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Building Envelope Design with Glass Curtain Wall to Reduce OTTV, Study Case: WU Tower Building at Bandung, Indonesia

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ABSTRACT

Indonesia can get exposure to frontal solar radiation with a high enough intensity so that excessive external thermal loads a building receives can cause thermal discomfort for users. Generally, the building envelope of the office building uses a glass curtain wall; this causes increasing the consumption of electrical energy. For this reason, it is essential to design the right building envelope to reduce heat transfer. A tool to determine the external thermal load received by the building envelope is OTTV. The analysis was carried out quantitatively and qualitatively based on data on the condition of the WU Tower building, which became the case. The value of the benefits obtained from this research is the acquisition of proposals for improving the design of the building envelope in Bandung, which can be applied to mixed-use buildings with the office's primary function.

Keywords: Building Design, Building Envelope, Glass Specification, Overall Thermal Transfer Value

1. Introduction

The building envelope is a medium for transmitting energy from the exterior to the interior, so proper design is needed to reduce the transmission of solar heat radiation that enters the building. The design of the building envelope is mainly determined by the shape of the facade, including the shading elements, the type of facade material, the ratio of the opening area to the wall area, and the glass specifications.

WU Tower, as a case study, is a multi-function building in Bandung with the primary function as an office whose facade is designed according to the function of the interior space. As the main exterior material, glass is used, which is very easy to transmit heat into the building, and on certain floors, there is a substrate as a shading effort. For this reason, it is essential to study how heat transfer occurs in the building through the OTTV calculation. Suppose the OTTV that happens has not reached the criteria. In that case, it can be proposed that efforts can be made without changing the shape of the building mass, and this can be input, especially in designing the envelope of office buildings in Bandung.

2. Material and Methods

2.1. Building Design and Building Envelope

The energy consumption of the building sector in the world has reached 40% of the world's total energy use [1]. This occurs mainly in building construction and operational processes and has resulted in 1/3 of greenhouse gas (GHG) emissions worldwide [2]. Therefore, building design should consider operational energy savings to reduce this carbon emission [3]. It is essential since the design process has predicted how much energy the building will need when it is used later [4].

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Indonesia is a country with a tropical climate that gets sunlight all year round, and this has an impact on efforts to obtain thermal comfort [5]. Due to hot tropical climate conditions, energy use for air conditioning systems can exceed 50% of building requirements [6]. With high exposure to solar heat radiation, the external thermal load received by the building becomes large, and the consumption of electrical energy for the operation of the air conditioning system increases. Indonesia is one of 23 countries with high energy consumption [7].

The design parameters include building orientation, wall and roof materials, building envelope color, glass type, and shading on facades and openings [8]. There is a relationship between this parameter and energy consumption for construction and building operations, where about 30% to 40% of energy requirements are determined by the orientation and shape of the building [9].

In anticipating thermal constraints due to climate and weather, it is necessary to reduce the use of space heating/cooling energy by adequately designing the building envelope [10], [11]. The building envelope functions as a barrier from the indoor environment to the outdoor environment [8] and plays a role in producing thermal comfort, which has an impact on the heating/ cooling load [12]. In designing the building to obtain thermal comfort and energy savings, it must respond to the effects of solar heat radiation entering the room [5]. Failures in the building envelope design result in inefficient use of energy for building operations [4]. The shape of the facade, the type of material, and the ratio of the opening area to the facade area determines the design of the building envelope.

With Indonesia's hot and humid tropical climate, obtaining thermal comfort requires a shade and filter strategy. Sun shaders are massive without holes, so they can't transmit sunlight, for example, the subtract shape on building facades and fins. Facades with shader shapes, such as subtracts and fins, can provide shade to the openings from exposure to solar heat radiation. [13].

Openings with a large area and exposed to direct sunlight can only be received when equipped with solar screening [14]. Shading can help reduce air conditioning use in the room [15]. External screening efficiency can be 3 to 5 times more efficient in reducing air conditioning load, even if the building facade is exposed to weather [14]. Based on a 2013 study of air-conditioned buildings in Jakarta, it is known that with the application of a sun barrier at the same room temperature, electrical energy use can be reduced by 30% to 50% [16].

To reduce heat transmission into the building, the type of material must have low thermal conductivity (λ) and low solar radiation absorbtance (α). Solar radiation absorbtance is the value of thermal energy absorption due to solar radiation on a material and is also determined by the material's color [17]. The higher the thermal conductivity, the easier it is to conduct heat and increase the room temperature [13].

Table 1: Thermal Conductivity (λ)

No.	Material	λ (W/mK)
1.	Concrete, medium density	1.35
2.	Concrete, aerated	0.11 – 0.31
3.	Aluminium	160

Source: (G. Hausladen, M. de. Michael, and P. Liedl, 2014 [14])

Table 2: Solar Radiation Absorbtance (α)

No.	Material	α
1.	Exposed concrete	0.61
2.	Glazed aluminium sheet	0.12
3.	Semiglossy white wall paint	0.30

Source: (Nasional, Badan Standardisasi, 2000, processed [17])

The larger the opening area, the higher the heat transmission into the building. For this reason, exposure to heat radiation can be reduced through a design strategy in the form of Window to Wall Ratio (WWR) analysis [18].

Table 3: Impact of WWR on Energy Savings (%) for Different Types of Buildings

WWR	Office	Retail	Apartment
69%			
60%	0.0%		0.0%
50%	1.1%		3.1%
40%	2.3%		6.8%
30%	3.3%	0.0%	10.4%
20%	4.4%	0.2%	13.7%

Source: (Dinas Tata Ruang dan Cipta Karya Pemerintah Kota Bandung, 2016, processed [19])

2.2. Glass Specification and OTTV

Office buildings require natural lighting for work activities during the day, which enters through the Glass in the facade opening. Glass is thin and transparent, more easily penetrated by solar radiation than walls. This results in an increase in the external thermal load of the AC system, which increases electrical energy consumption. For this reason, choosing the right solar control glass is essential to reduce Energy Transmittance. [3].

For the Energy Transmittance of the Glass to be low, the Glass must have a low Shading Coefficient (SC) specification so that the Solar Heat Gain Coefficient (SHGC) is automatically common (maximum 0.40). The SHGC determines the percentage of solar radiation received and transmitted into space, with a value between 0 and 1 [20]. The lower the SHGC value, the lower the external thermal load of the AC system [21].

On Glass with the same color (same type of Glass), the thicker the Glass, the lower the Solar value, the SF value, and the SHGC value. In Glass with the same thickness, the darker the color of the Glass, the lower the SF value and SHGC value. [13]. It would be even better if the U-Value glass specifications were reasonable [21]. Use Glass with the lowest possible U-Value for successful thermal comfort [14].

The building envelope can be designed to reduce the reception of solar heat radiation into the building, where based on the calculation, the Overall Thermal Transfer Value (OTTV) is not more than 45 Watts/m2 [3]. OTTV is a measure of the heat gain received through the building envelope, which serves as an index for comparison of the thermal performance of the building. The greater the OTTV, the greater the heat gain that enters through the building envelope. If this heat gain can be controlled and the AC thermal load can be reduced, then the electrical energy consumption can be reduced. [8].

3. Results and Discussions

3.1. Building Data

WU Tower building is located on Jl. Dr. Djunjunan No. 588, district Sukajadi, Bandung City, Indonesia, at coordinates -6.8905º South Latitude, 107.5786º East Longitude. See Fig. 1 and Fig. 2. The number of floors of the building is 12 plus 1 basement floor, with naming/ numbering according to Feng Shui, namely basement floor, ground floor, 1, 2, 5, 6, 7, 8, 9, 10, 11, 12, and 15. Site area ± 5,760 m^2 and building area ± 13,200 m^2.

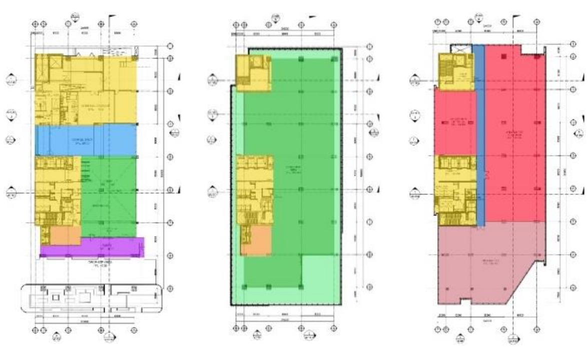
Source: (Google Earth, 2021)
Figure 1: Map of WU Tower Building

The construction process of the WU Tower building is estimated to be completed in 2022. As a multi-function building, WU Tower is equipped with supporting facilities such as a restaurant, a food court, a coffee shop, meeting rooms, and penthouses. Based on permission from the management, only particular areas/ floors can be entered and studied, namely the ground floor and the 2nd, 7th, 8th, 9th, and 15th floors. See Fig. 3 and Fig. 4.

Source: (https://wutower.com/gallery/, 2021)
Figure 2: Perspective View of WU Tower Building (Left: Bird Eye View; Right: Human Eye View)

= Penthouse
= Office
= Gion Restaurant
= Research & Development (RnD) Area
= Foodcourt
= Meeting room
= Lobby, ATM center, coffee shop, service area

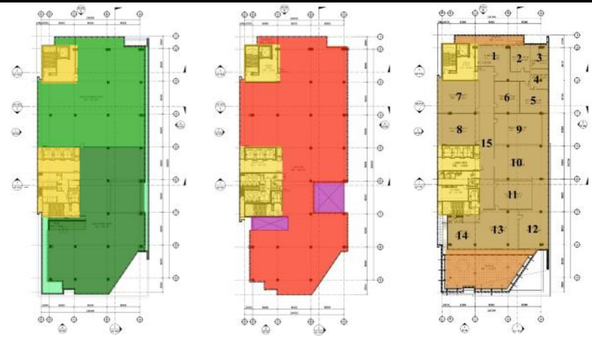
Source: (Nur Laela Latifah et al, 2021)
Figure 3: Function Zone of WU Tower Building



= Terrace
= Lobby
= ATM center
= Coffee shop
= Service area
Ground Floor

= Foodcourt
= Balcony
= Lift lobby
= Service area
2nd Floor

= Office area
= Open plan office
= Corridor
= Service area
7th Floor



= Gion restaurant
= Gion storage
= Service area
8th Floor

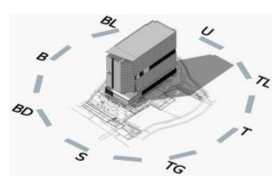
= Office area
= Void
= Service area
9th Floor

= Penthouse area
= Balcony
= Service area
15th Floor

Source: (Manager of WU Tower - processed, 2021)
Figure 4: Function Zone per Floor of WU Tower Building

3.2. Building Orientation and Opening Orientation

The orientation of the front of the building facing the main road Jl. Dr. Djunjunan, to the South, is tilted about 10º to the Southwest. See Fig. 5. The shape of the building mass extends North-South, so the long side of the dominant building faces East and West. A building envelope dominates the entire side of the building in the form of a glass curtain wall that acts as an opening for natural light so that the facade gets a fair amount of exposure to solar radiation every day. See Fig. 6.



Source: (Nur Laela Latifah et al, 2021)
Figure 5: Building Orientation of WU Tower Building

3.3. Building Facade Shape

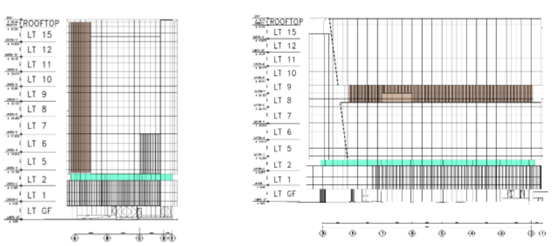
The facade of the building is not entirely flat but in certain areas/ floors there are subtracts with certain dimensions that result in the form of recessed sun spaces or transitional spaces. This subtract provides shade at a certain time so that it can reduce exposure to solar heat radiation on the facade. See Fig. 6 and Fig. 7.

Front/ South Facade | Southeast Facade

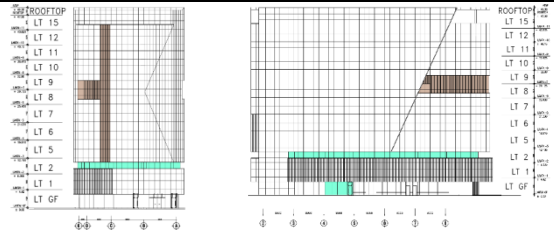
Back/ North Facade | Right/ West Facade

Source: (Nur Laela Latifah et al, 2021)
Figure 6: Exterior View/ Facade of WU Tower Building

Recessed sun spaces (green) are located on the West facade of the ground floor to provide a shadow over the coffee shop area. They also surround the entire side of the 2nd floor to form a balcony to reduce heat radiation exposure in the whole area of the food court. Transitional spaces (brown) are located on the East, South, and West facades of the 8th and 9th floors so that there is a little shadow in the Gion Storage, Gion Restaurant, and office areas, also on the North and South facades of 5th to 15th floors, so there is also a little shadow in the area office, open plan office, Gion Storage, Gion Restaurant, and penthouse area. See Fig. 7 and see Fig. 4.



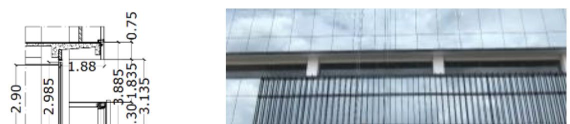
North Facade | East Facade



South Facade | West Facade

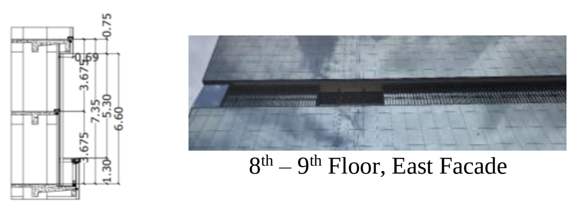
Source: (Manager of WU Tower - processed, 2021)
Figure 7: Allocation of Recessed Sun Spaces (Green) and Transitional Spaces (Brown)

The dimensions of the recessed sun spaces (on the 2nd floor) are 1,835 m high with 1.88 m depth so that they can optimally provide shade when the sun's altitude is high but still provide flexibility for users to view outside the building. See Fig. 8. The dimensions of the transitional spaces (on the 8th and 9th floors) are 5.30 m high with a depth of only 0.59 m so that they do not interfere with the user's view outside the building but are still less effective in providing optimal shade. See Fig. 9.



2nd Floor, East Facade

Source: (Left: Manager of WU Tower - processed, Right: Nur Laela Latifah et al, 2021)
Figure 8: Detail of Recessed Sun Spaces



8th – 9th Floor, East Facade

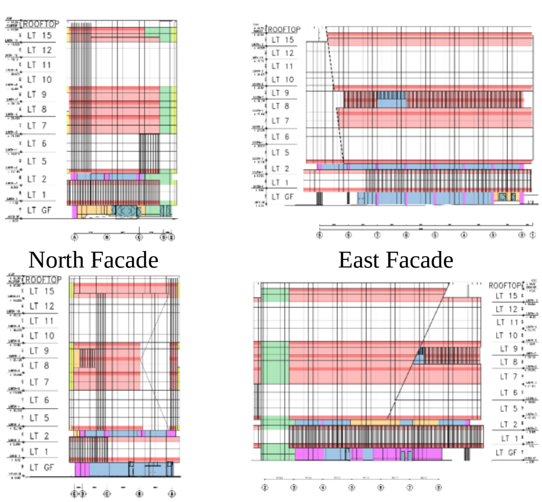
Source: (Left: Manager of WU Tower - processed, Right: Nur Laela Latifah et al, 2021)
Figure 9: Detail of Transitional Spaces

3.4. Building Facade Material

The WU Tower building's facade wall/ building envelope uses several types of materials. See Fig. 10. The dominant facade material is glass as a curtain wall which is applied to every floor and all sides of the building.

Specifically, Indoflot 6 mm clear glass, which cannot reduce the transmission of solar heat radiation, is applied to the ground floor, where there are many public areas, and the 2nd floor, where there is a food court, so the facade needs protection against exposure to excessive solar heat radiation. With recessed sun spaces like balconies on all sides of the 2nd-floor facades, the foodcourt area gets a shadow when the sun's altitude is high.

The facade material concrete + ACP is applied vertically to the wall of the service area at the back of the building (North and West facades), which does not require a view. In contrast, ACP is applied to certain parts of the wall of the service area (especially on the North facade of the ground floor). The thermal conductivity (λ) of concrete walls 1.35 W/mK is moderate. Still, the ACP as an exterior coating is very high, reaching 160 W/mK, so it is very easy to conduct heat into the building and must be given a thermal insulation layer that is filled in the space between the concrete wall and the ACP. The solar radiation absorbtance (α) of concrete is relatively high at 0.61 while the ACP is low at only 0.12. With the application of concrete + ACP facade material and limited ACP, it does not cause a high external thermal load for the building.



North Facade East Facade

South Facade West Facade

= Double glass (T-Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm)
= Double glass (T -Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm) + GRC
= Concrete + ACP
= Clear glass Indoflot 12 mm
= Aluminum Composite Panel (ACP)
= Column concrete & aerated concrete wall

Source: (Manager of WU Tower - processed, 2021)
Figure 10: Facade Material of WU Tower Building

The aerated concrete facade material is applied mainly to the ground floor's west facade, a service area covered with semi-gloss white paint. Thermal conductivity (λ) is relatively low, 0.11 - 0.31, so it is not easy to conduct heat into the building, and the absorbance value of the paint that coats it is 0.30, so it does not absorb heat too high. Based on the specifications, aerated concrete facade material does not cause a high external thermal load for the building.

3.5. Window to Wall Ratio (WWR)

Window Wall Ratio (WWR) is calculated based on the proportion of the opening area to the wall area. Regarding WWR, the definition of openings is translucent material on a facade, while walls are all types of material on the facade, both translucent and opaque. The WU Tower building as a translucent material, namely double glass (T-Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm) and clear glass Indoflot 12 mm. On the other hand, as an opaque facade material, double glass (T-Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm) + GRC, concrete + ACP, ACP, and aerated concrete.

The calculation of WWR is done separately per side of the facade, where each gets a different intensity of exposure to solar heat radiation according to the angle of the sun's fall. Then it is broken down per floor of the building so that it can be identified according to the function of

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the space in it. Facades, where there are an ATM center, coffee shop, food court, Gion Restaurant, and Gion Storage, are categorized as retail with a WWR value limit of 30.0%. Facades, where there are offices and open plan offices, are categorized as the office with a WWR value limit of 60.0%. Facades with a penthouse area are categorized as apartments with a WWR value limit of 60.0%. See Fig. 4 and Table 3.

Based on Table 4 for the North facade, the average WWR value is 50.44%, slightly above the criteria average of 50.0%. The 2nd, 7th, 8th, and 9th floors, exceed the criteria limit, so there is a risk of receiving excessive external thermal loads.

Table 4: Window to Wall Ratio (North Facade)

Window Area	Wall Area	Result of WWR	Criteria of WWR (Max.)	Status of WWR
Ground Floor (Office)				
8.52 m^2	95.76 m^2	8.90%	60.0%	OK
2th Floor (Retail)				
51.83 m^2	114.15 m^2	45.41%	30.0%	NOT OK
7th Floor (Office)				
70.36 m^2	110.39 m^2	63.74%	60.0%	NOT OK
8th Floor (Retail)				
63.40 m^2	99.80 m^2	63.53%	30.0%	NOT OK
9th Floor (Office)				
70.36 m^2	105.64 m^2	66.60%	60.0%	NOT OK
15th Floor (Apartment)				
56.75 m^2	104.18 m^2	54.47%	60.0%	OK
	Average	50.44%	50.0%	NOT OK

Source: (Nur Laela Latifah et al, 2021)

Based on Table 5 for the East facade, the average WWR value is not good, which is 76.44% above the average criteria of 45.0%. The WWR values on the ground floor and 2nd, 7th, 8th, 9th, and 15th floors are also not good above the maximum limit with the highest value on the 7th floor reaching 80.71%.

Table 5: Window to Wall Ratio (East Facade)

Window Area	Wall Area	Result of WWR	Criteria of WWR (Max.)	Status of WWR
Ground Floor (Retail)				
141.29 m^2	219.08 m^2	64.49%	30.0%	NOT OK
2th Floor (Retail)				
178.94 m^2	238.55 m^2	75.01%	30.0%	NOT OK
7th Floor (Office)				
191.57 m^2	237.37 m^2	80.71%	60.0%	NOT OK
8th Floor (Retail)				
151.32 m^2	188.18 m^2	80.41%	30.0%	NOT OK
9th Floor (Office)				
181.34 m^2	227.51 m^2	79.71%	60.0%	NOT OK
15th Floor (Apartment)				
174.41 m^2	222.64 m^2	78.34%	60.0%	NOT OK
	Average	76.44%	45.0%	NOT OK

Source: (Nur Laela Latifah et al, 2021)

Based on Table 6 for the Southeast facade, the average WWR value is 80.33% above the criteria average of 50.0%. On the ground floor as well as 2nd and 15th floor there is no Southeast facade. The WWR values on the 7th, 8th, and 9th floors are also not good above the maximum limit with the highest value on the 9th floor reaching 80.68%.

Table 6: Window to Wall Ratio (Southeast Facade)

Window Area	Wall Area	Result of WWR	Criteria of WWR (Max.)	Status of WWR
7th Floor (Office)				
38.39 m^2	47.89 m^2	80.16%	60.0%	NOT OK
8th Floor (Retail)				
38.39 m^2	47.89 m^2	80.16%	30.0%	NOT OK
9th Floor (Apartment)				
39.66 m^2	49.16 m^2	80.68%	60.0%	NOT OK
	Average	80.33%	50.0%	NOT OK

Source: (Nur Laela Latifah et al, 2021)

Based on Table 7 for the South facade, the average WWR value is not good, which is 65.93% above the criteria average of 40.0%. Only on the 9^{th} floor can still qualify. On the ground floor and the 2^{nd}, 7^{th}, 8^{th}, and 15^{th} floors exceed the criteria limit so that there is a risk of receiving excessive external thermal loads.

Table 7: Window to Wall Ratio (South Facade)

Window Area	Wall Area	Result of WWR	Criteria of WWR (Max.)	Status of WWR
Ground Floor (Retail)				
81.12 m^2	113.56 m^2	71.43%	30.0%	NOT OK
2th Floor (Retail)				
64.14 m^2	108.82 m^2	58.94%	30.0%	NOT OK
7th Floor (Office)				
57.18 m^2	79.63 m^2	71.81%	60.0%	NOT OK
8th Floor (Retail)				
50.78 m^2	73.13 m^2	69.44%	30.0%	NOT OK
9th Floor (Office)				
54.65 m^2	112.71 m^2	48.49%	60.0%	OK
15th Floor (Apartment)				
77.72 m^2	103.00 m^2	75.46%	60.0%	NOT OK
	Average	65.93%	45.0%	NOT OK

Source: (Nur Laela Latifah et al, 2021)

Based on Table 8 for the West facade, the average WWR score is 54.56% above the criteria average of 45.0%. Only on the ground floor that can still meet the requirements. On the 2^{nd}, 7^{th}, 8^{th}, 9^{th}, and 15^{th} floors exceed the criteria limit so that there is a risk of receiving excessive external thermal loads.

Table 8: Window to Wall Ratio (West Facade)

Window Area	Wall Area	Result of WWR	Criteria of WWR (Max.)	Status of WWR
Ground Floor (Retail)				
55.39 m^2	277.66 m^2	19.95%	30.0%	OK
2th Floor (Retail)				
93.39 m^2	263.32 m^2	35.47%	30.0%	NOT OK
7th Floor (Office)				
172.61 m^2	253.47 m^2	68.10%	60.0%	NOT OK
8th Floor (Retail)				
164.85 m^2	236.19 m^2	69.80%	30.0%	NOT OK
9th Floor (Office)				
155.41 m^2	231.29 m^2	67.19%	60.0%	NOT OK
15th Floor (Apartment)				
131.90 m^2	197.29 m^2	66.86%	60.0%	NOT OK
	Average	54.56%	45.0%	NOT OK

Source: (Nur Laela Latifah et al, 2021)

3.6. Glass Type and Glass Configuration

Basically, there are only two types of glass used in the facade of the WU Tower building, namely clear glass, and magnetron-coated glass. See Table 9 and Table 10. Clear glass has a low ability to reduce heat transmission into the building. Its application is limited to areas such as the ground floor and 2nd-floor facades, shaded by the subtract recessed sun spaces and the inner glass in the double glass configuration. Coated glass can reduce heat transmission. Its application is dominant on all facades as outer glass in a double-glass configuration.

Table 9: Specification of Clear Glass

CLEAR GLASS - INDOFLOT			
Type of Glass		Indoflot Clear	
Standard Thickness (mm)		6	12
Energy Characteristic	Transmittance (%)	79	69
	Reflectance (%)	7	6
	Absorption (%)	14	25
Light Characteristic	Transmittance (%)	89	86
	Reflectance (%)	8	8
Solar Factor (%)		83	76
Shading Coefficient		0.95	0.87
U-Value (W/mK)		5.8	5.6

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Source: (http://amfg.co.id/id/produk/kaca-lembaran/exterior-kami/indoflot.html, processed, 2021, [22])

Table 10: Specification of Magnetron Coated Glass

MAGNETRON COATED GLASS - T-SUNLUX		
Type of Glass		CS 120 #2
Glass Substrate		On Clear
Standard Thickness (mm)		8
Energy Characteristic	Transmittance (%)	18
	Reflectance (%)	19
	Absorption (%)	63
Light Characteristic	Transmittance (%)	21
	Reflectance out (%)	25
	Reflectance in (%)	29
Solar Factor (%)		32
Shading Coefficient		0.36
U-Value (W/mK)		4.8

Source: (http://amfg.co.id/en/product/flat-glass/our-exterior/t-sunlux.html, processed, 2021, [23])

3.7. Glass Thickness and Glass Coating

Indoflot 6 mm clear glass is used as the inner glass in the double glass configuration, with the T-Sunlux CS-120 8 mm clear as the outer glass. Between the two sheets of glass, there is a 12 mm vacuum spacer to prevent heat transfer, so the total thickness of the double glass construction is 26 mm enough to anticipate exposure to solar heat radiation. The coated T-Sunlux glass surface is applied in the indoor position (#2) so that its heat transmission reduction capability is not easily damaged due to the cleaning/ maintenance process. Indoflot 12 mm transparent glass is used as single glass with limited allocation on the facade. See Table 9 and Table 10.

3.8. Energy Characteristic

The ability of clear glass Indoflot 12 mm to reduce exposure to solar heat radiation entering the building is higher than the 6 mm thick one. Still, it is not used as inner glass in a double glass configuration because the T-Sunlux CS 120 #2 8 mm performance could be better. This T-Sunlux glass has a very low heat transmission capability of only 18% and a fairly high heat absorption capability of 63%. In the configuration of double glass with T-Sunlux CS 120 #2 8 mm as outer glass and clear glass Indoflot 6 mm as inner glass, excellent performance was obtained where energy transmittance was only 14.22%, and energy absorption was only 8.82%. See Table 11. See too Table 9 and Table 10.

Table 11: Specification of Double Glass (T-Sunlux CS 120 #2 8 mm + Clear Glass Indoflot 6 mm)

Specification of Double Glass	Claculation of Double Glass	Status of Double Glass
Energy Transmittance (%)	= Inner Glass x Outer Glass = 79% x 18% = 14.22%	OK
Energy Absorption (%)	= Inner Glass x Outer Glass = 14% x 63% = 8.82%	OK
Solar Factor (%)	= Inner Glass x Outer Glass = 83% x 32% = 26.56%	OK
U-Value (W/mK)	= (Inner Glass + Outer Glass)/2 = (5.8 + 4.8)/2 = 5.3 W/mK	NEED IMPROVEMENT

Source: (Nur Laela Latifah et al, 2021)

3.9. Solar Factor (SF)

With the configuration of double glass T-Sunlux CS 120 #2 8 mm as the outer glass and clear glass Indoflot 6 mm as the inner glass, the performance is very good where the Solar Factor (SF) is only 26.56%. With this low heat transmission capability, it does not result in heat accumulation in the building, which increases the consumption of electrical energy for the AC

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system. See Table 11. See too Table 9 and Table 10.

3.10. Shading Coefficient (SC) and Solar Heat Gain Coefficient (SHGC)

In order for heat transmission into the building to be low, the Shading Coefficient (SC) and Solar Heat Gain Coefficient (SHGC) values must also be low. The maximum SHGC value that can support a significant reduction in heat transmission is 0.40 with the calculation of SHGC = 0.87 x SC. Of all the types of glass used in the WU Tower building, only T-Sunlux CS 120 #2 8 mm does not exceed the maximum limit of the SHGC so as to reduce the occurrence of excessive external thermal loads in the interior. In the configuration of double glass T-Sunlux CS 120 #2 8 mm as outer glass and clear glass Indoflot 6 mm as inner glass, excellent performance was obtained where SC was low at only 0.34 and SHGC was also low at only 0.30 below the maximum limit of 0.40. See Table 12. See too Table 9 and Table 10.

Table 12: Shading Coefficient (SC) and Solar Heat Gain Coefficient (SHGC) of Glass

Type of Glass	Shading Coefficient (SC)	Solar Heat Gain Coefficient (SHGC)	Status of Glass
Clear Glass Indoflot 6 mm	0.95	SHGC = 0.87 SC = 0.87 x 0.95 = 0.83	NOT OK
Clear Glass Indoflot 12 mm	0.87	SHGC = 0.87 SC = 0.87 x 0.87 = 0.76	NOT OK
T-Sunlux CS 120 #2 8 mm	0.36	SHGC = 0.87 SC = 0.87 x 0.36 = 0.31	OK
T-Sunlux CS 120 #2 8 mm + Clear Glass Indoflot 6 mm	SC = 0.95 x 0.36 = 0.34	SHGC = 0.87 SC = 0.87 x 0.34 = 0.30	OK

Source: (Nur Laela Latifah et al, 2021)

3.11. U-Value

In the configuration of double glass T-Sunlux CS 120 #2 8 mm as outer glass and clear glass Indoflot 6 mm as inner glass, the performance is quite good (still needs improvement) where the U-Value is 5.3 W/mK. See Table 11. See too Table 9 and Table 10.

3.12. OTTV Calculation

OTTV calculation is carried out using the OTTV Calculator tool with data on the Identification of Exterior Wall Specification, Identification of Exterior Fenestration System Specification, Outer Shader Element, and Facade Identification. Input on Facade Identification based on space conditioned using the AC system. It is assumed that the service area is not conditioned using an AC system, so the concrete + ACP and ACP material whose application to the facade has been limited will not be included in the OTTV calculation. Especially for aerated concrete, it is still considered in the OTTV calculation because its application to the facade of the service area is quite large, such as the West facade of the ground floor. This OTTV Calculator file is specific for Bandung City, with a maximum OTTV limit of not more than 45 W/m2.*Identification of Exterior Wall Specification*

Based on the material on the facade of the WU Tower building, there are three types of wall construction which are distinguished by the constituent materials of brick, glass, or concrete, as well as the existence or not of thermal insulation properties obtained from the spacer between 2 pieces of glass and GRC.

There are 3 types of wall construction, namely:

1. EW 1 (Glass-Back Panel)
   = Clear glass Indoflot 12 mm
2. EW 2 (Glass-Back Panel-Insulation)

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= Double glass (T-Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm)
= Double glass (T-Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm) + GRC

3. EW 3 (Bata Ringan)
   = Aerated concrete

3.13. Identification of Exterior Fenestration System Specification

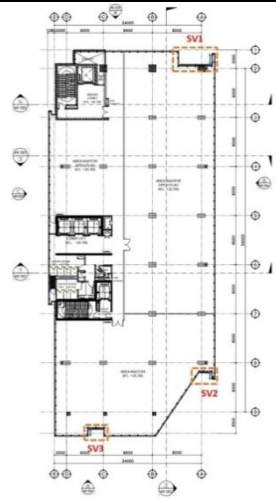
Fenestration systems are distinguished by glass type and glass configuration, glass thickness, and depth of shader. There are 24 types of fenestration system construction on all facades of the WU Tower building. F1 - F23 all have outer shaders (horizontal type or vertical type) with their own shader depth.

Generally the fenestration system are:

1. F1 – F12, F14, F18
   = Clear glass Indoflot 12 mm dengan SHGC 0.75 dan U-Value 5.60 W/mK
2. F13, F15 – F17, F19 – F24
   = Double glass (T-Sunlux CS 120 #2 8 mm + clear glass Indoflot 6 mm) dengan SHGC 0.29 dan U-Value 5.30 W/mK

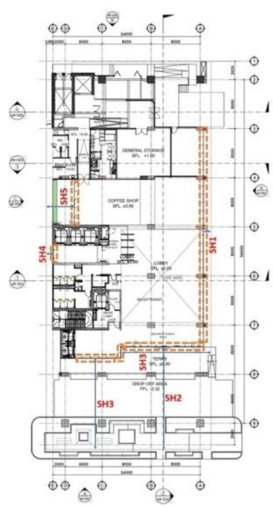
3.14. Outer Shader Element

The outer shader element consists of a horizontal type and a vertical type. The identification is not only based on the shape of the recessed sun spaces and transitional spaces, but also based on the presence of set-backs and all protrusions on the facade. There are 3 outer vertical shader codes, namely SV1 - SV3 with each depth and depth, and all of them have a slope of 0º. There are 20 horizontal outer shader codes, namely SH1 - SH20 with length of depth and height of depth respectively, and all of them have a slope of 0º. See Fig. 11 and Fig. 12.

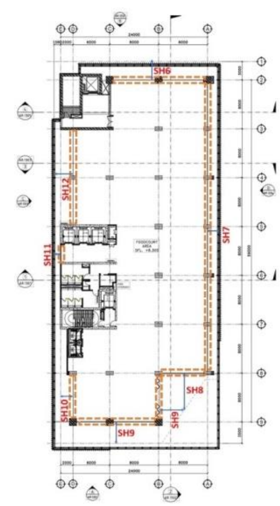


7th Floor

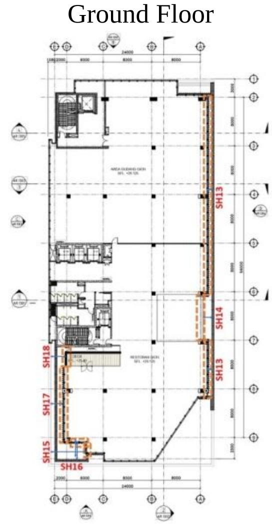
Source: (Manager of WU Tower - processed, 2021)
Figure 11: Mapping of Vertical Type Outer Shader Element at WU Tower Building



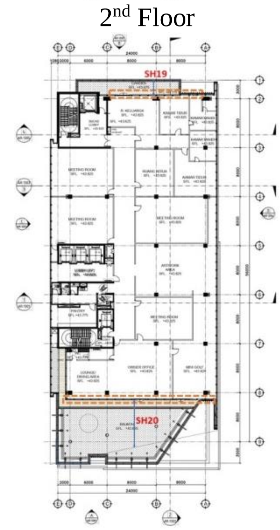
Ground Floor



2nd Floor



8th and 9th Floor



15th Floor

Source: (Manager of WU Tower - processed, 2021)
Figure 12: Mapping of Horizontal Type Outer Shader Element at WU Tower Building

3.15. Facade Identification

According to the condition of the WU Tower building, the input facade identification is only on the North, East, Southeast, South, and West sheets. Each side of the facade of this building is broken down into several components that have a height (distance of floor to floor), length, type of wall construction, code of fenestration system construction type, and opening area, respectively, with a total of floor number 1. There are six components of the North facade, eight components of the East facade, two components of the Southeast facade, ten components of the South facade, and 11 components of the West facade.

3.16. Summary of OTTV

The OTTV Calculator outputs not only the calculation results of the OTTV but also heat transfer data consisting of conduction through the wall, conduction through the opening, radiation through the opening, also Window Wall Ratio (WWR).

The OTTV average of the entire facade at the WU Tower Building is very high, reaching 56.93 W/m2, exceeding the maximum limit of 45 W/m2. This is due to the high OTTV on the East facade reaching 68.44 W/m2 and on the West facade of 59.19 W/m2. See Table 13.
The high OTTV on these two facades is due to a large amount of heat transfer from the outside to the inside of the building, mainly through the glass material. The wider the glass area, the higher the heat transfer, so the higher the OTTV. On the East facade, the total opening area (glass) is 867.03 m2, and the total heat transfer that occurs is 73,829.23 watts. On the west facade, the total opening area (glass) is 722.90 m2, and the total heat transfer is 54,610.57 Watt. See Table 14 and Table 15.

Table 13: OTTV of WU Tower Building

No	Side	Total	Total of Facade Area	OTTV
		Watt	m2	Watt/m2
		D = A + B + C	E	D / E
1	NORTH	15.600,54	392,00	39,80
2	NORTHEAST	-	-	-
3	EAST	73.829,23	1.078,75	68,44
4	SOUTHEAST	6.640,91	149,24	44,50
5	SOUTH	20.058,81	456,72	43,92
6	SOUTHWEST	-	-	-
7	WEST	54.610,57	922,60	59,19
8	NORTHWEST	-	-	-
		170.740,08	2.999,31	56,93
		TOTAL	TOTAL	TOTAL
			COMPLY?	NO

Source: (Nur Laela Latifah et al, 2021)

Table 14: Heat Transfer at Facade of WU Tower Building

No	Side	Conduction through Wall	Conduction through Opening	Radiation through Opening	Total
		Watt	Watt	Watt	Watt
		A	B	C	D = A + B + C
1	NORTH	551,31	3.346,66	11.702,58	15.600,54
2	NORTHEAST	-	-	-	-
3	EAST	1.095,05	12.681,24	60.052,94	73.829,23
4	SOUTHEAST	68,70	1.685,68	4.886,54	6.640,91
5	SOUTH	489,74	5.318,73	14.250,35	20.058,81
6	SOUTHWEST	-	-	-	-
7	WEST	680,38	10.454,93	43.475,26	54.610,57
8	NORTHWEST	-	-	-	-
		2.885,17	33.487,24	134.367,66	170.740,08
		TOTAL	TOTAL	TOTAL	TOTAL

Source: (Nur Laela Latifah et al, 2021)

Table 15: Window to Wall Ratio of WU Tower Building Based on OTTV Calculator

No	Side	Total of Opening Area	WWR
		m2	(%)
		F	F / E
1	NORTH	231,24	58,99
2	NORTHEAST	-	-
3	EAST	867,03	80,37
4	SOUTHEAST	117,80	78,93
5	SOUTH	364,28	79,76
6	SOUTHWEST	-	-
7	WEST	722,90	78,35
8	NORTHWEST	-	-
		2.303,25	76,79
		TOTAL	TOTAL

Source: (Nur Laela Latifah et al, 2021)

3.17. Weighting of esearch Variables

The weighting is done in order to obtain the value of the research variables quantitatively. The rating scale per variable is 1 to 4, where the higher is the better. Based on the total value of the scale of all variables, the percentage calculation on a scale of 100 is calculated. See Table 16.

Table 16: Weighting of WU Tower Building Research Variabels

No.	Variabels	Scale
	Design of Building	
1.	Building orientation and opening orientation	2
2.	Form of building facade	4
3.	Material of building facade	3
4.	Window to Wall Ratio (WWR)	1
	Specification of Glass	
5.	Type and configuration of glass	3
6.	Thickness and coating of glass	4
7.	Energy characteristic	4
8.	Solar Factor (SF)	4
9.	Shading Coefficient (SC) and Solar Heat Gain Coefficient (SHGC)	4
10	U-Value	3
	OTTV Calculation	
11.	Identification of exterior wall specification	3
12.	Identification of exterior fenestration system specification	3
13.	Outer shader element	3
14.	Facade identification	3
15.	Summary of OTTV	2
	Total of Scale	46

Source: (Nur Laela Latifah et al, 2021)

Number of scale = 46
Maximum of scale = 15 x 4 = 60
Persentase = (46/60)x100%
= 76.67% (pretty good)

The design of the building envelope of WU Tower Building with glass curtain wall dominance has quite good success in reducing the OTTV.

4. Conclusion

Based of analysis of WU Tower building that has been carried out, the following conclusions are obtained:

1. Recessed sun spaces can provide shade at high solar altitudes, but with sufficiently high WWR values this cannot guarantee a reduction in external thermal load gain to produce a qualified OTTV.
2. The type (and construction) of the opaque facade material is good for reducing the transmission of solar heat radiation into the building.
3. The average WWR value for each facade is not below the criteria average. On the East and Southeast facades it is + 30 points higher, on the South facade it is + 20 points, and on the West facade it is + 10 points.
4. Glass performance can be improved by means of a double glass configuration. With T-Sunlux C120 #2 8 mm as the outer glass, clear glass Indoflot 8 mm as the inner glass, then there is a spacer between the two sheets of glass, so it can reduce exposure to solar heat radiation entering the building.
5. The very high OTTV average does not meet the criteria, because of the high heat transfer on the East and West facades. There is a facade area limit so that the heat transfer that occurs is not too high and the OTTV gain does not exceed the 45 W/m^2 limit.
6. Based on the weighting of all research variables, the percentage is 76.67%, where the design of the building envelope is quite good in an effort to reduce the acquisition of OTTV with the climate and weather of Bandung City. This OTTV can be lowered to make it better through improving the performance of the building envelope design without changing the shape of the building mass, namely through shadowing by secondary skin construction.

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for complete data collection and analysis process in this research.

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