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BIM-based Automation for OTTV Calculation and Construction Cost Estimation in Energy-Efficient Building Design

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Abstract **-** Due to the increasing trend of building energy consumption in Thailand, the Department of Alternative Energy Development and Efficiency (DEDE) established the Building Energy Code (BEC) to promote energy conservation. The BEC standard evaluates energy-efficient buildings with initial assessments conducted using the DEDE-developed software, BEC Version 1.0.6. The Overall Thermal Transfer Value (OTTV) is a crucial index in the BEC code for evaluating building energy efficiency. However, adding OTTV calculation task during the design stage may hinder the flow and time consuming. This study introduces a BIM-based tool developed using Dynamo, an add-in for Autodesk Revit, to assist designers in evaluating building designs while simultaneously controlling construction costs. The 3D model of eight alternative cases was created according to various building envelope and orientation settings. The instruction sets for OTTV calculation and construction cost of the wall extracted from the software were compared to the BEC program to validate its efficiency. The results demonstrate that the OTTV calculation using the developed instruction set closely aligns with the BEC program, achieving an R^2 value of 0.9898. Additionally, the instruction set for construction cost estimation produces lower costs compared to traditional methods. This workflow streamlines OTTV evaluation and construction cost estimation, enhancing design efficiency while ensuring compliance with energy standards.

Keywords**:** BIM, OTTV, Construction Cost, Wall

1. Introduction

Thailand's hot and humid climate is intensifying, leading to increased indoor living and a significant rise in building energy consumption. Thus, strategies for reducing building energy use have become a key focus of government initiatives. An "energy-efficient building" is one that prioritizes the reduction of energy consumption. The building envelope play a vital role in evaluating energy-efficient buildings [1]. Researchers evaluated heat transfer through building envelopes using Overall Thermal Transfer Value (OTTV) as a key indicator [2, 3]. The Building Energy Code (BEC), developed by the Department of Alternative Energy Development and Efficiency (DEDE) under the Ministry of Energy, utilizes OTTV as a key metric for assessing the energy performance of building envelopes. DEDE developed the BEC software (named after the standard) to assist designers in evaluating the preliminary requirements for buildings under construction. The OTTV value can be calculated using equation (1):

$$OTTV = (U_W)(1 - WWR)(TD_{eq}) + (U_f)(WWR)(\Delta T)(WWR)(SHGC)(SC)(ESR) \tag{1}$$

The OTTV measured in watts per square meter (W/m²), quantifies the average rate of heat transfer into a building through its envelope. The thermal transmittance of the wall (U_n), measured in W/m²·K, determines how efficiently the wall conducts heat, with lower values indicating better insulation. The Window-to-Wall Ratio (WWR) represents the fraction of the exterior wall occupied by windows, affecting both conductive and solar heat gain. The equivalent temperature difference (TD_{eq}) accounts for the combined effects of solar radiation and ambient temperature variations on the wall. Similarly, the thermal transmittance of the fenestration (U_f) defines how much heat is conducted through windows, while the temperature difference (ΔT) between indoor and outdoor air drives the overall heat transfer. Solar heat gain through windows is further influenced by the Solar Heat Gain Coefficient (SHGC), which represents the fraction of solar radiation transmitted as heat, and the Shading Coefficient (SC), which measures the efficiency of shading devices in reducing this heat gain. Lastly, the Effective Solar Radiation (ESR) represents the intensity of solar radiation contributing to heat transfer. Together, these variables determine the OTTV, helping assess the thermal performance and energy efficiency of a building's façade.

OTTV refers to overall heat transfers through the building envelope, the higher OTTV means outside heat transfers into the building higher [4]. The energy performance in the building will be decreased which makes the building unable to save energy consumption. Therefore, efficient building envelope design should be able to control OTTV. DEDE [5] classifies types of buildings into 3 groups according to the energy usage period of each group which the OTTV criteria can be shown in Table 1.

Table 1: The standards for energy-efficient building design.

Building Type	**OTTV (W/sq.m.)**
1. Educational Building, Office	≤ 50
2. Theaters, Shopping Centers, Entertainment Places, Department Stores, Assembly Building	≤ 40
3. Hotel, Hospital, Condominium	≤ 30

In the process of building design development, considering the cost of energy, design, and construction is also important. Architects and engineers attempt practicality and validation to achieve BEC. Consequently, some designers explore technological solutions to streamline processes, saving time and improving the precision of design advancement.

Building Information Modeling (BIM) has become an outstanding solution that is more widely used in Thailand as its advantages in the construction industry [6]. The structure of BIM consists of two main parts: a 3D building model and information. The important part that makes BIM different from traditional work systems is the information section which is completely interconnected. It can be easily transmitted and accessed as a result. Work progress will be efficient with BIM playing a role throughout the building life cycle [7]. From previous studies, Abanda & Byers [8] applied BIM to investigate the impact of building orientation on energy consumption in small-scale construction. Changnawa & Baltazar [9] developed BIM to calculate the OTTV in the schematic design stage. The researcher used Dynamo, an add-in tool in Autodesk Revit to create the instruction set for controlling, extracting, and calculating data to estimate OTTV. The result of this research confirmed that using BIM can reduce the repetitive procedure. However, this research only focuses on the instruction set development for OTTV calculation without considering the construction cost of the building by using the instruction set. Accordingly, the instruction sets development for OTTV calculation and construction cost to help designers in the design stage has become notable and has been the aim of this study

2. Methods

The procedures of this research are the formulation of an instruction set for OTTV calculation and construction cost estimation which can evaluate the design efficiency and the result by comparison with the conventional methods. The research framework can be shown in Fig. 1.

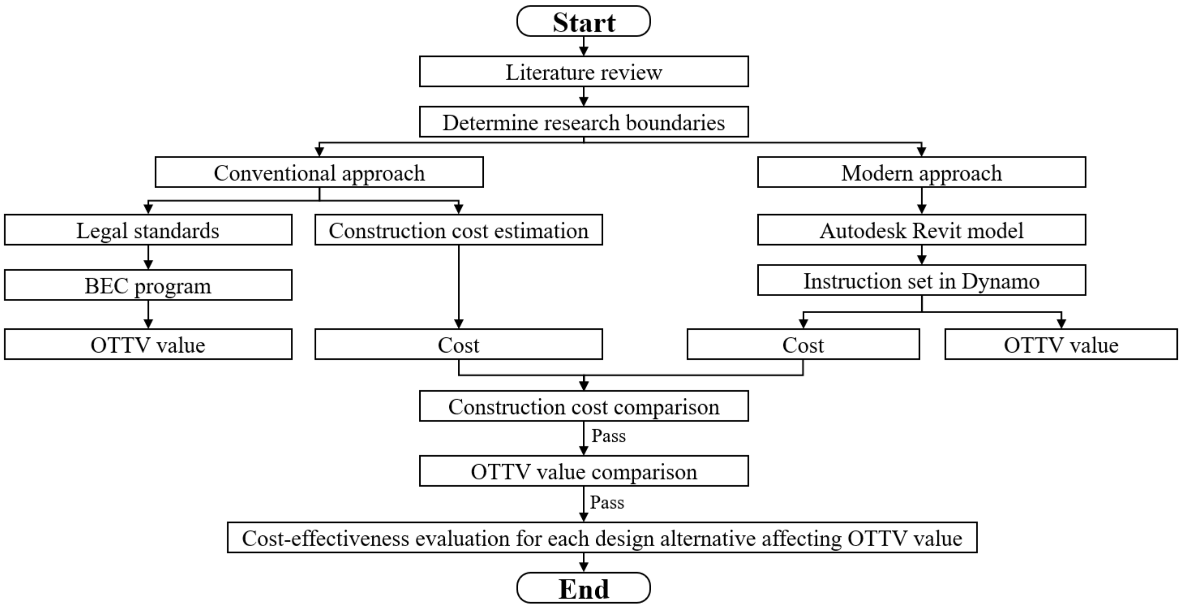

Fig. 1: Research Methodology.

2.1. Formulation of instruction sets for OTTV computation

Instruction sets developing for OTTV calculation and construction cost using Dynamo, an add-in within Autodesk Revit program, a requisite case study example model needs to be created. Subsequently, various fundamental properties influencing OTTV values which are the wall's materials, wall layer, sections of walls, and direction of the wall must be configured. These properties include wall construction material, thickness, area, as well as the orientation and angle of the building envelope. Furthermore, multiple case studies have been defined to facilitate a comparative evaluation of wall design performance. The specificities of each case study are shown in Table 2.

Table 2: Case studies for wall design efficiency validation.

Case No.	No. of Floor	No. of Translucent Wall sizes 45x75 cm.	Angle of Building to North and South (degrees)
1	1	-	0
2	1	-	45
3	1	2	0
4	1	2	45
5	2	-	0
6	2	-	45
7	2	5	0
8	2	5	45

OTTV calculation in accordance with Equation 1, the selection of pertinent data and variables from the database is imperative. All parameters were used for OTTV calculating using the equation in Fig. 2. To Fig. 5. This process uses Code Block node for defining formula of the equation then displays in Watch node as shown in Fig. 6.

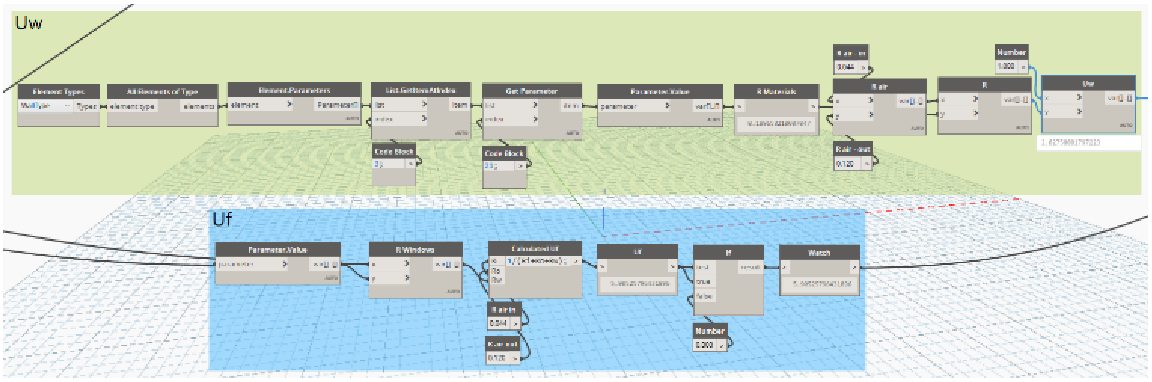

Fig. 2: The instruction sets of U_w and U_f calculations.

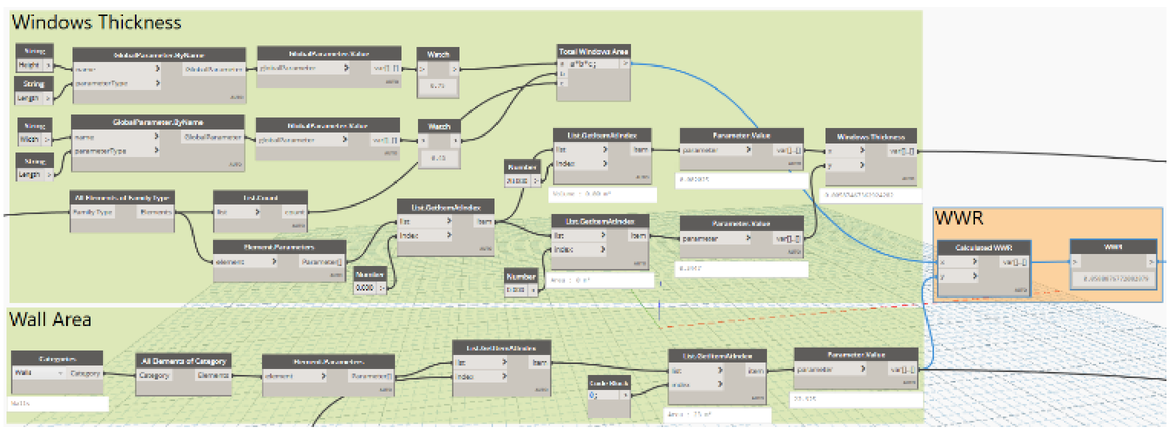

Fig. 3: The instruction sets of WWR calculation.

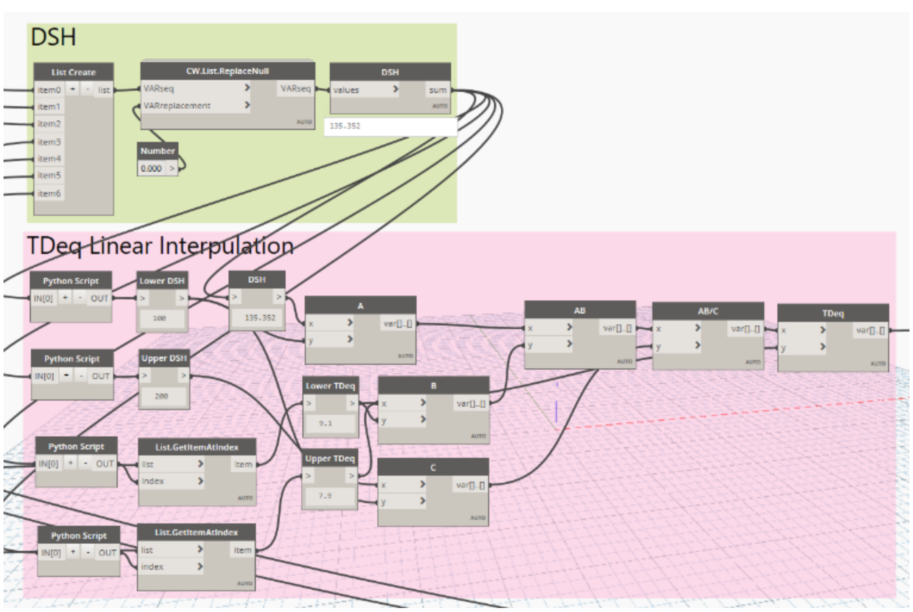

Fig. 4: The instruction sets of TDeq calculation.

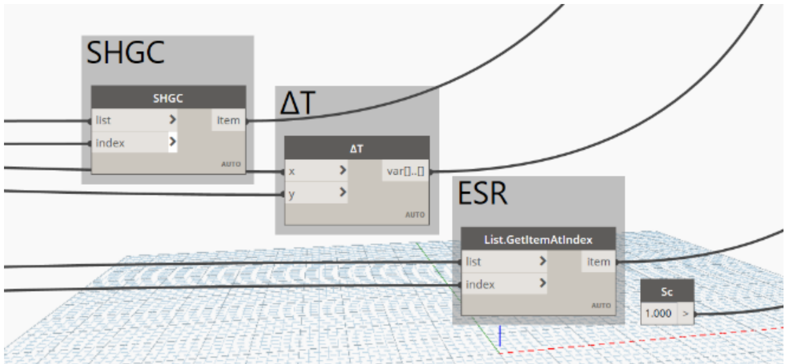

Fig. 5: The instruction sets for SHGC, ESR, ΔT, and SC calculations.

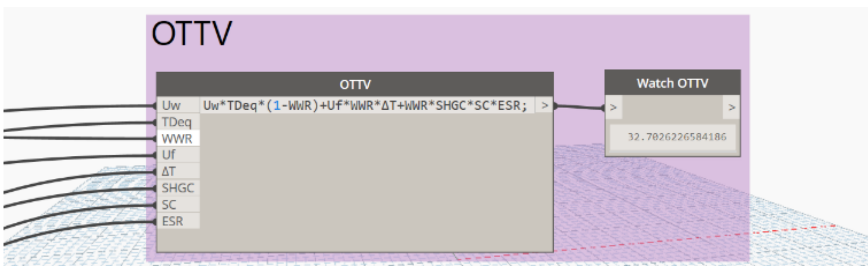

Fig. 6: The instruction sets for OTTV calculation.

2.2. Formulation of instruction sets for construction cost estimation

The cost estimation for wall construction utilizes the data extracted alongside material prices sourced from Division of Information and Trade and Economic Indices, Office of Policy and Strategic Trade Ministry of Commerce. This involves computing the expenses encompassing materials, labor, equipment, assorted tools, and other operational costs in baht per square meter. In this study, material abbreviations are employed to denote specific codes, subsequently stored within the database under their abbreviated names. This approach ensures convenient and quick extracted data for utilization, employing Node conditions to filter the data to be integrated into the Dynamo program. The examples of instruction sets for cost estimation can be shown in Fig. 7.

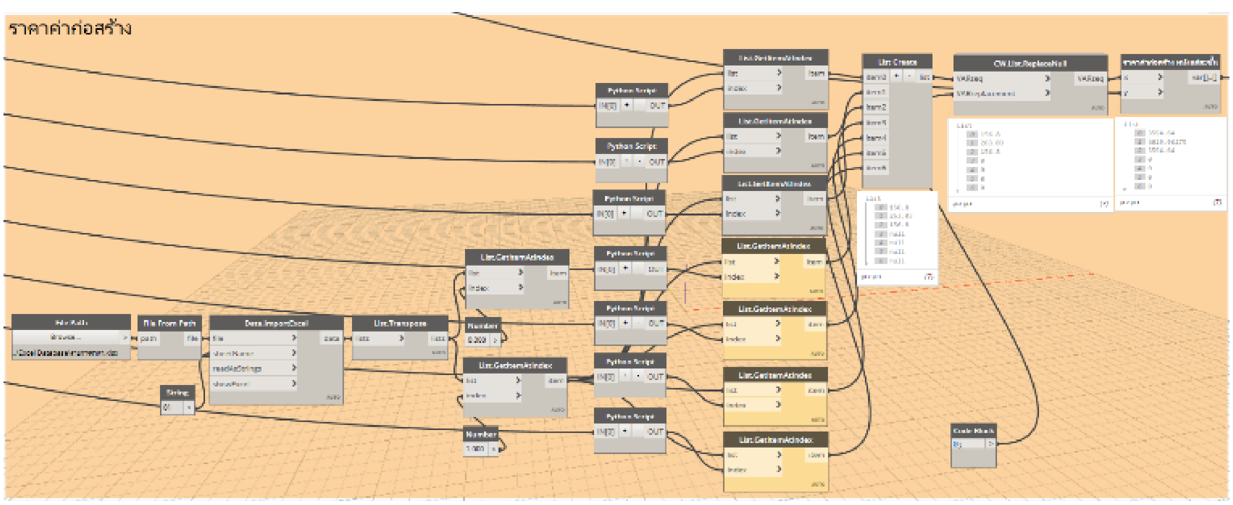

Fig. 7: Instruction set for calculating the construction cost of wall.

3. Results

3.1. Comparison of OTTV obtained from the BEC program and the instruction set within Dynamo

Calculating OTTV values from the instruction sets in Dynamo provides slightly higher OTTV values from BEC program for every case. OTTV calculation by using the angle of building envelope as the criteria can be defined that OTTV value from the BEC program and Dynamo at the angle of 45 degrees provide higher value than the angle of 0 degrees for every case. Therefore, the building envelope is the influential variable of OTTV value. Additionally, the number of windows also affects the OTTV value, causing the ratio of translucent walls to increase, so the OTTV value increases accordingly. This is because translucent walls allow sunlight, solar radiation, and heat from outside the building to enter the building more easily. Another notable point involves the complication of a building by incorporating more floors into its design. The greater the number of windows, the more apparent the tendency towards deviation. While the deviation rate changes gradually, this could be attributed to the model created in the Revit program, where walls overlap between the first and second floors. Hence, a critical factor directly impacting the computation of the OTTV is the resolution of construction drawings and the proficiency of the designer in using the Revit program. When comparing OTTV value data from the BEC standard program and the commands executed in the Dynamo program, a graph is generated to assess the effectiveness and accuracy of the instruction set. The graph displays accuracy, as shown in Fig.

Table 3: Efficiency validation in OTTV calculation of the instruction set from Dynamo compared to the BEC program.

Case Study	**OTTV from BEC Program**		**OTTV from Dynamo**	
	Angle of Building Envelope (degree)		**Angle of Building Envelope (degree)**	
	0	**45**	**0**	**45**
One-story building without window	24.32	27.94	24.53	28.10
One-story building with 2 windows	28.57	32.67	28.78	32.25
Two-story building without window	24.32	27.94	24.53	28.10
Two-story building with 5 windows	31.59	33.81	32.32	34.62

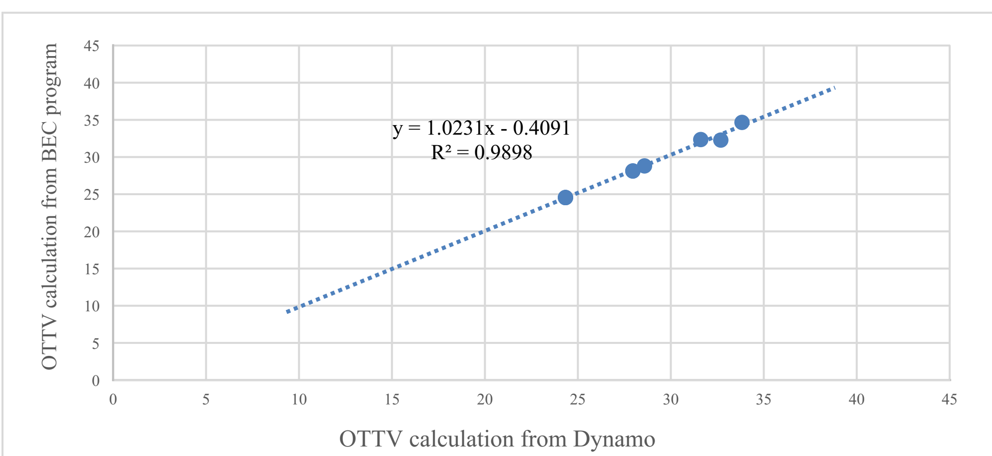

Fig. 8: Accuracy in OTTV calculation of the instruction set from Dynamo compared to the BEC program.

3.2. Construction cost comparison of wall between basic cost estimation and cost estimation from Dynamo

This study is primarily focused on developing an instruction set capable of interfacing with the database to extract related information. Specifically, selecting data from the price list within the database is utilized to estimate the construction cost of the wall. The data extraction process includes only information concerning construction materials and plastering materials commonly employed in Thailand. Subsequently, a comparative analysis is conducted between the basic construction cost estimation and the estimation used in the instruction set within Dynamo, encompassing both material and labor costs. Upon considering the accuracy of the Dynamo instruction set through the R-square value, it was observed that for a basic single-story building wall, the construction cost calculation instructions proved to be efficient. Notably, the Dynamo's wall cost calculation deducts the area of translucent walls, aligning more closely with actual construction conditions compared to preliminary cost estimations that may overlook this deduction. Furthermore, if the designer decides on a wall design with over 50% of the area comprising translucent elements, it significantly impacts the overall cost of wall construction. The accuracy analysis can be shown in Fig. 9.

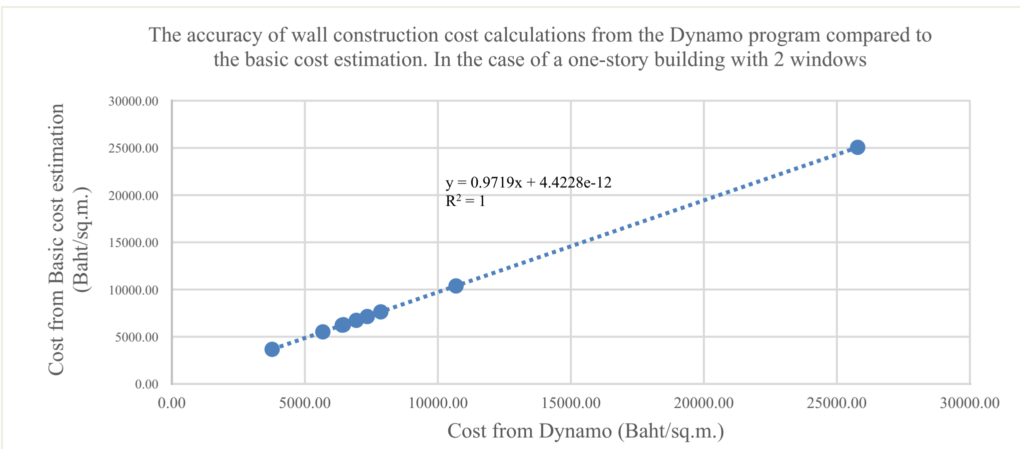

Fig. 9: The accuracy of wall construction cost calculations from the Dynamo program compared to the basic cost estimation. In the case of a one-story building with 2 windows.

3.3. Efficiency of wall design that affects OTTV

Evaluation of wall design that affects OTTV can be calculated by using construction cost per unit of OTTV through the instruction set on Dynamo which the result can be given follow Table 4. The result shows more floors in the building which means the area of solid walls is greater affecting the wall design efficiency will be less. The construction cost used per unit of OTTV per square meter will be decreased. The greater efficiency of wall design can save more construction cost and the building with greater number of windows used more construction cost.

Table 4: Comparison of design performance affecting OTTV values in each case study.

Case Study	OTTV (W/sq.m.)	Cost (Baht)	OTTV/cost (Baht/W/sq.m.)
One-story building without window	24.53	5673.12	0.00432
One-story building with 2 windows	28.78	5513.56	0.00522

Two-story building without window	24.53	10495.27	0.00233
Two-story building with 5 windows	32.32	10947.35	0.00295

4. Conclusion

This research focuses on formulating computer instructions to compute the Overall Thermal Transfer Value (OTTV) of walls and estimate construction costs within a computer-aided design program. The objective is to develop instruction sets that closely align with the BEC program, falling within an acceptable range. Additionally, these instructions aim to calculate construction costs and conduct comparisons with fundamental cost estimation principles. Furthermore, the sets are designed to assess the efficiency of wall designs influencing OTTV. The potential beneficiaries of these instruction sets are designers, encompassing both engineers and architects, utilizing Building Information Modeling (BIM) for the design of energy-efficient buildings subject to legal energy assessments. Simultaneously, these instructions empower designers to manage wall construction costs effectively. Suggestions for future studies, for OTTV calculation, should consider the shading tool which affects the SC value since this study set up the SC value in the case of buildings without the shading tool and for construction cost estimation, should calculate with more details such as a reinforced concrete wall, color painting wall protection.

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