Optimizing Building Planning and Design to Control External Energy Loads

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Abstract. In Indonesia, the building sector is responsible for 50% of the total energy consumption from all sectors and more than 70% of overall electricity consumption. The highest energy loads of the office sector is around 57% of the building and 50% of the energy loads on the building belongs to the air conditioning. This study attempted to optimize planning and design, especially through controlling the external energy loads (heating) that enter the building envelope (wall and vents). Case study was conducted in Makassar at Residential and Building Development Information Center (PIP2B Building). The method utilized OTTV (Overall Thermal Transfer Value) consisting of planning and building design analysis especially accounting for heat energy entering the building through windows and vents of the building. According to the Ministry Public works regarding OTTV, the standard for building the energy conservation was 45 W/m² but the standard was increased to 30-35 W/m². From the results of OTTV calculations, an external energy load entered into the building through the building envelope (walls and windows). The result of OTTV calculation shows that some sides of building have an increased amount of energy that went through the wider windows. Through optimizing and planning the windows area, the decreasing external energy (heat energy) that entered from the outside is encouraged.

Keywords: Optimizing, Planning, Design, Energy, Building

1. Introduction

Energy needs are a very noticeable issue; therefore, some strategies are required to control energy consumptions from various sectors of energy use especially in the building sector (about 40% of total energy consumption in the world) [4, 20, 22]. In Indonesia, the building sector is responsible for 50% of energy consumption from all sectors and more than 70% of the overall electricity consumption [8, 12]. Office sector consumes about 57% of the energy, which are the highest energy loads compared with other building sector and the air conditioning’s loads which is 50% of the energy loads in the office building [13]. There are energy saving programs in the building sector which was a program launched by the world [3, 7, 17, 18], that aims for the efficiency and conservation of energy use. From the building sector, the office sector has the largest energy loads of the office sector at around 57%. Therefore, it require less control in reducing the energy loads. Energy loads is divided into 2 parts, including external loads (solar radiation that enters the building) and internal loads (human heat and equipments). There are several ways for measuring and reducing the energy consumption in building,
such as: thermal insulation, sensitivity and optimization, life cycle analysis, technical and economic analysis of renovation of the existing buildings, strategies to control heating/cooling, ventilating, air-conditioning (HVAC) and lighting system [9]. This study evaluates the external loads that entered the building from the planning and design of the PIP2B office through the building envelopes with OTTV (Overall Thermal Transfer Value) analysis. The standards and procedures for planning the energy conservation in buildings and the standar of buildings thermal condition are compiled by the Ministry of Public Works, where OTTV on the walls of a buildings must not exceed 45W / m²[16], but their values are now reduced to 30-35 W/m² [10].

1.1 Optimization Planing and design

Design in architecture becomes a strategy in solving problems that uses the ability of creativity, art and science to get a solution to a problem [21]. Design involves a complex activity that produces various and varied forms from each of the different designer backgrounds [5]. The purpose of architectural design as a basic course is to build the environment and human’s relationship with the environment [14]. The design of a building is expected to reduce the amount of energy consumption, along with increasing window ratio settings and visible transmission with a higher impact on energy consumption level [1]. The window to wall ratio (WWR) also influences the intensity of energy use (EUI) in buildings [19], especially with the fact that increased the electricity usage at around 40-50% for air conditioner loads [11]. Facade planning in every building orientation should consider more specifically on natural ventilation [15], to control the increasing external energy.

1.2 Case Study

The case study is located at the Residential and Building Development Information Center (PIP2B) in Makassar. The research location is on Jl. Batara Bima KM 16 Kec. Biringkanaya Makassar South Sulawesi. It is a business and industrial area in Makassar with a total area of 1,185.74m², ground floor area of 403.61 m² and the 2nd floor area of 324.24m². The building utilizes red brick plaster with thickness of 144 cm that is coated with shiny white paint; the roof uses zinc with red wavy pattern.

1.3 Existing Condition

Building materials have different absorption values (α) depending on its material type red brick plaster with 144 cm thickness with shiny white paint) [6], wall transmission value of 3.64 W/m², and windows transmission value of 2.94. The shading coefficient values (SC) is 0, 61 W/m², (it can be found from glass fabric), depending on the kind of glass. Solar factor (SF) depends on city that the building is located.

| Wall Construction | Mass/area (kg/m²) | ΔTeq |
|-------------------|------------------|------|
| Low               | <125             | 15   |
| Medium            | 126-95           | 12   |
| High              | >195             | 10   |

Table 1. The value of equivalent temperature difference (ΔTeq) depends on the kind of wall material and its areal density, such as: mass/area (kg/m²).
Table 2. The value of solar factor

| Orientation | North | North East | East | South East | South | South West | West | North West |
|-------------|-------|------------|------|------------|-------|------------|------|------------|
| Solar Factor| 37    | 150        | 154  | 125        | 105   | 176        | 243  | 211        |

Table 2. Solar factor value took place in Makassar city

Figure 1. Each View of Building the PIP2B office

2. Methods

The research method applies the OTTV analysis (Overall Thermal Transfer Value). It is a method of which the (quantitative) calculation is carried out by theoretically determining the amount of heat load that will enter through the building envelope (Heryanto, 2004). The OTTV formula that was used to calculate the heat entering through wall and glass conduction and glass radiation is as follows:

$$ OTTV = (Wall \ Conduction + Glass\ Conduction + Glass \ Radiation) $$

$$ OTTV = \alpha (U(1 - WWR)) \Delta Teq + (Uf.WWR.\Delta T) + (SC). (WWR). (SF) $$

$\alpha$ : Absorption of solar radiation on the surface of the wall

$Uw$ : Wall transmission, W/m²⋅degC

$Ug$ : Window transmission, W/m²⋅degC

$WWR$ : Comparison between window area and outer wall area, such as: window-to-wall ratio.

$\Delta Teq$ : Equivalent temperature differences between the inside and outside

$\Delta T$ : Difference in planning for outside and inside temperatures within 5degC

$SF$ : Solar radiation factor, W/m²

$SC$ : Shade coefficient of penetration system (openings)

To calculate the average OTTV every 1m² on the entire wall surface, the equation is as follows:

$$ OTTV = \frac{\left( OTTV_n \times A_n \right) + \left( OTTV_e \times A_e \right) + \left( OTTV_s \times A_s \right) + \left( OTTV_b + A_w \right)}{Au + At + As + Ab} $$

$OTTV$ : Heat transfer value for all outer walls, W/m²

$OTTV_n$: OTTV value on the north side outer wall, W/m²

$An$ : The total area of the outer wall and the north side window, W/m²

$OTTV_e$: OTTV value on the east side outer wall, W/m²

$Ae$ : Total area of the outer wall and east side window, W/m²

$OTTV_s$: OTTV value on the south side outer wall, W/m²

$As$ : Total area of the outer wall and south side window, W/m²
OTTVw: OTTV value on the west side outer wall, W/m²
Aw : Total area of the outer wall and west side window, W/m²

2.1. Analysis of External Energy Loads on buildings
Analysis of external energy loads on the buildings used OTTV on the existing building envelopes (windows and walls). Firstly, a partial OTTV calculation was performed from each orientation (8 orientations) of the sheath; and secondly, the average OTTV that entered every 1m² of wall and window surfaces was calculated.

2.2. Strategy optimizing external energy loads on building planning and design.
The results of the OTTV calculation from each orientation of the building envelope showed results that indicate whether any of them do not meet the OTTV standards (more than 35 W/m²).

3. Result and Discussions
The analysis of the calculation result of external energy loads was calculated by using OTTV to find out the external energy that entered the building through the building envelope. Analysis of External Energy Expenses on buildings.

Before calculating the OTTV for each building envelope, the first step is conducted to look at the absorption value, the wall transmittance value and the equivalent temperature of difference value.

3.1. Determining the value of sun absorption on the surface of the building (α), of all sides of the building are the same)
Building materials use brick walls (aw = 0.89) with shiny white paint with a value of ap = 0.30
\[ α = \frac{(αw + ap)}{2} \]
\[ α = \frac{(0.89 + 0.30)}{2} = 0.595 \]

3.2. Determining the wall transmittance value
The thickness of plastered bricks on both sides are 114 mm with a U value of 3.64 / m²degC

3.3. Determining the transmittance value of the wall with specifications of plastered bricks with both sides are 114 mm thick with a value of U = 3.64 / m²degC (attachment 2).

\[ P = \frac{Mass}{Volume} \] (3)

Mass : (2400 kg / m³) x (1 m³ x 1 m³ x 114 m³)
Mass : 273.6 kg
From the results of the weight of the wall of 273.6 kg the value of ΔTeq = 10K (10 degC) is obtained. (Table 1).

3.4. Calculating the OTTV value of each building envelope orientation (W / m²)

Table 3. The value of OTTV each for side of walls

| Elevation     | Area m² (A) | Window Area m² | WWR % | SF  | SC  | a    | Uw/Ug | ΔT/ΔTeq (degC) | OTTV (W/m²) |
|---------------|-------------|----------------|-------|-----|-----|------|-------|----------------|-------------|
| Northeast     | 192.2922    | 58.0704        | 30.1  | 150 | 0.61| 0.595| 3.64/2.94| 5/10 | 47                  |
| Walls         |             |                |       |     |     |      |       |                 |             |
| East          | 20.2975     | 3.116          | 15.3  | 154 | 0.61| 0.595| 3.64/2.94| 5/10 | 34.7                |
| Southeast     | 144.0021    | 27.2447        | 18.9  | 125 | 0.61| 0.595| 3.64/2.94| 5/10 | 34.4                |
Table 3. The results of OTTV for each of the building envelope orientation are obtained. The OTTV standard is more than 35 W/m² on the northeast wall (47 W/m²), the west wall (35.3 W/m²), and the northwest wall (44.4 W/m²).

3.5. OTTV Calculation value of each building envelope orientation (W/m²)

\[
\text{OTTV} = \frac{(\text{OTTVl} \times \text{Atl}) + (\text{OTTVt} \times \text{At}) + (\text{OTTVg} \times \text{Atg}) + (\text{OTTVs} + \text{As})}{(\text{Atl} + \text{At} + \text{Atg} + \text{As} + \text{Abd} + \text{Ab} + \text{Abl} + \text{Au})} \\
\text{OTTV} = \frac{(47 \times 192.2) + (34.7 \times 20.2) + (34.4 \times 144) + (29.7 \times 64.6) + (24.2 \times 136.4) + (35.3 \times 64.6) + (44.4 \times 144) + (28.2 \times 20.2)}{192.2 + 20.2 + 144 + 64.6 + 136.4 + 64.6 + 144 + 20.2} \\
\text{OTTV} = \frac{9,033.4 + 700.9 + 4,953.6 + 1,918.6 + 3,300.8 + 2,273.3 + 6,393.6 + 569.6}{192.2 + 20.2 + 144 + 64.6 + 136.4 + 64.6 + 144 + 20.2} \\
\text{OTTV} = \frac{29,143.8}{786.2} = 37.07 \text{ W/m}^2
\]

From the calculation of the average OTTV for each m², result shows value of 37.07 W/m², which is greater than the standard set (more than 35 W/m²).

3.6. Strategies in optimizing external energy loads on building planning and design

The strategy to reduce external energy load is by decrease the WWR in each of building’s envelope orientation where the value is more than 35W/m² (i.e. northeast wall, west wall, and northwest wall) which used the OTTV equation to obtain the following results.

3.6.1. The strategy reducing the external energy loads on the northeast wall
Table 4. Northeast Wall OTTV values

| Elevation       | Area m² | Window Area m² | WWR % | SF   | SC   | $\alpha$ | $U_{w}/U_{f}$ | $\Delta T/\Delta T_{eq}$ | OTTV (W/m²) |
|-----------------|---------|----------------|-------|------|------|----------|---------------|--------------------------|-------------|
| Northeast Walls | 192.2922| 58.0704        | 30.1  | 150  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 47          |
| Northeast Walls | 192.2922| 48.05          | 25    | 150  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 42.63       |
| Northeast Walls | 192.2922| 38.44          | 20    | 150  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 38.21       |
| Northeast Walls | 192.2922| 34.59          | 18    | 150  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 36.45       |
| Northeast Walls | 192.2922| 30.75          | 16    | 150  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 34.69       |

Table 4. The northeast wall shows the results of WWR 16% reducing the external energy load entering through the building envelope of 34.69 W/m² in the standard set (35 W/m²).

3.6.2. The strategy reducing the external energy loads on the west wall

Table 5. The value of OTTV of the Western Wall

| Elevation       | Area m² (A) | Window Area (m²) | WWR % | SF   | SC   | $\alpha$ | $U_{w}/U_{f}$ | $\Delta T/\Delta T_{eq}$ | OTTV (W/m²) |
|-----------------|-------------|------------------|-------|------|------|----------|---------------|--------------------------|-------------|
| West Walls      | 64.6245     | 6.4              | 9.9   | 243  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 35.3        |
| West Walls      | 64.6245     | 6.3              | 9.8   | 243  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 31.2        |

Table 5. The west walls’s WWR were reduced by 0.1% (6.3 m²). The reduction lead to the decrease of external energy load that enters the building envelope by 31.2 W/m², which is under specified standard (35 W/m²).

3.6.3. The strategy reducing the external energy loads of the northwest wall

Table 6. The value of OTTV Northwest Walls

| Elevation       | Area m² (A) | Window Area (m²) | WWR % | SF   | SC   | $\alpha$ | $U_{w}/U_{f}$ | $\Delta T/\Delta T_{eq}$ | OTTV (W/m²) |
|-----------------|-------------|------------------|-------|------|------|----------|---------------|--------------------------|-------------|
| Northwest Walls | 144.0021    | 27.2467          | 18.9  | 211  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 44.4        |
| Northwest Walls | 144.0021    | 20.16            | 14    | 211  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 38.25       |
| Northwest Walls | 144.0021    | 17.28            | 12    | 211  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 35.77       |
| Northwest Walls | 144.0021    | 15.84            | 11    | 211  | 0.61 | 0.595    | 3.64/2.94     | 5/10                     | 34          |

Table 6. The northwest walls (Table 3.4) through the reduction WWR to 11% (15.84 m²) decreases the external energy load that enters the building envelope by 34 W/m² which is under the specified standard (35 W/m²).

3.6.4. Average OTTV calculation in every m² on the surface of walls and windows
From the results of OTTV, the average yield of each m² is 31.07 W/m², where this is in accordance with the standard (not more than 35 W/m²). Therefore, the profitable strategy in the Planning and Design aspect which decrease the external energy loads of the building is executed through the reduction of window area or WWR (Windows Wall Ratio).

4. Conclusion
The reduction of external energy (heat energy) can be controlled by optimizing planning and design of a building. OTTV strategies were applied with changes in windows-wall-ratio (WWR). Initially, the Residential and Building Development Information Center (PIP2B) had an average OTTV of 37.07 W/m², which was above the standard (35 W/m²). There was a lot of external energy (heat energy) that entered the inside of building from Northeast widows (47 W/m²), West windows (35.3 W/m²), and Northwest (44.4 W/m²), because the windows area is wider than the other side. For achieving the standard (35.3 W/m²), there should be a decrease in the in the amount of energy with regards to the windows-wall-ratio. Northeast windows area should be 16% in order to reduce the external energy load (34.69 W/m²) that entered through the building envelope. West windows area were set at 9.8% in order to achieve the size of 31.2 W/m², while 11% of WWR was implemented on the northwest windows area in order to reach the size of 34 W/m². The reduction of each sides of the windows (Northeast, West, and Northwest) can decrease the average OTTV by 31, 07 W/m² which is below the specific standard.

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