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THE ENERGY PERFORMANCE OF A UNIVERSITY LIBRARY BUILDING

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Abstract. The energy performance of a four-storey library (PSZ) building of Universiti Teknologi Malaysia (UTM) has been simulated using a microcomputer-based building energy simulation program, SHEAP. The simulation results give a comparative estimate of the potential annual savings for nine parameters. Significant savings (greater than 3.7% of RM 815,680 in operating cost) can result from the use of a Variable Air Volume (VAV) system, reduced air-conditioning times and reduced electrical lighting intensity. A 25% glazed-facade can contribute about 1% in saving, while the other parameters contribute less than 0.2% in savings to be of any significance.

1 INTRODUCTION

Building energy simulation programs are important tools for identifying strategies to conserve energy in buildings. Application at the design stage can result in optimum energy utilization. In existing buildings, they provide a means of ranking competing upgrades. In this paper, a microcomputer-based building energy simulation program, SHEAP [3], has been used to analyse the energy performance of the library building (PSZ) of Universiti Teknologi Malaysia in Skudai, Johor Bahru.

2 SHEAP COMPUTER PROGRAM

SHEAP is a locally developed microcomputer-based building energy simulation package. It uses the Weighting Factor Method of Ashrae [1] to determine the hourly air-conditioning sensible loads and air dry bulb temperatures in air-conditioned buildings for typical days of the year. The credibility of SHEAP is partly ensured by utilizing only established algorithms from reliable sources, such as the ASHRAE publications. A detailed description of SHEAP and its validation can be obtained from reference Senawi [3].

3 THE UNIVERSITY LIBRARY (PSZ) BUILDING

The PSZ is a four-storey building, with a total air-conditioned floor area of 16,670 m^2. The building has about 67% of glass windows covering almost all of the facades. A centralized air-conditioning plant serves 12 Constant Air Volume (CAV) air handling units three on each floor from 8 a.m. to 11.00 p.m. on normal weekdays and Saturdays. On Sundays, the plant operates from 8 a.m. to 4 p.m.. The extended hours of air-conditioning and

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electrical lighting contribute a significant amount of annual electrical energy consumption, when compared to other equally-sized buildings on the UTM campus. Arguably, on a unit-floor-area basis, the PSZ is the largest long term consumer of electricity.

4 MODELLING OF PSZ

In an effort to minimize the CPU time, the PSZ is divided into four perimeter zones and a single core zone, which extend from the first floor to the fourth floor, as shown in Figure 1. The zones are of an equal floor area, with identical lighting, occupancy and equipment (i.e. office equipment) usage patterns. These zones are served by a single CAV air handling unit, which in turn is served by a single plant. Detailed input data used by SHEAP is given in Appendix A.

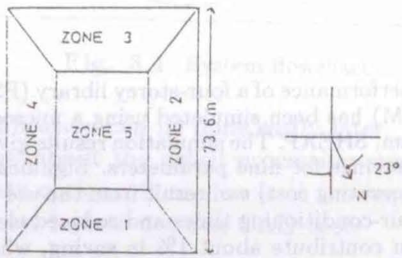

Fig. 1 Idealized plan view of PSZ building

The design cooling capacity of PSZ is 2218 KW. However, the chiller plant is at present providing only half of this capacity (one chiller set operating, the other one turned off). This is expected because there are still three more faculties which are yet to occupy the Skudai campus. At present, these faculties are located in Kuala Lumpur. In other words, the occupancy of PSZ is at present assumed to be about 50% of the design value. This reduces the air-conditioning loads considerably from the design values.

5 PARAMETERS STUDIED

The effects of nine parameters on the energy performance of PSZ have been studied. The parameters are:

1. Air system types: Dual-Duct/Multizone (DDMZ) and Variable Air Volume (VAV). The base system is Constant Air Volume (CAV) system.
2. Glass to facade area ratio (GFAR), defined as the net area of glass window to the facade area. Base is 0.67.
3. Air-conditioning operating time, OPTIME. The base value is from 8 a.m. to 11 p.m. on normal weekdays.
4. Solar absorptance of walls (ALPAW), base value is 0.2.
5. Fresh air intake ratio (XOA), defined as the flow rate of the outdoor air intake divided by the system air flow rate. The base value is 0.05.
6. Ground reflectance (RHOG), with a base value of 0.3.

7. Orientation of building (ORI), defined as the net clockwise rotation of building from the base case. The base value is 0.

8. Lighting heat gain (LHG), defined as the intensity of electrical lighting per unit floor area. The base value is 1.7 W/ft^2.

9. Horizontal sunbreak ratio (HSB), defined as the depth of window overhang divided by the height of glass window. The base value is 0.63.

Using the data in Appendix a as the base case (the existing building, system and plant configurations), the effects of each of the nine parameters were then simulated using SHEAP, one at a time, while holding all the other parameters at their base values.

5 RESULTS OF PARAMETRIC RUNS

The annual electrical energy consumption for the PSZ building base case is estimated at 4,078,400 KWHRS, which is equivalent to RM 815,680 in operating cost, assuming that 1 KWHR costs RM0.20. The electrical energy includes lighting, equipment, fans, pumps and compressor energy consumption. Figure 2 gives the breakdown in energy consumption between the major energy consuming components for the base PSZ building. Electrical lighting is the greatest consumer with 38.1 the cooling plant compressor, pumps and tower fans at 35.3 at 22.3 total electrical energy.

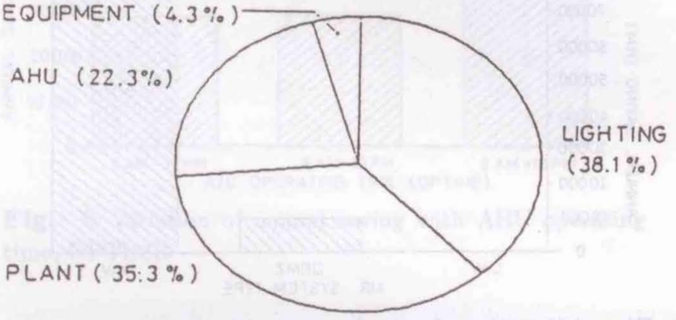

Fig. 2 Percentage breakdown in annual energy consumption for the PSZ building

Figure 3 shows the breakdown in the annual electrical energy consumption, for the base CAV system and the alternative DDMZ and VAV systems. The annual savings for the various systems, when compared to the base CAV system are shown in Figure 4. A RM 9,889 saving can be obtained by converting the present system to a DDMZ system. This saving originates from reduced compressor energy consumption. However, a significant saving RM 77,820 can result from the use of a VAV system, where most of the saving 76consumption of the inlet vane controlled supply air fan.

Lowering the GFAR to 0.25 saves RM 7,778 in operating cost, as shown in Figure 5. This is due to the reduced solar transmission and conduction heat gains through glazings. Conversely, increasing GFAR from the base value penalizes the compressor energy which results in negative savings. A 100 to the base annual utility bills. The effects of operating time, OPTIME, on the annual saving are shown in Figure 6. Savings of RM 28,000 can be obtained by either starting up an hour late or shutting off the central cooling plant an hour

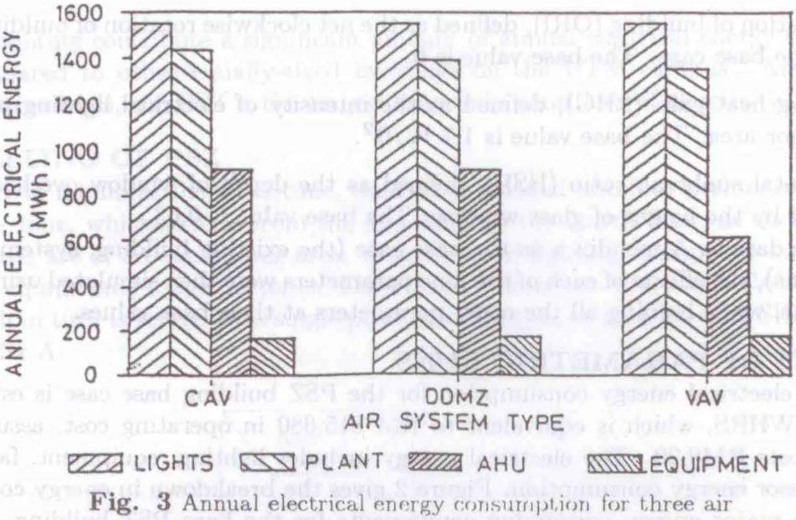

Fig. 3 Annual electrical energy consumption for three air distribution systems

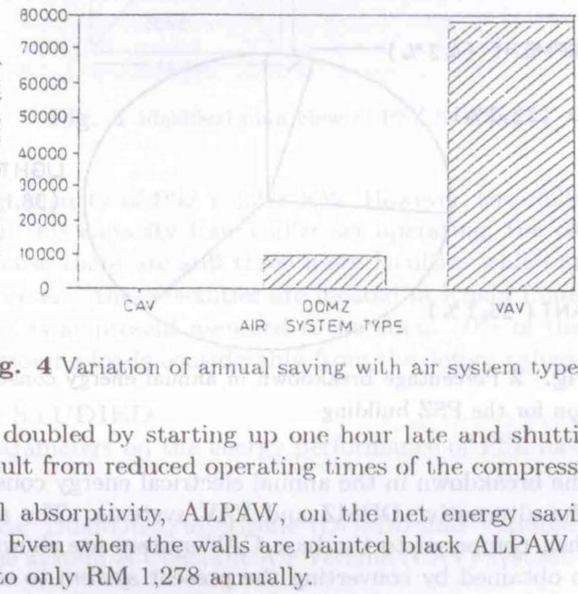

Fig. 4 Variation of annual saving with air system types

early. This saving is doubled by starting up one hour late and shutting off earlier by an hour. The savings result from reduced operating times of the compressor, pumps and fans.

The effects of wall absorptivity, ALPAW, on the net energy savings are minimal as depicted in Figure 7. Even when the walls are painted black ALPAW= 1, the penalty on utility bills amounts to only RM 1,278 annually.

The amount of fresh ventilation air, XOA, has a dramatic impact on the net energy saving, as shown in Figure 8. Substantial energy penalties (> RM 30,000 in utility bills) can be expected if XOA greater than 0.05 were used. This is explained by the fact that the outdoor air dry bulb temperatures and humidities are substantially higher than those inside the PSZ. Increasing XOA from the base value will result in a higher coil inlet air dry bulb temperatures and humidities. These will increase the coil loads, which in turn increase the compressor power demand. When the coil is overloaded XOA > 0.1 , the coil load is assigned the design capacity, which explains the flattened curve for XOA greater than 0.1. Ground reflectivity RHOG higher than 0.4 can result in a substantial energy penalty (>

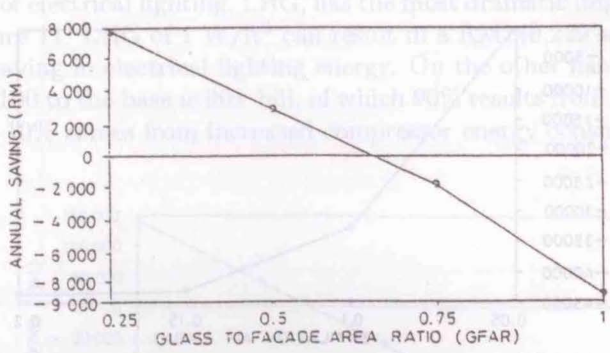

Fig. 5 Variation of annual saving with glass to facade area ratio, GFAR

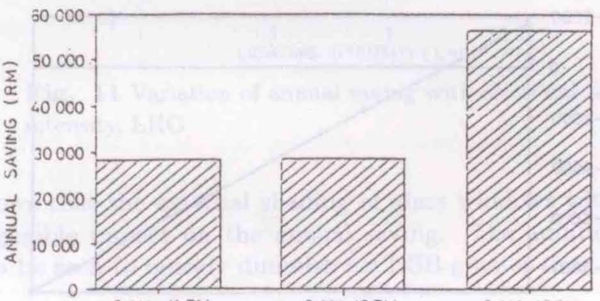

Fig. 6 Variation of annual saving with AHU operating time, OPTIME

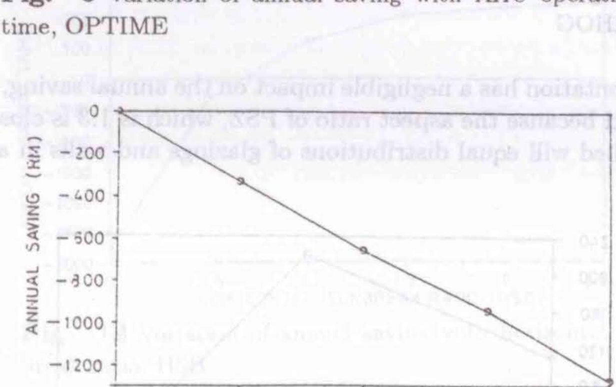

Fig. 7 Variation of annual saving with wall solar absorptivity, ALPAW

RM 5,000 in utility bills), as shown in Figure 9. However, normal ground coverings asphalt, crushed rocks etc. have RHOG of the order of 0.3, and these should not cause any great concerns.

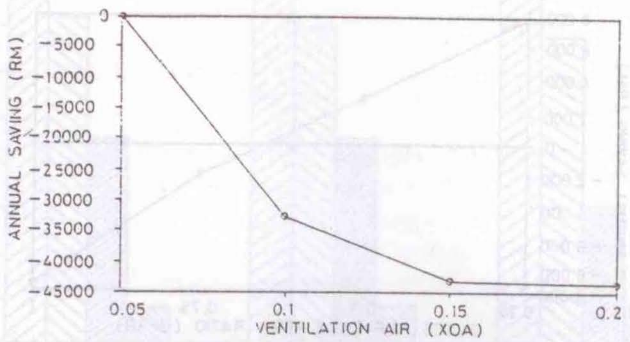

Fig. 8 Variation of annual saving with fresh air intake, XOA

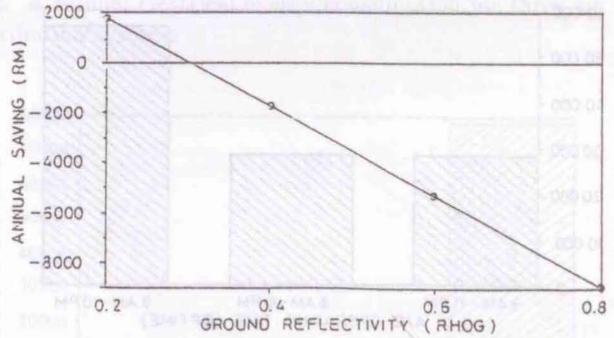

Fig. 9 Variation of annual saving with ground reflectivity, RHOG

The building orientation has a negligible impact on the annual saving, as shown in Figure 10. This is expected because the aspect ratio of PSZ, which is 1.3 is close to 1. In addition, the PSZ was modelled will equal distributions of glazings and walls in all facades.

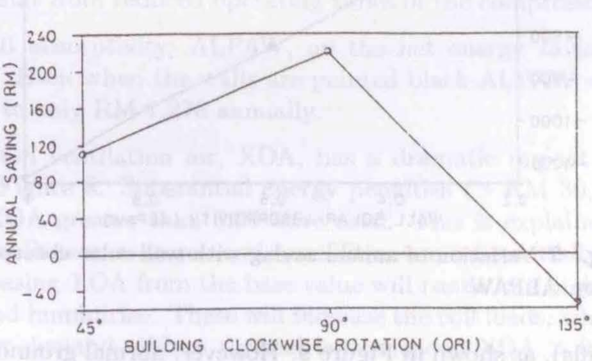

Fig. 10 Variation of annual saving with net building clockwise rotation, ORI

The intensity of electrical lighting, LHG, has the most dramatic impact on energy savings, as shown in Figure 11. LHG of 1 W/ft^2 can result in a RM140,229 saving, 91% of which is due to a direct saving in electrical lighting energy. On the other hand, a 3 W/ft^2 intensity can add RM263,100 to the base utility bill, of which 90% results from the additional lighting energy and only 10% comes from increased compressor energy consumption.

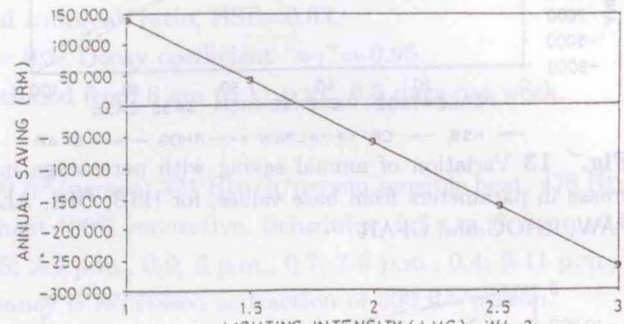

Fig. 11 Variation of annual saving with electrical lighting intensity, LHG

Figure 12 shows that the external shading of glass windows with horizontal overhangs, HSB, has a negligible impact on the annual saving. The additional benefit of external shading can also be seen to quickly diminish for HSB greater than 1.5.

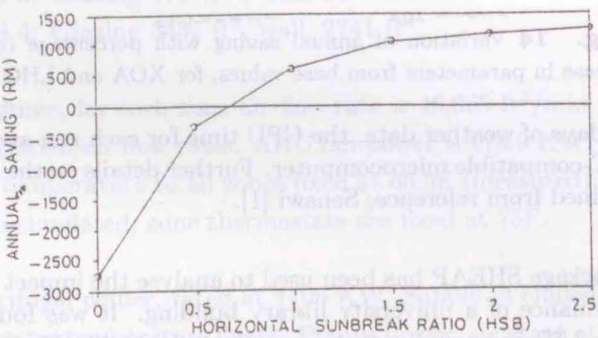

Fig. 12 Variation of annual saving with horizontal sunbreak ratio, HSB

Figure 13 and Figure 14 give the annual savings for each percentage increase in the parameters from the base values, where 0% refers to the base case and 100% represents the maximum parametric value. The maximum values are as follows: GFAR 1.0, ALPAW 1.0, XOA (0.20), RHOG (0.8), ORI 180 degrees, (LHG 3.0 W/ft^2) and HSB (2.5). It is evident that XOA and LHG have the largest impact on the energy penalties compared to the other parameters.

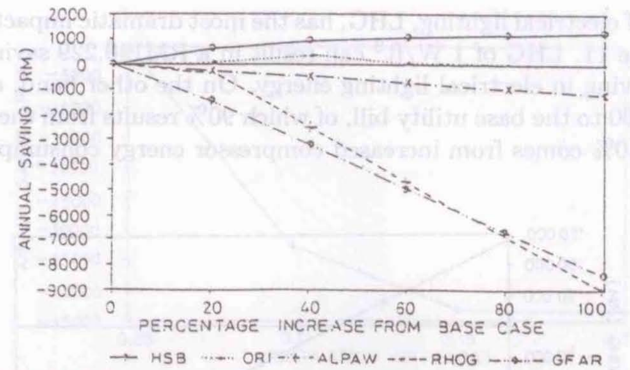

Fig. 13 Variation of annual saving with percentage increase in parameters from base values, for HSB, ORI, ALPAW, RHOG and GFAR

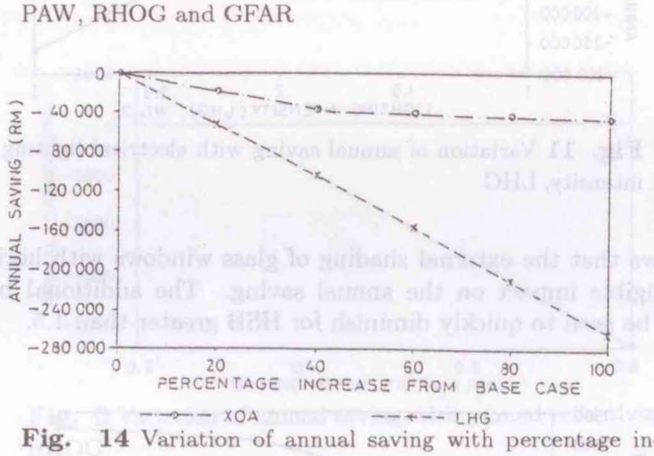

Fig. 14 Variation of annual saving with percentage increase in parameters from base values, for XOA and LHG

Using six typical days of weather data, the CPU time for each run averaged at 3 minutes with the use of an AT-compatible microcomputer. Further details on the computing package SHEAP can be obtained from reference, Senawi [1].

6 CONCLUSION

The computing package SHEAP has been used to analyse the impact of nine parameters on the energy performance of a university library building. It was found that significant savings (greater than 3.7% in annual operating cost) can be realized by upgrading to a VAV system, reducing the operating time (OPTIME) and reducing the intensity of electrical lighting energy (LHG). The other parameters contribute less than 0.2% in annual savings to be of any importance. However, excessive use of fresh air XOA and electrical lighting (LHG) have the most detrimental impact on operating costs for the PSZ building.

Appendix A

Building, operational, system and plant data.

Location : Longtitude 103 deg. east of Greenwich, latitude is 1.3N.

Wall : 19m plater, 114mm brick, 19mm plaster. Solar absorptivity is 0.2.

Glazing : 4mm clear glass, Sc=0.97, U=1.04 Btu/h/ft^2/F

Horizontal sunbreak ratio, HSB=0.63.

Ground reflectance = 0.3. Decay coefficient "w_1"=-0.95.

Building is air-conditioned from 8 am to 11 p.m., 6.5 days per week.

For all zones:-

Occupancy: 300 ft^2/person; 321 Btu/h/person sensible heat, 478 Btu/h/person latent heat. Sensible heat 100% convective. Schedules: 1-7 a.m, 0; 8 a.m, 0.5; 9 a.m.-12 noon, 0.9; 1 p. m. 0.5; 2-5 p.m., 0.9; 6 p.m., 0.7; 7-8 p.m., 0.4; 9-11 p.m., 1.0; 12 midnight, 0, where occupancy is expressed as fraction of 300 ft^2/person.

Lighting: "a" coefficient = 0.55. Schedules: 8 a.m. - 11 p.m., 1.7 W/ft^2; the rest of the time 0.

Equipment: (office equipment, e.g. computers From 9 a.m. - 10 p.m., 7.2KW; 8 a.,. and 11 a.,., 3.6 KW; other times.

Infiltration: 1 a.,. - 7 a.,. and 12 midnight, 6000 ft^3/min. 8 a.m. and 11 p.m., 3000 ft^3/min, else 0.

Floor area, 35,888 ft^2. Walls and glazings are vertical.

For zones 1 and 3: Glazing 4198 ft^2; wall, 2109 ft^2.

For zones 2 and 4: Glazing 5457 ft^2; wall, 2741 ft^2.

System:

Constant Air Volume, for each zone air flow rate is 46,065 ft^3/min. Constant fresh air intake at 5% of system air flow rates. AHU fan power is 178.9 KW. Coil capacity. 1109 KW. Supply air temperature to all zones fixed at 66.5F (measured). When DDMZ and VAV systems are simulated, zone thermostats are fixed at 75F.

Plant:

Open drive centrifugal chiller, rated at 1109 KW. Supply of chilled water at 44F; condenser entering water temperature floats. Pumps power, constant at 119.3 KW. Cooling tower fans rated at 29.8 KW, with the "approach" fixed at 10F. Default part-load performance curves are used for the chiller. Rated compressor power is 210 KW.

Weather data:-

The weather data was obtained from the BUNYIP's Singapore weather file (Moller and Wooldridge, 1985.)

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