UCSI University
Faculty of Engineering, Technology and Built Environment
School of Architecture and Built Environment

Master of Architecture

AM523 Computer Aided Modelling & Simulation

Assignment 3

OTTV & Energy Modelling

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TASK 1: OTTV EVALUATION

1.0 Introduction

The building is a commercial block designed for office use. The building is completely open on the ground floor without any air-conditioning, while the upper floors are fully enclosed and fully air-conditioned. Viewed from the north, the building can be separated into two sections, building 1 to the east and building 2 to the west, both connected by an enclosed bridge on the 4th floor.

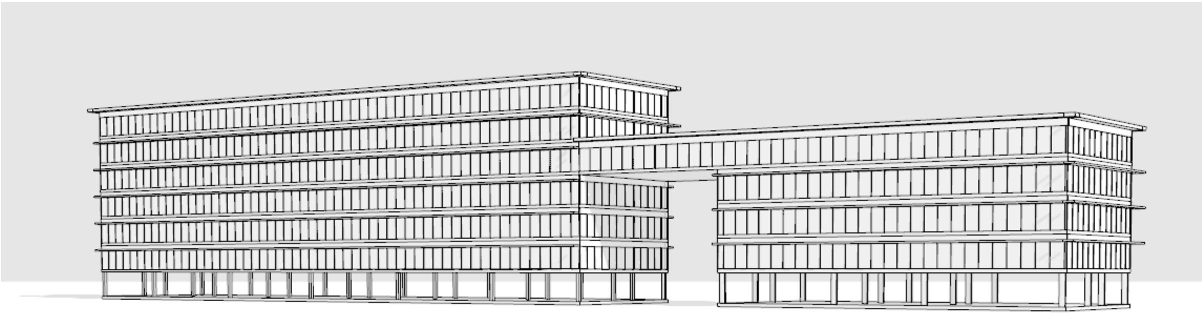


Figure 1.1.1: The perspective view of the building from the northwest

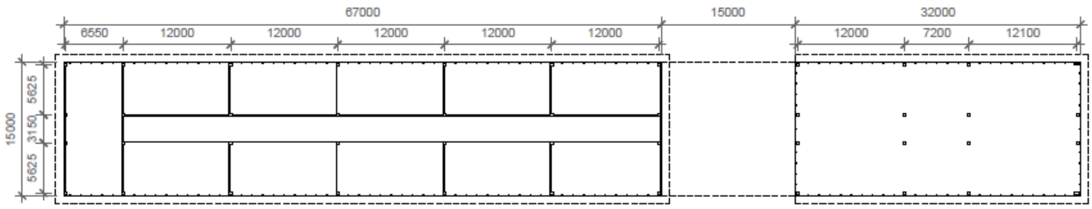


Figure 1.1.2: A typical floor plan of the air-conditioned floors

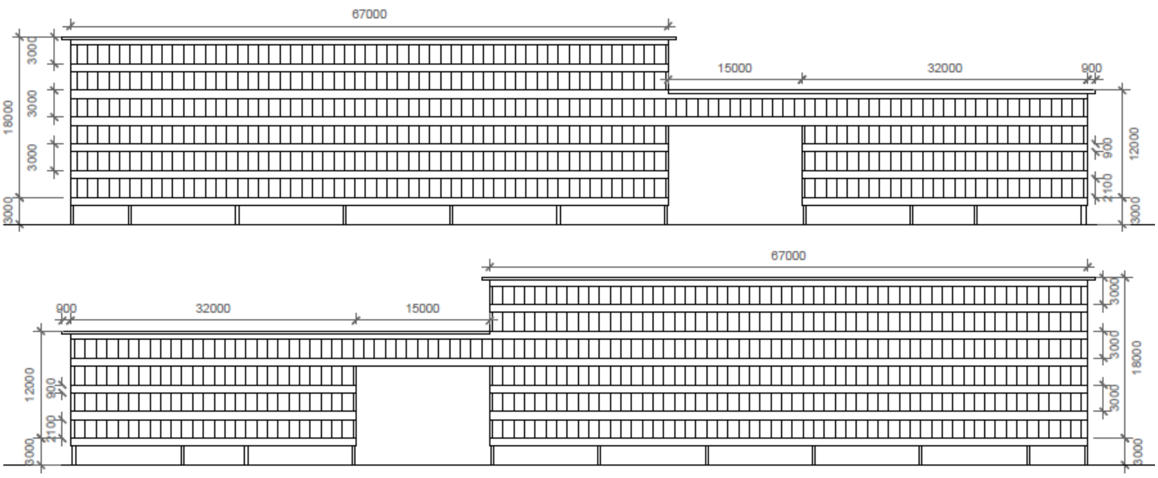


Figure 1.1.3: the North (above) and South (below) elevation

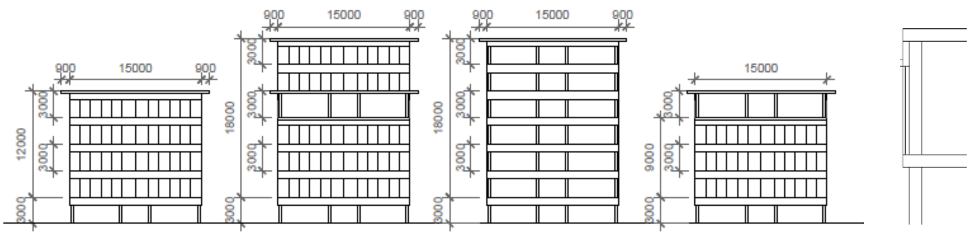


Figure 1.1.4: The West elevation (1, 2), the East elevation (3, 4) and a section of the building envelope (5)

The building and glazing parameters are shown as below:

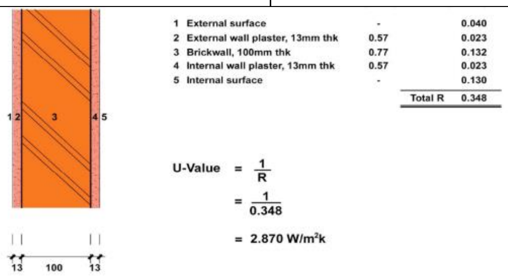
Parameters	Building 1 (excluding 4th floor)	Building 2 (excluding 4th floor)	Building 1 & 2 (4th floor only)
Length (m)	67	32	114
Width (m)	15	15	15
No. of floors	6	4	1
No. of air-conditioned floors	5	3	1
Floor-to-floor height (m)	3		
Façade area per floor (m^2)	492	282	327
Gross floor area per floor, GFA (m^2)	1005	480	1710
Building façade colour	White, alpha value, α = 0.34		
Building Orientation	North		
Roof overhang (m)	0.9		
	(at 6th floor)	-	(at 4th floor)
Wall composition	Plastered brickwall U-value = 2.87 W/m^2K *(source: Chan, 2012)*		

Table 1.1.1: Building parameters

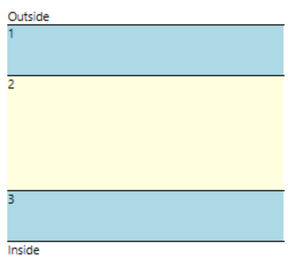
Parameters	Building 1 (excluding 4th floor)	Building 2 (excluding 4th floor)	Building 1 & 2 (4th floor only)
Glazing height (m)	2.1		
Glazing panel width (m)	1.2		
Full glazing width (m)	65.5	32	47
Glazing area per floor (m^2)	312.9	197.4	510.3
Window-to-wall ratio	0.7	0.7	0.7
Glazing composition	Azuria - Solarban 60 (3) (Argon) U-value = 1.36 W/m^2K SHGC = 0.301 Tvis = 0.468 *(source: Climate Studio)*		

Table 1.1.2: Glazing parameters

2.0 OTTV Calculations

The objective of the design options is to identify the optimal passive design strategy to be used to reduce the OTTV of the building.

According to MS1525:2019 clause 5.2, the OTTV of the building envelope for a building, having a total air-conditioned area exceeding 4000m^2 and above should not exceed 50 W/m^2. (Department of Standard Malaysia, 2019)

The equation for OTTV calculation is given by MS1525 as:

$$OTTV = [15 \times \alpha \times (1-WWR) \times U_x] + (6 \times WWR \times U_f) + (194 \times CF \times WWR \times SC)$$

Heat conduction through walls (0.2% - 5%)	Heat conduction through windows (10% - 20%)	Solar heat gain through windows (70% - 85%)

According to Tham (2016), based on the equation for OTTV, the main contributing factors to reducing OTTV is the shading coefficient, through the shading coefficient of glazing and shading coefficient of external shading devices. Tham laid out the ways to improve the OTTV of a building:

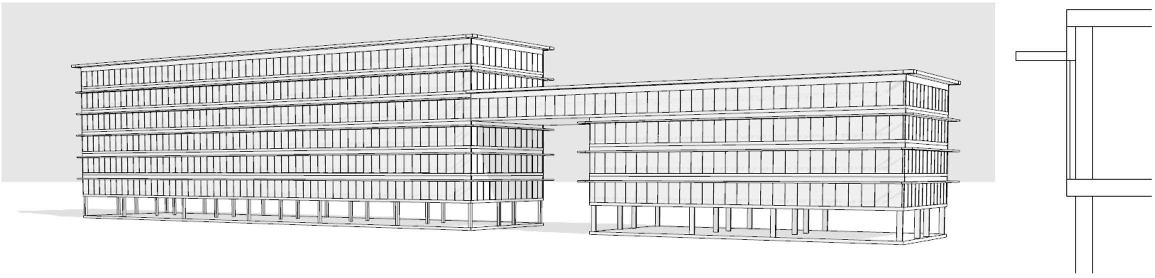
1. Review the solar correction factor (CF)
2. Review the glass selection and its shading coefficient (SC1)
3. Review the sunshades and the shading coefficient of external shading devices (SC2)
4. Review the WWR

The following design options and simulations test the reduction of OTTV following the ways laid out by Tham. To test the passive design strategies, the material selection is fixed, only changing the passive design of the building. To get the baseline OTTV below 50 W/m^2, a low-e glass with lower SHGC and U-value is selected.

The passive design strategies tested relates to item 3 and 4 by Tham and are listed below:

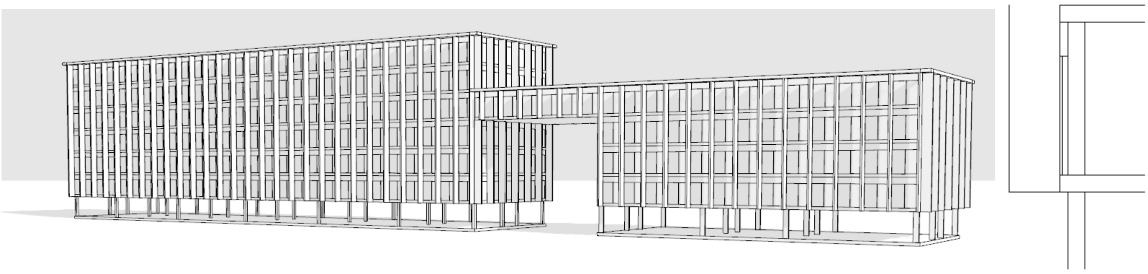
Design Option 1 – 900mm horizontal shading

A 900 x 150 mm concrete horizontal shading is employed all around the building, sitting above the glazing.



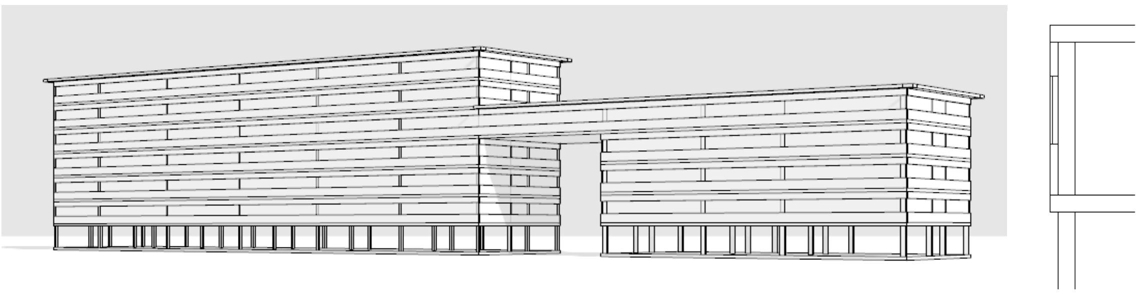
Design Option 2 – 900mm vertical shading

A 900 x 100 mm concrete vertical shading is employed at all the facades of the building. The shading devices are placed at 2.4m centre-to-centre.



Design Option 3 – Reduce WWR by 43%

The height of the glazing is reduced from 2.1m to 1.2m, adding in a 0.9m high brick wall below the glazing. The window-to-wall ratio is reduced from 0.7 to 0.4, resulting in a reduction of 43%.



The OTTV calculation is done based on the guidelines from MS1525. The building is separated into several sections for the calculation.

Zone	Building	Floors
1 (red)	1	1 – 3
2 (yellow)	1	5 – 6
3 (green)	2	1 – 3
4 (blue)	1 & 2	4

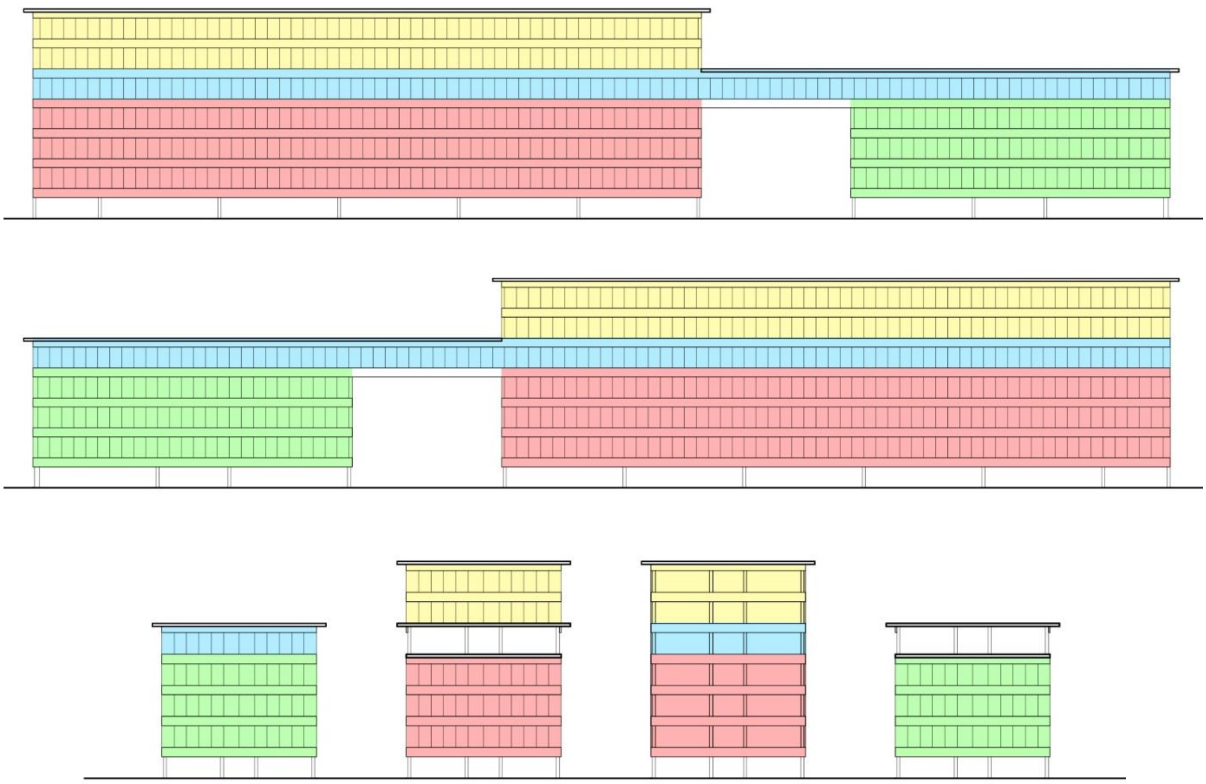


Figure 1.2.1: Diagram of the different zones for OTTV calculation

For zones with multiple floors, the OTTV calculation is calculated per floor, before being included in the final OTTV calculation.

The OTTV calculation for the baseline and each design option is shown in the following pages.

The comparison between each design option against the baseline is shown and discussed in the following section.

OTTV CALCULATION (BASELINE MODEL)

OTTV = [15 x α x (1-WWR) U] + [6 x WWR x U] + [194 x CF x WWR x SC]

	Building 1 (1st - 3rd floor)	Building 1 (5th - 6th floor)	Building 2 (1st - 3rd floor)	Building 1 & 2 (4th floor)
Total AC Floor Area *(m2)*	3015	2010	1440	1710
Floor Area per floor *(m2)*	1005	1005	480	1710
Total No of Floors, T	3	2	3	1
Floor to Floor Heigh *(m)*	3	3	3	3
Building Local North Orientation	North	North	North	North

Building 1 (1st - 3rd floor)

	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	201	45	201	45	492
	Glazing Length *(m)*	67	0	67	15	
	Glazing Height *(m)*	2.1	0	2.1	2.1	
	Glazing Area *(m2)*	140.7	0	140.7	31.5	312.9
	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	15	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	7.1	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	0.61	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.2110	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	42.2853	0.0000	43.2250	26.9404	112.4507

Building 1 (5th - 6th floor)

	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	201	45	201	45	492
	Glazing Length *(m)*	67	0	67	15	
	Glazing Height *(m)*	2.1	0	2.1	2.1	
	Glazing Area *(m2)*	140.7	0	140.7	31.5	312.9
	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	0	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	1	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.3460	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	42.2853	0.0000	43.2250	44.1647	129.6750

Building 2 (1st - 3rd floor)

	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	32	15	32	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	96	45	96	45	282
	Glazing Length *(m)*	32	15	32	15	
	Glazing Height *(m)*	2.1	2.1	2.1	2.1	
	Glazing Area *(m2)*	67.2	31.5	67.2	31.5	197.4
	Window-to-Wall Ratio (WWR)	0.7	0.7	0.7	0.7	
	(1-WWR)	0.3	0.3	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	4.3911	4.3911	4.3911	4.3911	17.5644
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	5.7120	5.7120	5.7120	5.7120	22.8480
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	15	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	1.67	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	0.61	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.2110	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	42.2853	57.7899	43.2250	26.9404	170.2407

Building 1 & 2 (4th floor)

	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	114	15	114	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	342	45	342	45	774
	Glazing Length *(m)*	114	0	114	15	
	Glazing Height *(m)*	2.1	0	2.1	2.1	
	Glazing Area *(m2)*	239.4	0	239.4	31.5	510.3
	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	0	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	1	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.3460	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	42.2853	0.0000	43.2250	44.1647	129.6750

	North	East	South	West	Total
Building 1 (1st - 3rd floor)					
OTTV FOR EACH ELEVATION (per floor)	52.3884	14.6370	53.3281	37.0435	
AREA X OTTV (per floor)	10530.0705	658.6650	10718.9449	1666.9593	23574.6397
AREA X OTTV (for total no of floors, T)	31590.2114	1975.9950	32156.8346	5000.8780	70723.9191
Building 1 (5th - 6th floor)					
OTTV FOR EACH ELEVATION (per floor)	52.3884	14.6370	53.3281	54.2678	
AREA X OTTV (per floor)	10530.0705	658.6650	10718.9449	2442.0491	24349.7294
AREA X OTTV (for total no of floors, T)	21060.1410	1317.3300	21437.8897	4884.0982	48699.4589
Building 2 (1st - 3rd floor)					
OTTV FOR EACH ELEVATION (per floor)	52.3884	67.8930	53.3281	37.0435	
AREA X OTTV (per floor)	5029.2874	3055.1861	5119.4961	1666.9593	14870.9289
AREA X OTTV (for total no of floors, T)	15087.8622	9165.5583	15358.4882	5000.8780	44612.7866
Building 1 & 2 (4th floor)					
OTTV FOR EACH ELEVATION (per floor)	52.3884	14.6370	53.3281	54.2678	
AREA X OTTV (per floor)	17916.8363	658.6650	18238.2047	2442.0491	39255.7551
AREA X OTTV (for total no of floors, T)	17916.8363	658.6650	18238.2047	2442.0491	39255.7551

TOTAL OTTV FOR EACH ELEVATION *(W/M2)*	
North Elevation	52.3884
East Elevation	32.3890
South Elevation	53.3281
West Elevation	42.7849

Total Façade Area *(m2)*	4080
Total Area x OTTV	203291.9197
OVERALL THERMAL TRANSFER VALUE FOR THE WHOLE BUILDING *(W/M2)*	**49.8265**

OTTV CALCULATION (OPTION 1 - 900MM HORIZONTAL SHADING)

OTTV = [15 x α x (1-WWR) U] + [6 x WWR x U] + [194 x CF x WWR x SC]

	Building 1 (1st - 3rd floor)	Building 1 (5th - 6th floor)	Building 2 (1st - 3rd floor)	Building 1 & 2 (4th floor)
Total AC Floor Area *(m2)*	3015	2010	1440	1710
Floor Area per floor *(m2)*	1005	1005	480	1710
Total No of Floors, T	3	2	3	1
Floor to Floor Heigh *(m)*	3	3	3	3
Building Local North Orientation	North	North	North	North

Building 1 (1st - 3rd floor)

Section	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	201	45	201	45	492
FAÇADE	Glazing Length *(m)*	67	0	67	15	
FAÇADE	Glazing Height *(m)*	2.1	0	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	140.7	0	140.7	31.5	312.9
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
FAÇADE	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0.9	0	0.9	15	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0.33	0	0.33	7.1	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.77	1	0.77	0.61	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2664	0.3460	0.2664	0.2110	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	32.5597	0.0000	33.2832	26.9404	92.7834
	OTTV FOR EACH ELEVATION (per floor)	42.6628	14.6370	43.3863	37.0435	
	AREA X OTTV (per floor)	8575.2206	658.6650	8720.6539	1666.9593	19621.4988
	AREA X OTTV (for total no of floors, T)	25725.6617	1975.9950	26161.9616	5000.8780	58864.4964

Building 1 (5th - 6th floor)

Section	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	201	45	201	45	492
FAÇADE	Glazing Length *(m)*	67	0	67	15	
FAÇADE	Glazing Height *(m)*	2.1	0	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	140.7	0	140.7	31.5	312.9
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
FAÇADE	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0.9	0	0.9	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0.33	0	0.33	0.33	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.77	1	0.77	0.79	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2664	0.3460	0.2664	0.2733	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	32.5597	0.0000	33.2832	34.8901	100.7330
	OTTV FOR EACH ELEVATION (per floor)	42.6628	14.6370	43.3863	44.9932	
	AREA X OTTV (per floor)	8575.2206	658.6650	8720.6539	2024.6931	19979.2325
	AREA X OTTV (for total no of floors, T)	17150.4412	1317.3300	17441.3077	4049.3861	39958.4650

Building 2 (1st - 3rd floor)

Section	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	32	15	32	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	96	45	96	45	282
FAÇADE	Glazing Length *(m)*	32	15	32	15	
FAÇADE	Glazing Height *(m)*	2.1	2.1	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	67.2	31.5	67.2	31.5	197.4
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0.7	0.7	0.7	
FAÇADE	(1-WWR)	0.3	0.3	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	4.3911	4.3911	4.3911	17.5644
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	5.7120	5.7120	5.7120	22.8480
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0.9	0.9	0.9	15	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0.33	0.33	0.33	1.67	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.77	0.77	0.77	0.61	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2664	0.2664	0.2664	0.2110	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	32.5597	44.4982	33.2832	26.9404	137.2816
	OTTV FOR EACH ELEVATION (per floor)	42.6628	54.6013	43.3863	37.0435	
	AREA X OTTV (per floor)	4095.6277	2457.0604	4165.0884	1666.9593	12384.7359
	AREA X OTTV (for total no of floors, T)	12286.8832	7371.1811	12495.2652	5000.8780	37154.2076

Building 1 & 2 (4th floor)

Section	Façade Orientation (per floor)	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	114	15	114	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	342	45	342	45	774
FAÇADE	Glazing Length *(m)*	114	0	114	15	
FAÇADE	Glazing Height *(m)*	2.1	0	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	239.4	0	239.4	31.5	510.3
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
FAÇADE	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0.9	0	0.9	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0.33	0	0.33	0.33	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.77	1	0.77	0.79	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2664	0.3460	0.2664	0.2733	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	32.5597	0.0000	33.2832	34.8901	100.7330
	OTTV FOR EACH ELEVATION (per floor)	42.6628	14.6370	43.3863	44.9932	
	AREA X OTTV (per floor)	14590.6738	658.6650	14838.1275	2024.6931	32112.1594
	AREA X OTTV (for total no of floors, T)	14590.6738	658.6650	14838.1275	2024.6931	32112.1594

TOTAL OTTV FOR EACH ELEVATION *(W/M2)*	
North Elevation	42.6628
East Elevation	27.9584
South Elevation	43.3863
West Elevation	39.6934

Total Façade Area *(m2)*	4080
Total Area x OTTV	168089.3284
OVERALL THERMAL TRANSFER VALUE FOR THE WHOLE BUILDING *(W/M2)*	**41.1984**

OTTV CALCULATION (OPTION 2 - 900mm VERTICAL SHADING)

OTTV = [15 x α x (1-WWR) U] + [6 x WWR x U] + [194 x CF x WWR x SC]

	Building 1 (1st - 3rd floor)	Building 1 (5th - 6th floor)	Building 2 (1st - 3rd floor)	Building 1 & 2 (4th floor)
Total AC Floor Area *(m2)*	3015	2010	1440	1710
Floor Area per floor *(m2)*	1005	1005	480	1710
Total No of Floors, T	3	2	3	1
Floor to Floor Heigh *(m)*	3	3	3	3
Building Local North Orientation	North	North	North	North

Building 1 (1st - 3rd floor)

Section	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	201	45	201	45	492
FAÇADE	Glazing Length *(m)*	67	0	67	15	
FAÇADE	Glazing Height *(m)*	2.1	0	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	140.7	0	140.7	31.5	312.9
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
FAÇADE	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0	0	0	15	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	1.67	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0.9	0	0.9	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0.375	0	0.375	0.375	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.82	1	0.82	0.38	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2837	0.3460	0.2837	0.1315	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	34.6740	0.0000	35.4445	16.7826	86.9010
	OTTV FOR EACH ELEVATION	44.7771	14.6370	45.5476	26.8857	
	AREA X OTTV	9000.1880	658.6650	9155.0649	1209.8551	20023.7730
	AREA X OTTV (for total no of floors, T)	27000.5639	1975.9950	27465.1948	3629.5654	60071.3191

Building 1 (5th - 6th floor)

Section	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	201	45	201	45	492
FAÇADE	Glazing Length *(m)*	67	0	67	15	
FAÇADE	Glazing Height *(m)*	2.1	0	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	140.7	0	140.7	31.5	312.9
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
FAÇADE	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0.9	0	0.9	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0.375	0	0.375	0.375	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.82	1	0.82	0.86	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2837	0.3460	0.2837	0.2975	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	34.6740	0.0000	35.4445	37.9816	108.1000
	OTTV FOR EACH ELEVATION	44.7771	14.6370	45.5476	48.0847	
	AREA X OTTV	9000.1880	658.6650	9155.0649	2163.8117	20977.7296
	AREA X OTTV (for total no of floors, T)	18000.3759	1317.3300	18310.1299	4327.6235	41955.4593

Building 2 (1st - 3rd floor)

Section	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	32	15	32	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	96	45	96	45	282
FAÇADE	Glazing Length *(m)*	32	15	32	15	
FAÇADE	Glazing Height *(m)*	2.1	2.1	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	67.2	31.5	67.2	31.5	197.4
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0.7	0.7	0.7	
FAÇADE	(1-WWR)	0.3	0.3	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	4.3911	4.3911	4.3911	17.5644
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	5.7120	5.7120	5.7120	22.8480
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0	0	0	15	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	1.67	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0.9	0.9	0.9	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0.375	0.375	0.375	0.375	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.82	0.87	0.82	0.38	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2837	0.3010	0.2837	0.1315	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	34.6740	50.2772	35.4445	16.7826	137.1782
	OTTV FOR EACH ELEVATION	44.7771	60.3803	45.5476	26.8857	
	AREA X OTTV	4298.5972	2717.1150	4372.5683	1209.8551	12598.1357
	AREA X OTTV (for total no of floors, T)	12895.7917	8151.3451	13117.7050	3629.5654	37794.4072

Building 1 & 2 (4th floor)

Section	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	114	15	114	15	
FAÇADE	Façade Height *(m)*	3	3	3	3	
FAÇADE	Façade Area *(m2)*	342	45	342	45	774
FAÇADE	Glazing Length *(m)*	114	0	114	15	
FAÇADE	Glazing Height *(m)*	2.1	0	2.1	2.1	
FAÇADE	Glazing Area *(m2)*	239.4	0	239.4	31.5	510.3
FAÇADE	Window-to-Wall Ratio (WWR)	0.7	0	0.7	0.7	
FAÇADE	(1-WWR)	0.3	1	0.3	0.3	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
HEAT CONDUCTION – WALL	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
HEAT CONDUCTION – WALL	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
HEAT CONDUCTION – WALL	**HEAT CONDUCTION THROUGH WALL** ***15 x α x (1-WWR) U***	4.3911	14.6370	4.3911	4.3911	27.8103
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
HEAT CONDUCTION – WINDOW	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
HEAT CONDUCTION – WINDOW	**HEAT CONDUCTION THROUGH WINDOW** ***6 x WWR x U***	5.7120	0.0000	5.7120	5.7120	17.1360
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
SOLAR HEAT GAIN THROUGH WINDOWS	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
SOLAR HEAT GAIN THROUGH WINDOWS	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
SOLAR HEAT GAIN THROUGH WINDOWS	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
SOLAR HEAT GAIN THROUGH WINDOWS	Horizontal Projection width *(m)*	0	0	0	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0.33	
SOLAR HEAT GAIN THROUGH WINDOWS	Vertical Projection width (m)	0.9	0	0.9	0.9	
SOLAR HEAT GAIN THROUGH WINDOWS	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0.375	0	0.375	0.375	
SOLAR HEAT GAIN THROUGH WINDOWS	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	0.82	1	0.82	0.77	
SOLAR HEAT GAIN THROUGH WINDOWS	Shading Coefficient *(SC1 x SC2)*	0.2837	0.3460	0.2837	0.2664	
SOLAR HEAT GAIN THROUGH WINDOWS	**SOLAR HEAT GAIN THROUGH WINDOW** ***194 x CF x WWR x SC***	34.6740	0.0000	35.4445	34.0068	104.1252
	OTTV FOR EACH ELEVATION	44.7771	14.6370	45.5476	44.1099	
	AREA X OTTV	15313.7526	658.6650	15577.2747	1984.9449	33534.6372
	AREA X OTTV (for total no of floors, T)	15313.7526	658.6650	15577.2747	1984.9449	33534.6372

TOTAL OTTV FOR EACH ELEVATION *(W/M2)*	
North Elevation	44.7771
East Elevation	29.8848
South Elevation	45.5476
West Elevation	33.5104

Total Façade Area *(m2)*	4080
Total Area x OTTV	173355.8228
OVERALL THERMAL TRANSFER VALUE FOR THE WHOLE BUILDING *(W/M2)*	**42.4892**

OTTV CALCULATION (OPTION 3 - REDUCED WWR 43%)

OTTV = [15 x α x (1-WWR) U] + [6 x WWR x U] + [194 x CF x WWR x SC]

	Building 1 (1st - 3rd floor)	Building 1 (5th - 6th floor)	Building 2 (1st - 3rd floor)	Building 1 & 2 (4th floor)
Total AC Floor Area *(m2)*	3015	2010	1440	1710
Floor Area per floor *(m2)*	1005	1005	480	1710
Total No of Floors	3	2	3	1
Floor to Floor Heigh *(m)*	3	3	3	3
Building Local North Orientation	North	North	North	North

Building 1 (1st - 3rd floor)

	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	201	45	201	45	492
	Glazing Length *(m)*	67	0	67	15	
	Glazing Height *(m)*	1.2	0	1.2	1.2	
	Glazing Area *(m2)*	80.4	0	80.4	18	178.8
	Window-to-Wall Ratio (WWR)	0.4	0	0.4	0.4	
	(1-WWR)	0.6	1	0.6	0.6	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	8.7822	14.6370	8.7822	8.7822	40.9836
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	3.2640	0.0000	3.2640	3.2640	9.7920
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	15	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	1.85	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	0.61	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.2110	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	24.1630	0.0000	24.7000	15.3945	64.2576
	OTTV FOR EACH ELEVATION	36.2092	14.6370	36.7462	27.4407	
	AREA X OTTV	7278.0561	658.6650	7385.9844	1234.8332	16557.5387
	AREA X OTTV (for total no of floors, T)	21834.1684	1975.9950	22157.9531	3704.4996	49672.6160

Building 1 (5th - 6th floor)

	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	67	15	67	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	201	45	201	45	492
	Glazing Length *(m)*	67	0	67	15	
	Glazing Height *(m)*	1.2	0	1.2	1.2	
	Glazing Area *(m2)*	80.4	0	80.4	18	178.8
	Window-to-Wall Ratio (WWR)	0.4	0	0.4	0.4	
	(1-WWR)	0.6	1	0.6	0.6	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	8.7822	14.637	8.7822	8.7822	40.9836
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	3.2640	0.0000	3.2640	3.2640	9.7920
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	0	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	1	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.3460	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	24.1630	0.0000	24.7000	25.2369	74.1000
	OTTV FOR EACH ELEVATION	36.2092	14.6370	36.7462	37.2831	
	AREA X OTTV	7278.0561	658.6650	7385.9844	1677.7416	17000.4471
	AREA X OTTV (for total no of floors, T)	14556.1123	1317.3300	14771.9687	3355.4832	34000.8942

Building 2 (1st - 3rd floor)

	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	32	15	32	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	96	45	96	45	282
	Glazing Length *(m)*	32	15	32	15	
	Glazing Height *(m)*	1.2	1.2	1.2	1.2	
	Glazing Area *(m2)*	38.4	18	38.4	18	112.8
	Window-to-Wall Ratio (WWR)	0.4	0.4	0.4	0.4	
	(1-WWR)	0.6	0.6	0.6	0.6	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	8.7822	8.7822	8.7822	8.7822	35.1288
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	3.2640	3.2640	3.2640	3.2640	13.0560
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	15	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	1.85	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	0.61	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.2110	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	24.1630	33.0228	24.7000	15.3945	97.2804
	OTTV FOR EACH ELEVATION	36.2092	45.0690	36.7462	27.4407	
	AREA X OTTV	3476.0865	2028.1056	3527.6343	1234.8332	10266.6596
	AREA X OTTV (for total no of floors, T)	10428.2595	6084.3169	10582.9030	3704.4996	30799.9789

Building 1 & 2 (4th floor)

	Façade Orientation	North	East	South	West	Subtotal
FAÇADE	Façade Width *(m)*	114	15	114	15	
	Façade Height *(m)*	3	3	3	3	
	Façade Area *(m2)*	342	45	342	45	774
	Glazing Length *(m)*	114	0	114	15	
	Glazing Height *(m)*	1.2	0	1.2	1.2	
	Glazing Area *(m2)*	136.8	0	136.8	18	291.6
	Window-to-Wall Ratio (WWR)	0.4	0	0.4	0.4	
	(1-WWR)	0.6	1	0.6	0.6	
HEAT CONDUCTION – WALL	Wall Constant	15	15	15	15	
	Alpha, α (Wall colour)	0.34	0.34	0.34	0.34	
	Wall U-Value *(W/m2K)*	2.87	2.87	2.87	2.87	
	HEAT CONDUCTION THROUGH WALL ***15 x α x (1-WWR) U***	8.7822	14.637	8.7822	8.7822	40.9836
HEAT CONDUCTION – WINDOW	Glazing Constant	6	6	6	6	
	Glazing U-Value *(W/m2K)*	1.36	1.36	1.36	1.36	
	HEAT CONDUCTION THROUGH WINDOW ***6 x WWR x U***	3.2640	0.0000	3.2640	3.2640	9.7920
SOLAR HEAT GAIN THROUGH WINDOWS	Glazing Heat Gain Constant	194	194	194	194	
	Correction Factor (CF) *(based on MS1525 5.2.2 table 4)*	0.9	1.23	0.92	0.94	
	Solar Heat Gain Coefficient (SHGC)	0.301	0.301	0.301	0.301	
	SC1 *(solar heat gain coefficient/0.87)*	0.3460	0.3460	0.3460	0.3460	
	Horizontal Projection width *(m)*	0	0	0	0.9	
	Projection Ratio 1 (R1) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0.5	
	Vertical Projection width (m)	0	0	0	0	
	Projection Ratio 2 (R2) *(shading/glazing, if < 0.3 not considered)*	0	0	0	0	
	SC2 (R1 x R2) *(based on MS1525 5.3.3 table 5, 6 & 7)*	1	1	1	0.71	
	Shading Coefficient *(SC1 x SC2)*	0.3460	0.3460	0.3460	0.2456	
	SOLAR HEAT GAIN THROUGH WINDOW ***194 x CF x WWR x SC***	24.1630	0.0000	24.7000	17.9182	66.7813
	OTTV FOR EACH ELEVATION	36.2092	14.6370	36.7462	29.9644	
	AREA X OTTV	12383.5582	658.6650	12567.1973	1348.3995	26957.8199
	AREA X OTTV (for total no of floors, T)	12383.5582	658.6650	12567.1973	1348.3995	26957.8199

TOTAL OTTV FOR EACH ELEVATION *(W/M2)*	
North Elevation	36.2092
East Elevation	24.7810
South Elevation	36.7462
West Elevation	29.9084

Total Façade Area *(m2)*	4080
Total Area x OTTV	141431.3091
OVERALL THERMAL TRANSFER VALUE FOR THE WHOLE BUILDING *(W/M2)*	**34.6645**

3.0 Discussion and Conclusion

The comparison between the baseline model and design options are shown in the table below:

		Baseline	<u>Design Option 1</u> – 900mm horizontal shading	<u>Design Option 2</u> – 900mm vertical shading	<u>Design Option 3</u> – reduce WWR 43%
OTTV for each elevation (W/m^2)	North	52.3884	42.6628 *(18.56%)*	44.7771 *(14.53%)*	36.2092 *(30.88%)*
	East	32.3890	27.9584 *(13.68%)*	29.8848 *(7.73%)*	24.7810 *(23.49%)*
	South	53.3281	43.3863 *(18.64%)*	45.5476 *(14.59%)*	36.7462 *(31.09%)*
	West	42.7849	39.6934 *(7.23%)*	33.5104 *(21.68%)*	29.9084 *(30.10%)*
Total OTTV (W/m^2)		**49.8265**	**41.1984** ***(17.32%)***	**42.4892** ***(14.73%)***	**34.6645** ***(30.43%)***

Table 1.3.1: Comparison of the OTTV between different design options against the baseline. The percentage indicates the percentage difference from the baseline

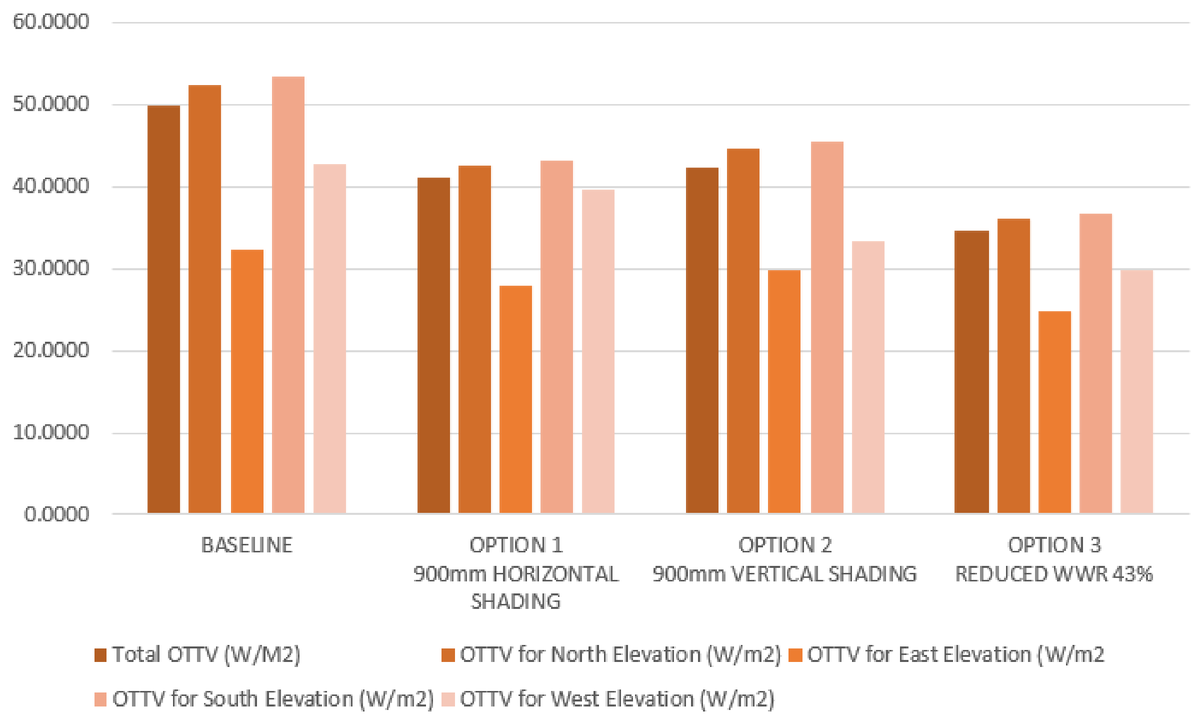


Figure 1.3.1: Bar chart showing the comparison between the OTTV of each design option against the baseline

From the comparison, the horizontal shading reduced the OTTV of the building more than the vertical shading. The vertical shading uses more material (1605 metre length) compared to the horizontal shading (1291.6 metre length), yet it provides less shading to the building envelope. However, the design that had the most impact on reducing the OTTV was reducing the WWR, which is reducing the among of glazing, and hence reducing the amount of solar heat gain through the windows. Reducing the WWR by 43% has reduced the OTTV by 30.43% compared to the baseline.

Even though the total OTTV value for the baseline model is less than 50 W/m^2, the North and South elevations are above 50 W/m^2. This is due to the high amount of glazing on both facades.

Looking at the graph, one outlier is the OTTV for the east elevation. It is generally understood that the east elevation is significantly higher than the west elevation due to the clear sky in the morning (east) and cloudy skies in the afternoon (west). For this simulation, the OTTV for the east elevation is much lower compared to the other elevations because the design already takes into consideration to reduce the heat gain on the east elevation by not providing any glazing or openings. This eliminates the heat conduction and solar heat gain through windows.

Another outlier in the data is the that the horizontal shading has less impact on the west elevation compared to the vertical shading. This is because sunlight hits the west elevation at an angle, which causes the vertical shading to provide more shading compared to the horizontal shading.

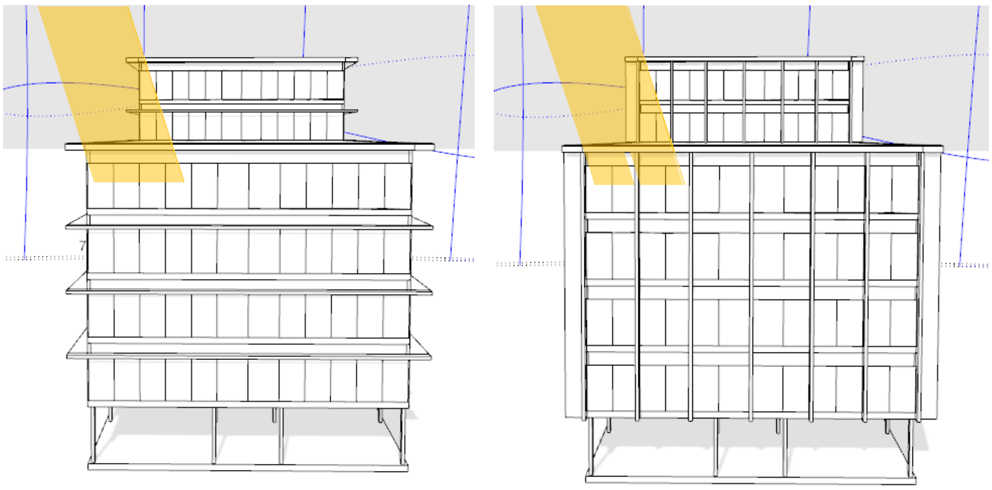


Figure 1.3.2: The sun path hitting the west elevation on September 21st, 6.00pm

In conclusion, the best way to reduce OTTV of the building is to reduce the amount of glazing used on the façade. Between horizontal and vertical shading, horizontal shadings are more effective overall, however, each façade might be different, and each façade could employ different designs to effectively reduce the OTTV of the building.

TASK 2: ENERGY MODELLING

1.0 Introduction

The purpose of the energy modelling is to understand the energy use within the building. The energy use is measured in energy use intensity (EUI). It measures the total energy consumed per year per square meter, and expressed as energy per square foot per year. The goal is to get the EUI as low as possible as to reduce the amount of energy use, thereby reducing the operation costs as well as reducing the non-renewable energy used to power the building. The shape of the building massing and the building orientation would affect the EUI as it affects the amount of solar energy entering the building and hence increasing the cooling load or decreasing the heating load. The mechanical and electrical systems as well as the type of glazing used would also impact the EUI.

In Malaysia, energy use is measured as Building Energy Index (BEI). According to MS1525:2019, BEI is defined as "the ratio between annual energy consumption of a building (kWh/year) and nett floor area of the building." (Department of Standard Malaysia, 2019) Based on the standard, the recommended BEI for new buildings is 200 kWh/m^2/year. However, according to energy audit results by the Pusat Tenaga Malaysia, it shows that most of the office buildings in Malaysia has the BEI between 200 to 250 kWh/m^2/year. (Chan, 2009) According to the study by the Malaysia Energy Commission, 58% of the energy is used for cooling, 20% for lighting, 19% for office equipment and 3% for others. (Suruhanjaya Tenaga, 2014)

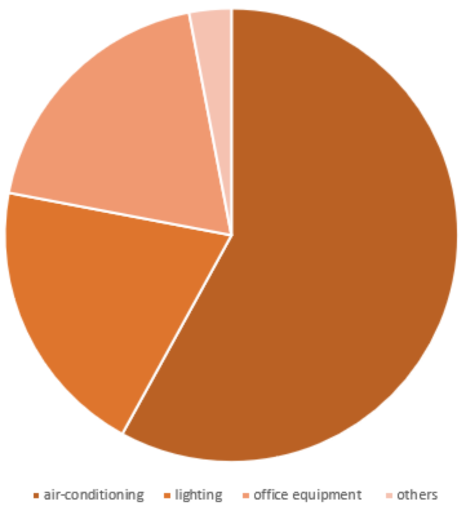
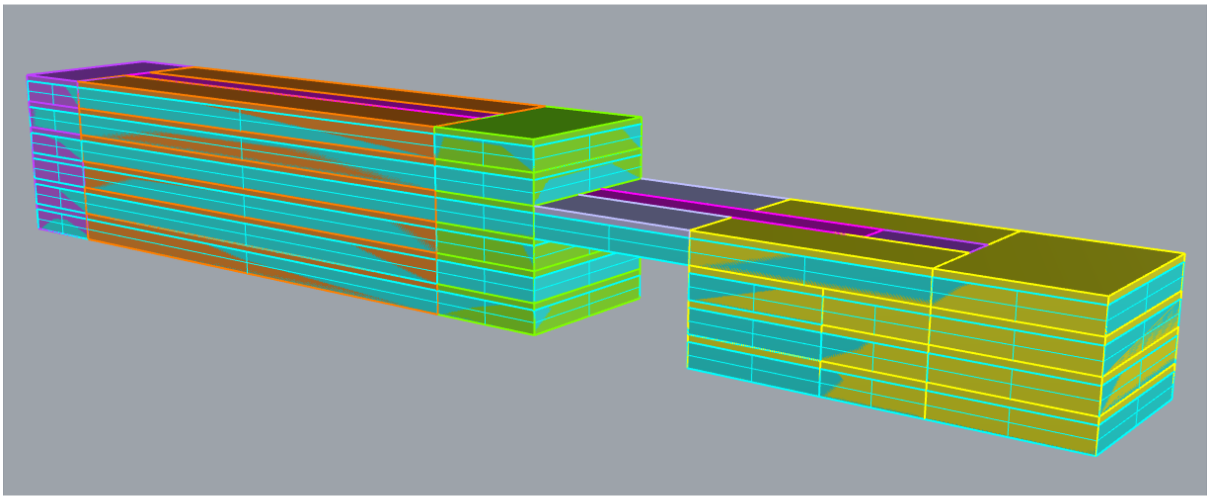


Figure 2.1.1: Energy use within the building in Malaysia (source: Suruhanjaya Tenaga, 2014)

2.0 Energy Simulation (EUI)

The objective of the design options in the energy modelling is to investigate the impact of the passive design systems on energy use within the building without any changes to the equipment, material and usage of the building.

For the energy modelling, a thermal model of the building is created in Rhino. The type of zone selected for the simulation are shown below:



Zone Colour	Zone
Orange	Closed Office CZ 0
Yellow	Medium Office - Open Office CZ 0
Green	Medium Office – Conference CZ 0
Lilac	Medium Office – Lobby CZ 0
Pink	Medium Office – Corridor CZ 0
Dark Purple	Office – Elevator Lobby CZ 0

Table 2.2.1: Classification of zones within the building

The following parameters are taken from the preset settings in Climate Studio.

Parameters	Data
People Density (P/m^2)	0.06
Metabolic Rate (met)	1.2
Equipment Power Density (W/m^2)	10.33
Lighting Power Density (W/m^2)	6.57

Table 2.2.2: Parameters for the energy use calculation

In the model, the ground is not considered as the air-conditioned spaces are above an open-air ground floor. Hence the ground is not considered an adiabatic surface in the thermal analysis.

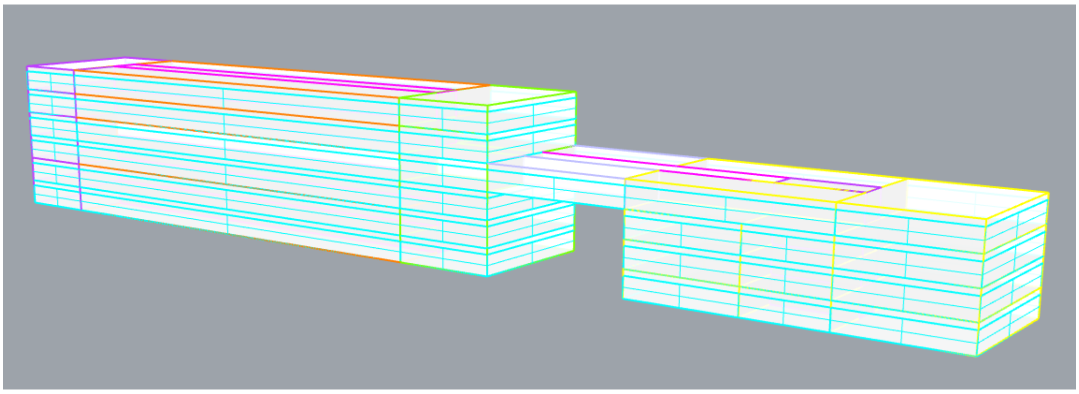


Figure 2.2.1: Baseline model

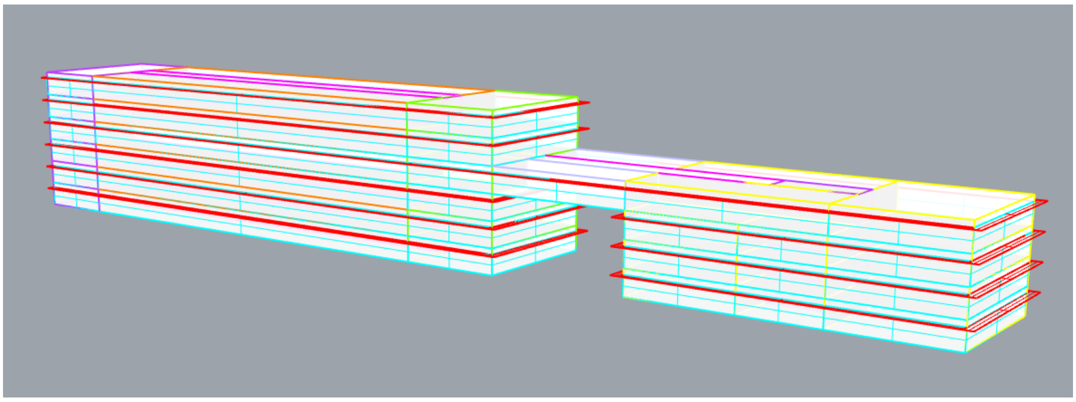


Figure 2.2.2: Design Option 1 – 900mm Horizontal Shading

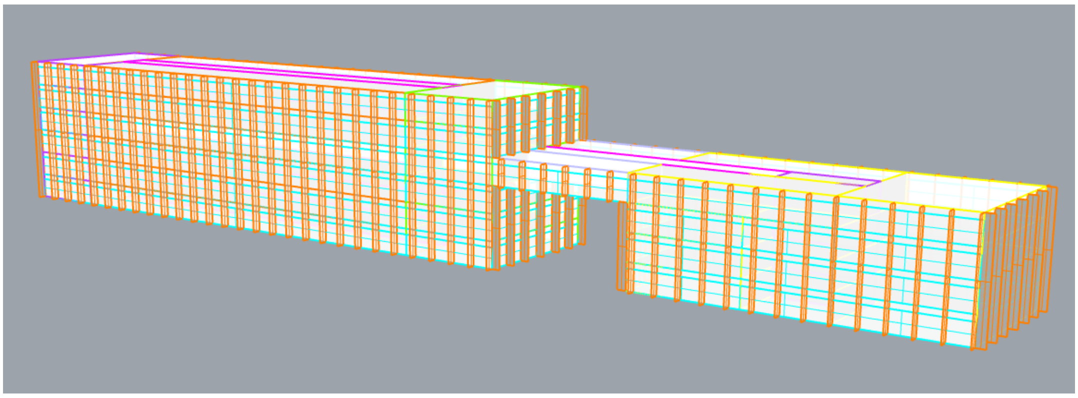


Figure 2.2.3: Design Option 2 – 900mm Vertical Shading

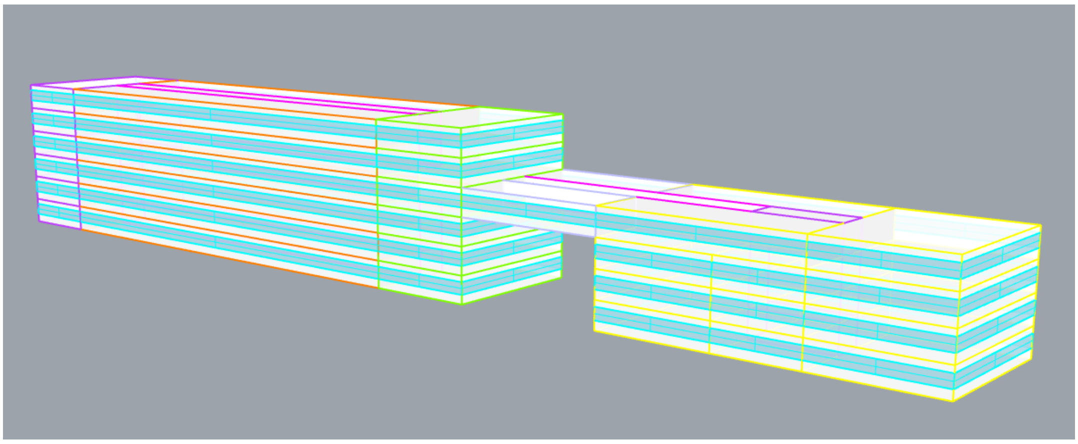


Figure 2.2.4: Design Option 3 – Reduce WWR 43%

3.0 Discussion and Conclusion

The results of the Energy Use Intensity are shown below:

	Baseline	Design Option 1 – 900mm horizontal shading	Design Option 2 – 900mm vertical shading	Design Option 3 – reduce WWR 43%
Total EUI ($kWh/m^2/year$)	**114.80**	**109.57** *(4.56%)*	**110.72** *(3.55%)*	**108.39** *(5.58%)*
Cooling Energy Load (kWh/m^2) *(indicates % diff from baseline)* *[indicates % in EUI]*	63.99 *[55.74%]*	58.77 *(8.16%)* *[53.64%]*	59.92 *(6.36%)* *[54.12%]*	57.58 *(10.02%)* *[53.12%]*
Lighting Energy Load (kWh/m^2) *[indicates % in EUI]*	23 *[20.03%]*	23 *[20.99%]*	23 *[20.77%]*	23 *[21.22%]*
Equipment Energy Load (kWh/m^2) *[indicates % in EUI]*	28 *[24.39%]*	28 *[25.55%]*	28 *[25.29%]*	28 *[25.83%]*
Operational Carbon ($kgCO^2/m^2/year$) *(indicates % diff from baseline)*	71.74	68.48 *(4.54%)*	69.20 *(3.54%)*	67.74 *(5.58%)*

Table 2.3.1: Comparison of the total EUI for all the different design options

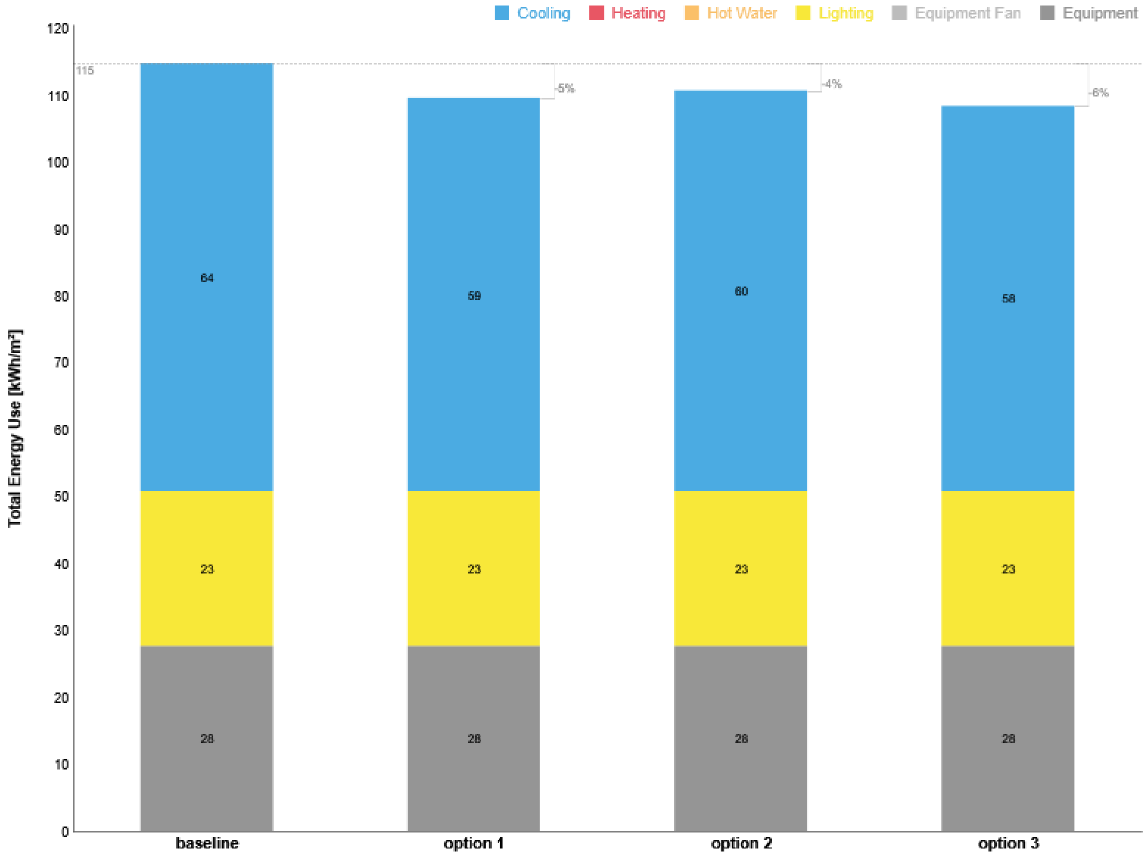


Figure 2.3.1: Comparison of the EUI in different design options

In the baseline model, the EUI is below 200 kWh/m^2/year at 114.80 kWh/m^2/year. As the equipment and lighting loads are constant across all options, the only change in energy load is from the cooling. Across all the simulations, option 3 reduces the cooling load by 10% compared to the baseline.

The findings from the simulation are similar to the results from the Malaysia Energy Commission (MEC), where 53% - 54% of energy is used for cooling (compared to 58% from MEC), 20% - 21% for lighting (compared to 20% from MEC), and 24% - 25% for office equipment (compared to 19% for office equipment and 3% others from MEC).

The overall trend of the EUI of the building follows the trend in the OTTV calculations. The EUI in design option 2 is higher in comparison to design option 1, but the overall lowest EUI is from design option 3, ie. reducing the window-to-wall ratio. As the majority of the energy in buildings in Malaysia are used to cool the building, a reduction of glass surface area reduces the amount of solar heat gain, reducing the interior temperature, in turn reduces the energy load, which is mainly the cooling load in our tropical climate.

Final Conclusions

Overall thermal transfer value (OTTV) and energy use intensity (EUI) are closely related. OTTV relates to the heat transfer through the building envelope, and that affects the interior temperature of the building, which in turn affects the energy load used to cool the interior.

The OTTV is a passive design strategy in reducing the heat transfer into the building, and it needs to be calculated before the additional mechanical and active systems are used to further cool the building to comfortable levels. The OTTV sets a baseline measurement to design the building mechanical and electrical systems. If the OTTV is lower, the building would need less energy in cooling the building, thus reducing the EUI/BEI. This means that to reduce the overall operation energy and cost of the building, OTTV plays an important factor in reducing the initial heat transfer and internal temperature, and in turn reducing the energy use.

The trend found in the OTTV calculation is similar to the EUI calculation. The best result is from design option 3 – reduce WWR 43%. A reduction in the glazing surface area reduces the amount of heat gain more effectively than any additional shading device.

In green building certifications, energy is a main concern in measuring the efficiency of the building. In Malaysia, in the Green Building Index (GBI) Non-Residential New Construction assessment criteria, it measures the building energy intensity (BEI) of the building. (Green Building Index, n.d.) The OTTV is a part of the BEI calculation, however an OTTV below 50 W/m^2 is a pre-requisite to qualify for the GBI certification. In the GBI assessment, the BEI accounts for 15 points from a total of 35 points for energy efficiency performance. Under the GBI assessment, the baseline, design option 1 and 2 would achieve 5 points, while the design option 3 would achieve 8 points.

There are many more factors that could affect the energy use in the building. In the BEI calculations from GBI, the energy calculations include lighting loads, plug loads, equipment loads and ACMV loads. These are dependent on the building use, occupancy load, operational hours etc. However, OTTV can be an indicator of the overall energy use of the building.

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