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# Practical-Empirical Modeling on Envelope Design towards Sustainability in Tropical Architecture

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**Abstract:** The building envelope's overall thermal transfer value (OTTV) is an essential aspect of creating sustainable and energy-saving architecture. The original OTTV formula makes it difficult for any user who is not an expert to calculate OTTV. Designers usually need an empirical formula to determine the design direction in the initial design stage. Instead of replacing the previous SNI (The Indonesian National Standard) 6389:2011, this paper will introduce several simple equations as empirical formulas covering solar factor (SF), effective shading coefficient ($S_{Ceff}$), and OTTV. Three hundred architraves units of facade models were investigated to make the formulas or equations. Regression analysis was used to make three practical formulas in this paper. The research validation consists of first and crossed-validation to determine the Root Mean Square Error (RMSE) and Average Percentage of Error (APE) between the rule of thumb and original equation of OTTV from the Indonesian standard. The results show that the RMSE is only 1.12 W/m$^2$, while the APE is 1.05%. By these results, the empirical formulas can be implemented to be the rules of thumb in the first stage of the design process because the values of RMSE and APE are still under the design margin of thermal design in the building.

**Keywords:** OTTV; practical formula; effective shading coefficient ($SC_{eff}$); solar factor (SF); façade projection

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**Citation:** Kusumawati, L.; Setyowati, E.; Purnomo, A.B. Practical-Empirical Modeling on Envelope Design towards Sustainability in Tropical Architecture. *Sustainability* **2021**, *13*, 2959. https://doi.org/10.3390/su13052959

Academic Editor: César Martín-Gómez

Received: 21 February 2021
Accepted: 2 March 2021
Published: 9 March 2021

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## 1. Introduction

Emerging environmental threats stemming from rapid urbanization and reduced energy availability in nature, the negative impacts of climate change, and sick building syndrome have led the government sector and various sectors of construction-based professional institutions to recognize the need to develop effective strategies for sustainable building designs. Accordingly, efforts to create effective solutions for sustainable improvement covering green and low carbon environment and building energy performance have been made in recent years [1,2]. For example, in 2009, Indonesia formally acknowledges the need for green design by establishing the Green Building Council of Indonesia (GBCI). One of the most important programs of GBCI is to give certificates and rank to building in terms of their energy-saving performance. Like other tropical countries, one of the essential indicators used by GBCI in ranking energy-saving performance is energy for cooling. GBCI considered that by decreasing the overall thermal transfer value (OTTV), the energy used for cooling can also be lowered. The building envelope design should be directed to optimize its ability to control thermal energy from the sun that goes into the interior of the building [3].

In an urban condition of a tropical country such as Indonesia, most buildings cannot have enough space for cross ventilation and other efforts to cool the building interior. Therefore, HVAC (Heating, Ventilation, and Air Conditioning) is used. It is known that 30% to 56% of the energy used in the building of a tropical country is for cooling. Building

envelope design should be aim to control the solar thermal energy that goes into the building interior [4,5]. Energy-saving efforts in a building should start with the facade design. A building façade as a part of a building envelope has to protect the interior of a building from solar radiation as much as possible and limit HVAC electricity consumption.

On the other hand, massive walls and inappropriate transparent walls in the building envelope can reflect heat radiation to the environment. However, urban developments and constructions cause the city to become denser and contribute more to the urban heat island effect [6]. More buildings are constructed, but less attention is paid to their impact on the environment and residents. Buildings are one of the primary sources of carbon emissions, as the cooling load of a building accounts for about 63% of its overall electrical load [7,8]. Due to the rapid growth of residential energy consumption, there is an urgent need to reduce carbon emissions [9]. Energy and environmental issues currently focus on the building sector as it represents nearly 33% of global energy consumption and around 20% of $CO_2$ emissions [10,11].

On the other hand, the building stock is increasing slowly [12]. At present, passive cooling systems are no longer a top priority on design concepts for public buildings in Indonesia. Usually, tropical climate problems with relatively high outdoor temperatures are resolved using artificial ventilation [12]. For instance, the issue of global warming increases rapidly. A building should be developed in terms of the green building concept to alleviate those problems [8].

Currently, the Indonesian government prioritizes low-carbon development and facilitates sustainable development [10,11]. In this paper, the green building concept is about the building envelope most affected by the outdoor environment. The building envelope is at the forefront that limits the radiation entry into a building. With a good design of the building envelope, building energy usage can save up to 31% [4,10]. As far as the building elements are concerned, the building envelope covers the building with transparent or opaque walls and roofs. The building envelope is where most of the thermal energy passes through and enters a building interior. Therefore, the energy performance of a building depends, among other things, on the parameters of the building envelope [11–13].

In anticipation of the heat carried by sunlight through the building envelope, it is necessary to understand the building envelope performance [14–18]. Several methods for calculating the heat entering a building include, for example, using experiments and simulations [19,20] One way to find out how effective the building envelope performs is to calculate the value of heat propagation in the building [21,22]. The OTTV formula consists of three main components: (a) conduction through massive walls, (b) conduction through transparent walls, and (c) solar radiation through glass. According to SNI 6389:2011, the OTTV formula is as follows [9,22,23].

$$OTTV = \alpha[Uw(1 - WWR)TDeg] + [Uf(WWR)(\Delta T)] + [(SC)(WWR)(SF)] \quad (1)$$

The $OTTV$ is the overall thermal transfer value ($W/m^2$). The term $\alpha$ is the absorbance of solar radiation of the wall. $U_w$ is the thermal transmittance on massive walls ($W/m^2K$). WWR is the window to wall area ratio. $TD_{eq}$ is the equivalent temperature difference ($K$). $U_f$ is the thermal transmittance of the transparent part of a wall ($W/m^2K$). $\Delta T$ is the planning temperature difference between the outside and the inside of the building (K). $SC$ is the shading coefficient of the shading device of the fenestration system. $SC$ is the multiplication between effective $SC$ ($SC_{eff}$) and the $SC$ of glass ($SC$ = ($SC_{eff}$) ($SC_{glass}$)), and $SF$ is the solar radiation factor ($W/m^2$).

The SNI 6389:2011 is an obligatory national standard in Indonesia used to evaluate building energy conservation performance, especially in facade design. The OTTV is an indicator to see whether a building meets the requirements of SNI 6389:2011. According to SNI 2011, the OTTV of a building must not exceed 35 $W/m^2$.

The heat transfer or OTTV consists of heat conduction through massive walls, heat conduction through transparent walls, and heat radiation through transparent walls or solar heat gain [17,20]. In the OTTV formula, the variable WWR always exists on the three

main components. Several researchers considered solar heat gain in the form of radiation as the largest part of OTTV [23–25]. The formula of solar heat gain is,

$$SHG = [(SC)(WWR)(SF)] \quad (2)$$

The solar heat gain can reach 87% of the OTTV if the architrave unit does not use a shading device, causing it to be exposed to full sunlight [26]. The radiation component or solar heat gain was used to simplify the OTTV; for example, Singapore adopted Equation (3) as the formula to calculate OTTV [27,28].

$$OTTV = 215(WWR)(SC) \quad (3)$$

The constant 215 in Equation (4) is obtained from the average of SF measured from 07.00 until 18.00 for a year. Later on, Singapore adopted Equation (4) as the formula to calculate OTTV [27]:

$$OTTV = 10(1 - WWR)U_w + 5(WWR)U_f + 130(WWR)(SC) \quad (4)$$

In Equation (4), the largest constant is related to the radiation part of OTTV. Equation (4) considered radiation as an essential part of the OTTV. From the results, they suggested revising the OTTV formula, where the radiation factor is 25 W/m$^2$ [27]. In 1988 another simplified formula was introduced in Singapore [28]. The formula can be seen as Equation (5).

$$OTTV = 11(1 - WWR)U_w + 4.8(WWR)U_f + 230(WWR)(SC) \quad (5)$$

Recently, Singapore developed OTTV to become ETTV (envelope thermal transfer value). Equation (6) is the formula to calculate ETTV [29]:

$$ETTV = 12(A_w)U_w + 3.4\left(A_f\right)U_f + 211\left(A_f\right)(CF)(SC) \quad (6)$$

In 2008 Singapore also developed RETV or the residence envelope transfer value. Equation (7) is the formula for RETV of housing [30]:

$$RETV = 3.4(1 - WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC) \quad (7)$$

Meanwhile, there was a review on OTTV SNI 6389:2011 compared to ETTV. The results show that ETTV is more strictly regulated than OTTV SNI 6389:2011, and it is found that buildings in the form of a parallelogram with a north-south orientation have the best results as energy-efficient buildings [31]. The ETTV has been used abroad, but Indonesia recently used OTTV as a national standard to regulate the building forms based on OTTV. The calculation of OTTV, according to Indonesian National Standard (SNI 6389:2011) at least involves 20 tables, three interpolations to calculate $SC_{eff}$, one table, and one interpolation to obtain SF. For material consideration, to calculate OTTV as the method in SNI 6389:2011, a designer has to look at additional five tables. Therefore, this paper considered SNI 6389:2011 is too complicated for designers, especially in the initial design phase, so that the implementation of OTTV still needs to be developed in Indonesia.

Furthermore, changing the OTTV index responds to climate change when the earth is getting warmer [32]. For example, Hong Kong and Taiwan have their formulas for calculating the heat transfer that enters the building [28,29]. Therefore, it is clear that the OTTV formula can continue to evolve with the ever-changing climate.

In SNI 6389:2011, the WWR presents in the conduction and radiation portion of OTTV. WWR plays a significant role in OTTV calculations. WWR determines the size of the area exposed to solar radiation. SC is the ratio between the heat gain through transparent walls and clear glass 3 mm thick, both with and without a shading device. The solar factor or SF is the average hourly rate of solar radiation reaching a surface at certain intervals.

Apart from WWR, other important heat radiation variables through a glass are SC and SF values [22]. Like WWR, SC is relevant to design the form of the building envelope. It is necessary to measure the depth of the overhangs and fins and the height and width of the opening framed by the fins' orientation to obtain SC. As a result, the influence of shading devices on OTTV is apparent [33–36]. SNI s6389:2011 provides a table for obtaining $R_1$ (OPF or overhang projection factor) and or $R_2$ (SPF—side fin projection factor) from the overhang and opening height. The SC is calculated using the values of $R_1$, $R_2$, and SF [23]. According to SNI 6389:2011, the value of SF is a function of the orientation of the facade towards the eight cardinal directions (north, northeast, east, southeast, south, southwest, west, and northwest). If the orientation is not correct in the eight cardinal directions, SNI 6389:2011 provides a special table for interpolation. However, if an area does not have an SF value, it can be calculated with a solar calorimeter, simulated with the Window7 program [37].

WWR can be considered as a variable of building form. SC is determined by horizontal ($R_1$) and vertical ($R_2$) wall projection or fin. The dimension of the horizontal and vertical fin can be considered as two more variables of building form. According to SNI 6389:2011, SF is determined by facade orientation angle and its geographical location. Surface orientation angle is another architectural variable that must be defined early in the design process. Therefore, SF can also be considered as an essential design variable that must be decided early in the conceptual and preliminary design phase especially in the terms of building orientation. Out of the three parts of OTTV, the thermal radiation part contains the largest number of design variables that must be decided in the earliest design phase. In the early stage of the design process, so as not to hinder the designer's creative process, it is a relatively simple and easy way to use the rule of thumb to estimate OTTV. Therefore, it is assumed for a quick estimate of OTTV, rules of thumb should be related as much as possible to the variables of building forms and orientation.

The method to calculate OTTV of SNI 6389:2011 is relatively complete but quite complex to use. Equation (1) is not only a set of simple mathematical operations, but it also contains logical thinking of thermal transfer in a building. The determination of some of the variables in Equation (1) involves looking at some tables and other non-mathematical processes. Therefore, our research objective is to simplify Equation (1) and develop a set of practical formulas that help designers for using the non-mathematical methods presented by SNI 6389:2011.

## 2. Materials and Methods

Most of the study on OTTV in Indonesia has focused on multi-story office buildings located in Jakarta [35–37]. Studies on the OTTV of other building types, such as campus buildings, are still needed to broaden the knowledge about thermal transfer in Indonesia, especially in Jakarta. This research was conducted in Jakarta city. Building C at Trisakti University was chosen as the framework of this study. Building C is located in a busy area where the streets are regularly congested with traffic. The dense and crowded environment that surrounds Building C is a challenge when thermal comfort should be established. This situation can be overcome with the help of an air conditioning machine.

Using the right building envelope will reduce both the heat entering the building and the use of electrical energy [13,38]. In Indonesia, building structures are generally made of concrete. However, shading devices are not always made of concrete. In general, the use of concrete can cause a lot of thermal release at night. Since Indonesia's daily temperature variations are not very significant, the day or night thermal condition is almost the same. Thermal dissipation at night is only slightly more than during the day in average weather conditions.

The formula of OTTV in SNI 6389:2011 covers the equations of heat conduction through the wall, heat conduction through transparent walls, and solar heat gain. The purpose of this current research is to formulate empirical models to simplify the OTTV equation explained in SNI 6389:2011. To make the discussion clear, some figures related to

the research object will be presented in detail. Figure 1 illustrates the Trisakti University campus location in western Jakarta, and the description will be followed by other related information and explanations.

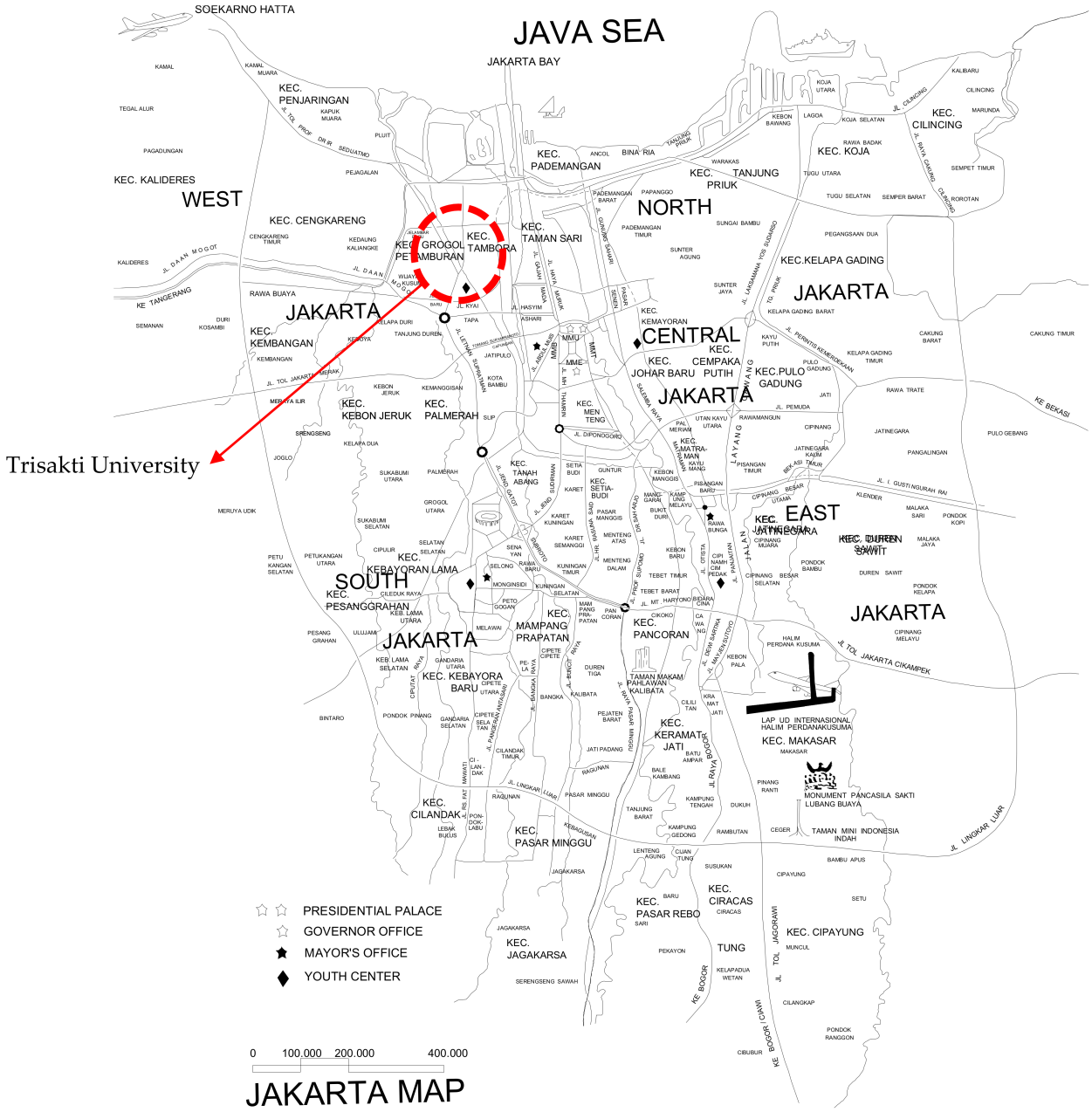



**Figure 1.** The location of Trisakti University in the Jakarta Capital Special Region.

Figure 1 shows the location of Trisakti University in Jakarta. The university is located in the western part of Jakarta, with high density and busy traffic, especially in the morning and evening, and in the relatively hot climate. The campus site is at Jenderal S. Parman and Kyai Tapa streets, in the West Jakarta area, Tomang, Grogol Petamburan District (see Figure 2).

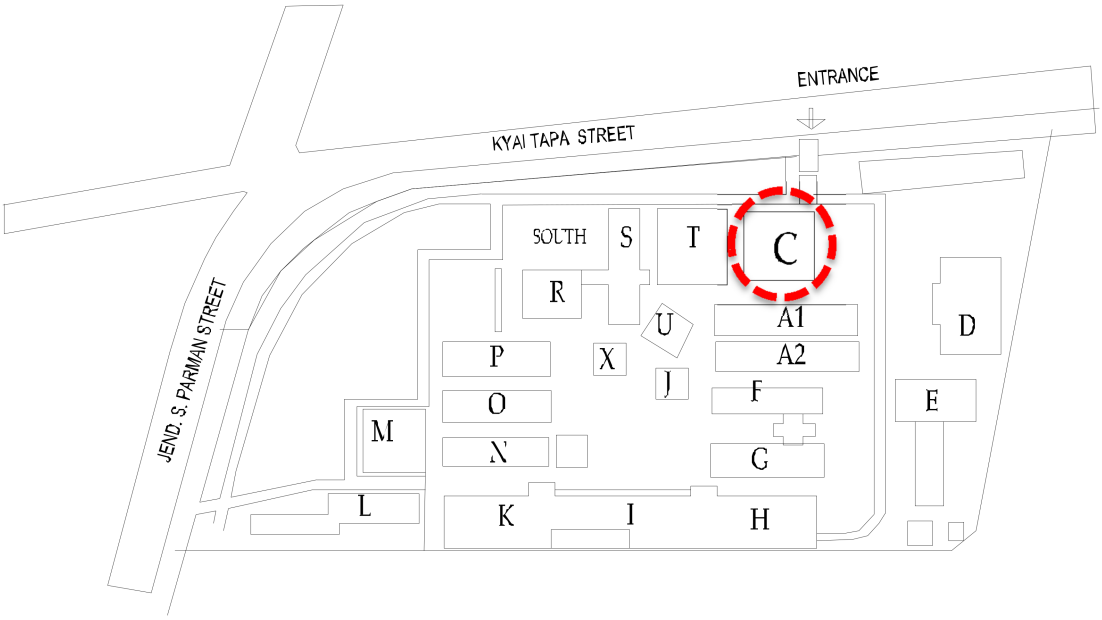



**Figure 2.** The location of Building C on Campus A of Trisakti University.

Figure 2 shows that Building C's location is right in front of Kyai Tapa street entrance, a very approachable entrance for pedestrians or public vehicle users because it is close to a pedestrian bridge and a *Trans Jakarta* bus stop.

Building C was chosen as the research object of this study. The building is located on Campus A of Trisakti University (see Figures 1 and 2). It is a Faculty building with diverse functions (offices, study rooms, libraries, and laboratories). The building was chosen to represent the buildings on the Trisakti University campus. It has a characteristic shape that is almost equilateral with two faces (north and south) with an overhang without louvers as sun protection and the other two faces (west and east) with overhangs and louvers (see Figures 3 and 4). There is no louver on the north and south sides because these orientations are considered less exposed to the sun and do not have any shading devices [39–42]. Indonesia and Singapore are near the equator, where the sun moves from East to West, making the East and West sides need more treatment to deal with solar radiation [43]. The effect of building orientation makes the average indoor air temperature on the East and West walls higher than the room temperature on the north-south sides. The mean temperature difference between the east-west and north-south spaces reaches almost 1 °C for walls 10 cm thick and over 1.5 °C for walls as thick as 20 cm [44].

Building C at the Campus of Trisakti University is redrawn using the Computer Aided-Design (CAD) program. The whole building is divided into parts delineated by two nearest columns and two consecutive floors or an architrave (see Figures 3 and A1). A simulation was done by applying various forms of shading devices and architrave orientation to different compass directions. Building C is only an initial framework for the simulation done to each of the building architraves. In reality, Building C only faces north, east, south, and west. In the simulation, the building was rotated towards the northeast, southeast, southwest, and northwest, resulting in another 8 (eight) architraves cases for the simulation. Building C's envelope has 18 architraves and nine stories and thus has 1296 bays or architraves of which 300 architraves were randomly chosen. The values of each variable on Equation (1) were a result of a randomization process. The OTTV of each architrave was calculated using the variables resulted from the randomization process.

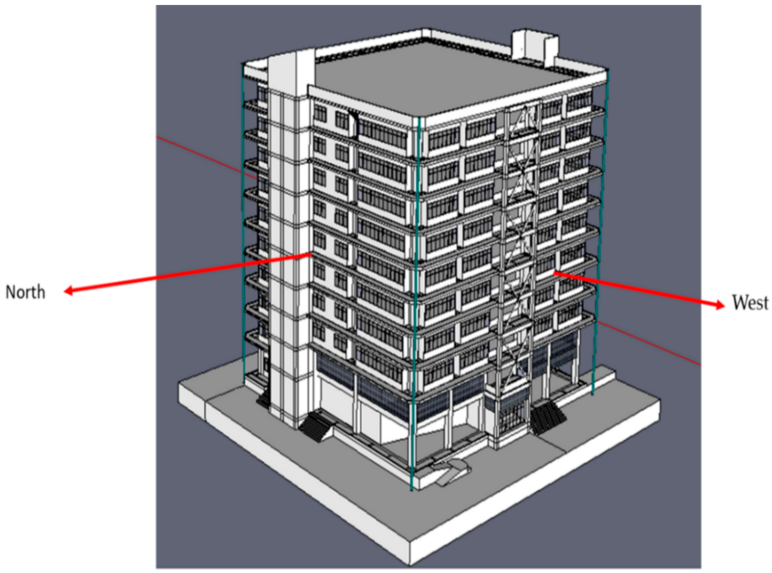



**Figure 3.** Building C Campus A Trisakti University.

Figure 3 shows Building C of the Trisakti University campus. Its facades on the north and south have an overhang, while the east and west sides have overhangs and aluminum louvers. The building envelope unit is taken from the whole building, namely an architrave bounded by consecutive columns and floors (see Figures 3 and A1). Figure A2 in Appendix A illustrates the north, south, east, and west facades of Building C. On the north and south sides, there are concrete walls containing emergency stairs. On the west side, at bay 14th on floors 1, 4, 5, 6, and 7 are open spaces.

Figure A3 (see Appendix A) describes a part of the eastern facade of the building. The architrave has an overhang equipped with a guardrail (fence), 5 mm thick clear glass, and grilles. The overhang is used as a service line.

Figure A4 reveals one architrave at the eastern facade of the building framed by column 4 to column 5, of which there are overhangs, louvers, grille, and 5 mm #1 clear glass. The overhang is used as a service line. Due to the hot, humid climate in the equator region, the building also has a concrete shading device to protect it from high solar radiation.

Figure A5 is drawings of the window section, with overhang and oriented to the north and south (see Figure A5a), while the east and west sides have overhangs equipped with louvers made of aluminum (see Figure A5b). The use of both overhangs and louvers can result in more significant energy savings than without shading devices [34]. Another architrave section of the simulation can be seen in Figure A6, which shows the number of facade details in the building. In the key-plan, numbering is given to the module starting from the south side; namely, the smaller OTTV values then move counter-clockwise: Model #92 (see Figure A6a,b) is located on the south side at the second floor, Model #3 is a window equipped with side fins; Model #2, located on the east side, eight-floor, Model #5 is an architrave with an overhang; Model #91 (see Figure A6c), located on the west side, first floor, Model #12 is an architrave equipped with overhangs and side fins; Model #50 (see Figure A6d) is located on the north side, the fifth floor, module 10 is a window equipped with overhangs and louvers.

Building C was rotated to the northeast, northwest, southwest, and southeast from the initial plan (east, north, west, and south orientation, see Figure A7a in Appendix A). The architrave on the seventh floor is oriented to the northeast, and it has an egg-crate as a shading device (Figure A7b). The northeast of the sixth-floor architrave is equipped with an egg-crate (Figure A7b). An architrave equipped with an egg-crate grille is located in the southeast part of the building (Figure A7c). The architrave shown in Figure A7e is provided with overhangs and louvers on the southwest side on the seventh floor.

This research used model simulation usually carried out in several studies. For example, Karim et al. simulated 54 windows to obtain the heat gain value [21]. The use of models has also been carried out with variations of glass, roller blinds, Venetian blinds using Vision5 software [45]. Likewise, the simulations have egg-crate shading devices (overhangs or fins) to minimize building energy consumption [46]. Some studies used simulated overhang designs by using building information modeling to obtain an optimal and comprehensive model. The study by Panteli et al. is one example of such a study [47]. Another study used the ShadingPlus program to simulate shading devices and calculate solar radiation value entering the building [48]. The steps taken in this study were: to form a simple OTTV formula and create a simulation, which was carried out using 300 cases of architraves based on the C building structure. The 300 architraves were obtained by varying the variables of OTTV in SNI 6389:2011. Many variations were undertaken by randomizing the variables of OTTV in SNI 6389:2011, where each of these randomized configurations forms a facade case. The simulation data was used to determine which part of the formula of OTTV in SNI 6389:2011 has the greatest effect on the OTTV value.

Regression equations can replace complex simulations to obtain a building energy performance based on a facade configuration, including construction material, window type, window length, and width [49]. The simulation data can also simplify the calculation of variables that are relatively unfamiliar to most designers, such as $SC_{eff}$, which would later be multiplied by the SC of the material to produce the SC value [50].

The simple formula for effective SC ($SC_{eff}$) can be obtained from regression analysis, where $SC_{eff}$ is the dependent variable, while $R_1$, $R_2$, and SF are the independent variables. Apart from design variables like WWR and $SC_{eff}$, SF data from SNI 6389:2011 were also used to create a simple SF formula using regression analysis [50]. SF as the dependent variable and AO (angle of orientation) as the independent variable. Regression to establish a simple formula for OTTV, ETTV, and another spatial index was undertaken in [51,52]. The solar factor data in SNI 6389:2011 consists of SF value, the orientation angle, or OA (Table 1). Table 1 is a modification of the SF data in SNI 6389:2011 to transform the architraves orientation into OA, which begins from the east (0°) and moves to the counter-clockwise direction.

**Table 1.** Solar factor or SF ($W/m^2$) and orientation angle of the architrave or OA [22].

| Orientation | SF | Orientation Angle (OA°) |
|---|---|---|
| East | 112 | 0° (360°) |
| Northeast | 113 | 45° |
| North | 130 | 90° |
| Northwest | 211 | 135° |
| West | 243 | 180° |
| Southwest | 176 | 225° |
| South | 97 | 270° |
| Southeast | 97 | 315° |

Figure 4 shows that OA is depicted as the orientation angle and SF as a vector. Polar coordinates describe the the OA and the value of the SF as east (OA = 0° (360°), SF = 112 $W/m^2$), northeast (OA = 45°, SF = 113 $W/m^2$), north (OA = 90°, SF = 130 $W/m^2$), northwest (OA = 135°, SF 211 $W/m^2$), west (OA = 180°, SF = 243 $W/m^2$), southwest (OA = 225°, SF = 176 $W/m^2$), south(OA = 270°, SF = 97 $W/m^2$), southeast (OA = 315°, SF = 97 $W/m^2$).

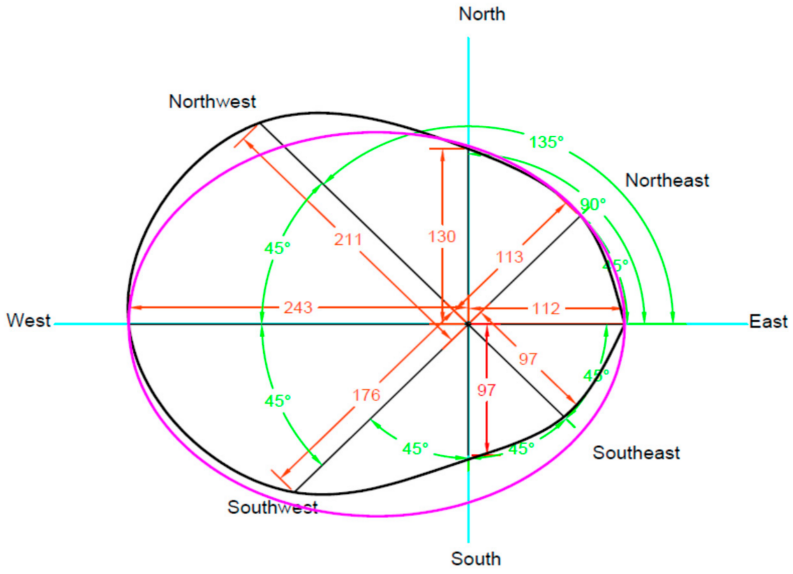



**Figure 4.** The solar factor (SF) is a function of the orientation angle (OA).

From Table 1 in SNI 6389:2011 and Figure 4, it can be hypothesized that the relationship between SF and OA can be depicted as a form of a conic section (see Figure 4) [53]. In other words, SF is a function of variables of sin(OA), cos(OA), sin(OA)cos(OA), $\sin^2$(OA), $\cos^2$(OA), and can be expressed as a polar equation of an ellipse in general [54]. A regression function can be obtained for SF as the dependent variable and OA trigonometric functions as the independent variables.

Several papers mentioned that the portion of the radiation of OTTV is larger than its percentage of conduction [24,25]. If the simulation data is following [24,25], then a simplification of the OTTV formula can be proposed using only the radiation portion. The calculation method of $SC_{eff}$ in SNI 6389:2011 involves observations of several tables and some interpolations. Simulation data can also be used to form a more straightforward formula for $SC_{eff}$. In the calculation method of $SC_{eff}$ in SNI 6389:2011, it is clear that $SC_{eff}$ is a function of $R_1$, $R_2$, and SF. By using multiple regressions from SPSS 26.0 it is expected that a simple formula can be obtained to calculate the $SC_{eff}$ from $R_1$, $R_{2s}$, and SF.

## 3. Results

### *3.1. Simplification of Equation (1)*

From the calculation of OTTV of the 300 cases of architraves, it is found that the OTTV consisted of 22% thermal conduction through walls, 20% thermal conduction through the glass, and 58% thermal radiation through glass (solar heat gain). Since the largest portion of OTTV is solar heat gain, the simple formula for calculating OTTV can be proposed as:

$$OTTV = (WWR)(SC)(SF)/(58\%) \quad (8)$$

$$OTTV = 1.724\,(WWR)(SC)(SF) \quad (9)$$

Equation (9) simplifies OTTV with the assumption that the variation of materials of the architraves is considered constant. The walls are masonry, and the fenestration is clear glass with SC equal to 0.95. This simplified formula of OTTV is introduced to quickly calculate OTTV needed in the early design phase, such as in the conceptual and preliminary design phases. However, in a more advanced design phase, such as in the design development phase or design school, students must be taught how to calculate OTTV. Equation (9) is not acceptable anymore. The original equation of OTTV (Equation (1)) is simple since it comprises addition and multiplication. Equation (1) becomes complex due to the variable SC and SF. In SNI 6389:2011, the methods used to obtain SC and SF are quite tedious. For instance, to obtain SC's value, one must consult many tables and make interpolations.

Therefore, simple formulas to calculate SC and SF are needed. Once it is established, Equation (1) can be considered a simple formula for OTTV and can be exchanged for Equation (9) and produce a more accurate estimation of OTTV.

### *3.2. Determination of Shading Coefficient (SC) Equation*

The step-wise regression analysis results on the data of the 300 cases of architraves, with $SC_{eff}$ as the dependent variables, $R_1$, $R_2$, and SF as the independent variables are in Tables 2 and 3.

**Table 2.** Model summary.

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | 0.563 [a] | 0.317 | 0.314 | 0.092 |
| 2 | 0.695 [b] | 0.483 | 0.480 | 0.080 |
| 3 | 0.733 [c] | 0.538 | 0.533 | 0.076 |

[a] Predictors: (Constant), $R_1$(OPF). [b] Predictors: (Constant), $R_1$(OPF), $R_2$(SPF). [c] Predictors: (Constant), $R_1$(OPF), $R_2$(SPF), SF.

**Table 3.** The result of regression of $SC_{eff}$ [a].

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 0.748 | 0.009 | | 82.414 | 0.000 |
| | $R_1$(OPF) | −0.137 | 0.012 | −0.563 | −11.754 | 0.000 |
| 2 | (Constant) | 0.806 | 0.010 | | 81.693 | 0.000 |
| | $R_1$(OPF) | −0.169 | 0.011 | −0.695 | −15.846 | 0.000 |
| | $R_2$(SPF) | −0.077 | 0.008 | −0.429 | −9.780 | 0.000 |
| 3 | (Constant) | 0.883 | 0.016 | | 54.893 | 0.000 |
| | $R_1$(OPF) | −0.167 | 0.010 | −0.688 | −16.559 | 0.000 |
| | $R_2$(SPF) | −0.078 | 0.007 | −0.435 | −10.475 | 0.000 |
| | SF | −0.001 | 0.000 | −0.233 | −5.900 | 0.000 |

[a] Dependent variable: $SC_{eff}$.

With $R_1$ is overhead projection factor (OPF) and it is defined as a ratio between the length of shading to the window height. Meanwhile, $R_2$ is the side fin projection factor (SPF), the ratio of the length of the side fin to the width of the window.

Table 2 shows three significant models that can be used to explain the relationship between $SC_{eff}$ and the independent variables, $R_1$, $R_2$, and SF. In accord with the value of R or R square of each model, Model 1 has the smallest R square, which means that the variation of $SC_{eff}$ being explained by the independent variables is less than that of other models with larger R square. The smaller R square model can be considered less accurate when used to estimate $SC_{eff}$ compare to the larger R square model. However, a smaller R square model is also more straightforward than a model with a larger R square. Therefore, there is a tradeoff between the simplicity and accuracy of the model used as a simple formula for $SC_{eff}$.

Table 3 describes how the three models can be considered significant. Sig. = 0 in Table 3 indicates that each model-independent variable significantly affects $SC_{eff}$ (dependent variable). The t value is a measure of how much the regression coefficient differs from 0. If t = 0, then the regression coefficient is not significant and should be considered as zero. In Table 3 the significant value is less than 0.05. Thus, it can be concluded that all coefficients are significant and not equal to 0 [55].

Table 3 describes three models of equations that describe the relationship between $SC_{eff}$ as dependent variables and $R_1$, $R_2$, and SF as independents variables. The three models shown in Table 3 are the same model in Table 2. From Table 3, the simplest relationship between $SC_{eff}$ and the dependent variables is Model 1, where $SC_{eff}$ is considered only dependent on one independent variable ($R_1$). Model 3, with the largest R square, is more complicated than Model 1. Model 3 has three independent variables to explain $SC_{eff}$. Table 3 shows that looking at its R square, Model 3 is proposed as the simple formula of

$SC_{eff}$, as shown in Equation (10). In Equation (10), the value of constant = 0.883 indicates that if $R_1$ and $R_2$ are equal to 0, then the value of $SC_{eff}$ is 0.883. Since the value of all regression coefficients in Model 3 (Equation (10)) is negative, it can be concluded that $R_1$, $R_2$, and SF negatively affect $SC_{eff}$.

$$SCeff = 0.833 - (0.167R_1) - (0.078R_2) - (0.001SF) \quad (10)$$

Figure 5 shows the distribution of $SC_{eff1}$ and $SC_{eff2}$. $SC_{eff1}$ (blue) is the effective shading coefficient calculated using the SNI method. $SC_{eff2}$ is the effective shading coefficient calculated using the empirical formula Equation (10). It appears in Figure 5 that the $SC_{eff2}$ value is relatively smaller than the $SC_{eff1}$ value. For example, on the blue chart, the value 1000 means $SC_{eff\ 1}$ = 1000, and the orange chart shows 0.3509 meaning $SC_{eff2}$ = 0.3509. From this description, it is possible to investigate further so that the $SC_{eff2}$ (Equation (10)) value is equal to or close to the $SC_{eff1}$ value (from the calculation using the SNI 6389:2011 table).

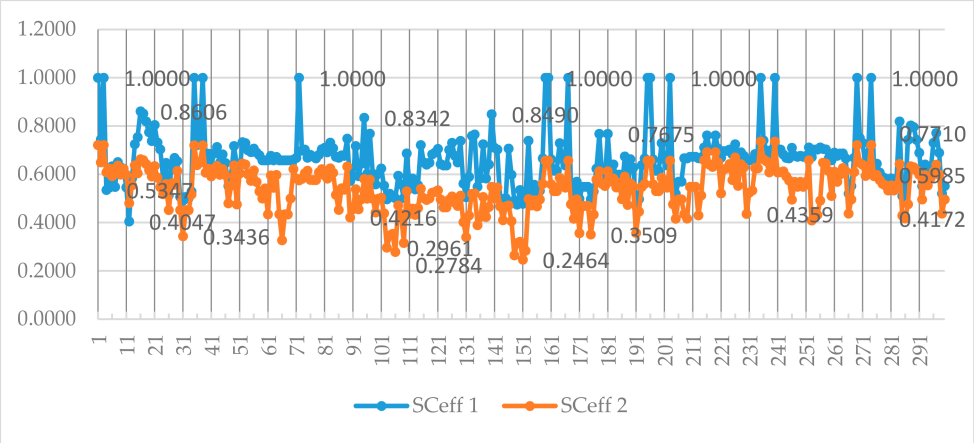



**Figure 5.** Comparison of $SC_{eff2}$ to $SC_{eff1}$.

### *3.3. Determination of Solar Factor (SF) Equation*

Tables 4 and 5 are the results of regression analysis with SF as dependent variable and sin(OA), cos(OA), sin(OA)cos(OA), $sin^2$(OA), and $cos^2$(OA) as independents variables. Table 4 shows four models that can describe the independent variable influence on SF as the dependent variable. Model 4 has the largest R square compared to the other three models. Therefore, it can be concluded that the best model for the simple formula of SF is the fourth model (see Tables 4 and 5).

**Table 4.** Model summary.

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | 0.859 [a] | 0.738 | 0.700 | 29.314 |
| 2 | 0.971 [b] | 0.942 | 0.923 | 14.880 |
| 3 | 0.997 [c] | 0.994 | 0.991 | 5.217 |
| 4 | 0.999 [d] | 0.998 | 0.996 | 3.386 |

[a] Predictors: (Constant), Cos(OA). [b] Predictors: (Constant), Cos(OA), $Cos^2$(OA). [c] Predictors: (Constant), Cos(OA), $Cos^2$(OA), Sin(OA). [d] Predictors: (Constant), Cos(OA), $Cos^2$(OA), Sin(OA), Sin(OA)Cos(OA).

**Table 5.** The result of the regression of SF [a].

| | Model | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 149.981 | 9.882 | | 15.178 | 0.000 |
| | cos(OA) | −58.828 | 13.258 | −0.859 | −4.437 | 0.003 |
| 2 | (Constant) | 115.632 | 8.995 | | 12.856 | 0.000 |
| | cos(OA) | −64.553 | 6.844 | −0.942 | −9.432 | 0.000 |
| | $\cos^2$(OA) | 62.974 | 13.688 | 0.460 | 4.601 | 0.004 |
| 3 | (Constant) | 115.632 | 3.154 | | 36.666 | 0.000 |
| | cos(OA) | −64.553 | 2.400 | −0.942 | −26.902 | 0.000 |
| | $\cos^2$(OA) | 62.974 | 4.799 | 0.460 | 13.122 | 0.000 |
| | sin(OA) | 17.266 | 2.609 | 0.228 | 6.619 | 0.001 |
| 4 | (Constant) | 115.632 | 2.046 | | 56.502 | 0.000 |
| | cos(OA) | −64.553 | 1.557 | −0.942 | −41.456 | 0.000 |
| | $\cos^2$(OA) | 62.974 | 3.114 | 0.460 | 20.221 | 0.000 |
| | sin(OA) | 17.266 | 1.693 | 0.228 | 10.199 | 0.001 |
| | sin(OA)cos(OA) | −9.500 | 3.386 | −0.063 | −2.806 | 0.049 |

[a] Dependent variable: SF.

Table 5 describes the equation of SF as dependent variable and cos(OA), $\cos^2$(OA), sin(OA), and sin(OA)cos(OA) as independent variables. Therefore, the simple formula for calculating SF is:

$$SF = 115.632 - (64.553\cos(OA)) + \left(62.9742\cos^2(OA)\right) + (17.266\sin(OA)) - (9.500\sin(OA)\cos(OA)) \quad (11)$$

Figure 6 shows the graph of Equation (1). The graph of SF as shown in Figure 6 is skewed to the west, thus reflecting the value of SF in Table 1.

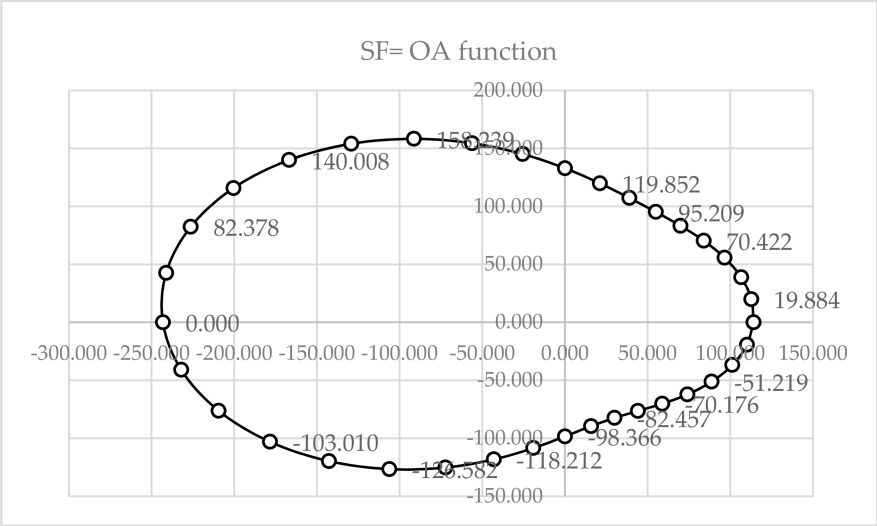



**Figure 6.** Graph of the equation model of solar factor (refer to Equation (11)).

### *3.4. Validation*

At the first validation to calculate $OTTV_1$ and $OTTV_2$ from 30 cases, the APE (average percentage of error) and RMSE (Root Mean Square Error) values were calculated using Excel 2019, with the Formulas (12) and (13):

$$APE = average((OTTV_1 - OTTV_2)/OTTV_1) \times 100\% \quad (12)$$

$$RSME = average\left((OTTV_1 - OTTV_2)^2\right)^{0.5} \quad (13)$$

where the $OTTV_1$ is derived from the formula from SNI 6389:2011, and $OTTV_2$ is derived from Equations (9)–(11) for the first validation and Equations (1), (10) and (11) for the

second validation (cross-validation). The second validation (cross-validation) on OTTV using various types of walls, surface colors (as seen in Table 6), and types of glass (see Table 7):

**Table 6.** Absorbance and material.

| The Absorbance Value of Solar Radiation for Wall Surfaces | | Material, α, D and K | | | |
|---|---|---|---|---|---|
| **Thermal Absorbance of Exterior Surface Paint** | **α** | **Material** | **α** | **Density (kg/m$^3$)** | **K (W/m·K)** |
| White | 0.25 | Concrete | 0.86 | 2400 | 1.448 |
| Light green | 0.47 | Brick | 0.89 | 1760 | 0.807 |
| Medium blue | 0.57 | | | | |
| Gray | 0.88 | | | | |

**Table 7.** Type of glass.

| No | Type of Glass | Thickness (mm) | SC | Uv (W/m$^2$K) |
|---|---|---|---|---|
| 1 | T-Sunlux OPTIMA 8 mm T-Sunlux CS 508 (#2) + AS.12+6 mm Planibel G (#3) | 26 | 0.12 | 1.9 |
| 2 | Evo ET 725 8 mm + 12 mm AS + Clear 6 mm | 26 | 0.19 | 2.0 |
| 3 | Stopsol Super silver Dark Blu (SSDH) SSDH.8(#2)+AS.12+PNGFL.6(#3) | 26 | 0.29 | 1.9 |
| 4 | SSDH.8(#2) + AS.12 + FL.6 | 26 | 0.34 | 2.8 |
| 5 | Stopsol Classic Green (CGN) 5#1 | 5 | 0.42 | 5.8 |
| 6 | New Stopsol Supersilver New Dark Blue (SSDHNF) 5#1 | 5 | 0.50 | 5.8 |
| 7 | Panasap dark grey (DGFL) | 6 | 0.55 | 5.7 |
| 8 | Panasap New Dark Blue (DHNFL) | 5 | 0.63 | 5.8 |
| 9 | Panasap Bronze (BRFL) | 6 | 0.73 | 5.7 |
| 10 | Planibel G Single Glassing 6 mm#2 | 6 | 0.80 | 3.7 |
| 11 | Stopsol Clear Glass 5#1 | 5 | 0.95 | 5.9 |

Then the next step is the calculation of $OTTV_1$ and $OTTV_2$ to obtain the APE and RSME:

After Equations (9)–(11) are obtained, cross-validation was undertaken using 30 cases not included in the 300 architraves that had already been used to obtain the three equations. The three equations are used to calculate the OTTV value of the 30 architraves. For each of the 30 architraves, the calculation of the $OTTV_1$ is conducted as the OTTV that was calculated using the method in SNI 6389:2011 (see Table 8). From each architrave used in the validation process, Equations (9)–(11) are used to calculate $OTTV_2$. The average percentage of error (APE) is the average of $((OTTV_1 - OTTV_2)/OTTV_1)$ multiplied by 100%. The next step is to calculate the root mean square error (RMSE), which can be defined as the root square of the average squared difference between $OTTV_1$ and $OTTV_2$ (see at the last rows of Table 8). The cross-validation shows that the value of RMSE is 3.68 W/m$^2$ and of APE is 9.21%. These values are still under the design margins of thermal design [56]. According to Jones and Eckert [56], the maximum design margin is 25% in the preliminary design phase in the design development phase; the margin is plus-minus 15%. If $OTTV_2$ is calculated for the 30 cross-validation cases using Equations (1), (10), and (11), the RSME is 1.12 W/m$^{2,}$ and the APE is 1.05% both are smaller than if the OTTV is calculated with Equations (9)–(11). Therefore, the simple practical formulas are validated as rules of thumb in the early design process.

**Table 8.** Calculate overall thermal transfer value ($OTTV_1$) and $OTTV_2$ to obtain the average percentage of error (APE) and Root Mean Square Error (RMSE).

| No. | 1st Validation | | 2nd Validation (Cross-Validation) | |
|---|---|---|---|---|
| | **$OTTV_1$ (OTTV SNI) W/m²** | **$OTTV_2$ (Equations (9)–(11)) W/m²** | **$OTTV_1$ (OTTV SNI) W/m²** | **$OTTV_2$ (Equations (1), (10) and (11)) W/m²** |
| 1 | 27.0998 | 29.5278 | 29.2164 | 28.1545 |
| 2 | 29.7501 | 30.6974 | 41.6351 | 40.9069 |
| 3 | 11.2160 | 5.8723 | 26.2128 | 22.8425 |
| 4 | 22.0375 | 20.2206 | 15.7550 | 16.3636 |
| 5 | 30.3435 | 29.5750 | 11.0535 | 11.6360 |
| 6 | 37.4490 | 40.9612 | 16.6071 | 16.6610 |
| 7 | 30.4284 | 29.3289 | 11.3302 | 12.1756 |
| 8 | 37.3719 | 39.9135 | 34.4725 | 35.3443 |
| 9 | 25.0602 | 23.9799 | 33.8124 | 34.6274 |
| 10 | 20.2761 | 16.6102 | 24.6252 | 25.8696 |
| 11 | 52.1269 | 55.9995 | 31.0756 | 33.1905 |
| 12 | 37.2813 | 36.4103 | 22.0378 | 22.8852 |
| 13 | 22.9604 | 19.4676 | 24.5979 | 24.9611 |
| 14 | 23.7141 | 20.7138 | 31.6796 | 31.2634 |
| 15 | 41.0729 | 51.4957 | 16.6987 | 15.8096 |
| 16 | 31.8447 | 29.2084 | 14.0734 | 13.4990 |
| 17 | 34.3508 | 37.5276 | 22.4095 | 20.6966 |
| 18 | 17.0266 | 14.1588 | 23.5897 | 22.0660 |
| 19 | 24.3095 | 18.9950 | 17.1804 | 16.8288 |
| 20 | 36.9553 | 39.6779 | 23.0923 | 21.8217 |
| 21 | 28.4189 | 28.0338 | 4.7706 | 4.6088 |
| 22 | 11.3974 | 5.6198 | 18.5629 | 17.6429 |
| 23 | 23.8320 | 25.3229 | 45.6038 | 43.2740 |
| 24 | 13.7968 | 10.4199 | 22.6846 | 22.5141 |
| 25 | 20.1757 | 17.9119 | 8.4899 | 8.3849 |
| 26 | 20.9383 | 18.1168 | 12.4727 | 12.4434 |
| 27 | 35.3824 | 33.6410 | 33.1533 | 32.7199 |
| 28 | 10.2945 | 4.9295 | 10.5071 | 10.3448 |
| 29 | 21.9516 | 16.5476 | 19.9144 | 19.7627 |
| 30 | 14.5514 | 12.2291 | 18.3671 | 18.2421 |
| Total | 793.4137 | 763.1137 | 665.6816 | 657.5408 |
| Average | 26.4471 | 25.4371 | 22.1894 | 21.9180 |
| APE (%) | | 9.21 | | 1.05 |
| RSME (W/m²) | | 3.68 | | 1.12 |

## 4. Discussion

### *4.1. Equation (9) for the Overall Thermal Transfer Value (OTTV)*

From the simulation data, the average percentage of radiation = 58%, or OTTV = 1724 SHG. The value of massive field conduction, transparent field conduction, and radiation was calculated using the OTTV formula from SNI 6389:2011. Several ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) formulas highlighted that the radiation portion of OTTV was 87%; this study shows different results. Therefore, a practical formula can be written as OTTV = 1.724 (WWR) (SC) (SF).

The advantage of this first simple formula is the reduction in the number of variables and constants used to calculate OTTV from five constants ($\alpha$, $TD_{eq}$, $\Delta T$, $U_w$, $U_f$) and the three variables in the SNI 6389:2011 version of the OTTV formula to only 3 (three) variables. Constants also add complications to the SNI 6389:2011 version of OTTV calculations because they vary according to the type of materials used on the facade. With the five constants loss in the simple Equation (9), the OTTV calculation becomes easier for designers who usually create design variables for the dimension of room components, such as WWR. In the first simple formula, the variables are commonly used in designing facades covering

the dimension of overhangs and the area of transparent walls. The WWR is the variable determining the shape of the wall aperture; $SC_{eff}$ is a shading device design variable that is an integral part of building cladding design. SF is determined by the orientation of the facade, which can also be considered as conventional design variables.

The limitation of the first simple formula is that it disguises the physical principles of entering heat into the building. For example, the transparent conduction portion in the SNI 6389:2011 version of the OTTV formula is considered constant and only represented by the radiation portion. It certainly reduces the accuracy of OTTV calculations carried out using this simple formula. However, with the simplicity of this formula, the designer can immediately take design decisions at the beginning of the design process. In the advanced design stage, Equation (9) can be exchanged with the original OTTV formula of SNI 6389:2011 (Equation (1)). However, to use Equation (1), $SC_{eff}$ and SF should be calculated first. To calculate $SC_{eff}$ and SF in SNI 6389:2011 was quite complex for the early design phase. Therefore, to simplify Equation (1), we need to have simple formulas for $SC_{eff}$ (Equation (10)) and SF (Equation (11)).

### *4.2. Equation (10) for SC Effective in Shading System ($SC_{eff}$)*

According to SNI 6389:2011, SC effective ($SC_{eff}$) is a combined variable based on shading devices design variables $R_1$, $R_2$, and SF. Meanwhile, SF is a function of OA. The shading device design determined by the depth of the overhang ($R_1$) and the vertical fin ($R_2$) is the facade design formal variable, which is the designer's primary concern. In SNI, the $SC_{eff}$ value is calculated using 2 (two) types of the table (tables $R_1$ and $R_2$). The calculation of $SC_{eff}$ will be easier for the architect because by simply entering $R_1$, $R_2$, and SF values in Equation (10), the $SC_{eff}$ value can be obtained immediately.

The limitation of Equation (10) is because the assumption used by SNI 6389:2011 is that the form of shading devices can be easily used as overhangs and side fins. With a more complex form, we may have difficulty separating the facade into an overhang (horizontal) and a side fin (vertical). Another weakness is that Equation (10) contains the SF variable determined by operational variables such as the local climate. However, from Table 2 of SNI 6389:2011, SF is determined by OA (orientation angle). Therefore, it is also necessary to form a simple formula to calculate SF.

### *4.3. Equation (11) for the Solar Factor (SF)*

The SF (solar factor) is determined significantly by the local climate. Determining SF value requires data from Table 2. The SF is usually determined by the intensity of the sun that is recorded every day for several years [57]. Such activities are not possible for designers who need quick information on SF to compute $SC_{eff}$ and OTTV. The SF formula in Equation (11) only requires OA, often used by designers in the site and building design.

Data on SF in SNI 6389:2011 in Table 1 only applies in Jakarta. For other geographic locations, SF tables are different from those in SNI 6389:2011. Because Equation (11) is formed based on the SF table from SNI 6389:2011, Equation (11) only applies to buildings in Jakarta. For other cities, the equation must be adjusted to the local solar factor (SF).

The three simple formulas produced by this study are used in stages. First, SF must be calculated using Equation (11). Secondly, by substituting $R_1$, $R_2$, and SF into Equation (10), $SC_{eff}$ can be obtained. Finally, the OTTV value can be calculated by entering the WWR, $SC_{eff}$, SC material (glass), and SF values into Equation (9).

The building function studied in this study is one of the faculty buildings. It is similar to an office building, in which thermal transfer mostly comes from the radiation component [58]. Thus it is in line with previous research [26]. However, for residential houses, the portion of radiation on OTTV is smaller than conduction through walls [59]. Perhaps this is due to the smaller percentage of windows in residential houses than in office buildings. Therefore, it can be seen that the simple formula generated by this study is more appropriate for calculating OTTV for office buildings. As a result, research should

be directed to develop a simple OTTV formula for other building types different from the building in this current study.

### *4.4. Limitation of the Study*

The concept of OTTV should influence architecture and be included in the earliest design phase. In that case, there should be a simple way in the form of a particular rule of thumb to estimate OTTV that can give a designer a quick estimate of OTTV in the earliest phase of design, so it does not hinder their creative train of thought. The calculation steps of OTTV based on SNI (Indonesia National Standard) and the GBCI (Green Building Council of Indonesia) are too complicated to include the concept of OTTV in the early design phase. SNI 6389:2011 contains at least 14 steps, and 21 tables are needed to calculate the OTTV of a building while in this paper, only three equations are required to estimate OTTV. Of course, the equations reported in this paper are the rules of thumb. It cannot replace the complete calculation of OTTV. Therefore, there are some limitations to the three formulas or rules of thumb introduced in this paper. Firstly, the equation only considered the radiation parts of OTTV, while the conduction was considered constant. Secondly, the base of our rules of thumb is the OTTV defined in Indonesia National Standard. If we look at the OTTV of the SNI 6389:2011, it does not consider the vast and large differences of places in Indonesia. For instance, the SF in SNI 6389:2011 that has to be applied nationally actually results from weather measurement in Jakarta. Geographically, Indonesia is a vast country. The national standard for SF should be based on weather measurement across the country. Recently there other SF tables have been developed by other cities in Indonesia. It can be assumed that such efforts will give variations on how OTTV should be calculated for Indonesia. There seems to be no study yet on the possible regional differences from city to city and place to place in Indonesia in terms of OTTV. Future research on OTTV in Indonesia should include the geographical variation mentioned above.

## 5. Conclusions

Referring to the Indonesian standard of SNI 6389:2011, the formula of overall thermal transfer value in a building envelope consists of heat conduction through massive walls, heat conduction through a wall, and fenestration and solar heat gain. In this study, three simple formulas have been introduced for $SC_{eff}$, SF, and OTTV, respectively as Equation (11), Equation (10), and Equation (9). The first simple formula serves to calculate the value of the solar factor (SF) and the angle of orientation of the facade (OA) as explained in Equation (11). The second simple formula can be used to calculate the effective shading coefficient ($SC_{eff}$) based on $R_1$ and $R_2$ and SF (Equation (10)). The third simple formula can calculate OTTV from WWR, $SC_{eff}$, and SF (Equation (9) or Equation (1)). The three equations can be considered simple and practical because they contain essential architectural design variables that have been conventionally used. These formulas are suitable for a quick estimate of the OTTV and can be essential tools for architects to consider OTTV at the very beginning of the design process.

The simple formulas are generated from simulations on 300 educational building facade architraves located in Jakarta. The calculation of OTTV was also influenced by the geographical location and the type of building. Therefore, using these simple formulas for other building types (office, education, library, and laboratory) with various sites must be carefully validated beforehand. The three formulas produced in this study (Equations (9)–(10)) use the Jakarta data; therefore, it might be only applied to Jakarta. Further research will be needed to produce simple and unified formulas for OTTV before being applied to a broader area and represent Indonesia as a large country. The practical formulas in this paper do not replace the OTTV formula in SNI 6389:2011, but they tend to assist the designer in calculating OTTV at the beginning of the design process. Because the designer also needs to know the value of the OTTV in the design to ensure that the building design can be categorized as a green building to meet the provisions of the local government or not. In the next process, if the building material has been determined in the

design, it is necessary to calculate OTTV with the OTTV refer to the SNI 6389:2011 standard with a maximum value of OTTV 35 $W/m^2$.

**Author Contributions:** Conceptualization, L.K., and E.S.; Introduction and Methodology, L.K., A.B.P. and E.S.; Visualization map and graphs, L.K., and E.S.; Analyzing Data and Interpretation, L.K. and E.S.; Documentation and photography, L.K. and A.B.P.; Conclusion, L.K., and E.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research has been funded by the Indonesian Ministry of Education and Culture through the Doctoral Research grant number 225-22/UN7.6.1/PP/2020 and supported to high reputation international publication research grant number 329-120/UN7.6.1/PP/2020.

**Institutional Review Board Statement:** Ethical review and approval were waived for this study due to not involving humans or animals.

**Informed Consent Statement:** Not applicable.

**Acknowledgments:** The authors thank Trisakti University, Indonesia, for the opportunity to study in the Doctoral Program of Architecture and Urban Planning at Universitas Diponegoro—Semarang. Our gratitude also goes to the Ministry of Education and Culture, Directorate General of Higher Education, and Universitas Diponegoro for this valuable opportunity to be granted in doctoral program education.

**Conflicts of Interest:** There is no intervention in any part of this research from the grantor or other sector mentioned in this study.

## Abbreviations

| | |
|---|---|
| OTTV | Overall Thermal transfer value ($W/m^2$). |
| $\alpha$ | the absorbance of solar radiation. |
| $U_w$ | thermal transmittance of the opaque wall ($W/m^2K$). |
| WWR | window to wall ratio. |
| $TD_{eq}$ | the equivalent temperature difference (K). |
| $U_f$ | thermal transmittance of fenestration ($W/m^2K$). |
| $\Delta T$ | the temperature difference between exterior and interior design conditions (5° K). |
| SC | shading coefficient of fenestration. |
| SF | solar factor ($W/m^2$). |
| $SC_{eff}$ | effective shading coefficient of fenestration. |
| ETTV | envelope thermal transfer value ($W/m^2$). |
| RETV | residential envelope transmission value ($W/m^2$). |
| $R_1$ | OPF (overhead projection factor), the ratio between the length of shading to the window height. |
| $R_2$ | SPF (side fin projection factor), the ratio of the length of the side fin to the width of the window. |
| OA | orientation angle. |
| SHG | solar heat gain. |
| RMSE | Root Mean Square of Error |
| APE | Average Percentage of Error |

## Appendix A

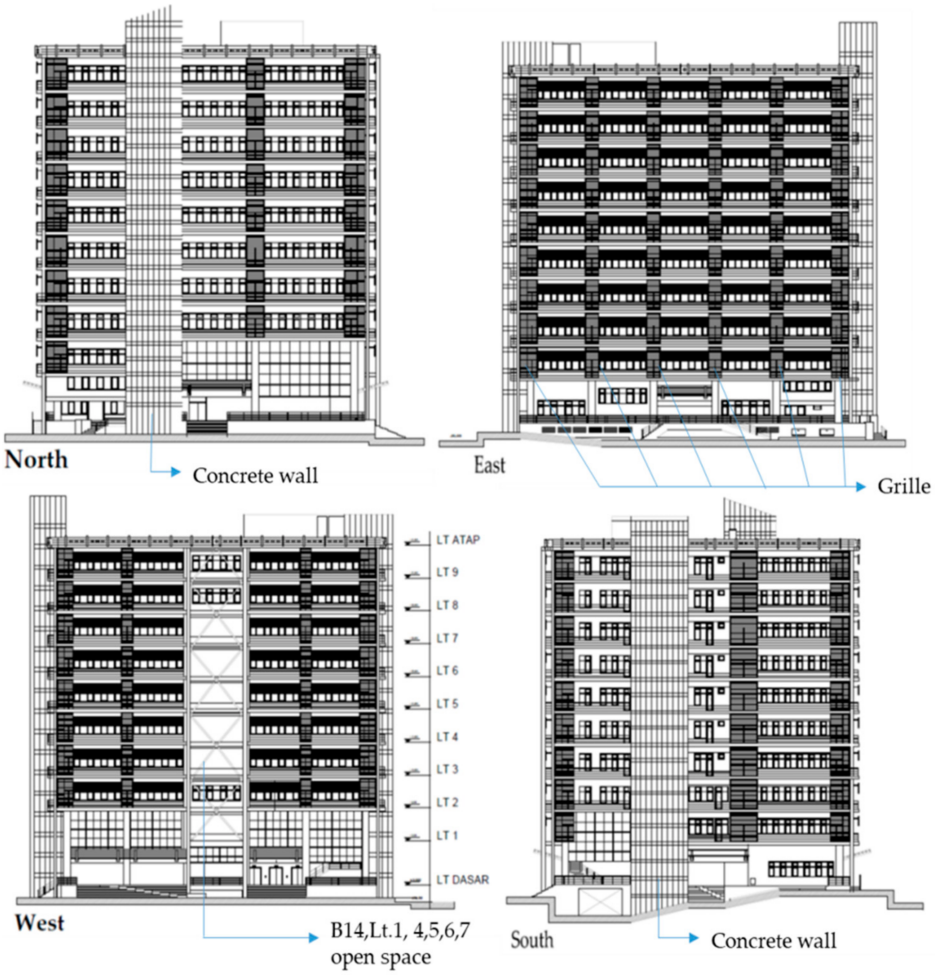



**Figure A1.** North, south, east, and west views.

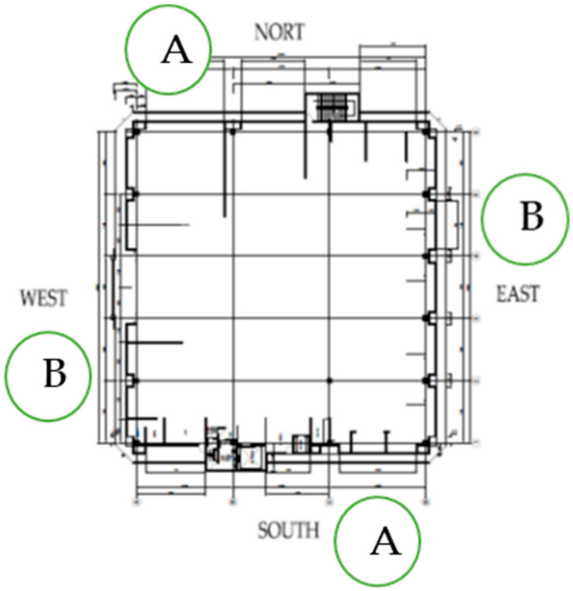



**Figure A2.** Key Plan.

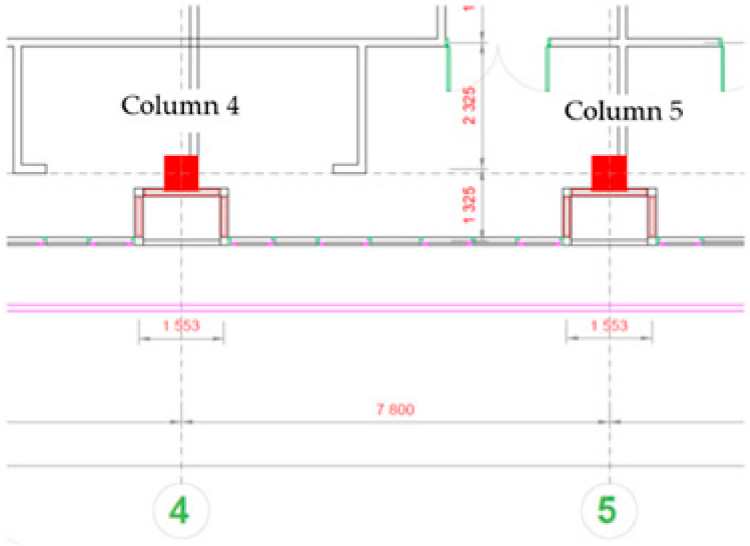



**Figure A3.** Plan of one module (from column 4 to column 5).

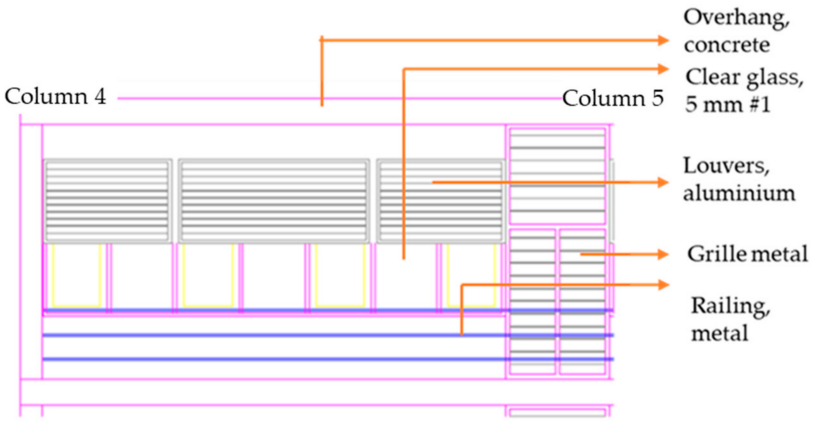



**Figure A4.** The detailed elevation of one module from column 4 to column 5.

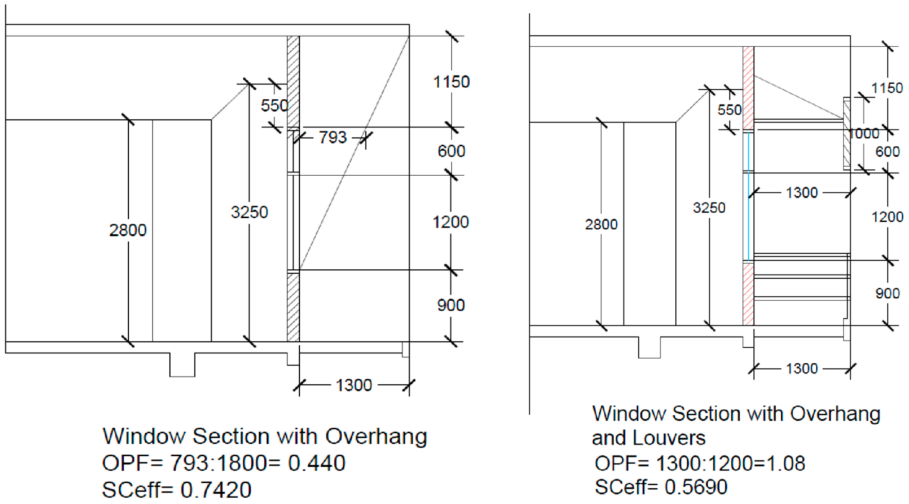
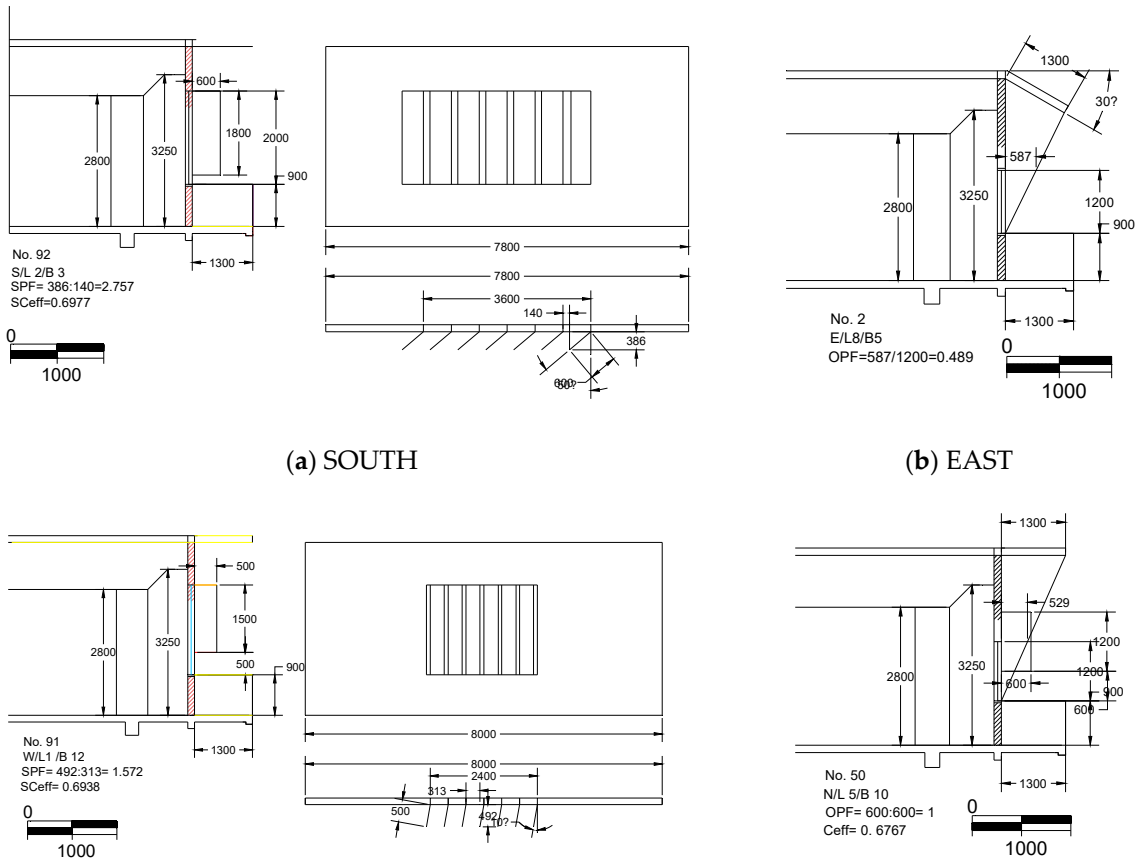


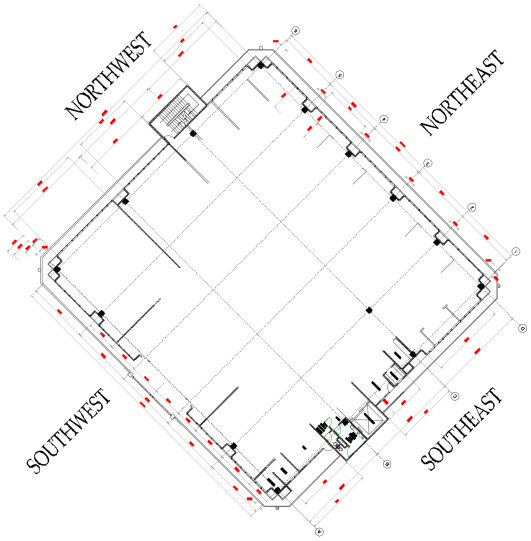

**Figure A5.** (**a**) Existing North and south Window section; (**b**) Existing East and West Window section.




(**a**) SOUTH (**b**) EAST

(**c**) WEST (**d**) NORTH

**Figure A6.** Several variant models on the (**a**) south, (**b**) east, (**c**) north, and (**d**) west sides.




(**a**)

**Figure A7.** *Cont.*

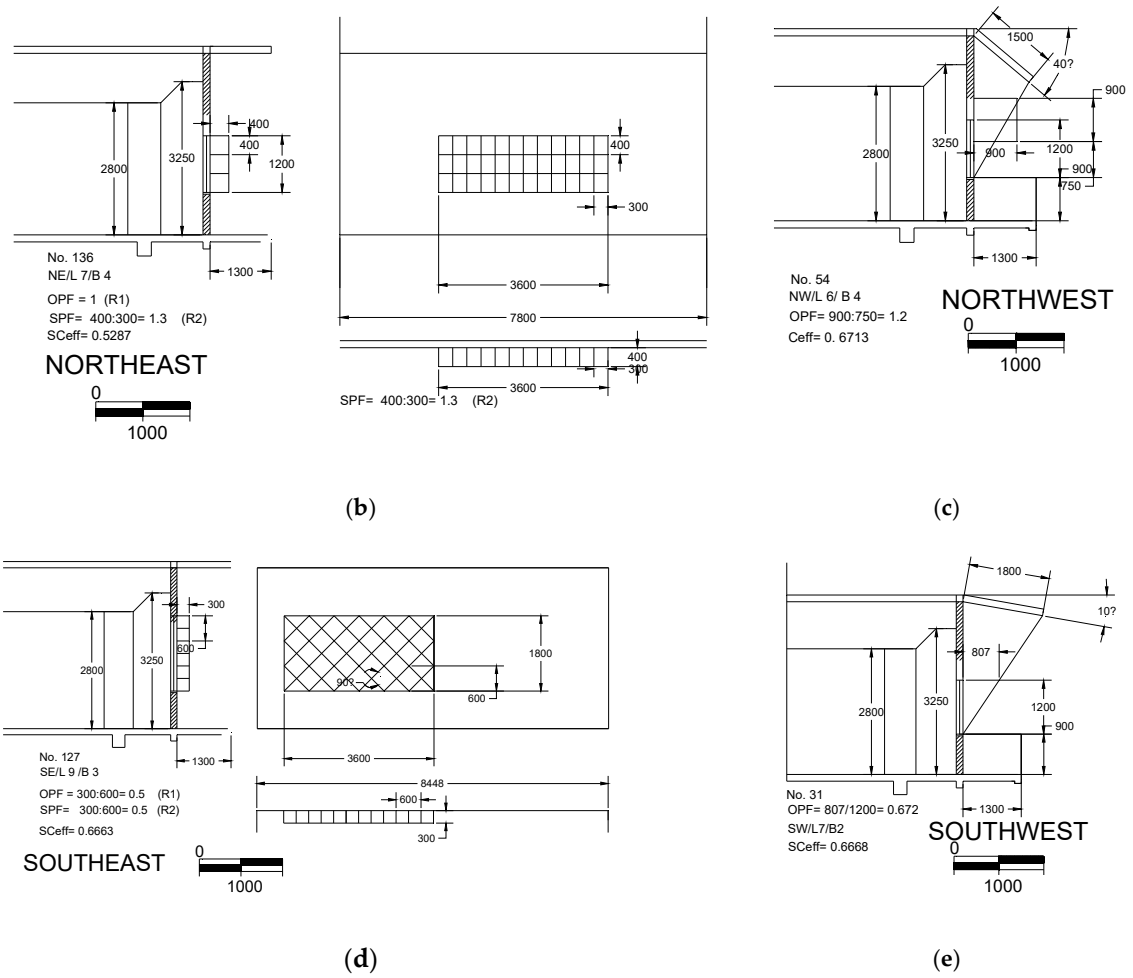



**Figure A7.** Several variant models on the (**a**) key-plan; (**b**) northeast, (**c**) northwest, (**d**) southeast, and (**e**) southwest sides.

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