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Developing The Building Envelope Thermal Transfer Value Calculator Based on BIM-VPL Framework

Rissa Fitria Syafutri[1, a)] Jatmika Adi Suryabrata[1, b)] Yani Rahmawati[1, c)]

[1] *Department of Architecture and Planning, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.*

[a)] Corresponding author: rissasyafutri@mail.ugm.ac.id
[b)] jatmika@ugm.ac.id
[c)] yani.rahmawati@ugm.ac.id

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Abstract. The use of formula to calculate OTTV (Overall Thermal Transfer Value) for buildings in Indonesia is written in the SNI (Indonesia National Standard) 6389:2020 document. There are at least 3 equations and 7 tables that require to refer for calculating the thermal transfer value of the building envelope. The series of formulas is quite time consuming and prone to human error if it is done repeatedly at the building design stage. This study aims to develop an OTTV formula based on the SNI 6389:2020 so that the OTTV calculation process can be carried out more effectively. The formula development process has done using the Autodesk Revit 2019 and Autodesk Dynamo 2.2 applications. From the studies that have been conducted, 11 scripts were written to calculate OTTV semi-automatically.

Keyword: OTTV, OTTV Calculator, BIM, Visual Programming Language

INTRODUCTION

In the design process, calculating the performance of building envelope in terms of indoor thermal reduction is essential. Thermal condition in the interior of the building is closely related to the behaviour of using conditioned ventilation systems [1] which will affect the electronic consumption index and annual expenditure costs. Indonesia has made regulations regarding the maximum OTTV (Overall Thermal Transfer Value) in the SNI (Indonesia National Standard) 6389:2020 document. The document states that the maximum OTTV limit is 35 W/m^2. To get the value of OTTV, it is necessary to know 3 main variables, namely the value of thermal conductivity through massive walls, the value of thermal conductivity through transparent surfaces, and solar radiance absorptance through fenestration [2, 3].

To get the 3 variables listed in the SNI document, it is necessary to perform calculations using several types of formulas and 7 tables of constant values. The calculations that need to be done to get the OTTV are quite complicated, require a relatively long time, and are prone to human error. In addition, there are at least 2 OTTV calculations are required in the design process. Firstly, at the initial calculation stage and secondly, at the calculation stage when design adjustments have been made. The initial calculation stage is carried out to see whether the OTTV value is below the maximum limit set, while the second calculation is carried out to ensure that the performance value of the building envelope is increased.

The complex and time-consuming calculation process makes repetitive calculations inefficient. In this study, the formula in the SNI 6389:2020 was developed into a series of scripts using an application based on VPL (Visual Programming Language) to calculate the performance of a building envelope designed using an application based on BIM (Building Information Modelling). The scripts built with VPL-based applications will work semi-automatically. This allows designers to calculate the OTTV formula more efficiently in terms of time and minimize human error.

THEORITICAL BACKGROUND

The OTTV calculation stated in the SNI 6389:2020 document is a development of several previous documents that discuss building thermal calculations, namely: The Development and Building Control Division Singapore 1992, ASEAN USAID 1992, BOCA 2000, BCA (Building and Construction Authority) Singapore 2004 and ASHRAE 90.1:2007 [2]. The main concept of calculating OTTV in the SNI document is to design buildings at the preliminary design stage so that they have good performance in using energy [4].

Based on the SNI 6389:2020 document, the formula for calculating the OTTV value on 1 side of the building envelope can be seen in equation (1).

$$OTTV = \alpha\ [(UW \times (1 - WWR) \times TDEk] + (Uf \times WWR \times \Delta T) + (SC \times WWR \times SF) \quad (1)$$

Where:
α = solar absorptance;
U_w = thermal transmittance through wall;
WWR = *windows-to-wall ratio*;
TD_{EK} = temperature equivalent difference;
U_f = thermal transmittance through fenestration;
ΔT = building temperature difference between the outside and the inside;
SC = shading system coefficient;
SF = solar factor.

Equation (1) is carried out for each orientation of the building façade. If the building envelope material has more than 1 type of material, it is necessary to use the OTTV formula which can be seen in equation (3) as follows:

$$OTTV = [\alpha_1 \{Uw_1 \times {}^{A1}/_{\Sigma A} (1-WWR) \times TD_{EK}\} + \alpha_2 \{Uw_2 \times {}^{A2}/_{\Sigma A} (1-WWR) \times TD_{EK}\} + \ldots\ldots\ldots\ldots + \alpha_n \{Uw_n \times {}^{An}/_{\Sigma A} (1-WWR) \times TD_{EK}\} + \{U_f \times WWR \times \Delta T\} + (SC \times WWR \times SF) \quad (2)$$

Where:
A_1 = Wall area with material 1;
A_2 = Wall area with material 2;
A_n = Wall area with material n;
ΣA = A1 + A2 + ……… + An.

To get the thermal transfer value of the building envelope as a whole, it can be done by equation (3) as follows:

$$OTTV = \frac{(Ao1 \times OTTV1) + (Ao2 \times OTTV2) + \ldots\ldots\ldots + (Aoi \times OTTVi)}{Ao1 + Ao2 + \ldots\ldots\ldots + Aoi} \quad (3)$$

Where:
A_{oi} = Wall area covering on the outer wall i (m^2);
$OTTV_i$ = Overall thermal transfer value (W/m^2).

BIM Framework in Sustainable Building Design

The utilization of BIM based framework is a common thing in the AEC (Architecture, Engineering and Construction) industry. BIM is identified as an effective framework for evaluating the effectiveness and efficiency of energy used in a building project [5]. The evaluation has a significant impact because the monitoring process to achieve energy efficiency targets is carried out at the preliminary design stage [6]. One element in the BIM workflow that provides many benefits in a design is automatic data integration [7].

The information embedded in a BIM models aim to make the parties involved in a project easier to collaborate during the work process [8]. A previous study has utilized BIM as an instrument to increase the effectiveness in the preparation of documentation for BEAM Plus assessments. The study results that the BIM model developed based on BEAM Plus will continue to be used despite changes to the requirements and guidelines in the assessment document. The model developed by the research can identify potential changes and avoid those changes. [9]. A finding in another study shows that BIM technology is successful in generating data quickly to find the best design that can achieve the highest credit score in the LEED scoring system [10]. Another result from a study shows that the use of the BIM framework can be utilized as an instrument to avoid design flaws with automatically integrated workflows [11]. The integration of information data embedded in a BIM model will be very beneficial for the designer in performing OTTV calculations.

Utilization of Visual Programming Language in Building Design

The role of VPL (Visual Programming Language) in the framework to simplify the process of analysing a building project is quite significant. In the BIM work environment, the concept of VPL was initiated to facilitate the work of professionals in the AEC field [12] in carrying out the process of parametric design, production of analytical charts and estimation analysis [13]. All applications with the VPL concept have 4 main components, which are: (a) input as initial information required by the VPL algorithm for further information processing; (b) nodes, namely elements that act as operators that produce certain functions by taking data information from input; (c) output is information generated from data processing at nodes, and (d) connector is a virtual line that indicates the connection from one node to another [14]

There are several previous studies regarding the use of VPL-based applications in building design projects as well as for estimating the efficiency of building energy use. Utilization of the visual coding process for the purpose of building efficiency analysis is more flexible than the traditional way [15] and the code that has been written can be applied to different buildings easily [16]. One of the uses of visual programming-based applications for building energy analysis is to extract data from a BIM model [17]. Another previous study has been done under the topic of the BIM-VPL-based framework benefit on the construction project scale. The result shows that that indicator measurements that were built with VPL framework were able to conduct dynamically, although the workflow would need adjustments for different VPL-based applications [18].

METHODOLOGY

The study uses the exploratory method by utilizing the Autodesk Revit 2019 application to build a BIM model and the Autodesk Dynamo application version 2.2 to script the OTTV calculation instrument. This research uses the BIM model with the embedded thermal and physical material data. The function of the BIM model in this research is to utilize the embedded data extraction into scripts that will written using Dynamo. The model that has been built on Autodesk Revit uses brick material with a thermal resistance value of 0.991 m^2.K/W and a heat transfer coefficient value of 1.009 W/(m^2.K). The BIM model uses window element that are already available in the Autodesk Revit 2019 application with embedded thermal values that is showed in Fig. 1.

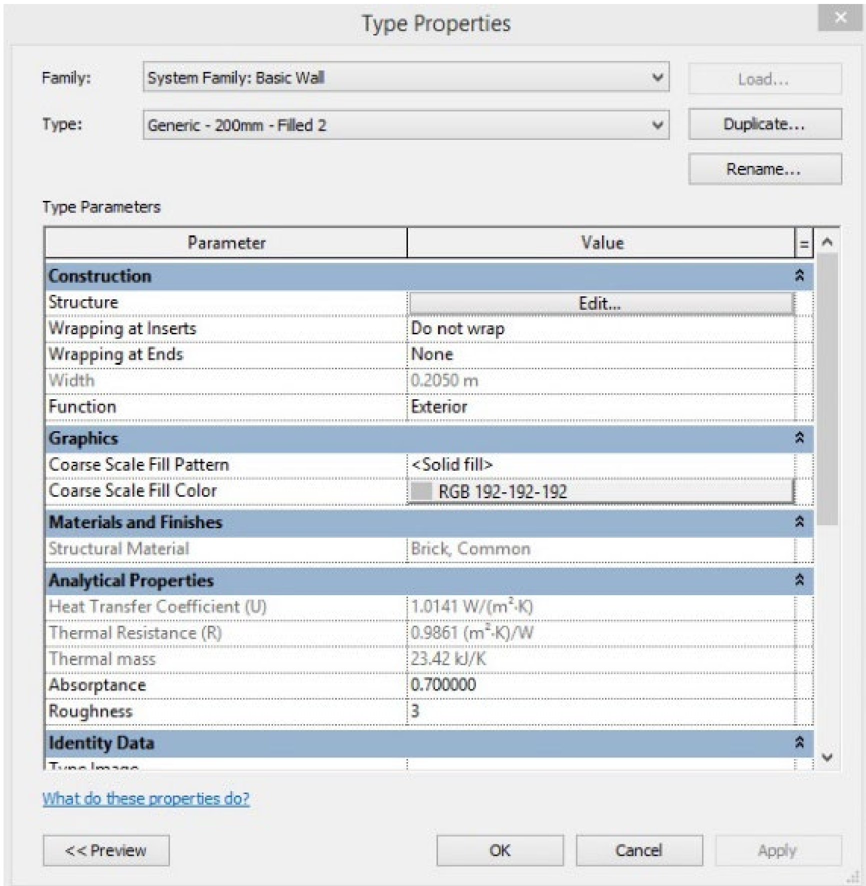

FIGURE 1. Type properties window of the building envelope with embedded thermal information

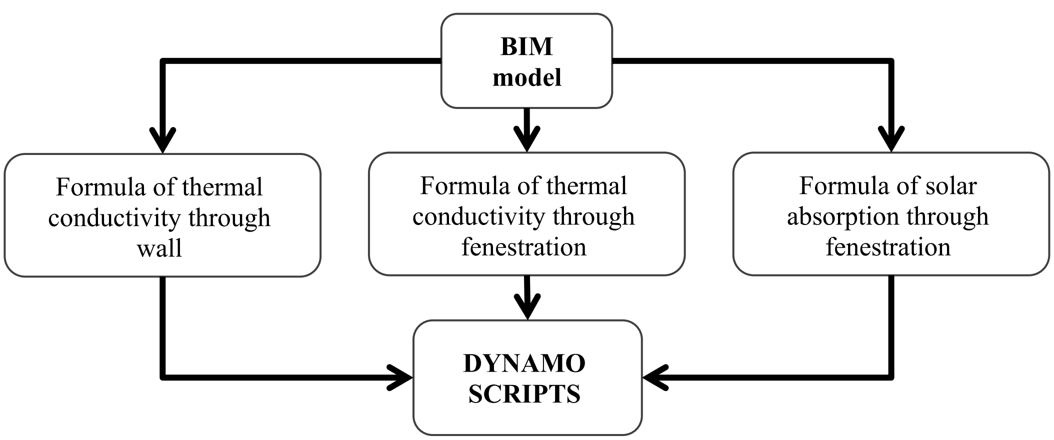

FIGURE 2. Developing process of OTTV formula based on SNI 6389:2020 document into Dynamo scripts

The research flow can be seen in Fig. 2. The first stage to develop the OTTV calculation formula into a dynamo script is to prepare a simple BIM model as a reference to take the embedded information for the OTTV calculation. The BIM model contains information about the location of the modelling object, the type of building material and information on physical and thermal materials, etc. to perform analyses related to energy efficiency [19]. Some of the embedded information in the model will be extracted in the formula development process. The rest information will be obtained by adapting data from the SNI 6389:2020 document. This information will be used to build scripts for the Dynamo application.

RESULTS AND DISCUSSION

OTTV calculation requires 3 main variables, namely the value of thermal conductivity through the wall, the value of thermal conductivity through the fenestration and the value of radiation absorption through the fenestration. Exploration of formula development was carried out with a simple BIM model with wall and window materials having thermal and physical information embedded. From the results of exploratory experiments that have been carried out, it is known that to get a value for calculating variables, it is necessary to do it in a different way. Broadly speaking, it can be divided into 3 types of methods, namely extracting data embedded in the BIM model, building a dictionary and performing mathematical logic processes (table 1).

TABLE 1. Data extraction method for each value

Value	Method
Solar absorptance	Dictionary with elseif logic
Sun factor	Dictionary with elseif logic
WWR	Mathematics function
Solar heat gain coefficient (SHGC)	Data extraction
Surface thermal conductivity	Data extraction
Surface area	Data extraction
Facade orientation	Data extraction with Dynamo
TD_{EK}	Constance
ΔT	Elseif logic
U_f (U-Value of fenestration)	Data extraction
U_w (U-Value of wall)	Data extraction

The solar absorptance and sun factor values were obtained by building a dictionary on the Dynamo application based on the data contained in the SNI 6389:2020 document. The dictionary in the dynamo allows the user to choose what data to use to execute equations. The dictionary of solar absorptance and sun factor data is embedded with elseif logic, so that users can retrieve data from one of the lists in the dictionary. SHGC values, thermal conductivity, surface area, U-Value can be retrieved by extracting data from the BIM model using certain nodes in Dynamo . For SHGC, U-Value and thermal conductivity, the nodes allow the scripts to run automatically. The nodes were utilized to extract data from the type properties of the material. However, the user needs to input the name of the parameter needed, for example, "Solar Heat Gain Coefficient". Users need to input parameters with the correct spelling as the nodes to retrieve the data from the type properties are case sensitive. The orientation of each building façade has to be done semi-automatically. The user needs to select the wall area and group it into specific orientation. This grouping is useful for calculating WWR and calculating sun factors based on different orientations.

The value of ΔT was obtained by entering a constant variable of 5. This value refers to SNI 6389:2020 which states that the value is generalized for simplification of calculations. The TD_{EK} value is obtained by calculating the weight/unit area (kg/m^2) of the building envelope wall. If the weight value is less than 125kg/m^2 then the TD_{EK} value is 15, if the weight value is 126 ~ 195 kg/m^2 then the TD_{EK} value is 12, and if the weight value is more than 195 kg/m^2 then the TD_{EK} value is 10. After obtaining the wall weight value/unit area, then the value is tested with elseif logic based on the TD_{EK} value. The logic is done using the same dictionary by getting the solar absorptance and sun factor values.

CONCLUSION

The main objective of this research is to develop a formula to calculate OTTV based on the SNI 6389:2020 document using a BIM-VPL-based framework. The results of the study in this study indicates that it is possible to develop formulas in the Dynamo script. The scripts built in this research are still not fully automated because some values need to be selected manually. Although writing scripts on Dynamo takes quite a long time, if it is used for repetitive calculations it will be very helpful in time efficiency. This is in line with the findings of previous research that the use of applications with the BIM-VPL framework will be very helpful in the assessment process (Habibi, 2017; Koo & O'Connor, 2021).

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