Automation of Building Envelope Thermal Performance Assessment Using Computational BIM

Taki Eddine Seghier
Department of Architecture, FAB, Universiti Teknologi Malaysia (UTM)
Johor Bahru, Malaysia
segatakieddine@gmail.com

Yaik-Wah Lim
Department of Architecture, FAB, Universiti Teknologi Malaysia (UTM)
Johor Bahru, Malaysia
limyaikwah@gmail.com

Mohd Hamdan Ahmad
Department of Architecture, FAB, Universiti Teknologi Malaysia (UTM)
drmedan@gmail.com
Johor Bahru, Malaysia

***Abstract*— Building Overall Thermal Transfer Value (OTTV/ETTV) is among building sustainability criteria in the tropics. This metric has been adopted by several green rating tools to evaluate building envelope thermal performance, hence, to assess buildings cooling loads. Currently, building project teams find it very challenging and time-consuming to assess the OTTV/ETTV using the currently available tools and methods. Therefore, this article presents a new tool for "Easy ETTV" assessment developed using computational Building Information Modelling (BIM) technology. The development process of the tool consists of three main stages; first, the requirements of OTTV are analyzed and interpreted to BIM-based rules. Then, based on these rules, the functionalities of the BIM authoring tool Revit and Dynamo (Computational BIM tool) are screened up in order to build scripts for data extraction compatible with the predefined rules. Finally, the tool was tested on a case study building and the generated results were compared to the manual calculations of OTTV. At this stage, Easy ETTV tool shows a very high potential for assessing OTTV in term of duration, accuracy, and friendliness. Nevertheless, this tool is still in its early stage of development, and additional enhancements and functionalities have to be integrated into it. This tool will support project team in designating and assessing building envelope thermal performance by allowing them to select the most appropriate façade configuration according to its performance.**

Keywords*— Thermal performance, Green Building Rating Tools, Building envelope, Automation, Dynamo, OTTV/ETTV

I. INTRODUCTION

A huge investment is devoted globally for environmentally friendly buildings that can provide both high performance and long-term cost saving [1]. In this context, building practitioners have realized the importance of creating consistent metrics for the quantitative and qualitative evaluation of building performance in order to efficiently guide the design and construction of green buildings [2]. As a result, many Green Building Rating Systems (GBRS) have been developed around the world such as LEED (US), BREEAM (UK), Green Mark (Singapore), GreenRE (Malaysia) in order to guide project teams in their design process and increase their awareness regarding buildings sustainability related issues.

Designing a building with additional objective related to sustainability and performance is by nature a complex process. For example, when a project team is seeking for a green certification, design decision making become very time consuming due to the fact that collecting, managing and documenting the relevant data is a very labor process [2]–[6]. Additionally, designers tend to rely on previous experience outcomes to make a design decision. Therefore, the project team may create several design options and then mentally test them against past cases to select what they think it is the best solution [7]. Nonetheless, taking the appropriate steps to automate the process of gathering the necessary information for building environmental analysis is argued to be very crucial [8].

Building Information Modelling (BIM) design process is based on one data-rich digital model that can be used to perform numerous analysis through building life cycle. It is argued that BIM can support design Decision-Making and sustainability analysis in the very early design stages [3], [4], [9]. Hence project team is able to use BIM tools to evaluate the performance of different design options in short time and achieve building sustainability goals more efficiently. In addition, with the integration of new building design technologies to BIM such as Visual Programming Languages (VPL), designers are able to automated and customize the design workflow to serve their needs.

Overall Thermal Transfer Value (OTTV/ETTV) is one of the most challenging performance criteria during the assessment process of building sustainability. It often time-consuming and requires complex data collection process to be assessed. Thus, this paper aims to develop a computational BIM-based tool for automated building Envelop Thermal Transmittance Value (ETTV/OTTV) assessment and rating called "Easy ETTV". Since OTTV and ETTV concepts are very similar, in this study OTTV and ETTV are used interchangeably. Different from other ETTV available assessment methods, this tool is directly linked to the BIM conceptual model and relies on the embedded information within the model components. Hence it extracts automatically the required data from the BIM model and performs the necessary calculation of ETTV according to the building envelop configuration. The applicability of tools is demonstrated through the use of a hypothetical office building, while ETTV assessment results are compared to manual calculations.

A. Green Building Rating Systems

In the last few decades, several green building rating systems and regulations have been adopted in many counties around the world in order to provide the project team a comprehensive guideline for implementing sustainability practices in the whole building lifecycle [10]. According to the green building research institute (GBRI), a green rating system is defined as "*A set of prerequisites and requirements that a project team must fulfill in order to receive certification*" [11]. Green rating systems cover different criteria and levels of sustainability that indicate how many credit points a project team should fulfill.

Green Building Index (GBI) is one of the leading green building rating tools in the Malaysian building industry which was developed in 2009. Besides, Green Mark and GreenRE are green building rating systems developed respectively in Singapore (2008) and Malaysia (2013). These tools are quite similar in term of sustainability criteria and their process of certification. Both rating systems cover six main pillars related to building sustainability as follows; Energy Efficiency (EE), Water Efficiency (WE), Indoor Environmental Quality (IEQ), Environmental Protection, Carbon Emission of development and other Green Features [12], [13]. Each pillar has sub-categories weighted with credit points. Hence, the final building sustainability rating is associated with the sum of all credit points of the sub-categories. Finally, based on the earned credit points, a provisional green certification is issued for building design before its construction.

B. BIM for Sustainable Building Design

The integration of BIM concept to green building has gained mountainous interest from scholars and practitioners interested in both BIM and building sustainability issues [6], [14], [15]. In this research area, several studies have investigated how energy performance can be optimized using both BIM (process and tools) and multi-objective optimization algorithms [16], [17], BIM for Daylighting optimization [18] and BIM for Green material selection [19].

Studies have also investigated how BIM can be integrated with Green Building Rating Systems in order to facilitate building sustainability assessment, potential achievable credit points and the provision of the necessary documents for green building certification [2], [4], [6], [9], [20]. Nevertheless, research in this areas is still limited in comparison to other sustainability-related issues. This is mainly due to several technical factors such as BIM interoperability issues in the one hand and the lack of integration between BIM authoring tools and green materials databases on the other hand [2], [4], [6].

C. Building Envelope Thermal Transmittance Value (ETTV).

Several green building rating tools have adopted the ETTV metric in building projects such as Green Building Index (OTTV-Malaysia), GreenRE (OTTV-Malaysia), GREENSHIP (OTTV-Indonesia), Green Mark (ETTV-Singapore), as well as BEAM Plus (OTTV-Hong Kong). ETTV is a prerequisite requirement in most of the green building certification, which means project team should fulfil its minimum requirement in order to be eligible for a green certification. Similar to OTTV, ETTV takes into consideration the three basic components of heat gain through building envelope (Building construction and Authority 2004).

- Heat conduction through opaque walls,
- Heat conduction through fenestration glazing,
- Solar radiation through fenestration glazing,

The ETTV requirements are simple, no simulation is required and applies only to air-conditioned buildings. It aims at achieving the design of building envelope to cut down external heat gain and hence reduce the cooling load of the air-conditioning system. In this case, the computation of ETTV for residential buildings (RETV) for both GreenRE and Green Mark is based on the methodology specified in the code on Envelope Thermal Performance for building by BCA (Building construction and Authority 2004). ETTV equation is given as follows:

Equation 1: ETTV Equation

$$ETTV = 12(1 - WWR)Uw + 3.4(WWR)Uf + 211(WWR)(CF)(SC)$$

Where:
ETTV: envelope thermal transfer value (W/m²)
WWR: window-to-wall ratio (fenestration area/gross area of exterior wall)
Uw: thermal transmittance of the opaque wall (W/m² °K)
Uf: thermal transmittance of fenestration (W/m² °K)
CF: correction factor for solar heat gain through fenestration
SC: shading coefficient of fenestration

ETTV target is one of the most challenging tasks for the project team to achieve due to its dependency on a huge amount of information related to building envelope configurations and materials. According to Inhabit (specialist engineering consulting group): *"ETTV compliance presents design challenges for architects, builders, and suppliers in Singapore's building and construction market […] ETTV has to be considered more closely when undertaking any design decisions that influence the façade outcome"* [21].

A web-based tool called 'ETTV façade designer' was developed for the Singaporean market by Inhabit for Green Mark rating system which aims to minimize the time and energy spent on the process of designing building envelope under the ETTV requirement [21]. However, this tool is not integrated into building information and it gives only preliminary insights on building ETTV performance. Recently, a model for OTTV assessment was developed by Lim et al. [5] as a part of integrating BIM to Green Building Index (GBI) of Malaysia. This model is based on the manual extraction of the data from the BIM model using scheduling (Revit functionality), and the export of data to external software for calculation.

II. Methodology

Easy ETTV tool is developed through the combination of three key components, namely; ETTV requirement interpretation, the minimum Level of Development (LOD) of the BIM model required for ETTV assessment, and computational BIM capabilities in data extraction, management, and automation (See Fig 1).

Firstly, all the relevant data related to ETTV/OTTV and its method of calculation were gathered from the relevant literature namely: envelope thermal transfer value for buildings guidelines (Singapore) and the MS 1525:2014 (Malaysia). This data consists of ETTV/OTTV equation, the relevant building elements, data request (Input), required variables, etc. Then, the minimum Level of Development (LOD) of the BIM model for ETTV assessment was identified through the integration of ETTV requirement and LOD concepts. Next, based on the finding of the previous two steps alongside the screening of Revit and Dynamo functionalities, a computational BIM model for ETTV data extraction was proposed. Finally, three main scripts compatible with the ETTV model workflow were developed using Dynamo for automatic data extraction and management. These scripts are:

- Script 1: Auto data extraction for walls
- Script 2: Auto data extraction for windows
- Script 3: Auto data extraction for curtain walls

At the end of the development process, Easy ETTV tool was then tested on a hypothetical building and the generated results were compared to manual calculations for validation purpose.

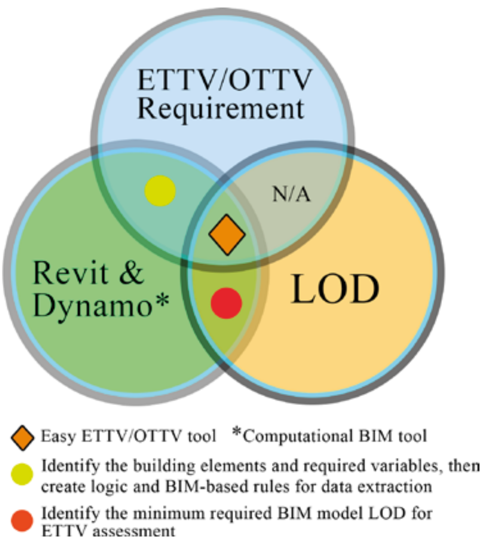


Fig 1. Proposed research method for Easy ETTV tool development

It is worthy to mention that Autodesk Revit is used in this study as the BIM authoring tool and Dynamo as the computational BIM tool. Dynamo was selected because of its flexibility in managing the BIM data, automating design workflows and more importantly its integration to Revit as a plug-in.

III. ETTV- LOD Integration and Interpretation

From the ETTV equation and description stipulated in the ETTV guide [22] and shown in TABLE I, it can be noticed that ETTV calculation is dependent on four main variables: building envelope materials specifications (opaque walls and glazing), shading devices configuration, building façades orientation and the window-to-wall ratio (WWR). Unfortunately, not all the data related to these variables can be extracted automatically from the BIM model using the conventional methods. For instance, current Revit functionalities do not support the detection of walls/windows orientation, thus developing a script for auto wall and window orientation is a necessary key step for the automation of ETTV assessment. On the other hand, some information relevant to ETTV calculation is already available in Revit. For example, U_f parameter can be found under the thermal proprieties of any windows object in Revit as long the glazing type is specified. In addition, U_w of the walls is calculated automatically inside Revit according to the thermal proprieties of each material layers that compose the wall structure. Hence, Dynamo scripts are needed to be developed for the extraction this information from the BIM model for ETTV assessment purpose.

Table I illustrates the interpretation of ETTV requirements. This will support Easy ETTV tool development in term of identifying the involved building element and the required parameters that should be extracted from the BIM model during the assessment process.

TABLE I. ETTV Requirement Interpretation

Item	Description
Involved building elements	Opaque Walls of the envelop – Transparent glazing of the envelope (Windows, Curtain walls), External Shading devices
Required variables	**Main variables:** U_w-value, U_f-value, envelop opaque walls area, Envelop Glazing area, SC1, SC2, CF **Other variables:** WWR, Shading device type/dimension (R1, R2), Elements Orientation, Correction Factor (CF)
Equation	$ETTV = 12(1 - WWR)Uw + 3.4(WWR)Uf + 211(WWR)(CF)(SC)$
Data type	Quantitative
Prerequisites Requirements	Maximum permissible ETTV = 50 W/m2 Credits scored = 75 – [3 x (ETTV)] where ETTV ≤ 50 W/m2 Gold: ETTV of 45W/m2 or less Platinum: ETTV of 38 W/m2 or less

Based on the Level of Development (LOD) definition introduced by the American Institute of Architects (AIA) which is available in the most recent LOD specification (2017) [23], ETTV requirements and LOD are integrated together. The integration process consists of the identification of the LOD of each element involved in ETTV calculation within the BIM model. When all elements' LOD are identified the minimum LOD of these elements is set as the minimum LOD of the whole BIM model for ETTV assessment satisfaction. The "minimum" term is used here because the BIM model often contains different elements with different LOD. Thus, the user needs to make sure that all the required data for ETTV assessment are available in the BIM model. Table II shows the relationship between the variables and their availability in the BIM model according to their LOD. From these finding, it is argued that the minimum required LOD for ETTV calculation is an LOD ≥ 300. This is because several variables related to ETTV calculation are available only in a BIM model with LOD = 300, such as Uw and Uf. Hence, for ETTV assessment project team are adviced to use a BIM model with an LOD of 300 or higher during the usage of Easy ETTV tool.

TABLE II. ETTV INTEGRATION WITH LOD

Item	Variables	LOD	Comment
ETTV	Uw	300	▪ **U**$_w$ and **U**$_f$ values are auto-generated in Revit according to the element materials proprieties ▪ **Wall area** is defined automatically in Revit based on wall geometry ▪ **Windows area** is a type parameter that can be calculated by multiplying the Height and width of the window ▪ **SC2** requires more complex calculations
	Uf	300	
	Wall area	200	
	Window area*	200	
	SC*	300	
	SC1*	300	
	SC2**	200	
	OF*	200	
	WWR*	200	
	Element orientation**	200	
ETTV assessment requires a BIM model with a minimum LOD ≥ 300			
Remarque: * Parameters cannot be documented directly using Revit some additional steps must be taken to get the end value. **Parameters are not supported by Revit, further, development using visual scripting may solve the problem.			

IV. COMPUTATIONAL BIM-BASED ETTV MODEL

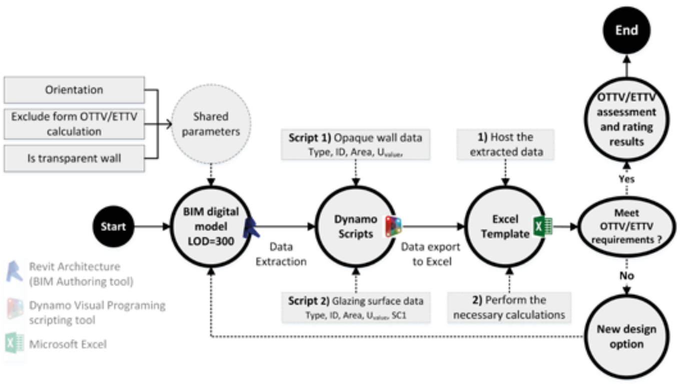


Fig 2: Proposed Easy ETTV model architecture

The model consists the foundation for the development of Easy ETTV tool (See Fig 2). Its development is based on both ETTV requirement interpretation, its integration with LOD and its match up with computational BIM functionalities discussed previously. Data extraction within the model is performed automatically through three scripts (Opaque walls data and glazing surfaces [windows and curtain walls]) which are developed using Dynamo for Revit. Moreover, four main shared parameters have been added to Revit namely: "Orientation"; to host the orientation parameter of walls and fenestration, "Exclude from ETTV/OTTV calculation"; to exclude elements that do not enclose an air-conditioned space such as walls in staircase, "Is transparent wall"; to differentiate between opaque walls and curtain walls (transparent) and "Is AC room?"; in order to assign only air-conditioned spaces. The scripts are designed to extract the required data according to a predefined workflow as illustrated in Fig 3. Then, this data is exported to an excel template for ETTV calculation (See Fig 5). By using Easy ETTV tool, designers are able to assess the ETTV and make a comparison of several building envelope design options in a very short time.

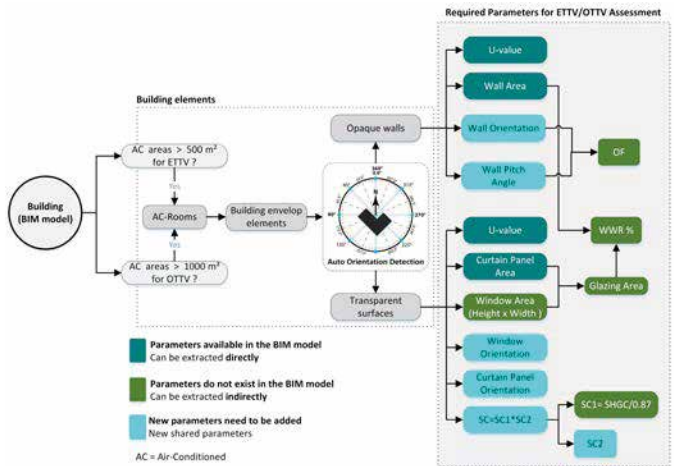


Fig 3. Data extraction flow for ETTV/OTTV requirement

Figure 3 shows the main stages of ETTV data extraction from the BIM model. At first, the user has to check if the building meets the requirement related to the minimum air-conditioned spaces inside the building (ETTV ≥ 500m², OTTV ≥ 1000m²). In this context, the user is able to assign only the air-conditioned spaces within the building envelope using a Boolean parameter (Yes/No) created for that purpose called 'Is AC Room?' (see Fig 4-B). By running the scripts, the relevant building envelope elements are collected and its orientation is detected automatically. Then all the required variables (i.e. U-value, orientation) are collected, managed and exported to an excel template. It is worthy to mention that some calculation is performed within Dynamo scripts, thus only the final output is exported to the excel template. Additionally, the shading coefficient of shading devices (SC2) is not calculated using Easy ETTV tool.

V. Validation and Testing of Easy ETTV

For validation and testing purpose of the developed Easy ETTV tool, a hypothetical building is modeled using Revit (see Fig 4 [A]). The building consists of an office building of nine levels. All the levels except the 2nd level (parking) are considered as air-conditioned spaces (see Fig 4 [B]). Besides, it has six façades with different orientations (N, S, E, NW, SW, and SE) and different materials that consist of opaque brick and transparent glassing (windows and curtain walls) with different thermal properties. The building does not contain any shading devices.

By using Easy ETTV tool, the user needs only to execute three Dynamo scripts using Dynamo Player to get the ETTV results which are exported to an Excel template developed for that purpose (see Fig 5). According to the tool, the initial ETTV result of this hypothetical building is 53.94 W/m² which is higher than the required baseline (50 W/m²). Thus, several testing experiments have been carried out to reduce this value by changing the façade design configurations, changing building orientation, etc. Then, each of the design option assessed by Easy ETTV is compared with the manual calculation which is performed using Material Take-off functionality as a calculation support tool. The results of the comparison are shown in Table III. It can be seen that the results of Easy ETTV and manual calculations are very similar. The minor differences in the results are assumed to be due to inaccurate calculation of the building WWR using manual calculation.

By using Easy ETTV tool project team is able to assess the ETTV of several design options and make a well-informed decision. This will save project teams a considerable amount of time by avoiding manual calculations and rework during the design process. Different from other tools (i.e IES-VE), Easy ETTV does not require the user to export the BIM model to an external software and manually reset the material specification of building elements.

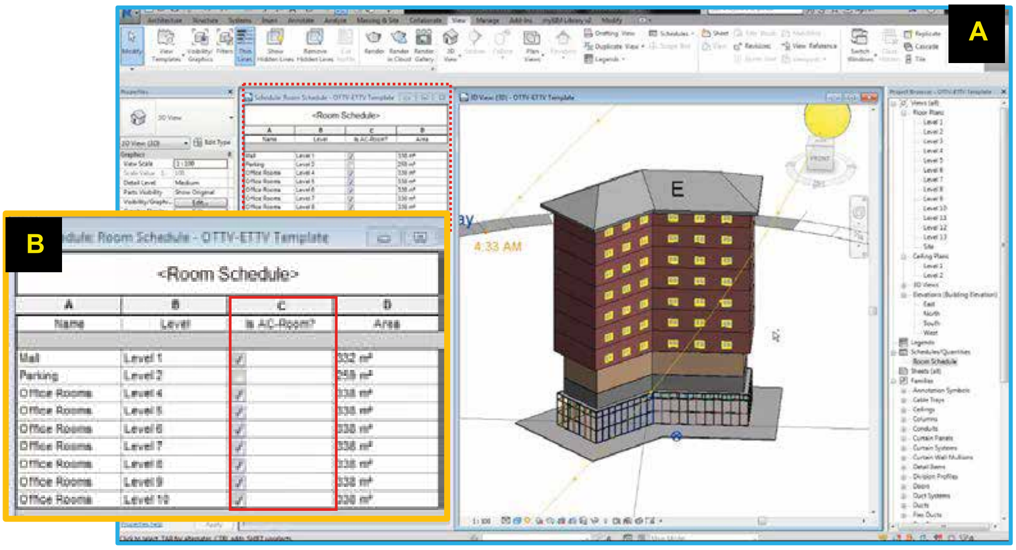
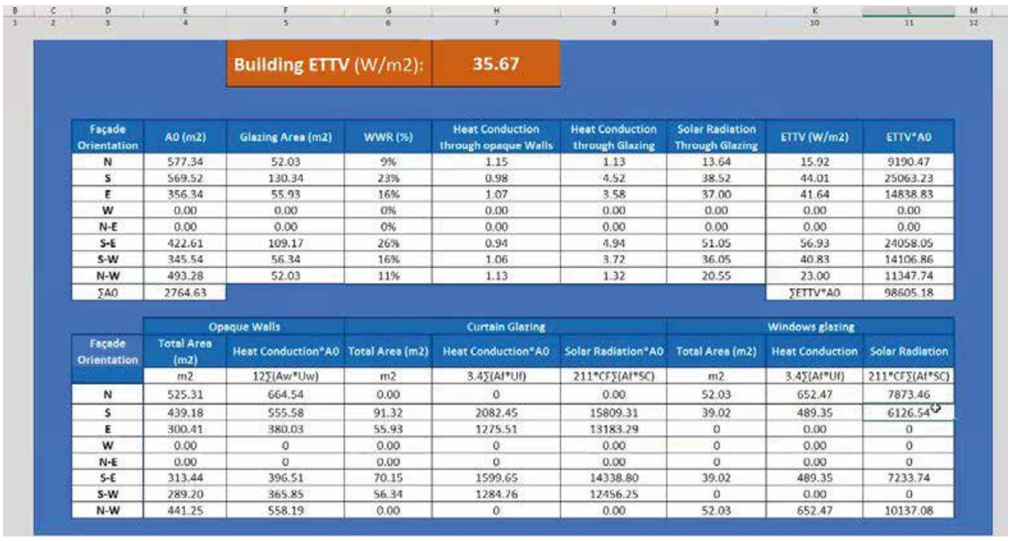


Fig 4. A Hypothetical model for Easy ETTV tool testing in Revit



Building ETTV (W/m2): 35.67

Façade Orientation	A0 (m2)	Glazing Area (m2)	WWR (%)	Heat Conduction through opaque Walls	Heat Conduction through Glazing	Solar Radiation Through Glazing	ETTV (W/m2)	ETTV*A0
N	577.34	52.03	9%	1.15	1.13	13.64	15.92	9190.47
S	569.52	130.34	23%	0.98	4.52	38.52	44.01	25063.23
E	356.34	55.93	16%	1.07	3.58	37.00	41.64	14838.83
W	0.00	0.00	0%	0.00	0.00	0.00	0.00	0.00
N-E	0.00	0.00	0%	0.00	0.00	0.00	0.00	0.00
S-E	422.61	109.17	26%	0.94	4.94	51.05	56.93	24058.05
S-W	345.54	56.34	16%	1.06	3.72	36.05	40.83	14106.86
N-W	493.28	52.03	11%	1.13	1.32	20.55	23.00	11347.74
∑A0	2764.63						∑ETTV*A0	98605.18

	Opaque Walls		Curtain Glazing			Windows glazing		
Façade Orientation	Total Area (m2)	Heat Conduction*A0	Total Area (m2)	Heat Conduction*A0	Solar Radiation*A0	Total Area (m2)	Heat Conduction	Solar Radiation
	m2	12∑(Aw*Uw)	m2	3.4∑(Af*Uf)	211*CF∑(Af*SC)	m2	3.4∑(Af*Uf)	211*CF∑(Af*SC)
N	525.31	664.54	0.00	0	0.00	52.03	652.47	7873.46
S	439.18	555.58	91.32	2082.45	15809.31	39.02	489.35	6126.54
E	300.41	380.03	55.93	1275.51	13183.29	0	0.00	0
W	0.00	0	0.00	0	0.00	0	0.00	0
N-E	0.00	0	0.00	0	0.00	0	0.00	0
S-E	313.44	396.51	70.15	1599.65	14338.80	39.02	489.35	7233.74
S-W	289.20	365.85	56.34	1284.76	12456.25	0	0.00	0
N-W	441.25	558.19	0.00	0	0.00	52.03	652.47	10137.08

Fig 5. Auto-generated results of the hypothetical building using Easy ETTV tool (Excel template)

Table III. ETTV Assessment Using "Easy ETTV" Tool VS Manual

Design option modification	Easy ETTV (W/m²) (Dynamo scripts)	Manual ETTV calculation (W/m²)
Initial hypothetical building configuration	53.94	53.87
Change wall type (East-orientation) from transparent to opaque	39.7	39.4
Change building orientation Change angle to true North from 90° to 0°	35.67	35.63

VI. CONCLUSION

This study has presented the development of a computational a BIM-based tool for OTTV/ETTV assessment called "Easy ETTV". Within the scope of this study, ETTV requirement was interpreted, integrated with the Level of Development (LOD) and matched up with computational BIM functionalities. Then, a computational BIM-based model for ETTV data management and extraction is developed. By using Easy ETTV tool, designers are able to create several designs options for the conceptual design, compare the ETTV performance together with the earned credit point, then make a well-informed decision.

Further developments are needed to improve the current Easy ETTV tool. For instance, the effective shading coefficient of external shading devices SC2 was not taken into consideration, However, it is an important step to automate its calculation using the same workflow particularly in a tropical climate like in Malaysia or Singapore where shading contributes significantly in the reduction of heat gains.

It is expected that Easy ETTV would speed up the design process by allowing designers to avoid ETTV assessment rework and more importantly allow architects and designers to focus more on design ideas instead of the benchmarking and chasing credits. This study serves as proof of concept that building sustainability rating and compliance checking can be automatically proceeded through customized workflows developed using computational BIM technologies.

ACKNOWLEDGMENT

The authors would like to acknowledge the research funding by Universiti Teknologi Malaysia (UTM), Ministry of Higher Education, Malaysia (MOHE) through Research University Grant (GUP), project no. 13H40, titled "Retrofitting Building Information Modelling (RBIM) for Sustainable Buildings".

REFERENCES

[1] A. Jrade and F. Jalaei, "Integrating building information modelling with sustainability to design building projects at the conceptual stage," *Build. Simul.*, vol. 6, no. 4, pp. 429–444, 2013.

[2] W. Wu, "Integrating building information modeling and green building certification: The BIM - LEED application model development," *Vasa*, 2010. [Online]. Available: http://medcontent.metapress.com/index/A65RM03P4874243N.pdf.

[3] F. Jalaei and A. Jrade, "Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings," *Sustain. Cities Soc.*, vol. 18, pp. 95–107, 2015.

[4] B. Ilhan and H. Yaman, "Green building assessment tool (GBAT) for integrated BIM-based design decisions," *Autom. Constr.*, vol. 70, pp. 26–37, 2016.

[5] Y. Lim, F. Shahsavari, E. Sediadi, and N. F. binti M. N. Azli, "Building Information Modelling for Building Energy Efficiency Evaluation," in *Ace*, 2016, no. Ace, pp. 42–48.

[6] J. K.-W. Wong and K.-L. Kuan, "Implementing 'BEAM Plus' for BIM-based sustainability analysis," *Autom. Constr.*, vol. 44, pp. 163–175, 2014.

[7] S. Sukreet and K. Kensek, "Early design analysis using optimization techniques in design/practice.," *ASHRAE/IBPSA-USA, Build. Simul. Conf.*, 2014.

[8] T. Biswas, T.-H. Wang, and R. Krishnamurti, "From design to pre-certification using building information modeling," *J. Green Build.*, vol. 8, no. 1, pp. 151–176, 2013.

[9] S. Azhar, W. A. Carlton, D. Olsen, and I. Ahmad, "Building information modeling for sustainable design and LEED ® rating analysis," *Autom. Constr.*, vol. 20, no. 2, pp. 217–224, 2011.

[10] R. Steurer and M. Hametner, "Objectives and indicators in sustainable development strategies: Similarities and variances across Europe," *Sustain. Dev.*, vol. 21, no. 4, pp. 224–241, 2013.

[11] GBRI, "What is a Green Building Rating System? - Home Energy Pros," 2015. [Online]. Available: http://homeenergypros.lbl.gov/profiles/blogs/what-is-a-green-building-rating-system. [Accessed: 18-Sep-2016].

[12] Green Mark Singapore, "BCA Green Mark for New Residential Buildings," *BCA Green Mark*, pp. 0–18, 2010.

[13] REHDA, "Residential Building & Landed Home," no. October, 2015.

[14] L. C. Bank, M. McCarthy, B. P. Thompson, and C. C. Menassa, "Integrating BIM with system dynamics as a decision-making framework for sustainable building design and operation," *Proc. First Int. Conf. Sustain. Urban.*, 2010.

[15] S. Azhar and J. Brown, "BIM for Sustainability Analyses," *Int. J. Constr. Educ. Res.*, vol. 5, no. 4, pp. 276–292, 2009.

[16] M. R. Asl, A. Stoupine, S. Zarrinmehr, and W. Yan, "Optimo : A BIM-based Multi-Objective Optimization Tool Utilizing Visual Programming for High Performance," in *Proceedings of the 33rd International Conference on Education and Research in Computer Aided Architectural Design in Europe*, 2011, vol. 130, pp. 1–10.

[17] Y.-W. Lim, F. Shahsavari, N. Fazlenawati, M. N. Azli, D. R. Ossen, and M. H. Ahmad, "Developing a BIM-based process-driven decision-making framework for sustainable building envelope design in the tropics," vol. 149, pp. 531–542, 2015.

[18] S. Kota, J. S. Haberl, M. J. Clayton, and W. Yan, "Building Information Modeling (BIM)-based daylighting simulation and analysis," *Energy Build.*, vol. 81, pp. 391–403, 2014.

[19] A. Akanmu, B. Asfari, and O. Olatunji, "BIM-Based Decision Support System for Material Selection Based on Supplier Rating," *Buildings*, vol. 5, no. 4, pp. 1321–1345, 2015.

[20] T. E. Seghier, L. Y. Wah, M. H. Ahmad, and W. O. Samuel, "Building Envelope Thermal Performance Assessment Using Visual Programming and BIM , based on ETTV requirement of Green Mark and GreenRE," vol. 4, no. 3, pp. 227–235, 2017.

[21] Inhabitgroup, "ETTV Façade Designer released to Singapore Market - Inhabit Group," 2016. [Online]. Available: http://inhabitgroup.com/ettv-facade-designer-released-to-singapore-market-2/. [Accessed: 10-Feb-2017].

[22] Building and Construction Authority (BCA), *Code on Envelope Thermal Performance for Buildings*. BCA, 2008.

[23] BIM Forum, "DEVELOPMENT SPECIFICATION LOD Spec 2017 Guide," no. November, 2017.