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JohorLand Tower: Optimizing Energy Efficiency for a High Rise Office Tower in Tropics

ABSTRACT

A detailed building energy simulation study showed that it is possible for a building owner in a proposed multi-tenanted high rise office tower to reduce up to 73% energy consumption as the operator of the building. This energy reduction reduces the energy running cost for the building owner from a baseline of RM 2 million per year to a running cost of RM 500,000 per year. The building energy intensity of the building (including tenant energy consumption) reduces from 212 kWh/(m².year) down to 82 kWh/(m².year)

A holistic energy efficiency approach was proposed to achieve such high efficiency gain. Approximately 50 passive and active energy efficiency features were tested for this building. Many of the efficiency gains are in the region of 1~2% energy reduction per design improvement. In addition, the peak cooling load of the building was reduced by 34% due to these design improvements, allowing a smaller air-conditioning system to be implemented for this building.

The energy efficiency passive and active design features that will be implemented in this building is largely considered conventional design practises. However, by making small improvements at every design opportunity, the building can be made very efficient at minimal additional cost to the building. In addition, due to the smaller air-conditioning system, there is a cost reduction that would help to finance the design improvements proposed.

Keywords: Building energy simulation, High-performance building; Energy saving

1. INTRODUCTION

Johorland Tower is a proposed multi-tenanted office tower to be located on the podium of Komtar JBCC building. The building is located in the heart of Johor Bahru city, just north of Malaysia-Singapore boundary, approximately 5 minutes' drive from the immigration check point.

The construction of the building started in December 2014 and it is scheduled to complete mid of 2017. It is constructed above an 8-storey podium block and has 27 storeys of office levels as shown in Figure 1. The building will be owned and operated by owner, JohorLand, with the office space leased out to tenants as a multi-tenanted building.

The façade of the building has a curtain wall design (Figure 1) with an average of window to wall ratio of 63%. Large windows give opportunity for good internal daylight but also increases solar heat.

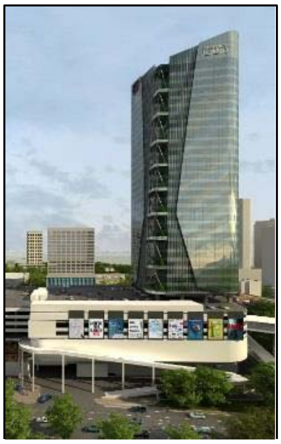

Figure 1 Architectural Perspective of JohorLand Tower

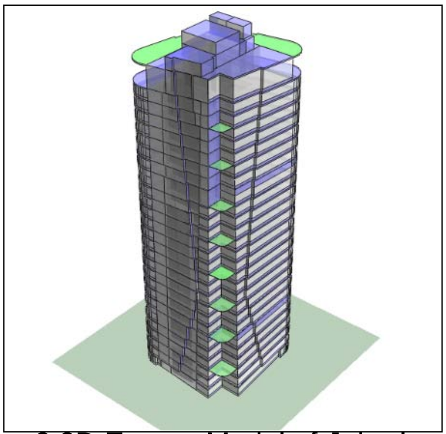

Figure 2 3D Energy Model of Johorland Tower

The building will be completed with full mechanical and electrical (M&E) services, providing the design team total control over M&E equipment design and specification.

A range of simulation studies were made to assess the improvements of 47 design enhancements, to reduce the energy consumption of JohorLand Tower. Each simulation case is an incremental step improving the building energy performance.

The energy consumption for this building is reported as Building Energy Intensity (BEI) with units in kWh/(m2.year). The BEI is a methodology of calculating a building's energy that is used by all major Green Building Rating System in Malaysia, i.e. the Malaysian Green Building Index and GreenRE. In simple terms, the BEI is the total energy consumed per year over the gross floor area of the building.

2. METHODOLOGY

A base case building is initially modelled with a building energy modelling software, using conventional building construction parameters. Design improvement is then incrementally applied to the building. The energy consumption and peak cooling load is then tabled as the output for each scenario.

Such a methodology allows the computed energy consumption and peak cooling load due to each case to be compared to the previous case. In addition, the combined effect of previous improvements made to the building will be accounted at all time.

Dynamic building energy simulation software IES<VE> was used to accurately simulate the building geometry (Figure 2), weather, heat gain and systems of the building. A detailed air-conditioning system of the air-handling unit and chiller plant was also modelled using the HVAC module of the software.

3. WEATHER DATA

Malaysia is located in the hub of a tropical climatic zone. It is summer all year long, with fairly consistent daily air temperature, relative humidity and solar radiation. The average air temperature ranges from a low of 24°C to a high of 31°C with a fairly consistent hourly moisture content of 18 g/kg day and night.

The simulation hourly weather data was based on a Test Reference Year (TRY) developed in University Teknologi Mara (UiTM) under DANCED (Danish International Assistant) project for Energy Simulations for Buildings in Malaysia. The TRY is based on 21 years (1975 to 1995) of weather data from a Malaysian Meteorological Station.

4. BASE BUILDING

The base case building was modelled with conventional building design practises in Malaysia. It complies with the minimum requirement of Malaysian Standard (MS) 1525 for Energy Efficiency in Non-Residential building on all Mechanical and Electrical requirements. Base building represents Case 1 of the study with simulation results of BEI = 212.08 kWh/(m².year) and peak cooling load of 7,394 kW

5. PASSIVE STRATEGIES

Passive strategies of daylight harvesting, envelope insulation, glazing properties and building air-tightness were assessed from Case 2 to 12. The results are shown in Table 1 below.

Table 1. BEI and Peak Cooling Load Result for Case 2 to 12

Cases	Descriptions	BEI (kWh/(m².year))	Peak Cooling Load (kW)
1	Base Case	212.08	7,394
2	Daylight 3m depth	200.63	7,260
3	Daylight 4m depth	197.24	7,220
4	Daylight 5m depth	194.28	7,182
5	Roof Insulation 50mm	193.44	7,153
6	Roof Insulation 100mm	193.00	7,149
7	Wall Insulation 25mm	191.46	7,012
8	Single Glazing Low-E	178.55	6,240
9	Partial Double Glazing Low-E	176.13	6,141
10	Full Double Glazing Low-E	172.51	5,924
11	Infiltration 0.25 ach	167.96	5,714
12	Infiltration 0.10 ach	165.12	5,584

Table 1 showed that the implementation of passive features reduces the BEI down to 165 kWh/(m².year), while the peak cooling load reduces by 24%.

<u>Daylight Implementation:</u> Cases 2 to 4, simulated a scenario of daylight harvesting. Malaysian climate has consistent daylight from the hours of 9am to 5pm daily, which is perfect for an office building. A daylight harvesting strategy was proposed with inclusion of daylight sensors at the office perimeter on each floor, and a window design to draw daylight deeper into the office area while preventing glare.

The window design consists of horizontal venetian blinds, light shelf and a sloped false ceiling as shown in Figure 4. Quantity of natural indoor daylight is measured by Daylight Factor (DF) as shown in Figure 5. An acceptable DF values for an office building in Malaysia are in the range of 1% to 3.5% [1]. The final daylight simulation showed that usable daylight exceeds 5m providing 47% office areas daylit.

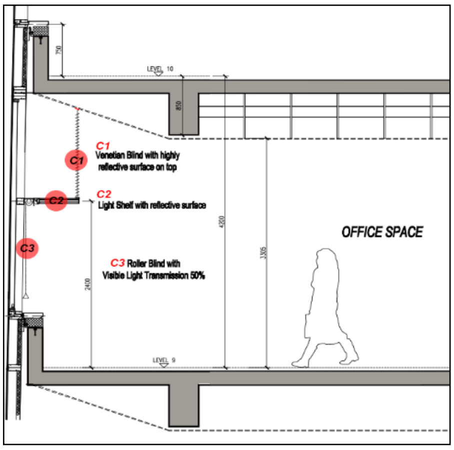

Figure 4. Section View of blinds and light shelf system.

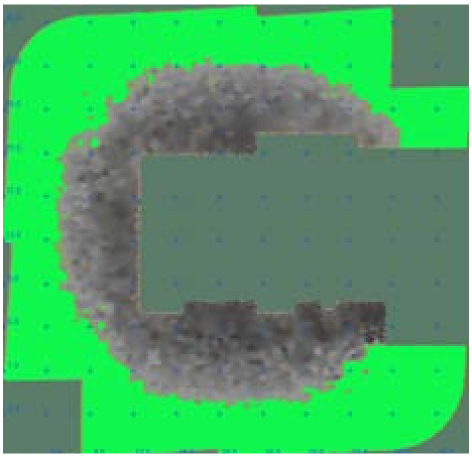

Figure 5. Plan View of DF in the range of 1%-3.5% coloured in green.

Roof and Wall Insulation: Base building was modelled with uninsulated concrete roof. Polystyrene roof insulation of 50mm (U-value 0.5228 W/m²K) and 100mm (U-value 0.2794 W/m²K) thickness was applied to Case 5 & 6. The BEI improves marginally from 50mm to 100mm, indicating that 50mm insulation is sufficient insulation on the roof. 25mm thick Rockwool insulation were then applied to all external walls in Case 7, reducing the wall insulated U-value to 0.8037 W/m²K from an uninsulated scenario of 1.79 W/m²K.

Glazing Properties: The building consists of 2 types of glazing with different tint as an architectural feature. Case 8 replaces standard glazing (both dark green and light green) with low-E properties. Case 8 reduces the average glazing SHGC to 0.27 from 0.43 and U-value to 3.8 from 4.8 W/m²K. Case 9 replaces the light green glazing as double glazed low-E with SHGC = 0.39 and U-value = 1.95 W/m²K with dark green glazing remaining as single glazed low-E. Case 10 is then simulated with all glazing specified as double glazed low-E. SHGC for the dark green double glazing is 0.23 and U-value = 1.95 W/m²K. Glazing performance was found to have a significant impact with a reduced BEI of 10% and cooling load by 15%.

Air Tightness: The average infiltration rate in office buildings in Malaysia was measured to be 0.5 air change per hour (ach) [7]. Improvements to the air tightness details and specification will be made on all external doors, windows and wall finishes. An assumption of infiltration rate reduced to 0.25 ach for Case 11 and 0.10 ach for Case 12 were made. BEI reduces by 1.3% and peak cooling load by 4.5%.

6. LIGHTING STRATEGIES

The lighting improvement strategies were largely based on selection of efficient luminaires to reduce the lighting power density (LPD) and controls to switch off the lights when the space is not used. The results of implementing lighting strategies are presented in Table 2 below.

Table 2. BEI and Peak Cooling Load Result for Case 13 to 20

Cases	Descriptions	BEI (kWh/-(m².year))	Peak Cooling Load (kW)
12	Base Case for Case 13	165.12	5,584
13	Office LPD 15 to 9 W/m²	156.89	5,479

14	Office LPD 9 to 7 W/m²	154.23	5,459
15	Walkway/Lift Lobby LPD 20 to 9 W/m²	144.51	5,300
16	Walkway/Lift Lobby LPD 9 to 7 W/m²	141.72	5,267
17	Walkway/Lift Lobby LPD Night 50% to 33% on	140.83	5,248
18	Toilet LPD 10 to 7 W/m²	140.61	5,248
19	Toilet Occupancy Sensor (50% off)	140.33	5,244
20	Fire Escape Stairwells LPD 15 to 3 W/m²	135.67	5,168

The implementation of all the lighting improvement strategies will further reduce the building BEI down to 136 kWh/(m².year). In addition, the peak cooling load of the building is reduced down by 30% from the base case.

Office LPD: The MS1525 guideline states that the maximum allowable office LPD is 15 W/m2. Case 13 and 14 improves the LPD down to 9 W/m2 and 7 W/m2 respectively. Significant savings are achieved by addressing these items (Table 2).

Walkway/Lift Lobby LPD: Case 15 and 16 showed that the LPD for Walkway and Lift Lobby has a significant influence in the building efficiency. While the MS 1525 allowed such spaced to have a LPD of 20 W/m², the JohorLand Tower is proposed to have a lighting power density of 9 W/m2 for Case 15 and 7 W/m2 for Case 16. Results in Table 2 showed that BEI reduce by 5.9% and cooling load by 2.6%.

Walkway / Lift Lobby Night Light: Case 17 proposed that the night lights be reduced from 50% to 33% (i.e. 1/3 of the lights remains on, instead of half), through strategic placement of light fittings adequate to give a sense of safety and security.

Toilet Lighting Power Density: Case 18 optimizes lighting power at the toilets from 10 W/m2 to 7 W/m2. Results in Table 2, showed marginal change, indicating that this feature is not a significant contributor to energy efficiency.

Toilet Occupancy Sensor: Case 19 introduces an occupancy sensor for all the toilets. An assumption is made that 50% of the time, the lights are switched off. This is modelled by reducing toilet LPD from 7.0 to 3.5 W/m2. Results showed marginal reduction.

Fire Escape Stairwells LPD: Case 20 improve these fire escape stairwells LPD from the MS1525 standard of 15 W/m2 to 3 W/m2. Staircase lux lighting levels is optimized to provide just enough light for access and as an escape route.

7. AIR-CONDITIONING STRATEGIES

There are many opportunities to optimise energy efficiency in an air-conditioning system. These are listed from case 21 to 47 as shown in Table 4 below.

Table 4. BEI and Peak Cooling Load Result for Case 21 to 47

Cases	Descriptions	BEI (kWh/-(m².year))	Peak Cooling Load (kW)
20	Base Case for Case 21	135.67	5,168
21	CAV to VAV	127.09	5,179
22	Duct Static 900 to 500 Pa	120.20	5,165
23	Duct Static 500 to 250 Pa	116.22	5,140
24	Air Filter Static 150 to 80 Pa	115.11	5,135.27
25	Air Filter Static 80 Pa to 50 Pa	114.64	5,130.60
26	Fan Eff. Backward curved to airfoil blade	113.54	5,128.65
27	Fan High efficiency motor used	113.38	5,127.10
28	CO2 Controlled Fresh Air Intake	110.56	4,973.87

29	Heat Recovery	108.16	4,924.63
30	Chilled Water ΔT 6.67°C-13.34°C to 5.56°C-14.44°C	107.09	4,864.44
31	Chilled Water ΔT 6.67°C-15.56°C	106.75	4,880.72
32	Chilled Water Pump Head 40m to 30m	105.60	4,875.36
33	Chilled Water Pump Head 30m to 20m	104.46	4,869.99
34	Chilled Water Pump Eff. 70% to 80%	104.18	4,868.64
35	Chilled Water Pump High Efficiency Motor	104.12	4,868.33
36	Variable Chilled Water Pump	102.64	4,866.38
37	Chiller Efficiency COP 5.5 to 6.2	98.69	4,837.72
38	Chiller Efficiency COP 5.5 to 6.6	96.81	4,807.00
39	VSD Chiller	91.28	4,772.84
40	Condenser Water ΔT 5.56°C to 6.67°C	89.62	4,772.78
41	Condenser Pump Head 40m to 30m	87.46	4,772.78
42	Condenser Pump Head 30m to 20m	85.30	4,772.78
43	Condenser Pump Eff. 70% to 80%	84.76	4,772.76
44	Condenser Pump High Efficiency Motor	84.64	4,772.77
45	Cooling Tower High Efficiency Fan	82.59	4,772.77
46	Variable Speed Cooling Tower	81.17	4,772.77
47	Upsized Cooling Tower	80.83	4,772.77

The implementation of all the air-conditioning system improvement reduces the building BEI down to 80 kWh/(m^2.year). In addition, the peak cooling load of the building is reduced down by 35.5% from the original base case.

Variable Air Volume: A constant air volume (CAV) system is typically installed for office buildings in Malaysia. Case 21 improves the system by implementing a variable air volume (VAV) system. Supply air flow will be regulated according to the cooling needs, reducing fan energy consumption. Table 4 showed that BEI reduces by 4%.

Duct Static Pressure: Larger duct with less bends reduces the fan static pressure. Case 22 reduces the duct static pressure from 900 to 500 Pa and Case 23 further reduced it to 250 Pa. By optimizing duct design BEI reduces by 8.5% and cooling load by 0.7%.

AHU Air Filter: Case 24 and 25 further improves the AHU static pressure by using improved filters. Case 24 specifies a low efficiency air filter which reduces total static pressure to 580 Pa. Case 25 specifies an electronic air filter which further reduces total static pressure to 550 Pa.

Fan Efficiency: The conventional fan selection for AHU is based on backward curve blades. Case 26 implements an airfoil type fan blades to improve the fan total efficiency to 70.2% from 61%. Case 27 uses a higher efficiency IE3 fan motor to improve total fan efficiency to 71.8%.

CO2 Sensor: CO2 sensors are introduced in Case 28 to regulate the fresh air intake system. This sensor allows the fresh air supply to be reduced when occupancy is low or when there is adequate fresh air in the building due to infiltration.

Heat Recovery System: A heat recovery system was introduced in Case 29 to recover energy rejected by the toilet exhaust system and transfer it to the outdoor air intake system located on the roof. The heat recovery system was specified with 50% efficiency for latent and sensible load.

Chilled Water Delta-T: A high delta-T chilled water system reduces the flow rate, thus chilled water pumps is smaller reducing energy consumption. Both Case 30 and Case 31 assumes a delta T of 16 °F. Case 30 has supply and return temperature of 42 °F and 58 °F respectively. While Case 31 has supply and return temperature of 44 °F and 60°F respectively. The results indicates that given the same delta-T, higher supply / return temperature gives a better BEI value.

Chilled Water Pump Pressure: Chilled water pump pressure is reduced by optimizing pipe size, reduce bends, tees, and transitions Case 32 simulates results for a pump pressure of 30m while Case 33; 20m. Results are shown in Table 4.

Chilled Water Pump Efficiency: Case 34 improves total pump efficiency from 63% to 72% and then further improve efficiency to 74.4% by specifying an IE3 motor instead of an IE2 motor for Case 35.

Variable Primary Chilled Water Pump: Case 36 upgrades the chilled water pump from a constant flow to a variable flow pump. The pumps are able to vary flow rate according to demand and heat load, hence have better performance at part load.

Chiller Coefficient of Performance (COP): The chiller is the biggest energy consumer in the air conditioning system. Standard chiller COP in the market currently ranges from 5.5 to 6.0. Case 37 and Case 38 simulates results for higher efficiency chillers, with COP at 6.2 and 6.6 respectively. A COP of 6.6 can be achieved by many high efficiency chillers in the market today. The results shown in Table 4, a chiller COP of 6.6 reduces BEI by 5.7%.

Variable Speed Drive (VSD) Chiller: To further improve the chiller performance, a variable speed drive was specified on the chiller and simulated in Case 39. VSD chillers have a variable speed compressor hence have better part load efficiency. BEI reduces by a further 5.7%.

Condenser Water Delta-T: Case 40 increases condenser water delta-T from 10 °F to 12 °F. As a result, condenser water pump flow rate decreases, thus reducing pump power. BEI reduces by 1.8%. The efficiency of the chiller was simulated to drop marginally. The resulting pump power reduction provided an overall higher energy reduction.

Condenser Pump Pressure: Decrease condenser water pump pressure by optimizing pipe size, reduce bends, tees, transitions and any others that will add to the pump pressure. Case 41 simulates results for a pump pressure of 30m while Case 42; 20m.

Condenser Pump Efficiency: Case 43 improves total pump efficiency from 63% to 72% by using a higher efficiency pump. And Case 44 further improves total efficiency to 74.4% by specifying an IE3 motor.

Cooling Tower Efficiency: Case 45 improve cooling tower efficiency to 0.0275 kW/HRT by specifying a more efficient fan motor.

Variable Speed Cooling Tower: Case 46 assess a variable speed fan on the cooling tower. Results show BEI reduces by 1.7%.

Oversized Cooling Tower: Case 47 oversize the cooling tower by designing the return temperature from 29.4 °C to 28.5 °C.

8. SUMMARY OF RESULTS

The results of the simulation are summarized on two levels:

Energy Efficiency

Overall, BEI reduces by 62% from base building to Case 47. Passive systems contribute to a reduction of 22%, lighting 14% and air conditioning 25%. Each case give a reduction of about 1 to 2%. Large reduction are provided by daylight implementation, glazing performance, office lighting and chiller performance. Total energy consumed per year by the building reduces by 5,041 MWh. With energy cost in Malaysia rated at RM0.51 per kWh, this is a savings of RM2.57 million (USD 600,000) per year. Since Johorland Tower is a multi-tenanted building, energy consumed by the owner can be estimated by deducting electrical energy for lighting & small power for all office spaces from Total Energy per Year. In which reduction energy cost per year by owner is RM1.49 million.

Peak Cooling Load

Overall peak cooling load reduces by 2,622 kW which is a reduction of 35.5%. Figure 9 shows cooling load reduction. The Passive design strategies contributed to more than 68% of the peak load reduction. Peak cooling load does not show much decrease after Case 30 because these cases improves air conditioning equipment performance and does not have significant impact on the cooling load. The reduction in peak cooling load means all air conditioning equipment capacities can be reduced thus reducing capital cost.

9. CONCLUSION

Simulation software allowed a possibility to track each improvement case and know its effectiveness in reducing overall energy consumption and air conditioning load. Each individual case brings small contributions to overall energy savings. However, when all these small contributions are added up, a substantial overall energy saving is achievable.

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