The influence of Overall Thermal Transfer Value (OTTV) on building energy consumption

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Abstract. Air Conditioning (AC) system is one form of energy consumption which heavily loads the total energy usage in a building. It is essential to find relation between power used by AC to design factor of a building. Numerous countries have been using Overall Thermal Transfer Value (OTTV) as consideration in designing energy efficient buildings. Indonesia even regulated it on SNI 03-6389 2011 on energy conservation of building envelopes. In this paper, we will discuss how OTTV derived from façade measurements and find its correlation to power of those air conditioners consumed.

1. Introduction

The nation’ awareness towards sustainable development has been gradually increasing for the last two decades. It is encouraged by Indonesia Government in Law No. 30/2007 on Energy and Government Regulation No. 79/2014 on National Energy Policy Direction. Consequently, provincial governments regulated their green building plan such as the Capital Jakarta as one of the lead with its Jakarta Building User Guide [1].

The guidance induces construction companies to implement certain approaches as mentioned in it. Two of the main measurements are Overall Thermal Transfer Value (OTTV) and Roof Thermal Transfer Value (RTTV). OTTV is an average value of heat transferred into a building through the building envelope [2] while RTTV an average value of heat transferred into a building through the building roof [3]. Both measures are often used to design energy efficient buildings.

The relation between OTTV and energy consumption has been investigated with four approaches which are (1) the equations derived by Chow and Chan through extensive energy simulations, (2) the ASHRAE 90A-80 method, (3) the one recommended in the Hong Kong Code of Practice (HKCOP) published by the HKSAR Government, and (4) the basic definition of OTTV using data generated from computer simulations by TRACE 600 [4].

It is highly important to know the relation between OTTV and building energy consumption to be able to design buildings that not only eco-friendly but is also sustainable as well as green.

The remain of this paper are organised as follows: the latest works done by other researchers are presented in Section 2 followed by method and analysis used in Section 3. Results are discussed in Section 4 ended with Conclusions and Future Works in the last section.
2. Related Works

The utilization of OTTV as a consideration in designing buildings could be traced back to 1995 when Chow and Chan proposed it as a parameter to design building envelopes. The ratio between wall to window, shading coefficient, absorptivity of the wall, and wall heat capacity were said to be key parameters in determining OTTV [5]. The growing interest to explore OTTV occurred in Hongkong where the government used the value in their regulations of building plan approval but yet another important factor namely daylighting was not included in their calculation yet [6].

OTTV has been then linked to energy consumption of air conditioners since they consume a huge part of electricity in comparison to other appliances. In Thailand, they used OTTV for determining energy model of commercial buildings [7]. They also investigated the effect of temperature variation to the OTTV, claimed that it can be used to improve energy efficiency of the buildings [8].

Regardless all the increasing attention in OTTV, the suitability of using OTTV was questioned, whether or not it truly represents the thermal performance of building envelope due to its pre-calculated parameters [9]. However, the insistence of OTTV avail was still growing with respect to reduction of CO₂ emission, researchers have then searched ways to refine the calculation so that the formulas will accurately estimate OTTV of diverse types of sophisticated buildings [10]. In further development, it was found that the OTTV approach was used not only for public spaces but for personal spaces as well, such as bedrooms and residential houses [11, 12].

3. Method

It is a research and development which obtained data by taking façade measurements including orientation, material types, and shading elements, and then calculate it to find OTTV. The campus buildings where data taken were several rooms at Department of Electrical Engineering Education, Yogyakarta State University including 5 classrooms and a laboratory chosen by employing Purposive Sampling Technique. The data was collected using questionnaire filled by lecturers, technicians, administrative staff and students who frequently use the rooms.

This research used quantitative approach. The calculation of OTTV was in accordance with Indonesia National Standards SNI 03-6389 2011 on Building Envelope and How to Calculate OTTV. The comparison results between OTTV and electricity power used by air conditioning system were plotted on a Scatter Graph.

4. Results and Discussion

In order to be able to calculate Overall Thermal Transfer Value (OTTV), a number of other measurements have to be computed first, namely absorptivity of sun radiation (α), window wall ratio (WWR), equivalent temperature difference (TDeq), shading coefficient (SC), solar factor (SF), wall surface thermal transmittance (Uw), surface thermal transmittance for fenestration (Uf), and temperature difference between indoor and outdoor conditions (ΔT).

Table 1. Pre-Calculated / Pre-Determined Values to Calculate OTTV.

| No | Measurements                              | Calculated / Determined Values       |
|----|------------------------------------------|--------------------------------------|
| 1  | absorptivity of sun radiation (α)        | 0.58                                 |
| 2  | window wall ratio (WWR)                  | Based on orientation                 |
| 3  | equivalent temperature difference (TDeq) | 10 K                                 |
| 4  | shading coefficient (SC)                 | Based on orientation                 |
| 5  | solar factor (SF),                       | 147 Wm⁻² (average value)            |
| 6  | wall surface thermal transmittance (Uw)  | 2.0085 Wm⁻²K⁻¹                      |
| 7  | surface thermal transmittance for fenestration (Uf) | 3.587 Wm⁻²K⁻¹ |
8. temperature difference between indoor and outdoor conditions ($\Delta T$).

The OTTV for each orientation (north, east, south, west) of every room (OTTVo) then computed using the following Equation 1 as mentioned in SNI 03-6389 2011 and the results are appeared in Table 2.

$$OTTV_o = (\alpha[U_w \times (1 - WWR)]) \times TD_{eq} + (SC \times WWR \times SF) + (U_f \times WWR \times \Delta T)$$  \hspace{1cm} \text{Eq. 1}

| No | Room | Orientation | $\alpha$ | $U_w$ | WWR | $TD_{eq}$ | $SC$ | $SF$ | $U_f$ | $\Delta T$ | OTTV (Wm$^{-2}$) |
|----|------|-------------|---------|-------|------|-----------|------|------|-------|-----------|----------------|
| 1  | RE 3 | North       | 0.58    | 2.0085| 0.285| 10        | 0.526| 130  | 3.587 | 5         | 32.928         |
|    |      | East        | 0.58    | 2.0085| 0.000| 10        | 0.749| 112  | 3.587 | 5         | 11.650         |
|    |      | South       | 0.58    | 2.0085| 0.588| 10        | 0.750| 97   | 3.587 | 5         | 58.119         |
|    |      | West        | 0.58    | 2.0085| 0.000| 10        | 0.749| 243  | 3.587 | 5         | 11.650         |
| 2  | RF 1 | North       | 0.58    | 2.0085| 0.157| 10        | 0.634| 130  | 3.587 | 5         | 25.587         |
|    |      | East        | 0.58    | 2.0085| 0.000| 10        | 0.784| 112  | 3.587 | 5         | 11.650         |
|    |      | South       | 0.58    | 2.0085| 0.233| 10        | 0.750| 97   | 3.587 | 5         | 30.101         |
|    |      | West        | 0.58    | 2.0085| 0.000| 10        | 0.784| 243  | 3.587 | 5         | 11.650         |
| 3  | RF 4 | North       | 0.58    | 2.0085| 0.157| 10        | 0.634| 130  | 3.587 | 5         | 25.587         |
|    |      | East        | 0.58    | 2.0085| 0.000| 10        | 0.784| 112  | 3.587 | 5         | 11.650         |
|    |      | South       | 0.58    | 2.0085| 0.233| 10        | 0.750| 97   | 3.587 | 5         | 30.101         |
|    |      | West        | 0.58    | 2.0085| 0.000| 10        | 0.784| 243  | 3.587 | 5         | 11.650         |
| 4  | RE 1 | North       | 0.58    | 2.0085| 0.138| 10        | 0.634| 130  | 3.587 | 5         | 23.854         |
|    |      | East        | 0.58    | 2.0085| 0.000| 10        | 0.784| 112  | 3.587 | 5         | 11.650         |
|    |      | South       | 0.58    | 2.0085| 0.588| 10        | 0.750| 97   | 3.587 | 5         | 58.119         |
|    |      | West        | 0.58    | 2.0085| 0.000| 10        | 0.784| 243  | 3.587 | 5         | 11.650         |
| 5  | RF 9 | North       | 0.58    | 2.0085| 0.157| 10        | 0.634| 130  | 3.587 | 5         | 25.587         |
|    |      | East        | 0.58    | 2.0085| 0.000| 10        | 0.784| 112  | 3.587 | 5         | 11.650         |
|    |      | South       | 0.58    | 2.0085| 0.233| 10        | 0.750| 97   | 3.587 | 5         | 30.101         |
|    |      | West        | 0.58    | 2.0085| 0.000| 10        | 0.784| 243  | 3.587 | 5         | 11.650         |
| 6  | Automation Lab | North | 0.58 | 2.0085 | 0.000 | 10 | 0.786 | 130 | 3.587 | 5 | 11.650 |
|    |      | East        | 0.58    | 2.0085| 0.117| 10        | 0.526| 112  | 3.587 | 5         | 19.287         |
|    |      | South       | 0.58    | 2.0085| 0.072| 10        | 0.786| 97   | 3.587 | 5         | 17.613         |
|    |      | West        | 0.58    | 2.0085| 0.200| 10        | 0.742| 243  | 3.587 | 5         | 49.030         |

We then calculated OTTV for each room using Equation 2 as mentioned in SNI 03-6389 2011.

$$OTTV = \frac{\sum_{i=1}^{n} A_i \times OTTV_i}{\sum_{i=1}^{n} A_i}$$  \hspace{1cm} \text{Eq. 2}

| No | Room | Orientation | OTTVp | A | AxOTTVp | OTTV | Range on SNI | State |
|----|------|-------------|-------|---|---------|------|--------------|-------|
| 1  | RE 3 | North       | 32.928| 25.50 | 839.676 | 32.928 | 35           | Approved |
|    |      | East        | 11.650| 18.00 | 209.692 |       |              |       |
|    |      | South       | 58.119| 25.50 | 1,482.026 |     |              |       |
|    |      | West        | 11.650| 18.00 | 209.692 |       |              |       |
Based on Table 3, we could conclude that all rooms are within SNI 03-6389 2011 OTTV Value limit which is 35 Watt/m².

The data of energy spent on air conditioning system was taken by measuring the current flowing on each air conditioner (AC). The power consumed on all the ACs was then calculated. The relation between OTTV and AC Power is shown on Table 4 and Figure 1.

Table 4. Relation between OTTV and Air Conditioning Power Consumption

| No | Room          | OTTV       | P AC 1     | P AC 2     |
|----|---------------|------------|------------|------------|
| 1  | RE 3          | 31.507 W/m² | 534.6 Watt | 541.2 Watt |
| 2  | RF 1          | 20.441 W/m² | 422.4 Watt | 426.8 Watt |
| 3  | RF 4          | 20.441 W/m² | 426.8 Watt | 429.0 Watt |
| 4  | RE 1          | 28.847 W/m² | 506.0 Watt | 499.4 Watt |
| 5  | RF 9          | 20.441 W/m² | 431.2 Watt | 433.4 Watt |
| 6  | Automation Lab | 24.731 W/m² | 459.8 Watt | 468.6 Watt |

Every country has its own OTTV [12]. Based on the relationship showed in Figure 1, it is clear that the higher power consumed the higher OTTV but all values is still under SNI 03-6389 2011 so it is safe to say all the rooms assessed in this research fulfills building plan guidelines regulated by the government.
Figure 1. Scatter Graph of Relation between OTTV and Air Conditioning Power Consumption

5. Conclusion and Future Works

The Overall Thermal Transfer Value (OTTV) is a parameter used to represent the heat gained through building envelopes. The formula has been improved from its original form according to diverse building types as development goes by. It is clear to see that the relation of OTTV calculated using SNI 03-6389 2011 and power consumption of air conditioning system is linear positive. The more OTTV increases the more energy used in campus buildings.

Our future works will be comparing Roof Thermal Transfer Value (RTTV) and OTTV in affecting decisions make on designing buildings and investigating the impact of OTTV regulations in Indonesia on shaping energy efficient building in Indonesia.

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