed by building [1]. The significant amount of energy requesting on buildings is to operate the mechanical cooling, which helps the occupants to achieve their level of thermal comfort. The considerable growth in CO₂ emissions alongside with the increase of energy demand is occurring in cities, where growing affluence and request for higher living standards caused by population is escalating [2]. An example, in Malaysia an enormous amount of electricity is consumed by conditioning units in commercial and residential buildings, mainly, during sunny days. Several challenges were faced by building designers when coming to maintain a comfortable environment and less energy consumption.

To increase the energy efficiency in buildings, building designers needs to become better aware of the thermal envelope performance and the selection of structural materials. Building thermal performance can be attributed to the procedure of modelling the heat transfer between the building envelopes to its surrounding environment. In simple words, thermal performance is a procedure of heat exchange through glazing and opaque wall. Modern materials like concrete, glass, and bricks are widely used in building construction in Malaysia, many studies nominated these materials as the producer of the non-comfort state for indoor spaces in a hot, humid climate. There is no doubt that the thermal
transmitter and the roof construction materials are the main reasons for indoor discomfort [3]. According to Leong [4], 5% of the heat was penetrated through the roof of the single-storey dwelling, compared with 50% for double storey dwelling.

The growing concern about building thermal performance and energy efficiency led to establishing many policies. These policies have a benefit to raise awareness and interest in energy conservation, encourage effective designs for energy, and promote the development of energy-efficient products. As an example to estimate the envelope thermal performance in building in hot, humid weather, a policy identified as the Overall Thermal Transfer Value (OTTV) was established to cut heat penetration over the exterior envelope, and hence decrease the electricity requesting for air conditioning. Whereas in cold countries, thermal insulation standard and the calculation of thermal transmittance value of envelope materials are more popular.

Typically, the OTTV has required a manual calculation method which could be time requiring for project team who are inexperienced through the calculation technique, especially when human errors during the calculation of the OTTV coefficient can drive to inaccurate results. Therefore, the adaptation of Building Information Modelling (BIM) and Visual Programming Language (VPL) has been progressively applied during the design and construction stages to help the designers to evaluate their design options [5]. The new integral of analyzing building thermal performance could help to maintain more design decisions regarding the selection of building materials to prevent the building from the excessive heat flow.

The primary key of this study is to develop an integrated model based on BIM and OTTV code, which is known as BOTTVC “Building Overall Thermal Transfer Value code.”. The development method could be used to evaluate the thermal performance of the building envelope compared with a manual calculation. When it comes to time-saving and minimization of human error, the proposed BOTTVC model could be a solution for analyzing building thermal performance, especially when it comes to reducing energy demand in buildings.

2. Theoretical background

2.1. Overall Thermal Transfer Value (OTTV) code

Since 2001, OTTV code has been taken into account in Malaysian Standard, especially for commercial conditioning buildings [6]. The main concern for Malaysian Standard is to consider the heat gain through windows of the building as a critical parameter. Due to energy inquiring to cool the indoor environment, the OTTV Equation generally focused on four important parameters which are U-value of structural materials, solar absorption, window-to-wall ratio, and shading coefficient; these components had a substantial impact on heat gain through the envelope [6]. In MS1525: 2014 “code of practice” [7], all the coefficients that influence the value of OTTV for walls or roof such as, solar absorptivity, orientation factors of fenestration wall, and shading coefficient were estimated based on several studies and simulations to accurate the Equation’s data with the climatic characteristic of Malaysia. Equation (1) illustrates the final OTTV equation for wall and equation (2) is ROTTVC for roof based on MS 1525:2014.

\[
\text{OTTV}_{i}=15 \alpha (1-WWR)U_w+6 (WWR)U_f+194 x CF x WWR x SC
\]  

(1)

\[
\text{ROTTVC}=(A_w x U_w x T_{d0}) + (A_r x U_r x \Delta T) + (A_s x SC x SF)/A_0
\]  

(2)

WWR: window to wall area ratio, \(\alpha\): a solar absorptivity of the wall color, \(U_w\), \(U_r\), \(U_s\) and \(U_f\): the thermal transmittance (U-value) of the opaque wall/roof, window glass, and skylight, CF: the solar orientation correction factor for roof/wall, SC: the shading coefficient of the fenestration wall based on orientation, \(\Delta T\): the temperature difference, and \(A_w\), \(A_r\): the area of opaque wall and skylight area.

OTTV requirements is considered simple without simulation process, especially when it applies to commercial condition building. OTTV evaluation is mostly calculated using excel spreadsheets during the design process to achieve less external heat penetration from outside building to inside. While it comes to residential buildings, there is no specific equation to calculate the OTTV in Malaysia, compared with other ASEAN countries which had their Envelope Thermal Transfer Transmittance
Value (ETTV) in Singapore and Thailand. For this reason, the current OTTV code in Malaysia for the assessment of residential building is by using both techniques of traditional calculation and simulation.

2.2. The integration of Building Information Modelling (BIM) in the analysis of building performance

The incorporation of BIM theory into the green building has acquired an enormous interest from practitioners and scholars concerned with both building sustainability issues and BIM [8]. Many studies have examined the optimization of energy performance using both BIM and multi-objective optimization algorithms [9], BIM for Green material selection [10], BIM for building with vegetation systems [11], and BIM for Daylighting optimization [12]. Currently, building performance evaluation via analysis software is mostly performed after the design stage; thus, it is not integrated into the design decision-making process. To effectively evaluate the multiple performance criteria in the building design, e.g., envelope material, form, and energy efficiency, the assessment of building performance should be seamlessly integrated into the design process [13].

Several packages of authoring software that is integrated with BIM allow designers to allocate the properties of structural material. While, these tools offer their Application Program Interface (API), which help to access and modify the thermal properties of construction materials in the BIM database. The users of BIM packages (Vectorworks, Bentley, Tekla BIM, ArchiCAD, MicrosoftStation BIM, and Catia) are required to have full knowledge in programming experience in order to use their API effectively, which is not achievable for designers who were not familiar with the programming. Thus, with understanding the importance of the link of BIM and VPL software, programming companies have been developing a VPL program that gives accessibility to access BIM database and customizes building elements with a reasonable understanding of programming.

2.3. The integration of Visual Programming Language (VPL) in the analysis of building performance

VPL tool has shown promising results when implementing to estimate building performance analysis such as daylighting optimization [9], energy efficiency, acoustical analysis structural analysis [14] and more. According to Kensek [15], the VPL could aid during the early design stages of deciding the sustainable optimized design. Several studies investigated the application of Visual Programming tools to generate workflows and frameworks related to analysis of building performance. As an example, Konis [16], established a framework to optimize the passive performance of the building. Façade design and enhancing shading are one of the hottest topics associated with the implementation of a BIM and VPL tool in the area of sustainable building analysis. More so, Kensek [15] demonstrated how VPL and BIM could be adapted to design a parametric shading device for elaborating façades and energy simulation performance. A similar study by Kim [17], determined a new method to analyze energy performance for elaborate kinetic façades.

The visual programming language can offer a new workflow to optimize building performance; the workflow could provide more access to advance the demand for energy during building design. In the last years, building designers become more concerned with Visual Programming tools that allow creating, modified, powerful, and flexible form of generating algorithms without having in-depth knowledge with coding [15]. Several of these VPL based tools accessible in the market are Marionette, Grasshopper, and Dynamo. However, since the first release of Dynamo as VPL, it was connected to one of the BIM authoring tool Revit.

VPL Dynamo is a free source tool devoted to developing the design process of building and workflows in both BIM and computational design fields. According to Vandezande [18], Dynamo offers incomes for designers with the constructing programmatic relationships using a Graphical User Interface (GUI). Therefore, rather than writing ‘code’ from scratch; the user is capable of making a custom algorithm by connecting pre-packaged nodes with assembling custom relationships. The ability of Dynamo in controlling the BIM parameters using Revit Architecture software added a further level of created and associativity new prospects for cross-discipline and cross-platform collaboration [19]. Various sorts of data can be controlled using Dynamo, such as family geometry, parameter values, and family placement. By creating new elements in Revit using Dynamo, the designer can modify its parameters manually within Revit. Moreover, the same Dynamo script can be reused in many projects.
3. Methodology

BOTTVc is a model that is originated by Natephra et al. [20] to create a connection between BIM and Dynamo as a visual programming language, to enhance the calculation of the thermal performance of building envelope during the design stages based on OTTV code adapted in Thailand, Hong Kong, and Singapore. BOTTVc model is a framework used to create an approach for data extraction and management, moreover, to reveal potential mechanization workflows for further improvement of the OTTV assessment tool.

Two main steps are required in order to develop the model of OTTV. First, the assessments of the OTTV requirement involve clarifying all the related criteria, such as OTTV’s coefficient data demand (input) and the specific coefficient description in MS1525:2014. In Malaysia Standard 1525:2014 “Energy efficiency and use of renewable energy for non-residential buildings - Code practice” [7], all OTTV’s requirement and the calculation methods were fully detailed in the standard.

Secondly, screening the available OTTV’s coefficient request in the BIM authoring tool that is used for this study (Autodesk Revit, 2016), therefore, if requested data could be automatically extracted from the 3D BIM’S model, it is then applied to Revit functionalities to modify requested equation. In a situation where there is no functionality available for the selected coefficient, gaps will be recognized, and additional improvement is conducted using Visual Programming scripting (Dynamo).

3.1. OTTV integration framework based on BIM – VPL

In this study, Revit Architecture 2016 and Dynamo 1.3 visual programming languages are used to improve the BOTTVc based on MS1525:2014. The adaption of VPL in this study is due to the limitation of BIM authoring software (Autodesk Revit) to perform some functions of OTTV coefficients. As an example, in equation (1), there are coefficients that the code primarily depends on them (opaque wall orientation, the WWR, and SC). These parameters could not be available in BIM database and required to follow equations to calculate them, which could be easy to estimate by developing a script in VPL (Dynamo).

3.1.2. Prepare 3D Modelling. The first step to calculate the OTTV for a building based on BIM started by creating a 3D model using authoring BIM software (Revit Architecture). The 3D contained the model of building elements (walls, windows, floor, shading device, roof, and doors) for the physical and thermal properties of the construction materials used on these elements developed using scripting tool.

3.1.3. Scripting the thermal and physical properties based on the BIM database and VPL. Materials construction of building elements could be automated from the BIM database or even modified during creating the 3D model, it is available in Revit object library, and it is automatically estimated based on the selected object. In a situation where there is a variant of building material combinations, the material properties are extracted from the BIM database and modify using two types of scripting available in dynamo, which is a Python and code black node.

1- Code Black node: Before starting using this type of scripting to access and extract material properties, linking between the BIM model and Dynamo base node “SelectModelElements” is required. Figure 1 explains the process of extracting the data using “CodeBlack.” Text script starts with select building element to access to material properties by “typeParameter” input; this step provides the user with access to a list of materials (IDs) in the properties list. A Parameter “ID” contains data and numerical units that scripting to obtain the value of “U” (value of wall and window glass) and the “R” (value of construction materials).

2- Python scripting is used to develop other coefficients of BOTTVc systems, by accessing to BIM material database in Revit using the API system. Some of the material coefficients could not be extracted using the Code Black node. Therefore, “ThermalAssesstClass” that symbolize the construction material properties related to energy assessment in Revit was used to access to material density, specific heat, and thermal conductivity. Figure 1 illustrates the process of extract material properties from BIM database using Code Black node and Python.
3.2. VPL to calculate OTTV coefficients

There are other coefficients that required estimating the value of OTTV and RTTV, which are SC, SF, CF, TDeq, A_s, A_r, ΔT and WWR, besides the calculation of the area of opaque wall/roof and the area of fenestration wall/roof, and the height and width of external shading devices.

3.2.1. Obtaining WWR, A_s and A_r value based on VPL.
To estimate the values of WWR, A_s and A_r using dynamo scripting, “SelectModelElements” node was applied to select the target wall, roof or skylight for every orientation. Then, “Element. Get Parameter Value by Name” node is implemented to extract the area of opaque wall/roof or fenestration wall from the 3D model using string node named “Area” after the extraction of the area a math node is adopted to calculate the value of WWR, A_s and A_r. After obtaining the surface area of the wall and roof, a solar absorption coefficient can be chosen as a constant provided in the practice code [7], in order to obtain the OTTV/RTTV as stated in equation (1) and equation (2).

3.2.2. Obtaining SC value based on VPL
According to MS1525:2014, SC could be estimated based on Equation (3):

\[ SC = SC_1 \times SC_2 \]  

Where: SC1 is a shading coefficient of glazing, and SC2 is the shading coefficient of the external shading device. In order to estimate SC2 for egg crate, horizontal or vertical shading device, “SelectModelElements” node is used to estimate the area width and the length of an overhang, and the sum of the area of the window and the distance between overhang and the window. After the extraction and the calculation of SC2, the output is then used to find the accurate value stated in [7]. At last, a math function code is used to estimate the final SC-based of the constant value of glazing and shading coefficient, figure 2 presents the proposed script to calculate SC based on the model of Natephra [20].

Figure 1. Process of accessing and extracting OTTV parameters from BIM database using VPL.

Figure 2. Process of obtaining SC coefficient using the Code Black node.
3.2.3 Obtaining SF value based on VPL

The equation of RTTV stated in section 2.1 required the calculation of A coefficient, which is the solar factor. Based on MS1525:2014, the solar factor could be estimated using equation (4)

\[ SF = 323 \times OF \]  

(4)

In this step, the math function node provided by Dynamo is used to state the numeric input value suggested by a code of practice for calculation of RTTV for Malaysia, as well as the solar orientation factor of roof (OF) coefficient. For the other coefficient provided by OTTV and RTTV calculation, including TDeq and AT values, were provided as constant in code of practice.

After developing the parameters of OTTV/RTTV, the final computing is required to estimate the total value of OTTV and RTTV and then followed by comparing with the value stated in the standard. In the case that the obtained value does not comply with the standard, a modification of the design and selection of materials is required, figure 3 concludes all the process of BOTTVc from modelling stage to final output.

![Figure 3. Process of the proposed model of BOTTVc based on BIM and VPL.](image)

4. Discussion

This study covers part of a research that is conducted to evaluate the optimization of thermal performance of the envelope and roof of a residential building covered with green vegetation as insulation material in Malaysia. The study included two main stages; first, by detecting required coefficients for OTTV and RTTV code based on MS 1525:2014 and followed by the developing of the OTTV model based on BIM-VPL software. During the first step, prescriptive requirements of OTTV and RTTV coefficients including WWR, solar absorption factor of wall and roof, U-value of an opaque wall, fenestration wall and roof, SC, CF were reviewed and categorized. In the second phase, it involved scripting the OTTV coefficient using BIM and VPL, towards evaluating the thermal performance.

Future works are required to establish the viability of this model when compared with manual calculation, which will be computed by calculator before the input is listed in the excel sheet. Hence all the data related to opaque and fenestration walls and roof are gained by observing the 2D drawings and by calculating the properties of the elements (thermal and physical) based on the provided equations. The hand-based calculation will be evident that the manual documentation process of OTTV and RTTV is a very mind-numbing and time-consuming task. The scripting of the developed model could be applied in varying building design, with different areas and construction materials; in simple word, the developed system could be considered as a time saver for building designers. Therefore, it could provide...
accurate results in a short period; besides the ability of designers to easily modify their design and materials selection by running the scripting until finding the ideal design solution.

5. Summary
This study aims to enhance the growing area of research of building thermal performance and energy efficiency by proposing a model of OTTV to attain the best thermal performance, the optimization of a building envelope could achieve a good selection of construction materials, proper and accessible insulation materials, and envelope performance. The expected results of this study will show that the proposed system will lessen the time to estimate thermal performance during the design stage. Moreover, the implementation of the BOTTv model will provide the guideline to designers when working on optimization of the thermal performance of the building envelope, especially when modifying the U-value and wall/roof absorption factors during the design process, which are considered an essential parameters compared to the other coefficients in OTTV and RTTV formula. The next phase of this study will focus on calculating the OTTV for wall and roof of some selected case studies using both manual and a model system, before and after lowering the U value of the wall and roof by using living insulation material (green vegetation).

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