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OTTV (SNI 03-6389-2011) and ETTV (BCA 2008) Calculation for Various Building's Shapes, Orientations, Envelope Building Materials: Comparison and Analysis

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Abstract: The Indonesian National Standard SNI 03-6389-2000 adapted the 1983 Singapore's Handbook on Energy Conservation and limited the Overall Thermal Transfer Value (OTTV) of the building envelope to 45 Watt/m^2. In 2008, the Singapore's Building and Construction Authority (BCA) shifted to Envelope Thermal Transfer Value (ETTV) value of 50 Watt/m^2, while SNI 03-6389-2011 continues to use OTTV. This paper reviewed the new SNI 03-6389-2011 and compared it with BCA by calculating OTTV and ETTV of prismatic buildings with eight different shapes and building orientations, 11 Window to Wall Ratio, and 27 building envelope materials. This study also tested those variables to find the best building shape and orientation for an energy saver building. The result shows that ETTV (BCA) is stricter than OTTV (SNI 03-6389-2011) except the OTTV with black building envelope, while parallelogram shape building with North-South orientation is the best combination of energy saver building.

Keywords: Building shape; building orientation; envelope building material; ETTV; OTTV.

Introduction

People started to pay attention on energy conservation due to increasingly high demand of energy, especially in residential and commercial building sectors. Specifically in Singapore and Indonesia, air conditioning uses most energy in commercial buildings. Therefore, it is essential to understand the condition of air system when designing a building since the amount of energy usage must be established early on [1].

Energy consumption in Indonesia is regulated by limiting the Overall Thermal Transfer Value (OTTV) [2,3], adopting the Handbook on Energy Conservation in Buildings and Building Services published by the Development & Building Control Division of Public Works Department of Singapore in 1983 [4]. In the meantime the new regulation in Singapore published by the Building and Construction Authority (BCA) [5] uses Envelope Thermal Transfer Value (ETTV) instead of OTTV. According to BCA [5] the later research works revealed that OTTV did not reflect accurately the relative performance of the different elements in an envelope system.

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The difference between OTTV [2,3] and ETTV [5] is in the limiting value and the level of sun radiation absorption. The OTTV in SNI 03-6389-2011 is limited to 35 W/m^2 and considers sun radiation absorption (α) due to the color of building envelope in the formulation. While the limiting ETTV value according to BCA is 50 W/m^2, and no sun radiation absorption coefficient α. in the formulation.

Concept of OTTV

The foundation of an energy efficient building starts with its design process. The main issue in creating an energy efficient building comes from the absorption of the building's solar heat load through its air conditioning system. Aligning the direction of the building's façade to East and West and choosing light colors for wall finish are some examples of the common design practice to reduce solar heat input.
Limiting OTTV is one of the energy efficiency strategies. OTTV takes into account the elements of heat gain through the external wall of a building, such as: heat conduction through opaque walls and glass windows as well as solar radiation through glass windows. OTTV value is measured by taking the average measurement of these three elements over the whole envelope area of the building.

OTTV based on SNI 03-6389-2011[3]

To calculate the OTTV of an external wall, the following basic equations shall be used:

$$OTTV = \alpha\,[U_w\,(1\text{-}WWR)\,TD_{ek}] + (U_f\,WWR\,\Delta T) + (SC\,WWR\,SF) \quad (1)$$

Where more than one type of material and/or fenestration is used, the following equation shall be used:

$$OTTV = [\alpha_1\{U_{w1}\ \ A_1/\Sigma A\ (1-\ WWR)\ TD_{ek}\ +\ \alpha_2\{U_{w2}\ \ A_2/\Sigma A\ (1-\ WWR\ )\ TD_{ek}\}\ +\ \ldots\ldots\ldots+\ \alpha_n\{Uw_n\ \ A_n/\Sigma A\ (1-\ WWR)\ TD_{ek}\}]\ +\ (U_f\ \ WWR\ \Delta T)\ +\ (SC\ WWR\ SF) \quad (2)$$

While to calculate the OTTV for the envelope of the whole building, the following equation shall be used:

$$OTTV = \frac{(A_{01}\ \ OTTV_{01}) + (A_{02}\ \ OTTV_{02}) + \ldots\ldots + (A_{0i}\ \ OTTV_{0i})}{A_{01} + A_{02} + \ldots.. + A_{0i}} \quad (3)$$

In Equations 1 to 3:

α	=	sun radiation absorption, depending on the material and color of the exterior wall
U_w	=	thermal transmittance of opaque wall (Watt/m^2.K).
WWR	=	window-to-wall ratio (%)
TD_{ek}	=	equivalent temperature difference for wall (10^{o}K for brick wall)
SC	=	shading coefficients of fenestrations, specified by the manufacturer
SF	=	solar factor (W/m^2), depends on building orientation
	=	130 for North (N), 113 for North East (NE),112 for East (E), 97 for South East (SE), 97 for South (S), 176 for South West (SW), 243 for West (W), 211 for North West (NW)
U_f	=	thermal transmittance of fenestration (Watt/m^2.^{o}K)
ΔT	=	temperature difference between exterior and interior design condition (5^{o}K)
A_1	=	wall area with material 1 (m^2)
A_2	=	wall area with material 2 (m^2)
An	=	wall area with material n. (m^2)
ΣA	=	A1+A2+…………+An
A_{0i}	=	gross area of exterior wall 0i (opaque wall area + fenestration area). (m^2)
$OTTV_{0i}$	=	overall thermal transfer value from wall $_0$i (W/m^2)

For the purpose of energy conservation, the maximum permissible OTTV is set to 35 Watt/m^2.

ETTV based on BCA of Singapore [5]

Since 1979, the Building Control Regulations had prescribed an envelope thermal performance standard known as OTTV. The OTTV standard applied only to air-conditioned non-residential buildings. A major review of the OTTV formula was carried out in the early 2000 to provide a more accurate measure of the thermal performance of building envelope. The new formula is named Envelope Thermal Transfer Value (ETTV) to differentiate from the original OTTV formula. The ETTV requirement does not apply to non air-conditioned buildings.

The ETTV formulas are given as follows:

$$ETTV = 12\ (1\text{-}WWR)\ U_w + 3.4\ (WWR)\ U_f + 211\ (WWR)\ (CF)\ (SC) \quad (4)$$

To calculate the ETTVfor the envelope of the whole building, the following equation shall be used:

$$ETTV = \frac{(A_{01}\ \ ETTV_{01}) + (A_{02}\ \ ETTV_{02}) + \ldots\ldots + (A_{0i}\ \ ETTV_{0i})}{A_{01} + A_{02} + \ldots.. + A_{0i}} \quad (5)$$

where:

ETTV	=	Envelope Thermal Transfer Value (Watt/m^2)
WWR	=	Window-to-Wall Ratio (Fenestration area/gross area of exterior wall) (%)
U_w	=	Thermal transmittance of opaque wall (Watt/m^2.K)
U_f	=	Thermal transmittance of fenestration (Watt/m^2.K)
CF	=	Correction Factor for solar heat gain through fenestration (Watt/m^2), depends on pitch angle and orientation. Pitch angle is the numerical measurement of the slope of a wall. The pitch angle used for this study is 90^o.
SC	=	Shading Coefficients of fenestration, specified by the manufacturer
A_{01}, $A_{02,}$ A_{0n}	=	gross areas of the exterior wall for each orientation (m^2)

For the purpose of energy conservation, the maximum permissible ETTV is set to 50 Watt/m^2.

Buildings Considered

This study uses data and building specification from Singapore Reference Office Building Description [6]. The buildings that will be analyzed are hypothetical buildings with eight different building shapes and eight different building orientations.

In this study, the Authors calculated OTTV [3] and ETTV [5] of prismatic buildings with eight different shapes, eight building orientations, 11 Window to Wall Ratio (WWR), and 27 alternative for building envelope material for OTTV as shown in Table 1, and nine alternative for building envelope material for ETTV as shown in Table 2.

The Authors then compared the results to find the OTTV/ETTV value that fits the energy-saver building standard. The eight hypothetical building shapes; circular, equilateral octagon, equilateral triangle, parallelogram, square, rectangle, ellipse, and trapezoid with eight orientations (N, NE, E, SE, S, SW, W, NW) are shown in Figure 1. Each hypothetical building is ten story with four meters floor to floor height. The overall floor area is 625 m^2 with 100 m^2 core, leaving the total floor that requires cooling as 525m^2. Total area of the whole building is 5250 m^2.

There are three materials considered for the building envelope.

1. Wall I: Aluminum Composite Panel 4 mm, Aluminum Frame, Steel Bracket, and Gypsum Board 9 mm (U_{wI}= 3.007 W/m^2.K)
2. Wall II: Glass Fiber Reinforced Concrete 12.7 mm, Steel Bracket, and Gypsum Board 9 mm (U_{wII} = 2.961 W/m^2.K)
3. Wall III: Brick wall, plaster and ceramic tile 9 mm (U_{wIII} = 2.741 W/m^2.K)

For outdoor painting, the Authors chose three different colors to represent: the largest α, overall black painting (α_1 = 0.95), the medium α, medium green or blue painting (α_2 = 0.57), and the smallest α, white varnish (α_3 = 0.21)

For single glazed window, the Authors used high shading coefficient of SC_H = 0.88, U_{fH} = 3.069 W/m^2.K, medium shading coefficient SC_M = 0.62, U_{fM} = 3.069 W/m^2.K, and low shading coefficient SC_L = 0.37, U_{fL} = 3.08 W/m^2.K. Only one building material is used for each alternative envelope building. WWR started from 0% to 100% with 10% interval.

Table 1 shows 27 different alternative combinations of materials for building envelope in OTTV calculation (marked with "✓" in Table 1). On the other hand, there are only nine different alternative combinations of materials for building envelope in ETTV calculation because ETTV calculation does not include the variable α (Table 2).

Table 1. 27 Alternatives of Building Envelope Materials on OTTV

	α			Building Envelope			Glass					
	α_1	α_2	α_3	U_{wI}	U_{wII}	U_{wIII}	U_{fH}	U_{fM}	U_{fL}	SC_H	SC_M	SC_L
	0.95	0.57	0.21	3.007	2.961	2.741	3.063	3.069	3.08	0.88	0.62	0.37
Alternative 1	✓			✓			✓			✓		
Alternative 2	✓			✓				✓			✓	
Alternative 3	✓			✓					✓			✓
Alternative 4	✓				✓		✓			✓		
Alternative 5	✓				✓			✓			✓	
Alternative 6	✓				✓				✓			✓
Alternative 7	✓					✓	✓			✓		
Alternative 8	✓					✓		✓			✓	
Alternative 9	✓					✓			✓			✓
Alternative 10		✓		✓			✓			✓		
Alternative 11		✓		✓				✓			✓	
Alternative 12		✓		✓					✓			✓
Alternative 13		✓			✓		✓			✓		
Alternative 14		✓			✓			✓			✓	
Alternative 15		✓			✓				✓			✓
Alternative 16		✓				✓	✓			✓		
Alternative 17		✓				✓		✓			✓	
Alternative 18		✓				✓			✓			✓
Alternative 19			✓	✓			✓			✓		
Alternative 20			✓	✓				✓			✓	
Alternative 21			✓	✓					✓			✓
Alternative 22			✓		✓		✓			✓		
Alternative 23			✓		✓			✓			✓	
Alternative 24			✓		✓				✓			✓
Alternative 25			✓			✓	✓			✓		
Alternative 26			✓			✓		✓			✓	
Alternative 27			✓			✓			✓			✓

Table 2. Nine Alternatives of Building Envelope Materials on ETTV

	Building Envelope			Glass					
	U_{wI}	U_{wII}	U_{wIII}	U_{fH}	U_{fM}	U_{fL}	S_{CH}	S_{CM}	S_{CL}
	3.007	2.961	2.741	3.063	3.069	3.08	0.88	0.62	0.37
Alternative 1	✓			✓			✓		
Alternative 2	✓				✓			✓	
Alternative 3	✓					✓			✓
Alternative 4		✓		✓			✓		
Alternative 5		✓			✓			✓	
Alternative 6		✓				✓			✓
Alternative 7			✓	✓			✓		
Alternative 8			✓		✓			✓	
Alternative 9			✓			✓			✓

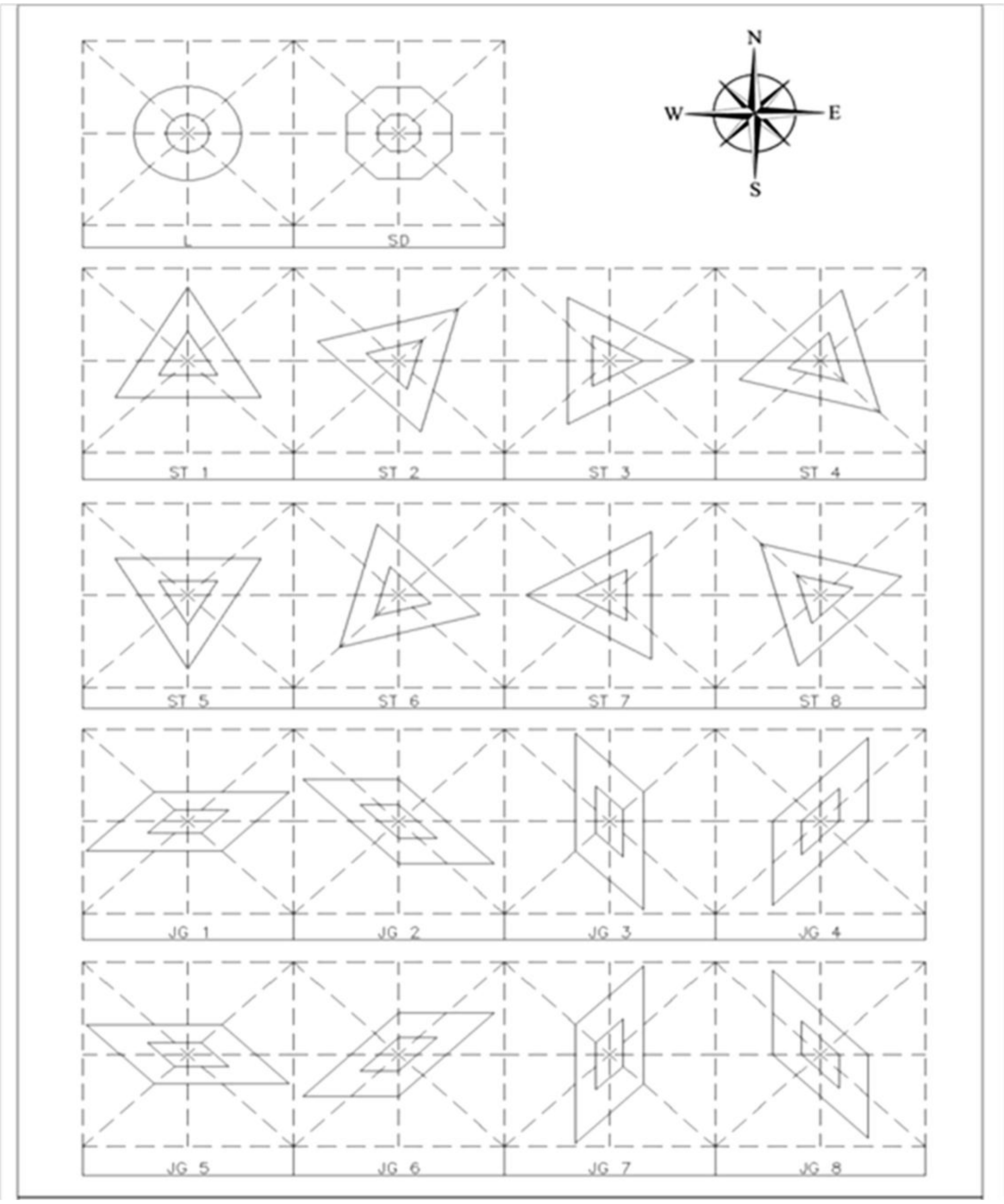

Figure 1.a. Four Building Shapes (Circular, Equilateral Octagon Equilateral Triangle, and Parallelogram) and Eight Building Orientations [7]

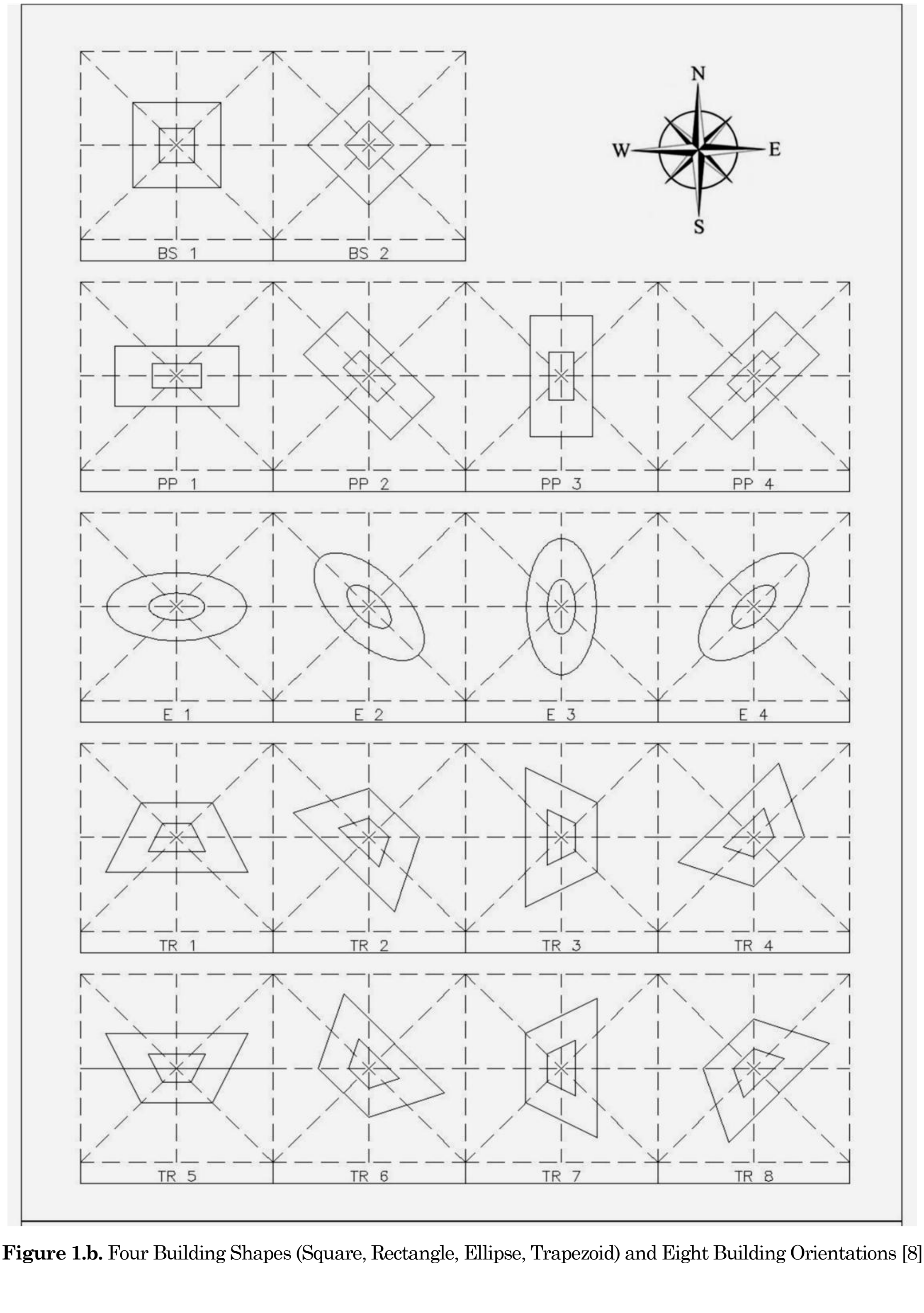

Figure 1.b. Four Building Shapes (Square, Rectangle, Ellipse, Trapezoid) and Eight Building Orientations [8]

OTTV Calculation

Table 3 shows a typical result of OTTV calculation on prismatic building, with circular shaped [7] using27 different materials and WWR from 0% to 100% with 10% interval. The shaded cells denote buildings with OTTV satisfying SNI 03-6389-2011

ETTV Calculation

Table 4 shows a typical result of ETTV calculation on prismatic building, with circular shape. This building was built with nine different materials with WWR from 0% to 100% with 10% interval. The shaded cells denote buildings with ETTV satisfying BCA 2008

Table 3. OTTV for Prismatic Building with Circular Shape (Alt 1-27)

WWR (%)	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9
0	28.57	28.57	28.57	28.13	28.13	28.13	26.04	26.04	26.04
10	40.21	36.38	32.70	39.82	35.99	32.31	37.94	34.11	30.43
20	51.85	44.20	36.84	51.50	43.85	36.49	49.83	42.18	34.82
30	63.50	52.01	40.98	63.19	51.71	40.67	61.73	50.24	39.21
40	75.14	59.83	45.11	74.88	59.56	44.85	73.63	58.31	43.60
50	86.79	67.64	49.25	86.57	67.42	49.03	85.52	66.38	47.98
60	98.43	75.46	53.38	98.25	75.28	53.21	97.42	74.45	52.37
70	110.07	83.27	57.52	109.94	83.14	57.39	109.32	82.51	56.76
80	121.72	91.09	61.66	121.63	91.00	61.57	121.21	90.58	61.15
90	133.36	98.90	65.79	133.32	98.86	65.75	133.11	98.65	65.54
100	145.01	106.72	69.93	145.01	106.72	69.93	145.01	106.72	69.93

WWR (%)	Alt 10	Alt 11	Alt 12	Alt 13	Alt 14	Alt 15	Alt 16	Alt 17	Alt 18
0	17.14	17.14	17.14	16.88	28.13	16.88	15.62	15.62	15.62
10	29.93	26.10	22.42	29.69	35.99	22.18	28.56	24.73	21.05
20	42.71	35.06	27.70	42.50	43.85	27.49	41.50	33.84	26.48
30	55.50	44.01	32.98	55.32	51.71	32.79	54.44	42.95	31.92
40	68.29	52.97	38.26	68.13	59.56	38.10	67.38	52.06	37.35
50	81.07	61.93	43.53	80.94	67.42	43.40	80.31	61.17	42.78
60	93.86	70.89	48.81	93.75	75.28	48.71	93.25	70.28	48.21
70	106.65	79.84	54.09	106.57	83.14	54.01	106.19	79.39	53.64
80	119.43	88.80	59.37	119.38	91.00	59.32	119.13	88.50	59.07
90	132.22	97.76	64.65	132.19	98.86	64.62	132.07	97.61	64.50
100	145.01	106.72	69.93	145.01	106.72	69.93	145.01	106.72	69.93

WWR (%)	Alt 19	Alt 20	Alt 21	Alt 22	Alt 23	Alt 24	Alt 25	Alt 26	Alt 27
0	6.31	6.31	6.31	6.22	6.22	6.22	5.76	5.76	5.76
10	20.18	16.35	12.68	20.10	16.27	12.59	19.68	15.85	12.17
20	34.05	26.40	19.04	33.98	26.32	18.96	33.61	25.95	18.59
30	47.92	36.44	25.40	47.85	36.37	25.33	47.53	36.04	25.01
40	61.79	46.48	31.76	61.73	48.42	31.70	61.46	46.14	31.43
50	75.66	56.52	38.12	75.61	56.47	38.07	75.38	56.24	37.84
60	89.53	66.56	44.48	89.49	66.52	44.44	89.31	66.33	44.26
70	103.40	76.60	50.84	103.37	76.57	50.82	103.23	76.43	50.68
80	117.27	86.64	57.21	117.25	86.62	57.19	117.16	86.53	57.09
90	131.14	96.68	63.57	131.13	86.67	63.56	131.08	96.62	63.51
100	145.01	106.72	69.93	145.01	106.72	69.93	145.01	106.72	69.93

OTTV satisfying the requirement of SNI 03-6389-2011

Table 4. ETTV for Prismatic Building with Circular Shape (Alt 1- 9)

WWR (%)	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9
0	36.08	36.08	36.08	35.53	35.53	35.53	32.89	32.89	32.89
10	52.15	46.65	41.36	51.66	46.15	40.86	49.28	43.78	38.49
20	68.32	57.22	46.63	67.78	56.77	46.19	65.67	54.66	44.08
30	84.30	67.78	51.91	83.91	67.40	51.52	82.06	65.55	49.67
40	100.37	78.35	57.18	100.04	78.02	56.85	98.45	76.43	55.27
50	116.44	88.91	62.46	116.16	88.64	62.18	114.84	87.32	60.86
60	132.51	99.48	67.73	132.29	99.26	67.51	131.23	98.20	66.46
70	148.58	110.05	73.01	148.41	109.88	72.84	147.62	109.09	72.05
80	164.65	120.61	78.28	164.54	120.50	78.17	164.01	119.97	77.65
90	180.72	131.18	83.56	180.66	131.12	83.50	180.40	130.86	83.24
100	196.79	141.75	88.83	196.79	141.75	88.83	196.79	141.75	88.83

ETTV satisfying the requirement of BCA, 2008

Table 3 shows that for circular building the minimum WWR (WWRmin) that can satisfy the OTTV requirement is 10% with building envelope material of Alt 3, 6, 8-27, while the maximum WWR (WWRmax) is 40% with building envelope material of Alt 21, 24, 27. Through interpolation, the Authors determined that the WWRmin satisfying the OTTV requirement (35 Watt/m²) as 5.52% with building envelope material of Alt 1, while the result of WWRmax is 45.57% with building envelope material of Alt 27.

Table 4 shows that for circular building the minimum WWR that can satisfy the ETTV requirement is 10% with building envelope material of Alt 2, 5, 7, 8 while the maximum WWR is 30% with building envelope material of Alt 9. WWRmin satisfying the ETTV requirement (50 Watt/m²) is 8.66%, with building envelope material of Alt 1, while the result of WWRmax is 30.59%, with building envelope material of Alt 9.

Interpolating other OTTV and ETTV for the rest of the buildings gives WWRmin and WWRmax as presented in Table 5.

Based on Table 5, the smallest WWR value for building material Alt 1(α_1 = 0.95, U_{wI} = 3.007,U_{fH} = 3.063, SC_H = 0.88) that satisfies OTTV requirements is Trapezoid TR7s(WWR = 4.66%). With the same building material (U_{wI} = 3.007, U_{fH} = 3.063, SC_H = 0.88), this WWRvalue is smaller than the WWR value that satisfied ETTV requirements (WWR = 7.69%). This phenomena was influenced by the inclusion of the largest α value black-painted on OTTV formula.

On the other hand, the largest WWR value that satisfies OTTV requirements could be seen in parallelogram JG5 (WWR = 51.86%) that used building material Alt 27(α_3 = 0.21, U_{wIII} = 2.741, U_{fL} = 3.08, SC_L = 0.37). For the same building material (U_{wIII} = 2.741, U_{fL} = 3.08, SC_L = 0.37), WWR value (WWR=35.89%) that satisfies ETTV requirement is smaller than 51.86%.

The Authors also calculated the WWR value for building material Alt 10 (α_2 = 0.57, U_{wI} = 3.007, U_{fH} = 3.063, SC_H = 0.88). The WWR value that satisfied OTTV requirement for parallelogram JG5 is 16.33%, while the WWR value that satisfied ETTV requirement is 9.87%.

The comparison of WWR maximum that satisfied OTTV and ETTV requirement is presented in Table 6.

Table 5. WWRmin and WWRmax (%) Satisfying OTTV and ETTV Requirements

	OTTV = 35 Watt/m²		ETTV = 50 Watt/m²	
	Material (alt 1)	Material (alt 27)	Material (alt 1)	Material (alt 9)
	WWR min (%)	WWR max (%)	WWR min (%)	WWR max (%)
Circular	5.52	45.57	8.66	30.59
Octagon	5.52	45.57	8.66	30.59
Triangle				
ST1	5.83	47.50	9.31	33.40
ST2	5.88	47.79	8.73	30.88
ST3	5.38	44.64	8.13	28.36
ST4	5.85	47.59	8.73	30.88
ST5	6.13	49.28	9.27	33.22
ST6	5.38	44.64	8.60	30.32
ST7	5.39	44.72	8.01	27.88
ST8	5.16	43.25	8.66	30.59
Parallelogram				
JG1	6.34	50.55	9.92	36.13
JG2	6.27	50.10	9.44	33.98
JG3	4.91	41.62	7.70	26.58
JG4	4.92	41.64	7.98	27.73
JG5	6.57	51.86	9.87	35.89
JG6	5.98	48.41	9.51	34.29
JG7	4.79	40.78	7.73	26.71
JG8	5.11	42.90	7.93	27.52
Square				
BS1	5.60	46.06	8.72	30.85
BS2	5.44	45.12	8.60	30.32
Rectangle				
PP1	6.10	49.13	9.39	33.75
PP2	5.51	45.49	8.58	30.25
PP3	5.18	43.37	8.15	28.42
PP4	5.39	44.68	8.61	30.39
Ellipse				
E1	5.31	44.18	8.36	29.30
E2	5.49	45.35	8.67	30.61
E3	5.77	47.07	8.99	31.98
E4	5.56	45.77	8.65	30.54
Trapezoid				
TR1	6.30	50.31	9.88	35.95
TR2	5.24	43.76	8.51	29.93
TR3	5.07	42.70	7.78	26.89
TR4	5.02	42.29	8.56	30.14
TR5	6.56	51.81	9.84	35.77
TR6	5.74	46.88	8.68	30.65
TR7	4.66	39.95	7.69	26.54
TR8	5.89	47.87	8.65	30.55

Table 6. The Value of WWR_{max} that Satisfies OTTV/ETTV Requirement for Energy Efficient

Building Shape	WWR_{max}	
	OTTV (Alt 27)	ETTV (Alt 9)
Circular	45.57%	30.59%
Equilateral Octagon	45.57%	30.59%
Equilateral Triangle	49.28%	33.40%
Parallelogram	51.86%	36.13%
Square	46.06%	30.85%
Rectangle	49.13%	33.75%
Ellipse	47.07%	31.98%
Trapezoid	51.81%	35.95%

Conclusions

The requirements of ETTV for outdoor paintings with medium α (α_2) and the smallest α (α_3) are stricter than OTTV requirement. But for outdoor painting with the largest α (α_1), OTTV has stricter regulation than ETTV.

From this study, the Authors concluded that the Parallelogram shape building with building orientation JG5/JG1 is the best combination of energy saver building. This combination created the biggest WWR value that satisfies the requirement of OTTV/ETTV regulation.

This study also highlighted the need for further analysis to determine the α value needed for creating a stricter ETTV value.

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