Passive design (building envelope) impact to cooling load of research centre building ITS

T. Soehartanto¹, Matradji² and Roekmono²

¹ Department of Instrument Engineering, Faculty of Vocation, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia
² Department of Physical Engineering, Faculty of Industrial Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia

totokstf@yahoo.com

Abstract. The ITS Research Center (RC) building as one of the new buildings in ITS has a unique architecture compared to ITS building architecture in general. The shape of this architecture is interesting to study because the side of the building facing north and south is the majority of tinted glass, which is given a frame on the left and right sides with a thickness of 4 meters each. The wall protrudes inside with a certain slope angle, so that it protects the glass window from solar radiation (from the east and from the west) directly. The 11th floor sheath is tinted glass that curves downward with a certain tilt angle, so it can provide a shade effect on the glass floor below. This type of building design is a passive design (one of the green building methods) to reduce thermal transfer through the building envelope. Thermal transfer through the envelope of the Research Center building will be presented in this paper, through the calculation of overall thermal transfer value (OTTV) covering the north and south side of the building from the second floor to the 11th floor. The covering from the 3rd to the 10th floor consists of spandrel, tinted glass and parapet, while the sheath on the 2nd and 11th floors is tinted glass. The calculation results show that the total OTTV from the north and south side of the building envelope is 6.18 Watt / m², this shows that the design of ITS research center building architecture is effective in reducing the thermal transfer through the sheath.

1. Introduction

40% of the cooling load in buildings comes from OTTV (Overall Thermal Transfer) of the building envelope, so the design of the building envelope and the direction of the building envelope play an important role in reducing cooling load from OTTV (passive design method). The ITS Research Center (RC) building as one of the new buildings in ITS has a form of modern architecture (applying the Green Building concept). The envelope of the ITS Research Center building facing North and South is a glass window with a frame on the left side and on the right side with a width of 4 meters each. The shape of the frame protrudes into a certain slope angle so that the glass window does not get direct sunlight radiation from the east or from the west. For this reason, the impact of the RC ITS building's passive design on the cooling load will be explained through the calculation of thermal transmittance per floor (from the 2nd floor to the 11th floor). Sheath design per floor (from the 2nd floor to the 10th floor) is in the form of a spandrel, tinted glass and parapet, while the 11th floor sheath is a tinted glass that protrudes out with a certain angle of brightness. This design is intended to provide a shade effect on the glass window below.
2. Methodology

OTTV calculations according to SNI-03-6389-2000, are shown in the following flow chart:

![Flow Chart](image)

**Figure 1. OTTV Flow Chart**

OTTV for each area of the outer wall of a building with a certain orientation:

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

(1)

Where:
- OTTV = Overall thermal transfer value (W/m²)
- \(\alpha\) = absorbance of solar radiation.
- UW = Thermal transmittance of opaque walls (W/m².K)
- WWR = Comparison of window area with the width of the entire outer wall at the specified orientation
- TDEk = Equivalent temperature difference (K).
- SF = Solar radiation factor (W/m²)
- SC = The shade coefficient of the penetration system.
- Uf = Thermal transmittance penetration (W/m².K)
- \(\Delta T\) = Temperature difference between the outside and the inside

OTTV throughout the outer wall, the following equation is used:

\[
\text{OTTV} = \frac{(Aoi \times \text{OTTVi}) + (Ao2 \times \text{OTTVi}) + \ldots} {Aoi + Ao2 + \ldots}
\]

(2)

Where:
- Aoi = Wall area on the outer wall i (m²).
  This total area includes all opaque wall surfaces and the surface area of the windows found on these walls
- OTTVi = The total thermal displacement value for the i wall as a result of the calculation using the equation 2
2.1. Passive Design of RC ITS Building

Figure 2 shows a photo of the ITS RC building, this picture shows a glass window facing the north side with a wall frame on the east side and west side, so that sunlight from the east and from the west cannot illuminate directly into the window.

![Figure 2. Passive Design of RC ITS Building](image)

RC ITS building consists of 11 floors, where the second floor of the sheath is the same colored glass as the 11th floor, while the 3rd floor to the 10th floor consists of spandrel, tinted glass, and parapet with width and height as shown in figure 3 (scale 2.2 cm = 3.6 m).

| Building Part                  | Width (cm) | Scale (2.2 cm = 3.6 m) |
|--------------------------------|------------|------------------------|
| 1 building bone concrete       | 0.6        | 2.95                   |
| 2 glass on the left and right side | 2.62      |                        |
| 3 left-right center side glass | 21.36      | 34.95                  |

**Figure 3.** Wide sheathing of the north side of the RC ITS building

The size of the sheath (width and height) per floor of the RC ITS building on the north and south side is shown in table 1, this size will be used to calculate the wall area per floor.
Figure 4. Looks north side of RC ITS building

Table 1. Size (width and height) of the sheath per floor of the RC ITS building north and south

| Floor | Function                              | Width (m) | Height (m) |
|-------|---------------------------------------|-----------|------------|
| 1     | Parking                               | 40.52     | 3.50       |
| 2     | Gallery & Cafetaria                   | 38.72     | 6.00       |
| 3     | Business Study & Innovation Centre    | 38.72     | 5.00       |
| 4     | Office of Research & PDPM Centre Mgmt | 38.72     | 4.00       |
| 5     | PPLH Study Room & Study Centre       | 38.72     | 4.00       |
| 6     | Centre for ITK & Robotics - Energy    | 38.72     | 6.00       |
| 7     | Centre of Study-Transportation & Logistics KBPI | 38.72 | 4.00 |
| 8     | Centre of Marine Study               | 38.72     | 4.00       |
| 9     | Centre & Applicable Science Study Cntr | 38.72     | 4.00       |
| 10    | Centre of Study Material & Nano Technology | 38.72     | 4.00       |
| 11    | Multipurpose Room                    | 38.72     | 6.00       |

Floors 3 to 10 on the north and south sides consist of spandels, tinted glass and parapets with high sizes as shown in table 2. The sheath of floors 3 to 10 has the same width.
Table 2. Spandrel Height, Glass Height and Parapet each level of RC ITS North and South Side

|            | North Side                | South Side                |
|------------|---------------------------|---------------------------|
|            | Upper Spandrel Height     | Lower Parapet Height      | Upper Spandrel Height     | Lower Parapet Height      |
|            | (m)                       | (m)                       | (m)                       | (m)                       |
| North Side | 6,00                      | 6,00                      |
|            | 0,50                      | 3,00                      | 1,50                      | 0,50                      | 3,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 4,00                      | 1,50                      | 0,50                      | 4,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 4,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 2,00                      | 1,50                      |
|            | 0,50                      | 2,00                      | 1,50                      | 0,50                      | 6,00                      | 6,00                      |

The results of the calculation of the sheath area per floor facing the north and south sides and the calculation of the area of the colored glass windows north and south side, are used to calculate the WWR (Wall Window Ratio).

Table 3. WWR per floor of RC ITS building on the north and south side

| Floor | North Side | South Side | South Side |
|-------|------------|------------|------------|
|       | WWR Spandrel (%) | WWR Glass (%) | WWR Parapet (%) | WWR Spandrel (%) | WWR Glass (%) | WWR Parapet (%) |
| 2     | 0,13       | 0,13       | 0,13       | 0,0106383       | 0,0106383       | 0,0106383       |
| 3     | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 4     | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 5     | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 6     | 0,0106383  | 0,09       | 0,03191    | 0,0106383       | 0,09           | 0,03191         |
| 7     | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 8     | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 9     | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 10    | 0,0106383  | 0,04       | 0,03191    | 0,0106383       | 0,04           | 0,03191         |
| 11    | 0          | 0,13       | 0          | 0              | 0,13           | 0               |

3. Results and Discussion
The calculation of OTTV RC building ITS is carried out in accordance with the flow chart (Figure 1), the calculation results are as follows:
The value of $\alpha$ (solar radiation absorptance) according to SNI-03-6389-2000 ($\alpha$ value for outer walls and opaque roofs) is shown in table 4.

| Bahan Dinding Luar   | $\alpha$ |
|----------------------|----------|
| Beton Berat          | 0,91     |
| Bata Merah           | 0,89     |
| Bitumunous Felt      | 0,88     |
| Batu Sabak           | 0,87     |
| Beton Ringan         | 0,86     |
| Aspal Jalan Setapak  | 0,82     |
| Kayu Permukaan Halus| 0,78     |
| Beton Ekspos         | 0,61     |
| Ubir Putih           | 0,58     |
| Bata Kuning Tua      | 0,56     |
| Atap Putih           | 0,5      |
| Cat Alumunium        | 0,4      |
| Kerikil              | 0,29     |
| Seng Putih           | 0,26     |
| Bata Gelazur Putih   | 0,25     |
| Lembaran Alumunium yang Dikilapkan | 0,12 |

The north side and the south side of the RC ITS building are in the form of GLASS and a small portion in the form of Spandrel and parapet, so that the absorption coefficient of solar radiation for the outer wall (SPANDREL) can be assumed to be $\alpha = 0.12$.

$U$, $SC$ and $SF$ values can be obtained from the glass manufacturer's data as shown in table 5, in this study only $U$ and $SC$ values were used.

| Type Of Glass | Standard Thickness (mm) | Transmittance (%) | Energy Characteristic Reflectance (%) | Energy Characteristic Absorption (%) | Ultra Violet Transmittance (%) | Light Characteristic Reflectance (%) | Solar Factor (%) | Shading Coefficient (3"4") | $U$ Value Wh/m²k |
|---------------|-------------------------|-------------------|---------------------------------------|-------------------------------------|---------------------------------|-------------------------------|-----------------|-----------------------------|------------------|
| Panasap       | 5                       | 56                | 5                                     | 39                                  | 25                             | 55                           | 5              | 67                          | 0.77             |
| Bronze        | 6                       | 50                | 5                                     | 44                                  | 20                             | 50                           | 5              | 64                          | 0.73             |
| (BRFL)        | 8                       | 41                | 5                                     | 54                                  | 14                             | 41                           | 5              | 58                          | 0.66             |

$SF$ Value use SNI-03-6389-2000 for many orientation.

| Orientasi | U  | TL | T  | TGR | S  | BD | B  | BL |
|-----------|----|----|----|-----|----|----|----|----|
|           | 130| 113| 112| 97  | 97 | 176| 243| 211|

Different Equivalent Temperature (TD ek) on the wall is calculated using data from SNI-03-6389-2000.
Table 7. $T_D$ Equivalent on the Wall Value

| Weight per unit area (kg/m$^2$) | $T_D$ eqv |
|---------------------------------|-----------|
| < 125                           | 15        |
| 126 – 195                       | 12        |
| > 195                           | 10        |

Based on Table 7, to know the equivalent TD of a wall, we must know the weight per unit area, done by multiplying the wall density against the wall thickness.

Table 8. The sheath in the form of SPANDREL

| Thick (m) | Density (kg/m$^3$) | Weight/Area (kg/m$^2$) |
|-----------|--------------------|------------------------|
| Tinted Glass | 0.008              | 20.000                 |
| Air Space (with high emissivity) | 0.010 | |
| Gypsum Board | 0.006 | 880.000 | 5.280 |
| Glasswool | 0.050 | 32.000 | 1.600 |

SPRANDEL weight / area is less than 125 kg/m$^2$, then $T_D$ ekivalen is 15 Kelvin.

Table 9. The sheath in the form of PARAPET

| Thick (m) | Density (kg/m$^3$) | Weight/Area (kg/m$^2$) |
|-----------|--------------------|------------------------|
| ACP       | 0.03               | 2,672.00               | 80.16 |
| External Wall Plester | 0.01 | 1,568.00 | 20.38 |
| Brick Wall | 0.10 | 1,760.00 | 176.00 |
| Internal Wall Plester | 0.01 | 1,568.00 | 20.38 |

PARAPET weight / area is more than 195 kg/m$^2$, then $T_D$ ekivalen is 10 Kelvin. The equivalent TD value for GLASS (according to SNI-03-639-2000) is 5 Kelvin.

3.1. Calculation $U$ Value

The sheath of the 3rd to 10th floor consists of spandrel, tinted glass and parapet, so that the translucent thermal transmittance value ($U_W$) and translucent thermal transmittance value ($U_F$) are calculated as Table 10.
Table 10. The translucent thermal transmittance value (UW) and translucent thermal transmittance value (UF)

| No  | Type of Façade | Components of The Façade | Thickness (m) | K (W.m.K) | R (m².K.W) | U Value (W/M².K) |
|-----|----------------|--------------------------|---------------|-----------|------------|-----------------|
| 2   | TINTED GLASS   | Penasap (Blue Green)     | 0,01          | 5,8       | 0,53       | 1,89            |
|     |                | Internal Surface         |               |           |            |                 |
| 3   | SPRANDEL       | External Surface         | 0,4           | 5,8       | 0,69       | 1,46            |
|     |                | Glass                    | 0,01          |           |            |                 |
|     |                | Air Space (with high emissivity) | 0,01          | 0,12      |            |                 |
|     |                | Gypsum Board             | 0,01 0,17     | 0,04      |            |                 |
|     |                | Glasswool                | 0,05          |           |            |                 |
|     |                | Internal Surface         | 0,13          |           | 0,78       | 1,28            |
| 4   | PARAPET        | External Surface         | 0,4           | 5,8       | 0,78       | 1,28            |
|     |                | ACP and Brick            | 0,03 0,4 0,08 |           |            |                 |
|     |                | External Wall            | 0,01 0,57 0,02 |           |            |                 |
|     |                | Plester                  | 0,1 0,77 0,13 |           |            |                 |
|     |                | Brick Wall               | 0,01 0,57 0,02 |           |            |                 |
|     |                | Internal Wall            | 0,13          |           |            |                 |

3.2. Calculation OTTV every floor in south and north side
The results of OTTV calculations on the north or south side on the 2nd to 11th floors are Q1, Q2 and Q3 in table 11.

Table 11. Result of OTTV

| Floor  | Façade Type | α  | Uw | WWR | l-WWR | TD Ek | Q1  |
|--------|-------------|----|----|-----|-------|-------|-----|
| 2nd Floor | Tinted Glass | 0,12 | 0  | 0,13 | 0,87  | 0  | 0  |
| 3rd Floor | Tinted Glass | 0,12 | 0  | 0,06 | 0,94  | 0  | 0  |
|          | Spandrel    | 0,12 | 7,29 | 0,01 | 0,99  | 5   | 4,33 |
|          | Parapet     | 0,89 | 1,28 | 0,03 | 0,97  | 15  | 16,54 |
| 4th Floor | Spandrel    | 0,12 | 7,29 | 0,01 | 0,99  | 5   | 4,33 |
|          | Parapet     | 0,89 | 1,28 | 0,03 | 0,97  | 15  | 16,54 |
| 5th Floor | Spandrel    | 0,12 | 7,29 | 0,01 | 0,99  | 5   | 4,33 |
|          | Tinted Glass | 0,12 | 0  | 0,04 | 0,96  | 0  | 0  |
|          | Parapet     | 0,89 | 1,28 | 0,03 | 0,97  | 15  | 16,54 |
| Floor   | Façade Type | α    | Uw  | WWR  | 1-WWR | TD Ek | Q1     |
|---------|-------------|------|-----|------|-------|-------|--------|
| 6th Floor | Spandrel    | 0.12 | 7.29 | 0.01 | 0.99  | 5     | 4.33   |
|         | Tinted Glass| 0.12 | 0    | 0.09 | 0.91  | 0     | 0      |
|         | Parapet     | 0.89 | 1.28 | 0.03 | 0.97  | 15    | 16.54  |
| 7th Floor | Spandrel    | 0.12 | 7.29 | 0.01 | 0.99  | 5     | 4.33   |
|         | Tinted Glass| 0.12 | 0    | 0.04 | 0.96  | 0     | 0      |
|         | Parapet     | 0.89 | 1.28 | 0.03 | 0.97  | 15    | 16.54  |
| 8th Floor | Spandrel    | 0.12 | 7.29 | 0.01 | 0.99  | 5     | 4.33   |
|         | Tinted Glass| 0.12 | 0    | 0.04 | 0.96  | 0     | 0      |
|         | Parapet     | 0.89 | 1.28 | 0.03 | 0.97  | 15    | 16.54  |
| 9th Floor | Spandrel    | 0.12 | 7.29 | 0.01 | 0.99  | 5     | 4.33   |
|         | Tinted Glass| 0.12 | 0    | 0.04 | 0.96  | 0     | 0      |
|         | Parapet     | 0.89 | 1.28 | 0.03 | 0.97  | 15    | 16.54  |
| 10th Floor | Tinted Glass| 0.12 | 0   | 0.13 | 0.87  | 0     | 0      |
| 11th Floor | Tinted Glass| 0.12 | 0   | 0.13 | 0.87  | 0     | 0      |

Table 12. The sum of Q1, Q2 and Q3 is the OTTV value on a floor with a certain wind direction

| SC | SF | Q2 | Uf | Δτ | Q3 | OTTV i | Façade Area |
|----|----|----|----|----|----|--------|-------------|
| 0.66 | 58.00 | 4.89 | 7.69 | 5.00 | 4.91 | 10.46 | 232.32 |
| 0.00 | 130.00 | 0.00 | 0.00 | 15.00 | 0.00 | 5.56 | 193.60 |
| 0.66 | 58.00 | 2.44 | 2.44 | 7.69 | 5.00 | 2.45 | 5.56 | 154.88 |
| 0.00 | 130.00 | 0.00 | 0.00 | 15.00 | 0.00 | 15.00 | 154.88 |
| 0.00 | 130.00 | 0.00 | 0.00 | 15.00 | 0.00 | 15.00 | 154.88 |
| 0.66 | 58.00 | 3.26 | 3.26 | 7.69 | 5.00 | 3.27 | 7.19 | 232.32 |
According to SNI 03-6389 concerning energy conservation of building envelopes in buildings, the OTTV value for buildings must not exceed 45 Watts / m$^2$.

The results of OTTV calculations per floor on the north side or south side of the RC ITS envelope are 6.18 Watts / m$^2$, so the OTTV value of the cover of the north and south sides is 12.36 Watts / m$^2$. The OTTV value of the RC ITS building is still below the standard, this indicates that the RC ITS building passive design is quite effective in reducing the cooling load of buildings originating from OTTV.

### 4. Conclusion

The colored glass windows of the RC ITS building are placed on the north and south sides with a protruding position and protected by a frame on the east side and on the west side, so that sunlight from the east and from the west cannot illuminate directly the glass window surface colored. The envelope of the east side and west side of the RC ITS building is a brick wall that is given a small window hole on each floor. The design of this building turned out to be quite effective in reducing the burden of cooling the building due to thermal transfer from the building envelope or commonly called the overall thermal transfer value (OTTV). The results of OTTV calculations on the north and south sides obtained a value of 12.36 Watts / m$^2$, this value is still below the SNI 03-6389 standard regarding energy conservation of building envelopes in buildings that OTTV values for buildings should not exceed 45 Watts / m$^2$.

### Acknowledgement

This work was supported by a grant (D42018 - LOKAL ITS 2018 (ABDIMAS) provided by the Institute of Research and Public Services (LPPM), Institut Teknologi Sepuluh Nopember (ITS), Indonesia. The authors thank Mr. Ali Musyaf’a and Mr. Tri Joko for valuable technical support.

### References

[1] S Loekito Analisis konservasi energi melalui selubung bangunan Available ; ced.petra.ac.id/index.php/civ/article/download/16465/16457.

[2] Badan Standardisasi Nasional 200 Konservasi energi selubung bangunan pada bangunan gedung SNI 03-6389-2000 Jakarta Indonesia

[3] Panduan Pengguna Bangunan Gedung Hijau Jakarta Selubung Bangunan vol. 1. Available https://id.scribd.com/document/337989857/Vol-1-Selubung-Bangunan

[4] Feri Harianto Konservasi Energi Selubung Bangunan Pada Gedung Graha Galaxy Surabaya Available : https://www.academia.edu/7985812/KARAKTERISTIK_FASADE_BANGUNAN_FACTORY_OUTLET_DI_JALAN

[5] International Energy Agency 2018 Global Energy & CO2 Status Report 2017