**University of Hong Kong**
**MEBS6008 Environmental Services II**
**2007-2008 Examples/ Revision Exercise**

***The solution may not be totally correct. In case you disagree with the solution, you may ask.***

## Question 1

### Load Profile

Church operates for 3 hours on Sunday morning. Load steady for each hour.
Instantaneous peak hour load of 40 ton. Chiller capacity at 40 ton if no storage.
The integrated cycle of cooling load is 40 Tons x 3 = 120 ton-hours.

### Day Cycle with Partial Storage

Plant operates 24 hours => Chiller Capacity is 5 tons (=120 ton-hours / 24 hours)
Storage capacity is 105 ton-hours (=120 ton-hours – 3 hours x 5 tons )
If plant cost is $4,800/ton => the saving is $168,000 ($4,800/ton x 35 ton).
If storage cost is $560/ton hour=> storage is $58,800 (= $560/ton x 105 ton-hours)
Cost saving = $168,000 - $58,800 = $109,200.

### Day Cycle with Full Storage - 3 hour load period was the on-peak period

Plant operates 21 hours => Chiller Capacity is 5.71 tons (=120 ton-hours / 21 hours)
Storage capacity is 120 ton-hours
Storage requirement increases by 15 tons
As plant cost is $4,800/ton and storage cost is $560/ton-hour
Increase in storage capacity comparing with partial storage is 5 ton x 3hr = 15 tons
15 tons x $560/ton = $8,400
The increase in plant capacity comparing with partial storage is 5.71 – 5 ton = 0.71ton
0.71 ton x $4,800/ton = $3,408.
Total increase in cost in comparison with partial storage = $8,400 + $3,408 = $11,808.

### Church Example -Weekly cycle- Partial storage plant

Operates for 168 hours at 0.71 ton (=120 ton-hours / 168 hours)
Storage capacity = 117.9 ton-hours (=120 – 3 x 0.71 ton-hours)

### Church Example -Weekly cycle- Full storage plant

The plant Capacity = 0.73 ton (=120 ton-hours / 168 – 3 x 0.73 hours)
Storage = 120 ton-hours

## Question 2

Option 1 – Conventional system

**Demand Charge**

On peak:
650kVA x $66.5 = $43,225.
(1344 - 650) kVA x $63.5 = $44,069
Off peak > on peak =$0
Total = $43,225 + $44,069 = $87,294.

**Energy Charge**

On peak
Total elect kWh per month is 964,600kWh/3.5 = 275,600kWh.
200,000 kWh x 0.692 = $138,400
(275,600 - 200,000) kWh x $0.677 = $51,182.

Off peak
Total elect kWh per month is 21,840kWh/3.5 = 6,240 kWh.
6,240 kWh x $0.617 = $3,850

Total energy charge = $138,400 + $51,182 +$3,850 = $193,432

The monthly electricity bill for this plant is therefore
Demand charge + energy charge = $280,726

Option 2 – Ice Storage System

Total cooling energy for producing ice is (2000kW) x 12 – (140kW x 6) = 24,000 – 840 = 23,160 kWh

That is, we can shed the cooling demand at day time, i.e. from 9:00 am to 9:00 pm, the hourly cooling output from the stored ice equals to 23,160/12 = 1930kW per hour

| Time | kW cooling | kW storage | kW chiller |
|---|---|---|---|
| 9 | 2800 | 1930 | 870 |
| 10 | 2900 | 1930 | 970 |
| 11 | 3100 | 1930 | 1170 |
| 12 | 2900 | 1930 | 970 |
| 13 | 4000 | 1930 | 2070 |
| 14 | 3600 | 1930 | 1670 |
| 15 | 3500 | 1930 | 1570 |
| 16 | 2800 | 1930 | 870 |
| 17 | 3700 | 1930 | 1770 |
| 18 | 2900 | 1930 | 970 |
| 19 | 2500 | 1930 | 570 |
| 20 | 2400 | 1930 | 470 |

On peak:
650kVA x $66.5 = $43,225.

(710 - 650) kVA x $63.5 = $3,810

Off peak
(840 – 710) kVA x $26 = $3,380

Total = $43,225 + $3,810 + $3,380 = $50,415.

**Energy Charge**
On peak
Total elect monthly kWh is 362,440kWh/3.5 = 103,554.
103,554 kWh x 0.692 = $71,660

Off peak
Total kWh per day is 840kWH and the monthly kWh is 21,840kWh/2.8 =7,800kWh.
7,800kWh x 0.617 = $4,813

The monthly electricity bill for this plant is therefore
Total = $50,415 + $71,660 + $4,813 = $126,888.

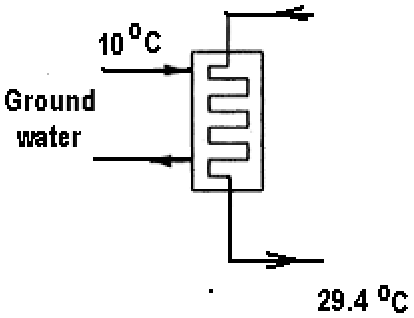
Include also pump operating cost, $126,888 + $20,238 = $147,126

The difference is $280,726 - $147,126 = $133,600.

## Question 3

### Cooling

Firstly you should place the given information of the heat exchanger in the diagram.




The heating and cooling capacity of water when it flows through an heat exchanger(heating or cooling ) can be calculated as follows: -

$$Q_w = \dot{V}_w \rho_w c_{pw} (T_{we} - T_{wl})$$

Where

| | | |
|---|---|---|
| $\dot{V}_w$ | = | Volume flow rate of water ($m^3/s$) |
| $\rho_w$ | = | Density of water ($kg/m^3$) |
| $c_{pw}$ | = | Specific heat of water (J.kg. °C) |
| $T_{we}, T_{wl}$ | = | Temperature of water entering and leaving the exchanger (°C) |
| $\Delta T_w$ | = | Temperature drop or rise of water after flowing through the coil(°C) |

For standard conditions in which the density is 1000 $kg/m^3$ and the specific heat is 4.18 kJ/(kgK)

Applying the above equation with correction factor 0.94 for use of anti-freeze, we get

$$\Delta T_w = \frac{372}{4.18x9.5x0.94} = 10^o C$$

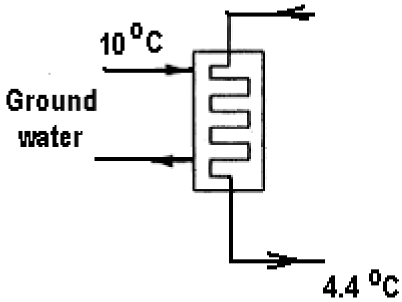
Hence, for water loop, the entering temperature (to the heat exchanger) is $29.4^o C + 10^o C = 39.4^o C$

For ground water side, leaving water temperature (from heat exchanger) is $39.4^o C - 2.8^o C = 36.6^o C$

For ground water side of heat exchanger $\Delta T_{gw} = 36.6^o C - 10^o C = 26.6^o C$

Using above equation, the flow rate of ground water side is $\frac{372}{4.18x26.6} = 3.3$ litre/sec

Heating




Using the same approach of cooling, you should get, for water loop side, (with 131kW, 9.5 litre/sec, 0.94 correction factor)

$\Delta T_w = 3.5^o C$

Hence, for water loop, the entering temperature (to the heat exchanger) is $4.4^o C$ - $3.5^o C$ $= 0.9^o C$
For ground water side, leaving water temperature (from heat exchanger) is $0.9^o C + 2.8^o C$ $= 3.7^o C$

For ground water side of heat exchanger $\Delta T_{gw} = 10^o C - 3.7^o C = 6.3^o C$

Again, by above equation, the flow rate of ground water side is 5 litre/sec.

## Conclusion

The maximum of flow rate chosen from cooling and heating condition, is 5 litre/ sec. Hence, the flow rate of 5 litre/ sec ground water should be specified in the tender document.

## Question 4

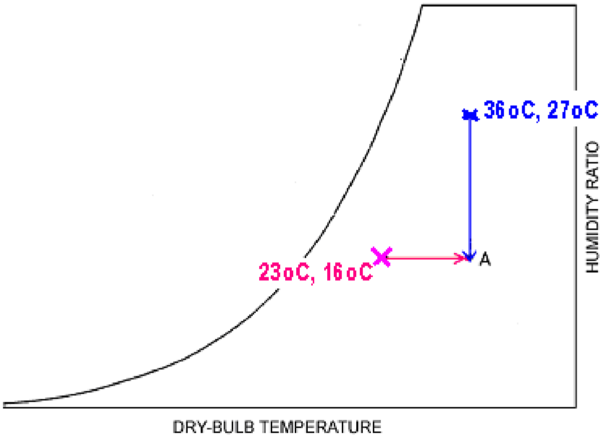
i) *Theoretical maximum total, sensible and latent heat transfer;*

The entering airstream enthalpies at supply inlet and exhaust inlet could be found from psychrometric chart as follows: -

Supply inlet (36 °C db, 27°Cwb ), *h* = 85.0 kJ/kg

Exhaust inlet (23 °C db, 16°Cwb ), *h* = 45.2 kJ/kg

The intersection of sensible and latent heat transfer, shown as point A in the Figure (20.2°C wb, *h* =59.2kJ/kg).




Hence, the theoretical maximum heat transfer.

$q_{max} = 1.15 \times 3.5(85.0 - 45.2\ ) = 160$ kW
$q_{latent} = 1.15 \times 3.5\ (85.0 - 59.2\ ) = 104$ kW
$q_{sensible} = 1.15 \times 3.5\ (59.2 - 45.2\ ) = 56$ kW

*ii) Sensible, latent and total heat recovered;*

Total energy recovered is:

$q = 0.52 \times 160 = 83.2$ kW

Sensible heat recovered

$q_{sensible} = -0.65 \times 56 = 36.4$ kW

Latent heat recovered

$q_{latent} = 83.2 - 36.4 = 46.8$ kW

*iii) Supply air dry bulb temperature, wet bulb temperature and enthalpy after leaving the heat wheel*

$$t_2 = 36 + \left(\frac{-36.4}{1.15x3.5x1.0}\right) = 27.0^{\circ}\text{C}$$

$$h_2 = 85 + \left(\frac{-83.2}{1.15x3.5}\right) = 64.3\text{kJ/kg}$$

From the psychrometric chart, supply wet bulb = 22°C.

## Question 5

The natural frequencies of the vibration isolators (i.e. spring)

For 500 kg piece of equipment installed on isolators with 25 mm deflection and using equation:-

$$f_n = \frac{15.8}{\sqrt{\delta_{st}}}$$

The natural frequency is $\frac{15.8}{\sqrt{25}} = 3.16$ Hz

The stiffness (i.e. k) of the vibration isolators (i.e. spring)

By using the following equation: -

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{M}}$$

$$3.16 = \frac{1}{2\pi}\sqrt{\frac{k}{500/4}}$$ → k = 49,277 N/m

The transmissibility

As the pump is operating at 564 rpm, that is, the driving frequency is 9.4 Hz.

By using the following equation: -

$$T = \left|\frac{1}{1-(f_d/f_n)^2}\right|$$

$$T = \left|\frac{1}{1-(9.4/3.16)^2}\right| = 0.127$$ , that is 12.7% of force would be transmitted to floor.

The displacement of the spring

$$X = \left|\frac{F/k}{1-(f_d/f_n)^2}\right| = \left|\frac{4800/49277}{1-(9.4/3.16)^2}\right| = 0.0124\text{m} = 12.5\text{ mm}$$

## Question 6

**Solution**

| octave band | center frequency (Hz) | actual sound pressure (dB) | A-weighting factor (dB) | A-weighted sound pressure (dB) |
|---|---|---|---|---|
| 1 | 63 | 63 | – 26 | 37 |
| 2 | 125 | 52 | – 16 | 36 |
| 3 | 250 | 45 | – 9 | 36 |
| 4 | 500 | 38 | – 3 | 35 |
| 5 | 1,000 | 31 | + 0 | 31 |
| 6 | 2,000 | 24 | + 1 | 25 |
| 7 | 4,000 | 16 | + 1 | 17 |
| 8 | 8,000 | 10 | + 0 | 10 |
| | | | | 42 dBA |

The following details may be found useful if you could still not get the 42dBA.

| SPL (dBA) | SPL/10 | $10^{(dBA/10)}$ |
|---|---|---|
| 37 | 3.7 | 5011.9 |
| 36 | 3.6 | 3981.1 |
| 36 | 3.6 | 3981.1 |
| 35 | 3.5 | 3162.3 |
| 31 | 3.1 | 1258.9 |
| 25 | 2.5 | 316.2 |
| 17 | 1.7 | 50.1 |
| 10 | 1.0 | 10 |
| | Sum | 17771.6 |

10 Log Sum = 42.4dBA say 42dBA.

The combined sound pressure level of 42dBA and 44dBA is as follows:-

$$42 = 10\log\frac{P_1}{P_{ref}} \quad \text{and} \quad 44 = 10\log\frac{P_2}{P_{ref}}$$

The combined level is $10\log(10^{4.2} + 10^{4.4}) = 46.1\text{dBA}$

## Question 7

Internal surface area of enclosure walls and roof = 54m$^2$

Surface area of the machine (i.e. compressor) = 26 m$^2$

The floor area (not covered by machine) = 6m$^2$

Surface area of machine and floor = 32m$^2$

By making use of the equation

$$\text{SPL}_1 - \text{SPL}_2 = \text{R} - 10\log \text{S}_\text{E} + 10\log \text{A}_\text{E}$$

| | | | |
|---|---|---|---|
| Octave Band Centre Freq | (Hz) | = | 8000 |
| $\alpha_{machine} = \alpha_{concrete} =$ | | = | 0.03 |
| $S\alpha_{machine/concrete}$ (S=32m$^2$) | (m$^2$) | = | 0.96 |
| $\alpha_{lining}$ | | = | 0.8 |
| $S\alpha_{lining}$ | (m$^2$) | = | 43.2 |
| $A_E$= (a) +(b) | (m$^2$) | = | 44.16 |
| 10 log $A_E$ | (dB) | = | 16 |
| 10 log $S_E$ ($S_E$= 54 m$^2$) | (dB) | = | 17 |
| Compressor Sound Power Level *at 8kHz* | (dB) | = | 75 |
| NC40 *at 8kHz* | (dB) | = | 37 |

Sound Reduction Index at 8kHz= 75 dB –37dB +17dB – 16dB = 39dB

## Question 8

**Solution**

*1) Determine the noise attention at 63Hz due to the duct section AC.*

The mean dimension is (800+600)/2 = 700mm

The rectangular, row 450-900 shows the attention per meter. Multiply 10m to each value to obtain the attenuation. That is, 6dB for 63 Hz

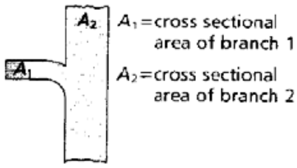
Approximate attenuation of unlined sheet metal ducts at octave frequencies

| Duct section | Mean dimension or diameter / mm | Attenuation / dB·m$^{-1}$ for stated octave band / Hz | | | |
|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 and above |
| Rectangular | ≤300 | 1.0 | 0.7 | 0.3 | 0.3 |
| | 300–450 | 1.0 | 0.7 | 0.3 | 0.2 |
| | 450–900 | 0.6 | 0.4 | 0.3 | 0.1 |
| | >900 | 0.5 | 0.3 | 0.2 | 0.1 |
| Circular | <900 | 0.1 | 0.1 | 0.1 | 0.1 |
| | >900 | 0.03 | 0.03 | 0.03 | 0.06 |

*2) Determine the noise attention at 125Hz due to the take-off at C.*

By using the formulae

$$\Delta L = 10 \lg \frac{A_1 + A_2}{A_1}$$




$$\Delta L = 10 \lg\left(\frac{0.36 + 0.27}{0.36}\right) = 2.4\text{dB}$$

$$\text{Noise attention after take-off (branch)} = 10\lg\left(\frac{0.6x0.45 + 0.6x0.6}{0.6x0.45}\right) = 3.7\text{dB}$$

$$\text{Noise attention after take-off (straight)} = 10\lg\left(\frac{0.6x0.45 + 0.6x0.6}{0.6x0.6}\right) = 2.4\text{dB}$$

*3) Compare the noise attention at 125Hz and 250Hz due to elbow D.*

The following table gives the result

| Frequency × width / kHz·mm | Attenuation / dB | |
|---|---|---|
| | Unlined | Lined |
| <50 | 0 | 0 |
| 50–100 | 1 | 1 |
| 100–200 | 5 | 6 |
| 200–400 | 8 | 11 |
| 400–800 | 4 | 10 |
| >800 | 3 | 10 |

Duct is usually expressed as width x height. The width of the duct is 600mm. Hence for example, for 125Hz, 125 x $10^{-3}$kHz x 600mm = 75, 1dB attenuation. For 250Hz, 250 x $10^{-3}$kHz x 600mm = 150. There would be 5dB attenuation.

*4) Compare the noise attention at 63Hz and 250Hz due to end reflection at E.*

Attention could be found from the below table.

| Duct dimension, *D* / mm | End reflection loss / dB at stated octave band / Hz | | | | |
|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1000 |
| 150 | 18 | 13 | 8 | 4 | 1 |
| 300 | 13 | 8 | 4 | 1 | 0 |
| 450 | 10 | 6 | 2 | 1 | 0 |
| 600 | 8 | 4 | 1 | 0 | 0 |

As the duct width is 600mm, for example, there would be 8dB at 63 Hz due to end reflection that is much larger than 1 dB at 250 Hz.