# Efficient Air-Conditioning
# &
# Heat Recovery

## Green Mark Manager Course


By

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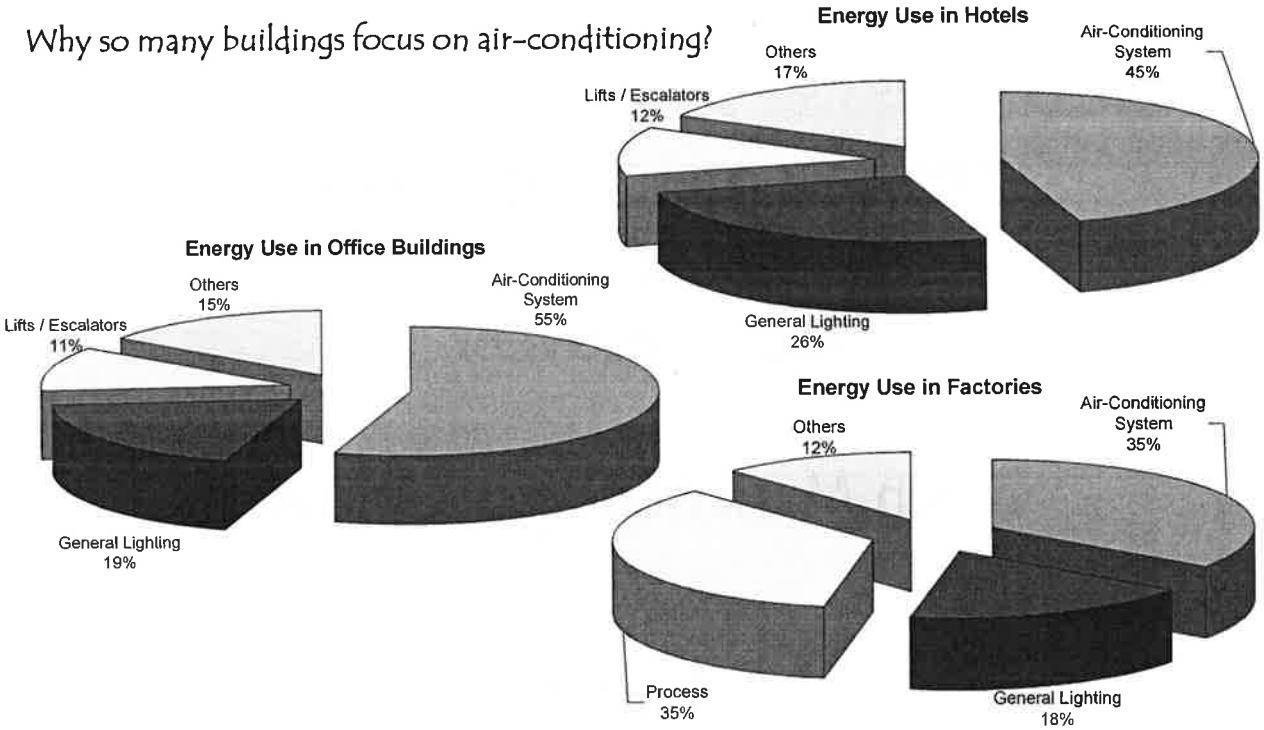
**VP G-Energy Global, Director ZEB Technology,**
**Director Ing-Energy**

**(KQP, GMP, SCEM Professional Level)**


# Agenda

1. How Air-Conditioning System impact Building Energy Consumption
2. Physic Lesson - Thermodynamics
3. Energy Code SS 530 & CP 13, minimum baseline efficiency
4. Methods of Optimizing Energy Consumption in Air-Conditioning Plant (With Many Case Studies)
    1. *Chiller Efficiency*
    2. *Fan Power on AHU and FCU*
    3. *Humidity controls & CO2 demand ventilation for energy savings*
    4. *Cooling Towers Efficiency*
    5. *Chilled/Condenser Water Pumps*
    6. *Chiller Plant System Control*
    7. *Under-Floor System*
3. Energy recovery systems – water side & air-side energy recovery
4. Economic Analysis for predicted savings
5. Conclusion

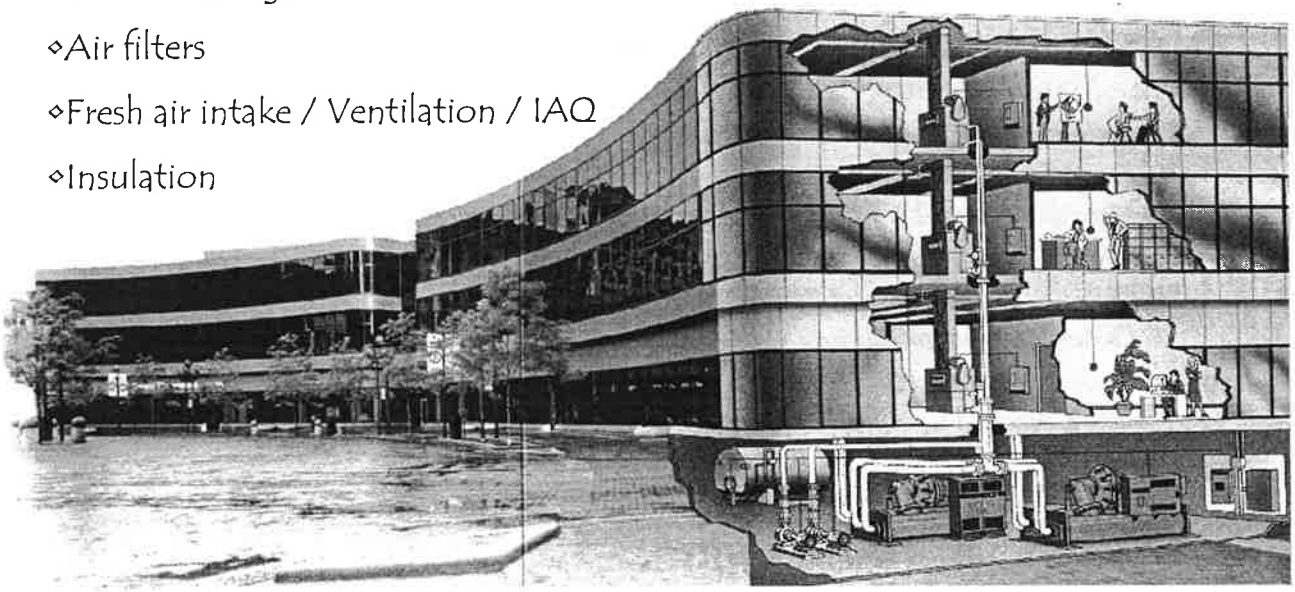
## Why so many buildings focus on air-conditioning?

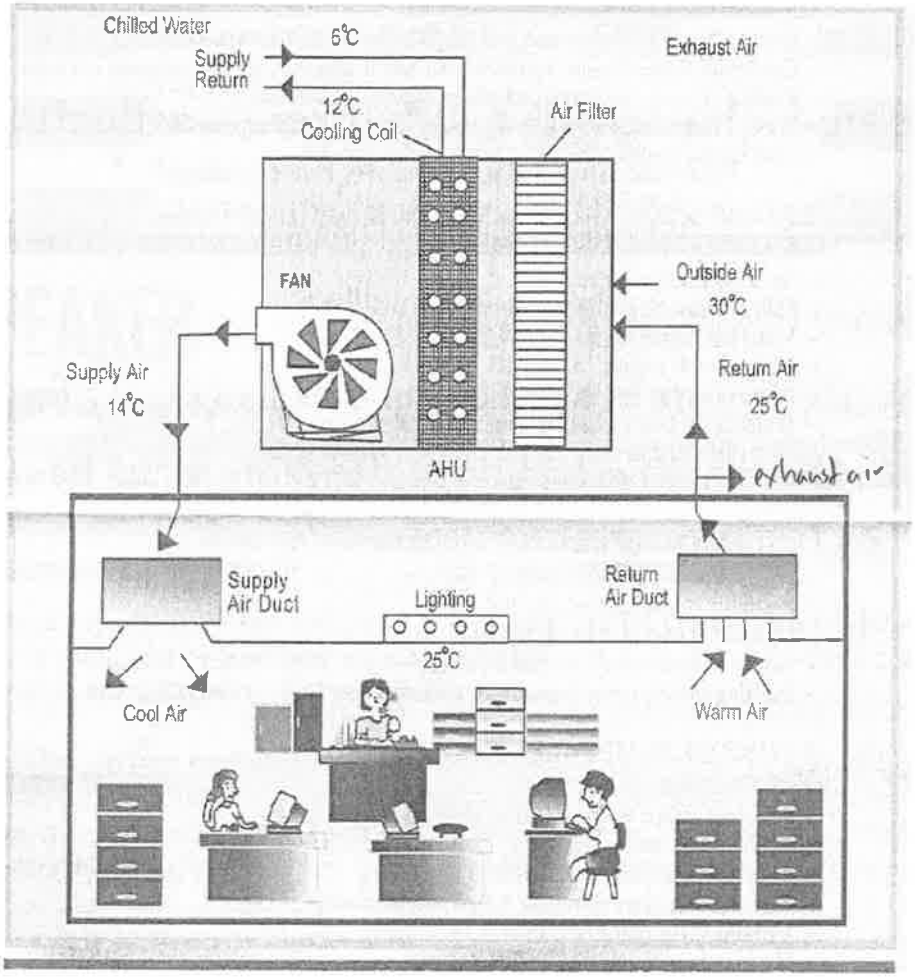



| | Air-Conditioning System | General Lighting | Lifts / Escalators | Process | Others | Annual Electrical Cost |
|---|---|---|---|---|---|---|
| **Office Buildings** | 55% | 19% | 11% | | 15% | $ 800,000 |
| | $ 440,000 | $ 152,000 | $ 88,000 | | $ 120,000 | |
| **Hotels** | 45% | 26% | 12% | | 17% | $ 1,500,000 |
| | $ 675,000 | $ 390,000 | $ 180,000 | | $ 255,000 | |
| **Factories** | 35% | 18% | | 35% | 12% | $ 2,400,000 |
| | $ 840,000 | $ 432,000 | | $ 840,000 | $ 288,000 | |

## Where & How should we start???

- Refrigerating Plant
- Air Handling Units
- Air distribution system (Air balancing)
- Air filters
- Fresh air intake / Ventilation / IAQ
- Insulation
- Water distribution system (Water balancing)
- Central Plantroom Automation (Hardware/Software)






## Most users practice energy conservation by adopting Demand Saving Method

use less

- Limiting minimum room temperature
- Reduce air flow rate
- Set higher chilled water leaving temperature at chillers
- Operate less chillers



# People are highly sensitive to temperature fluctuation

- Work rate and mental performance decline rapidly above 23 deg. C for sedentary thinker
- Accident rate also rise at high temperatures, especially for men. This is probably due to reduction in attention caused by the physiological need to relax.
- Caution should be used in adjusting space set points to save energy as occupant productivity costs are typically 100 times the potential energy savings



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Research Gallery



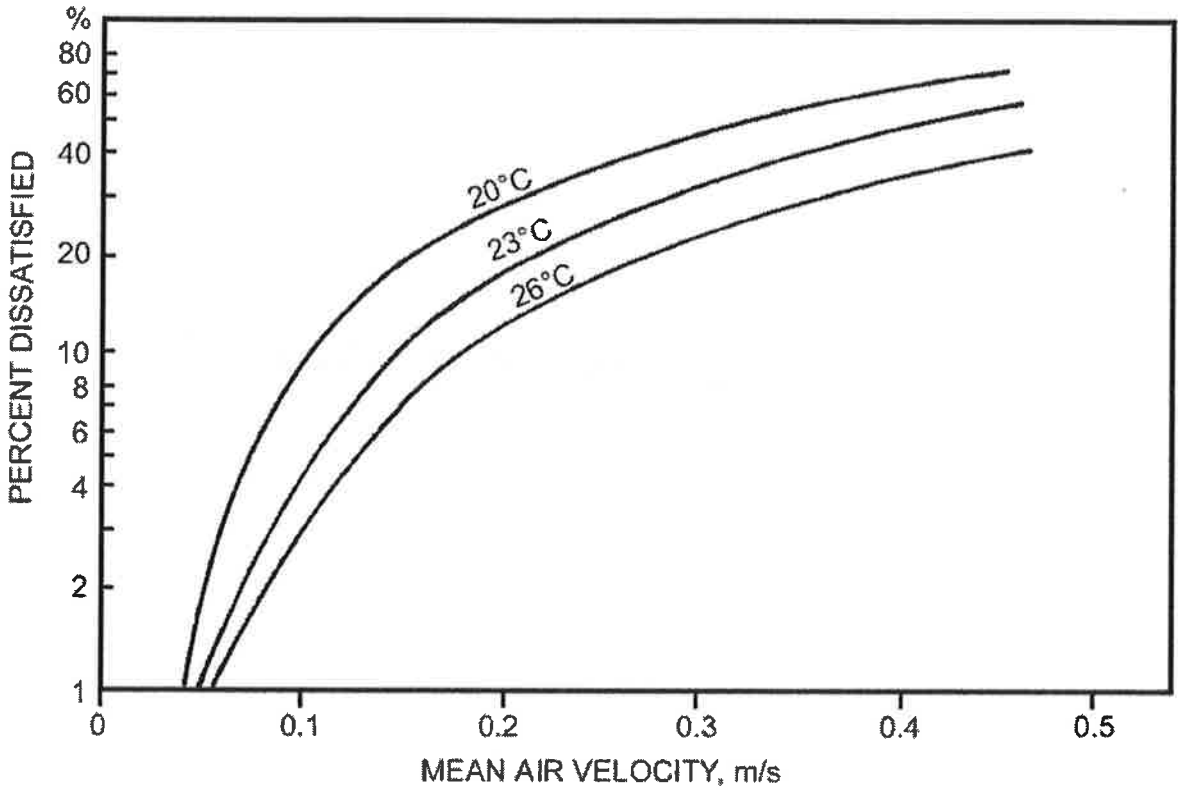
< All Research

**Air-conditioning and office productivity**

DO you know that air-conditioning can affect office productivity? NUS researcher, Dr Henry Cahyadi Willem has found out that room temperature and ventilation affect workers' alertness, concentration, numerical skills and tasks such as proofreading and creative thinking. Depending on the nature of each task, room temperature may need to be altered for someone to perform optimally.

*Tasks requiring concentration endurance, for example, would benefit from room air temperature that corresponds to cool thermal sensation."*
*-- Dr Henry Cahyadi Willem, Department of Building, School of Design and Environment.*





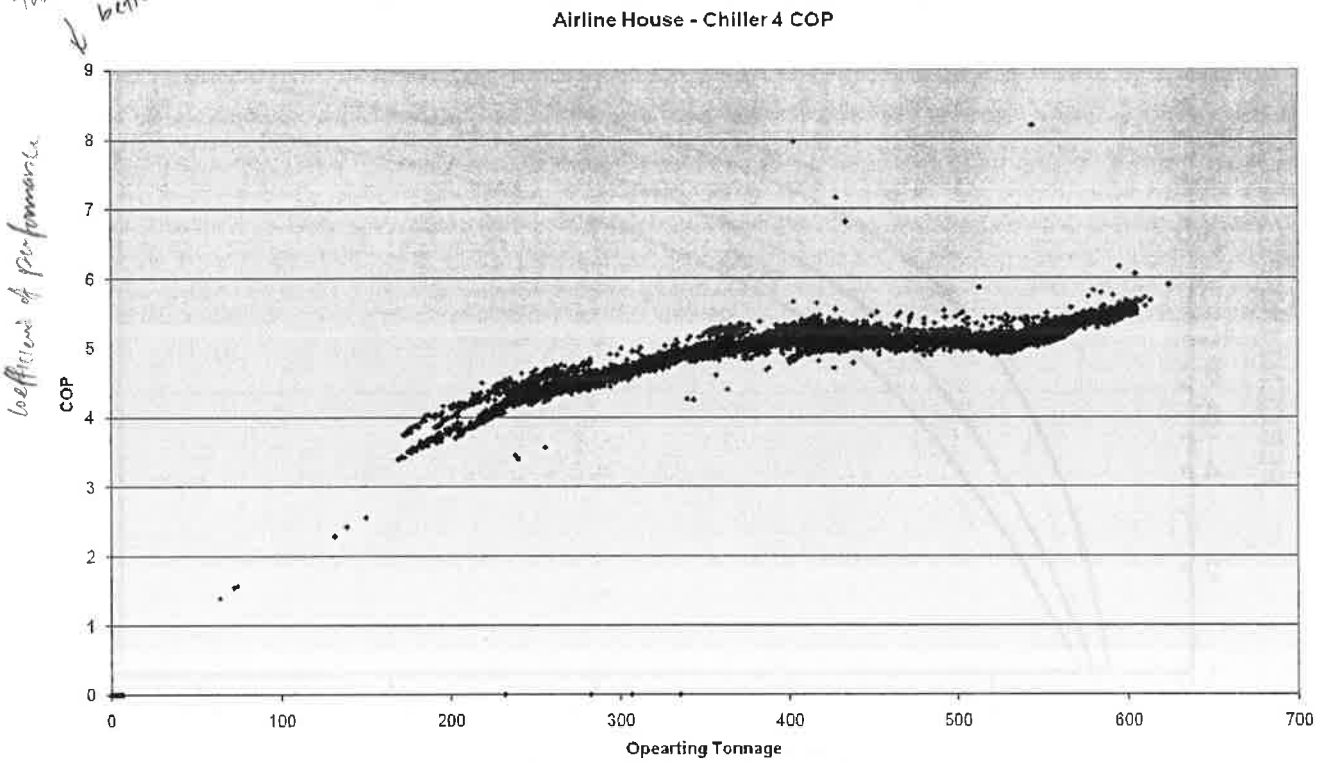

## The fundamental nature on energy savings in air-conditioning system are:

- Reduce solar heat entering the building
- Prevent untreated fresh air entering the building
- Control amount of treated fresh air entering the building
- Minimize receptacle load in the building
- Avoid over-cooling / over-heating the room
- Design SYSTEM that can operate efficiently* and can be OPTIMIZED in most load condition within the building constraints.

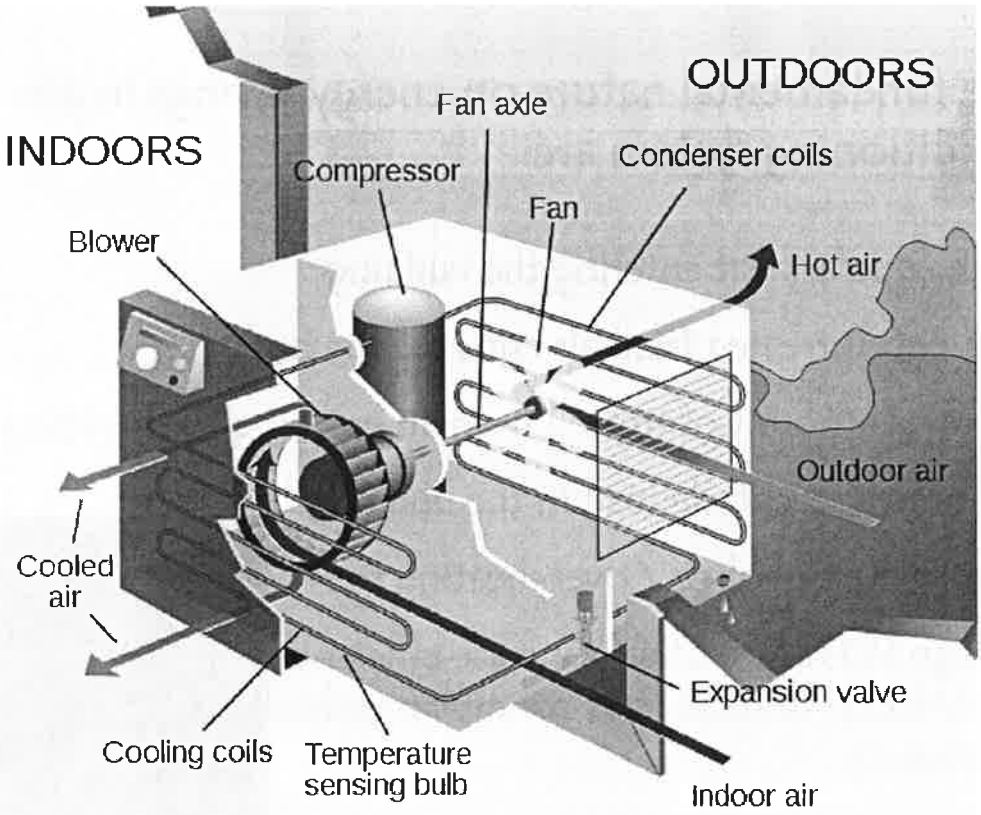
**Should not be at Full Load Condition*



The higher the better.

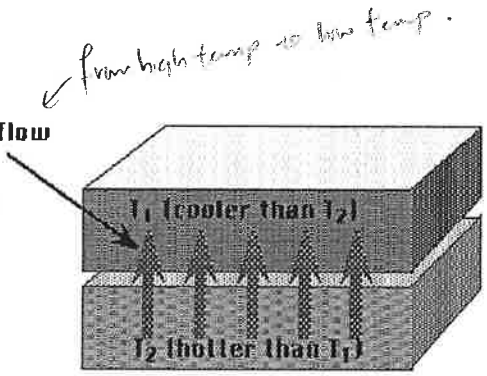



Coefficient of Performance



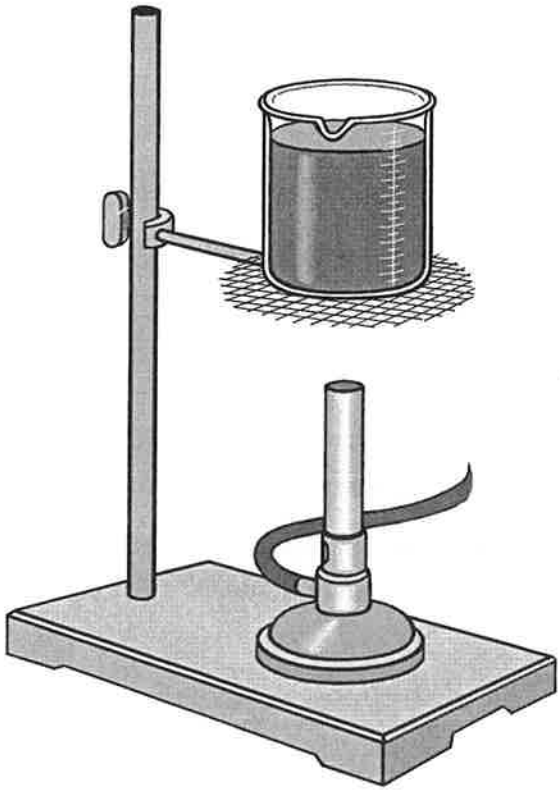

Basic Understanding on How Air-Conditioning Works

Heat, in its scientific meaning, is internal thermal energy that flows from one body of matter to another or from a system at a higher temperature to a system at a lower temperature. Temperature thus can be defined as a measure of the average molecular kinetic energy of a system. Temperature also governs the direction of internal energy flow between two systems. Two systems at the same temperature are said to be in a state of thermal equilibrium; when this occurs, there is no exchange of heat, and therefore heat exists only in transfer between two systems. There is no such thing as cold, only the absence of heat. If heat exists only in transit between systems, it follows that the direction of heat flow must *always* be from a system at a higher temperature to a system at a lower temperature. (This fact is embodied in the second law of thermodynamics). Heat transfer occurs through three means: conduction, convection, and radiation.




# Heat Measurement

- Btu = British Thermal Unit
- Heat quantity
- The amount of heat required raise the temperature of one pound of water one degree Fahrenheit.
- Specific heat
- The amount of heat required raise the temperature of one pound of a substance one degree Fahrenheit.
- Specific heat of water = 1



# Heat Measurement

- **Btu = British Thermal Unit**
- **12,000BTU = 1 Refrigeration Tonnage**
- **1 Refrigeration Tonnage = 3.5172 kW**
- **3.5172kW light bulb produce 12,000BTU or 1 RT of heat**

$$\text{Tonnage} = \frac{\text{Flow rate} \times \Delta T}{24}$$ (USGPM, °F)

$$kw = l/s \times 4.2 \times \Delta T^{oc}$$



### Total Heat Removed

The total heat removed by air condition chilled-water installation can be expressed as

$h = 500\ q\ dt$ (1)

where

$h$ = total heat removed (Btu/h)

$q$ = water flow rate (gal/min)

$dt$ = temperature difference (°F)

### Evaporator Flow Rate

The evaporator water flow rate can be expressed as

$q_e = h_{tons}\ 24 / dt$ (2)

where

$q_e$ = evaporator water flow rate (gal/min)

$h_{tons}$ = air condition cooling load (tons)

### Condenser Flow Rate

The condenser water flow rate can be expressed as

$q_c = h_{tons}\ 30 / dt$ (3)

where

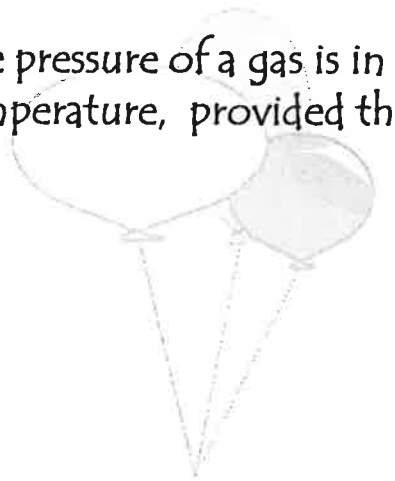
$q_c$ = condenser water flow rate (gal/min)

$h_{tons}$ = air condition cooling load (tons)



# Basic Physical Laws

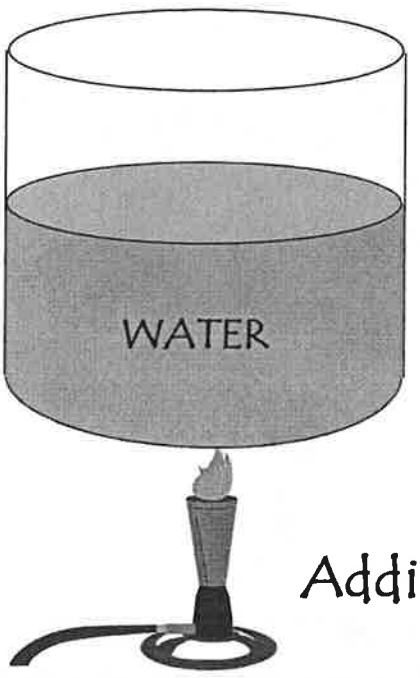
- Charles's Law:
  - The volume of a gas is in direct proportion to it's temperature, provided that the pressure is kept constant; and
  - The pressure of a gas is in direct proportion to it's temperature, provided that the volume is kept constant.



Temp ↑
pressure ↑
volume - constant

# Sensible Heat Gain

Atmospheric pressure

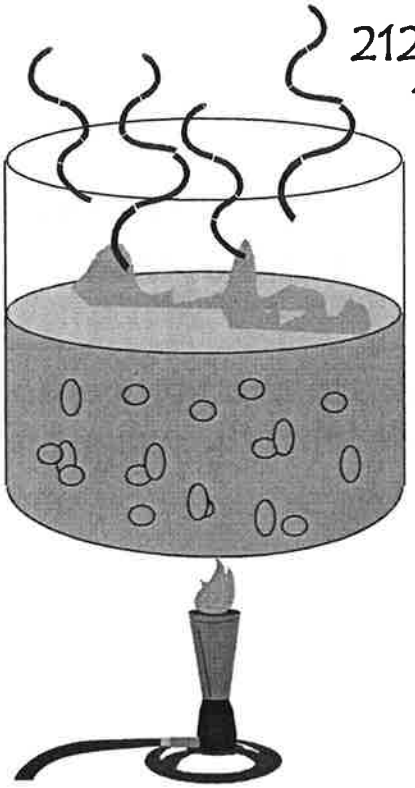



Adding Heat

# Saturation

Atmospheric Pressure

Both liquid and vapor in the same container

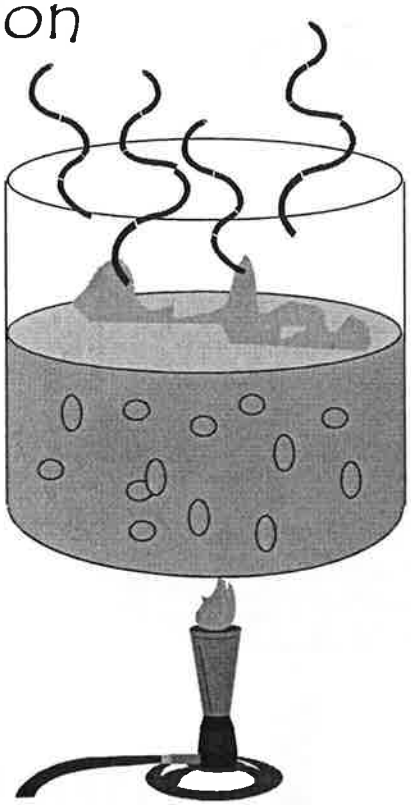


212° F
100° C

212° F
100° C

# Vaporization

Atmospheric Pressure



Water Boiling

Liquid turns to vapor

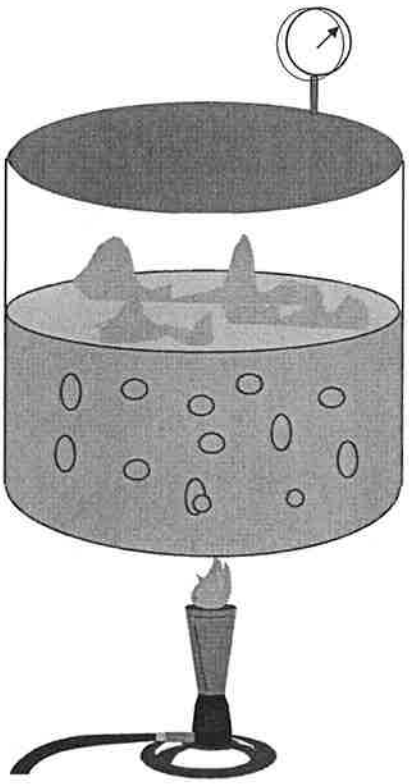
at 100 C

**Evaporation occurs when liquid absorb additional heat at boiling point**

# Changing the Saturation Point

A pressure cooker prevents vapor from escaping.

An increase in pressure on the surface of a liquid, will produce an increase of the boiling point of that liquid.

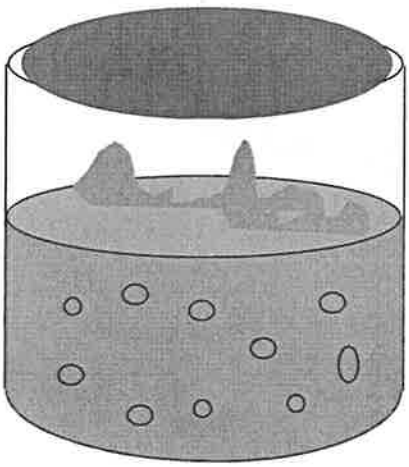


Water Boiling
3 psig
110° C

# Lowering the Saturation Point

A vacuum pump draws all air out of the vessel.

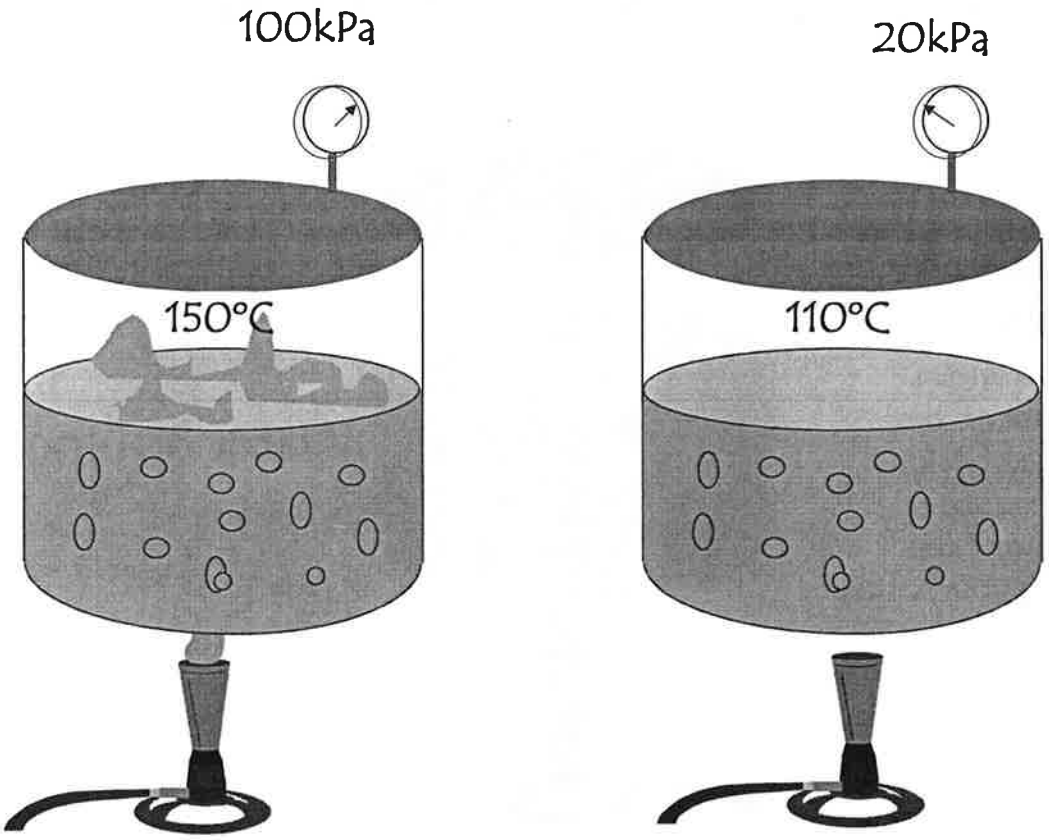
A decrease in pressure on the surface of a liquid, will produce a decrease of the boiling point of that liquid.

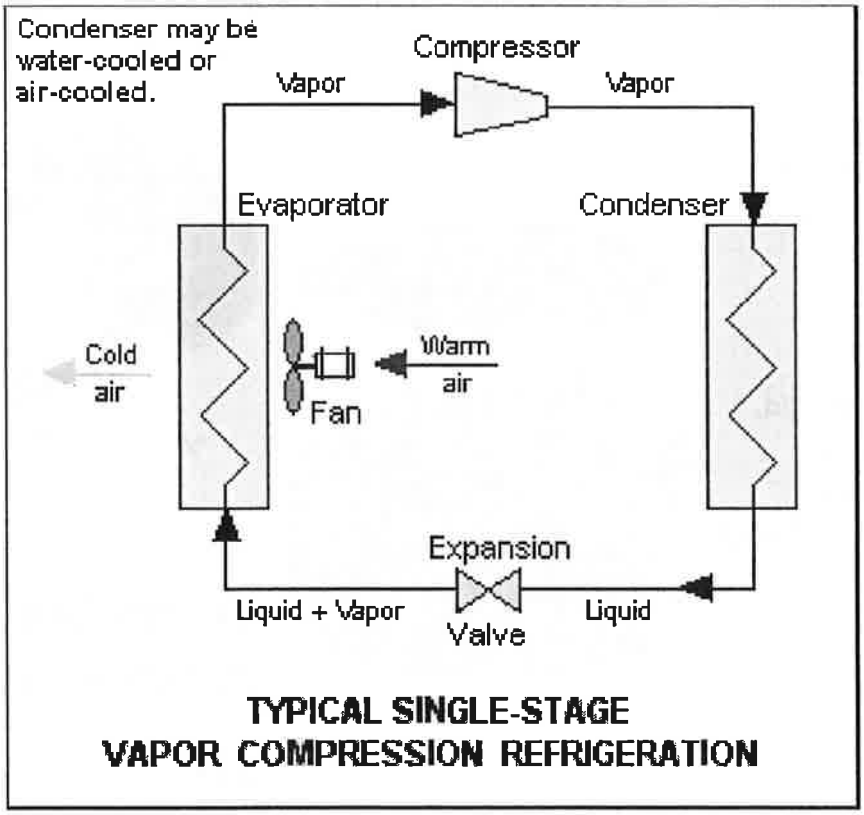




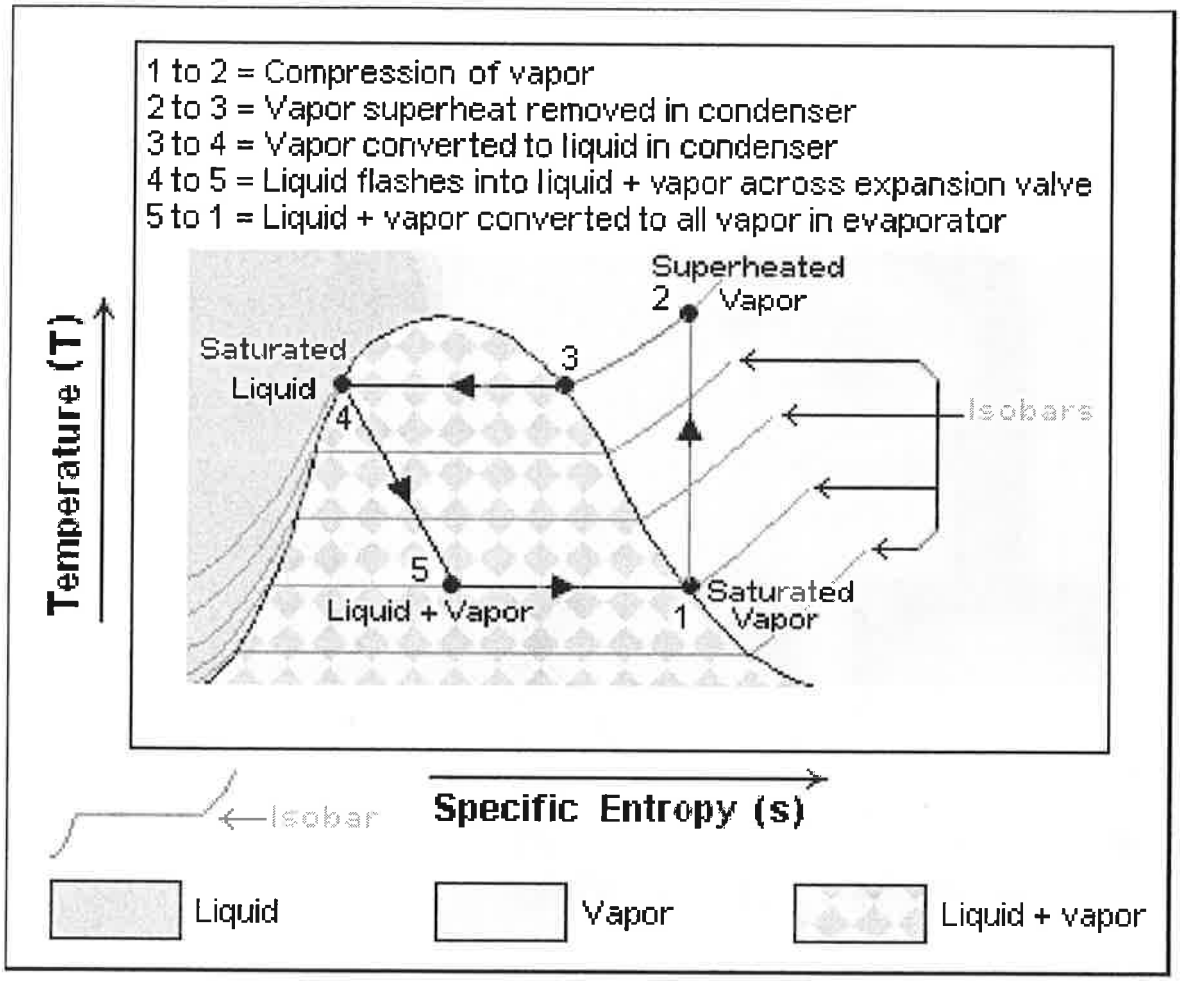
vacuum pump

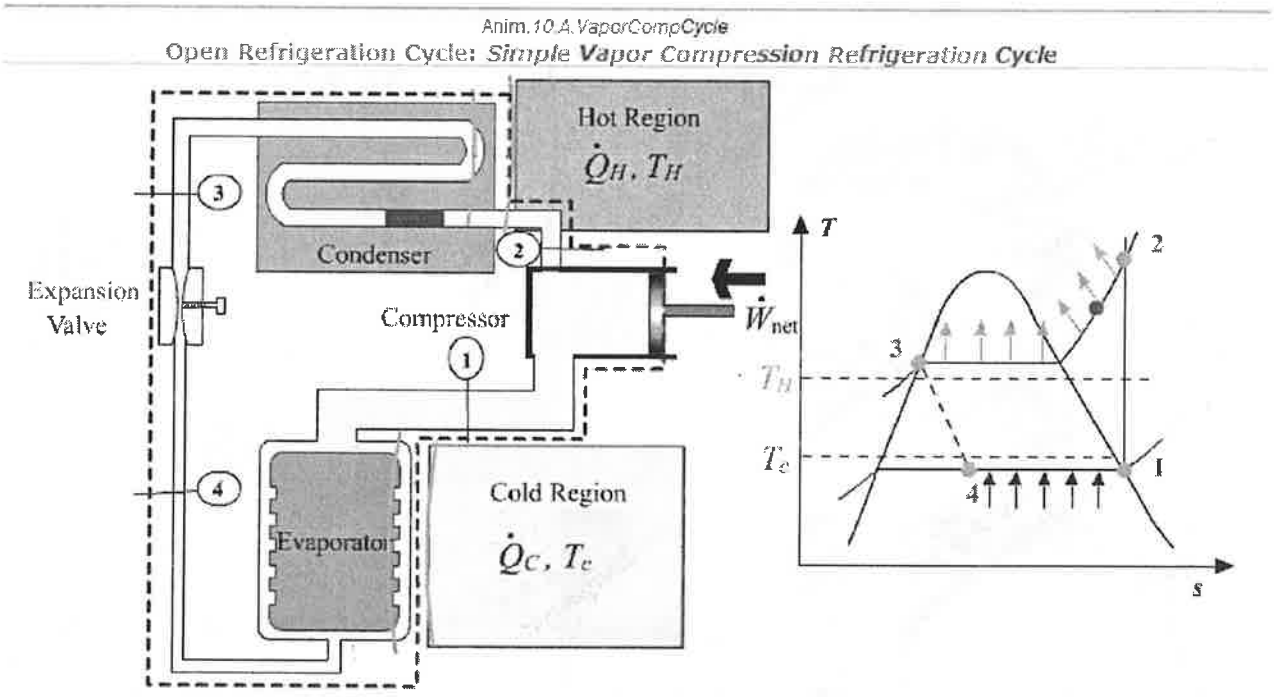
Water Boiling
29" vacuum
40° F



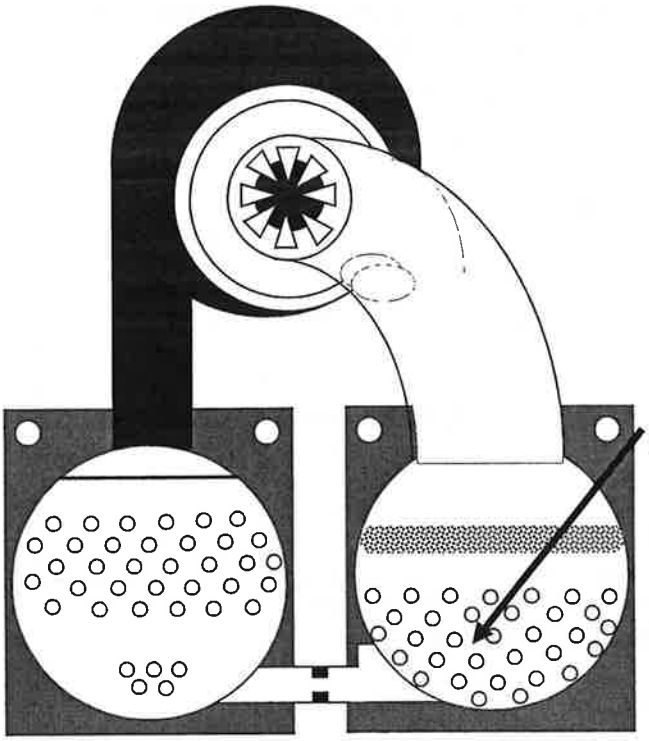

**TYPICAL SINGLE-STAGE VAPOR COMPRESSION REFRIGERATION**

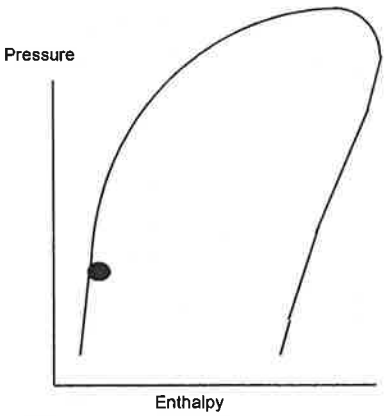



**http://energy.sdsu.edu/testcenter/testhome/vtAnimations/animations/chapter10/A-vaporCompress/vaporCompCycle.html**

# Centrifugal Chiller

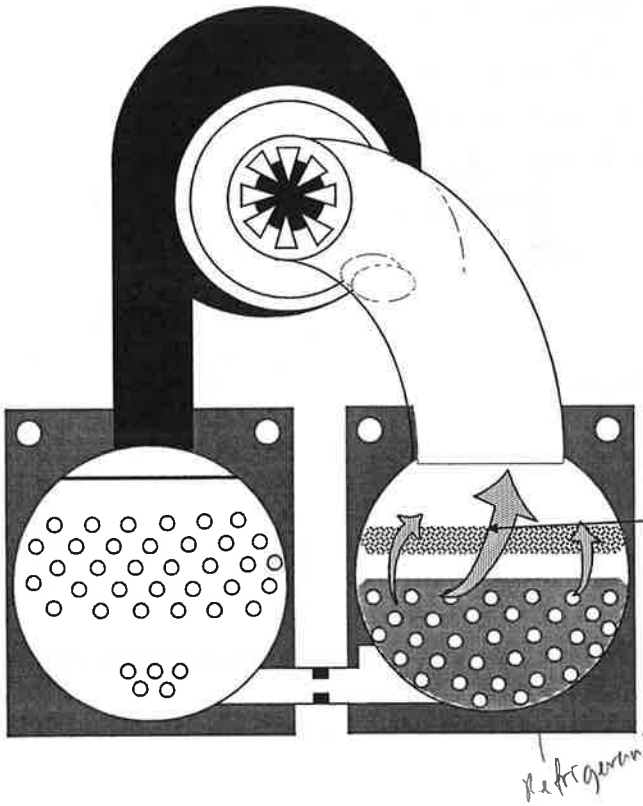


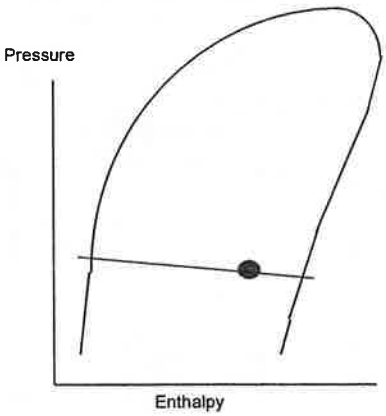



Flooded Evaporator

Water to be chilled flows inside tubes, refrigerant surrounds tubes

# Centrifugal Chiller





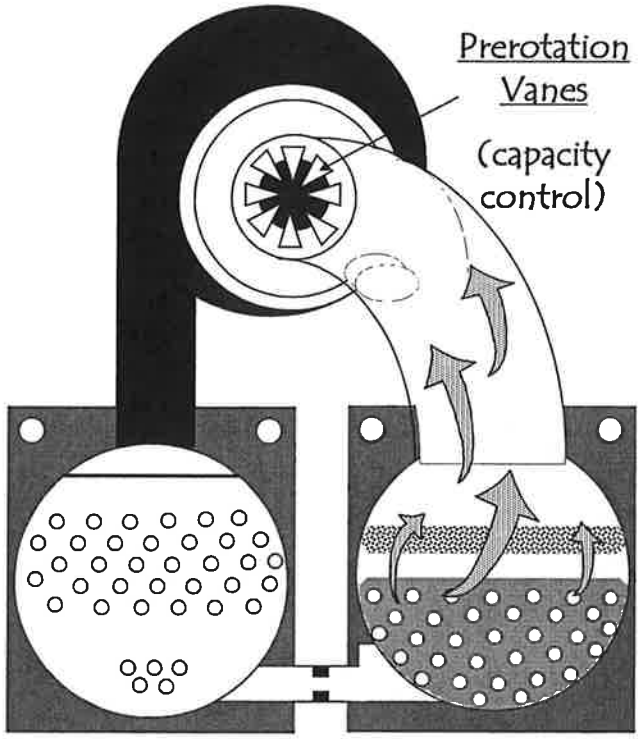

to remove liquid moisture

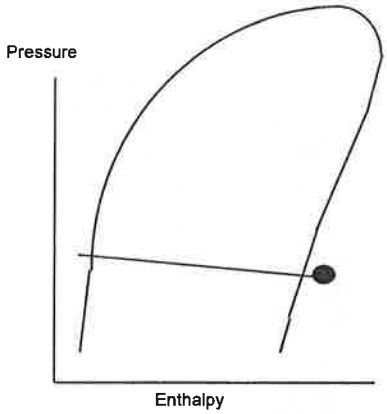
Mist Eliminator

(stops liquid refrigerant from entering suction line)

refrigerant

# Centrifugal Chiller

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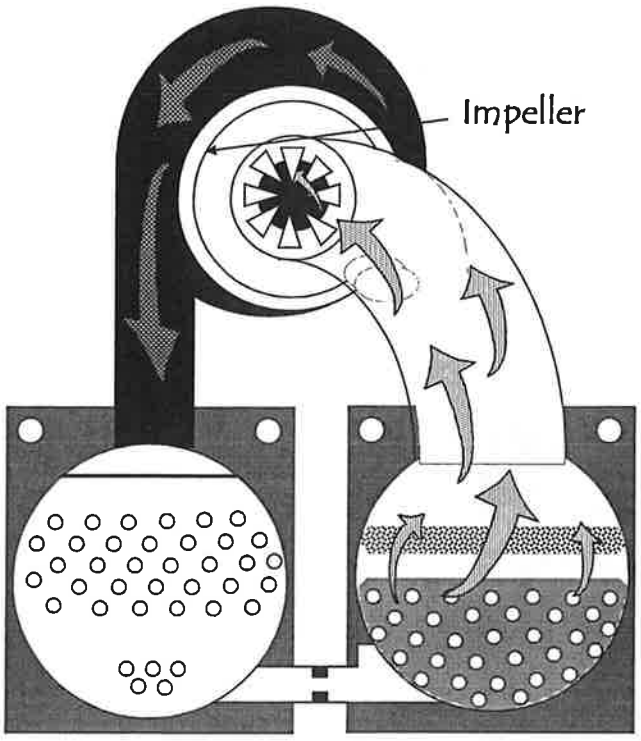


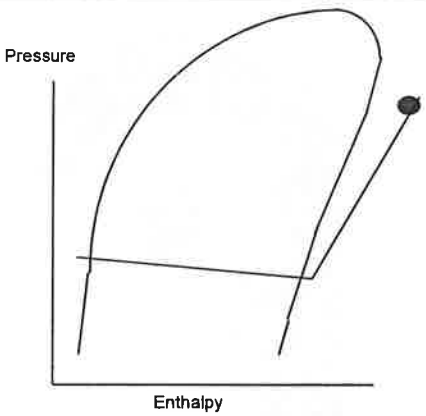

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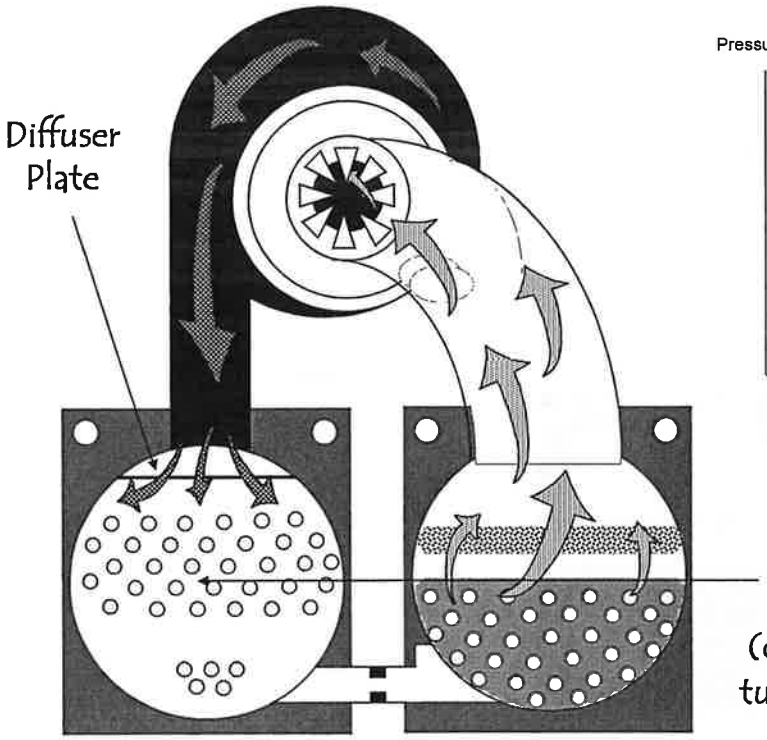
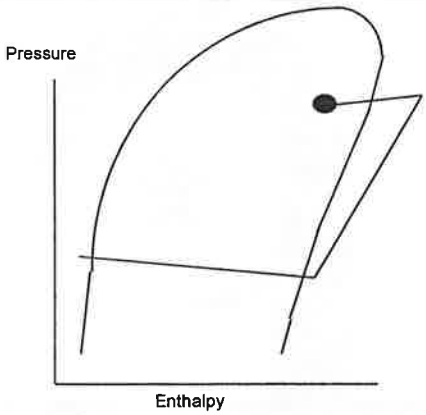
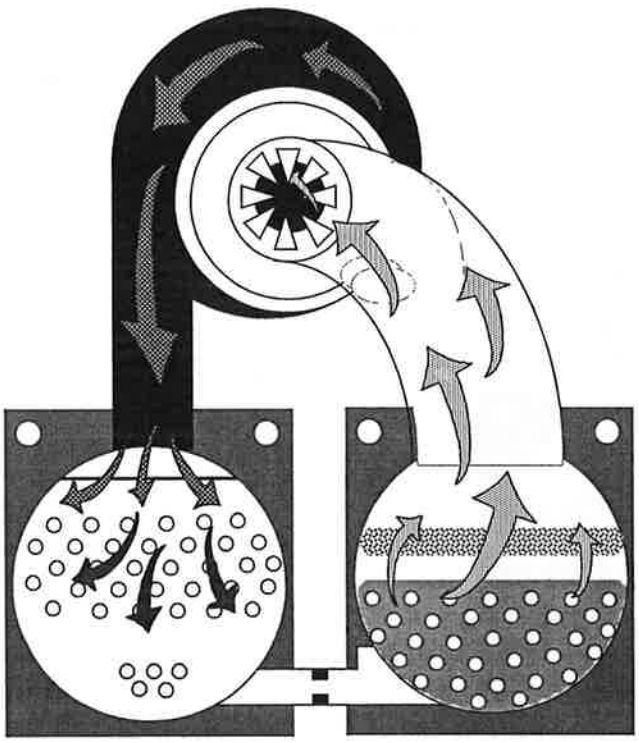


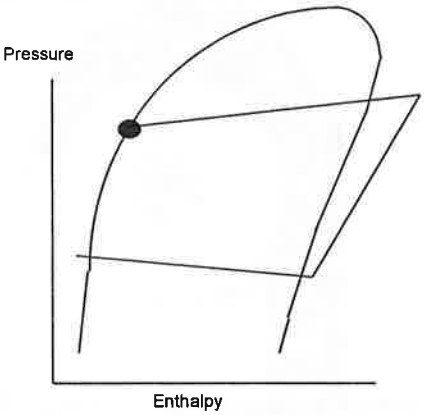

Condenser

(cooling tower water inside tubes, refrigerant surrounds tubes)

# Centrifugal Chiller



Condenser



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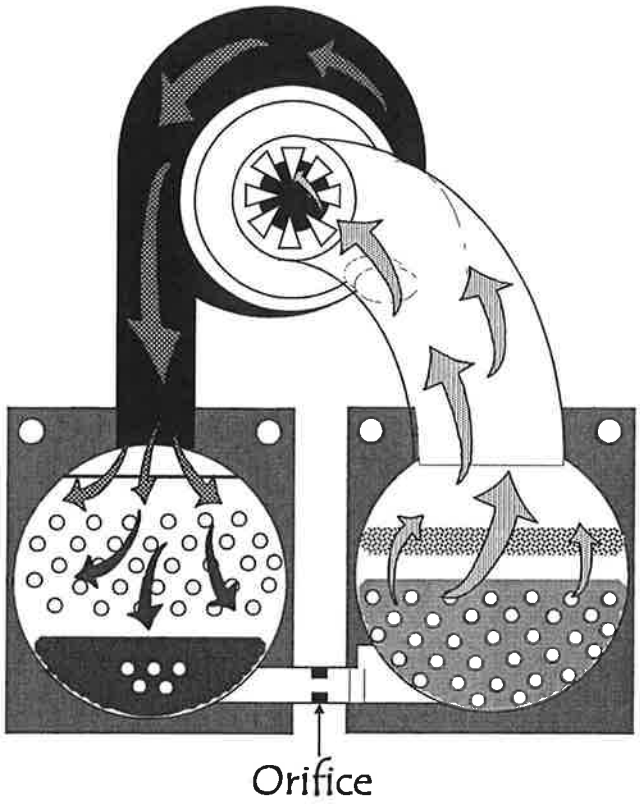


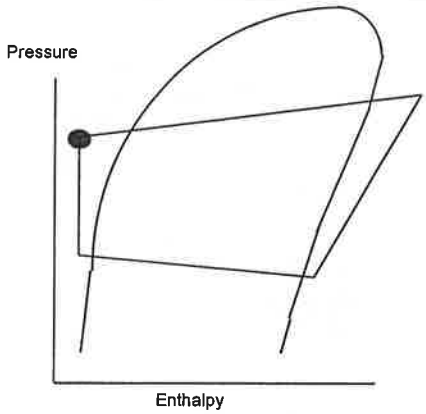


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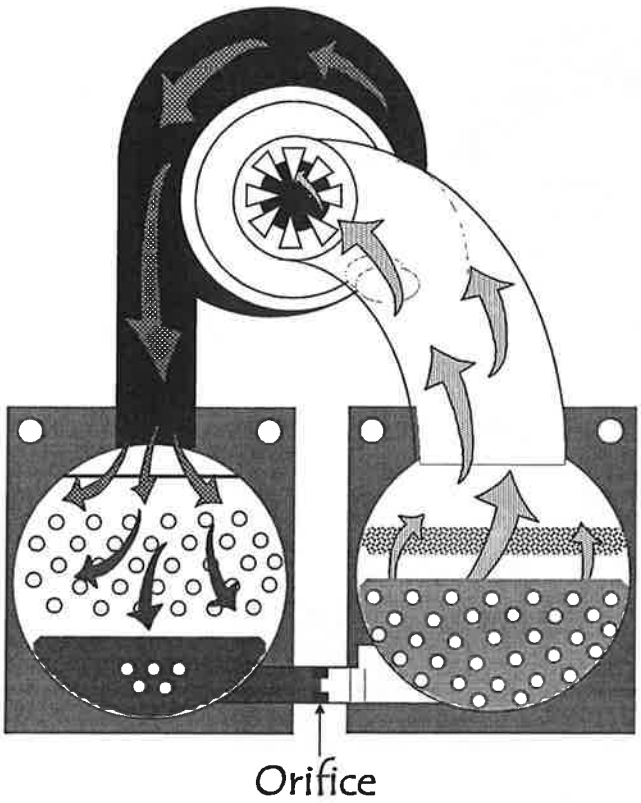


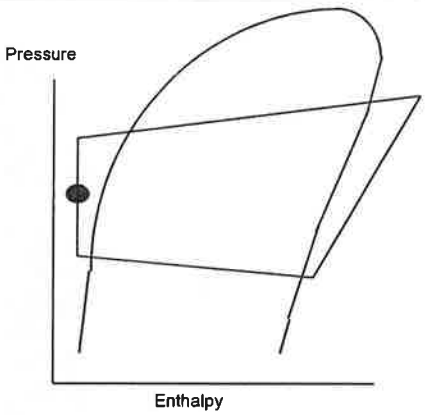

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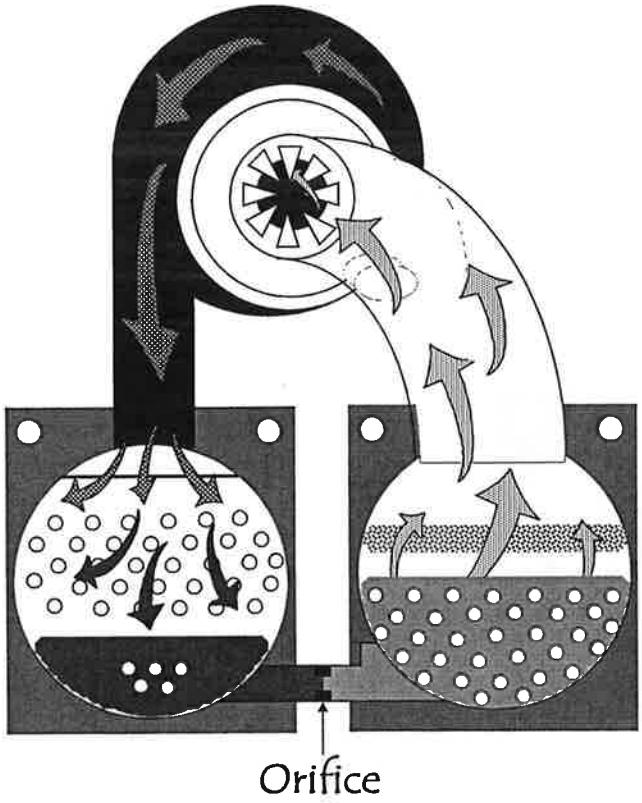


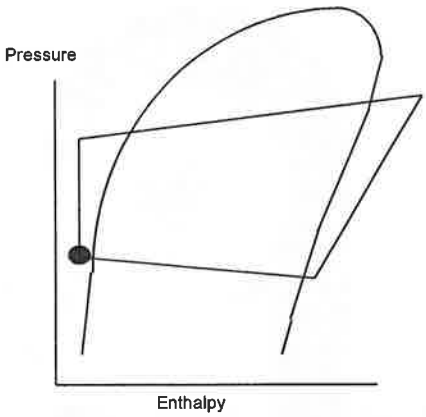


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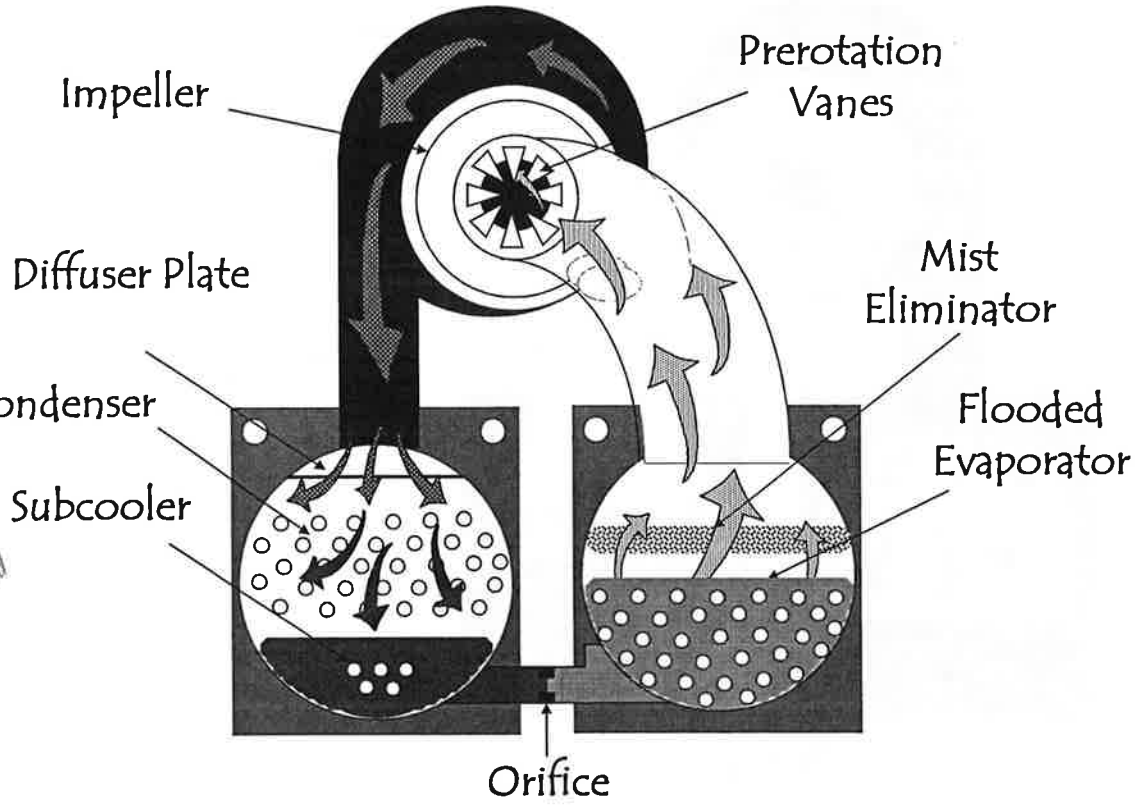
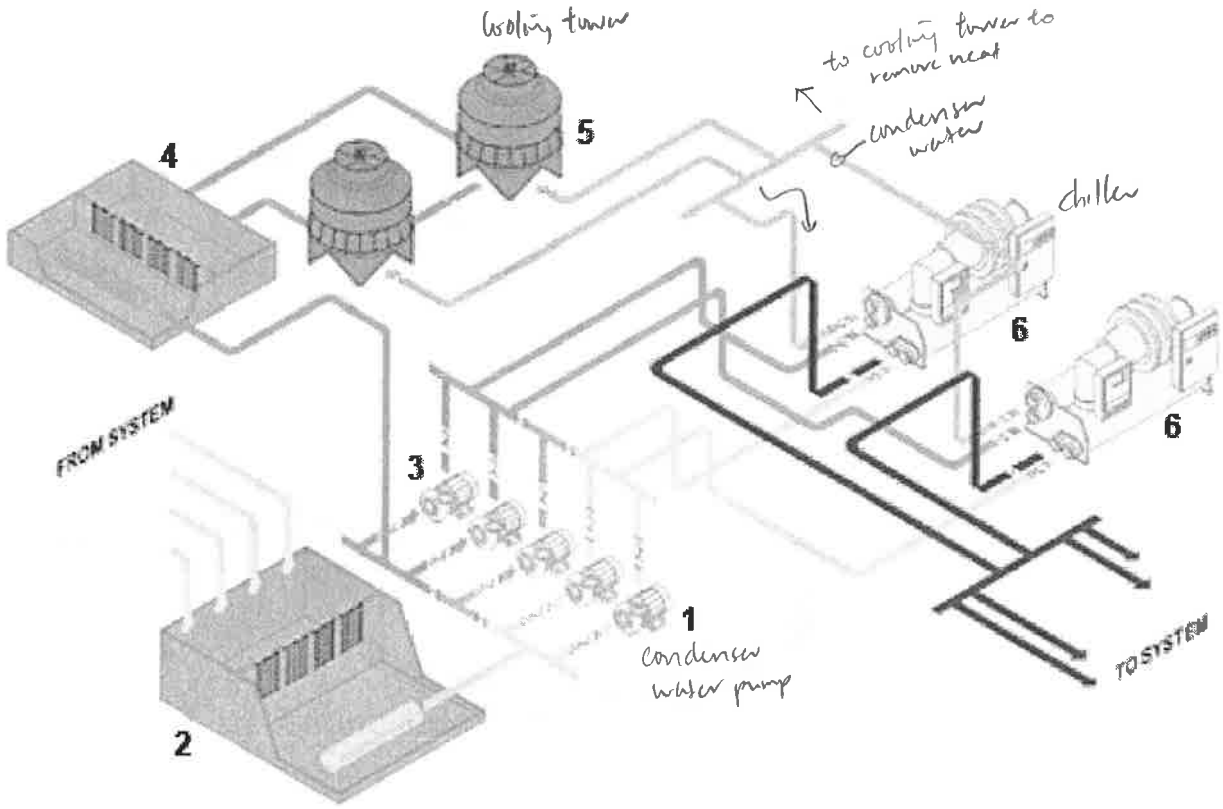
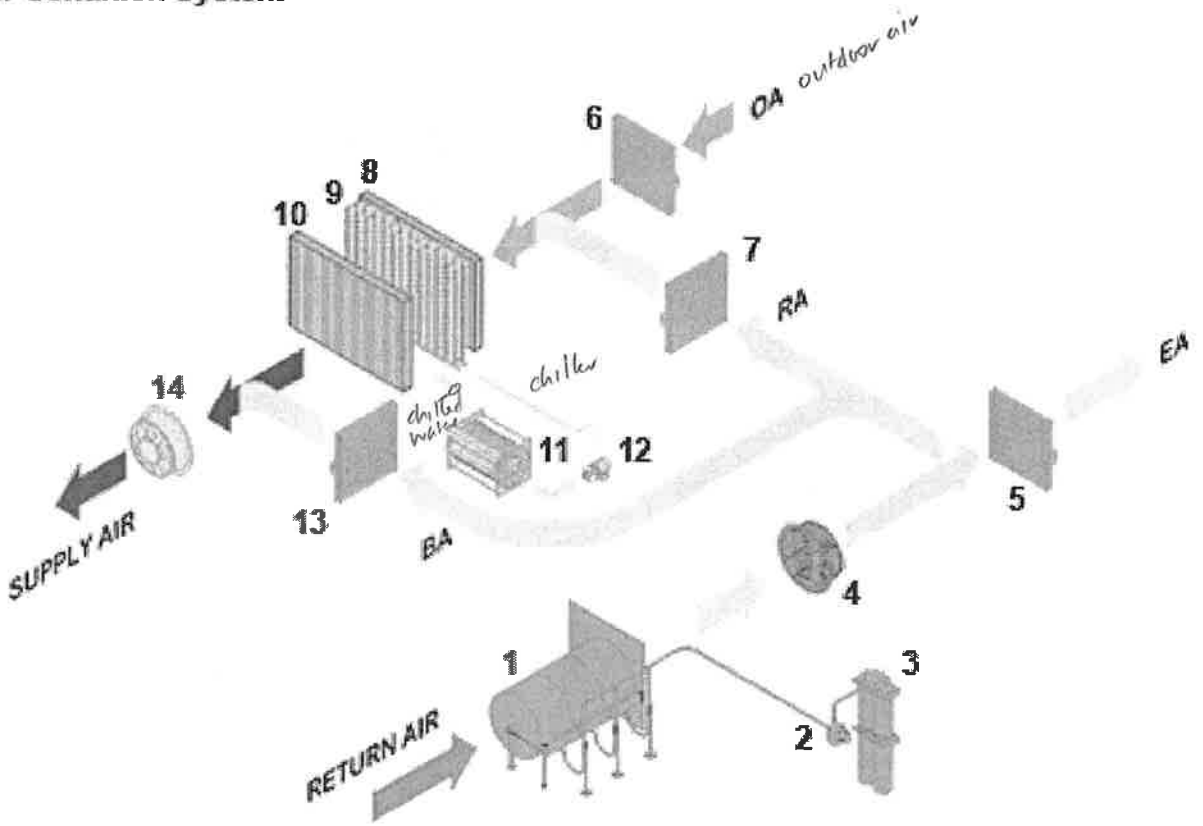



cool by fan for air cooled chiller

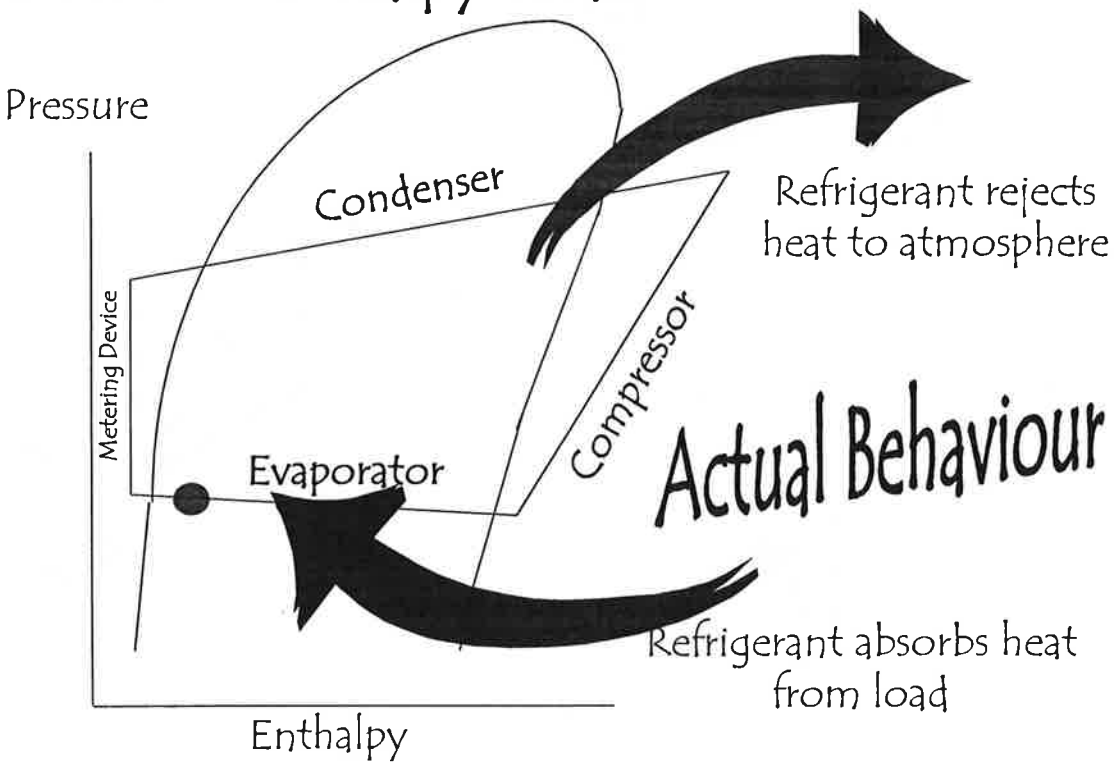
## Chiller System




## Air Condition System

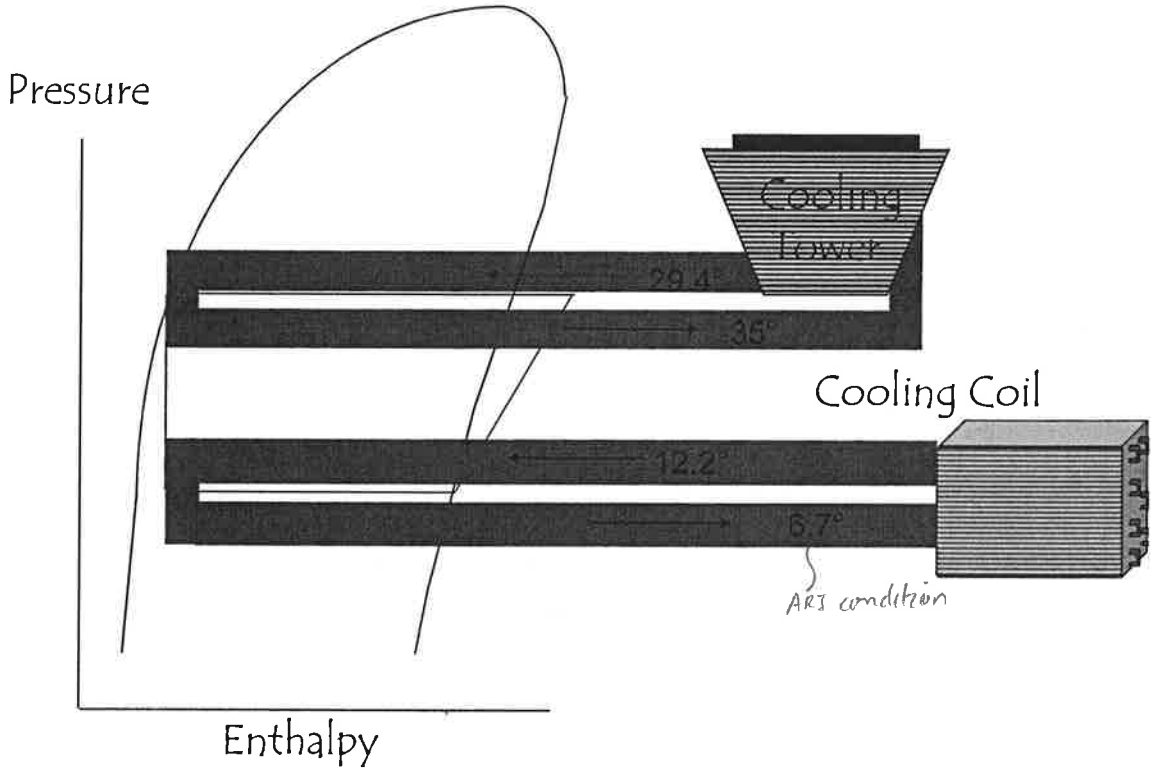


# Pressure - Enthalpy Chart




| Substance | Latent Heat Fusion kJ/kg | Melting Point °C | Latent Heat Vaporization kJ/kg | Boiling Point °C |
|---|---|---|---|---|
| Alcohol, ethyl | 108 | −114 | 855 | 78.3 |
| Ammonia | 339 | −75 | 1369 | −33.34 |
| Carbon Dioxide | 184 | −78 | 574 | −57 |
| Helium | | | 21 | −268.93 |
| Hydrogen | 58 | −259 | 455 | −253 |
| Lead | 24.5 | 327.5 | 871 | 1750 |
| Nitrogen | 25.7 | −210 | 200 | −196 |
| Oxygen | 13.9 | −219 | 213 | −183 |
| R134a | | −101 | 215.9 | −26.6 |
| Toluene | | −93 | 351 | 110.6 |
| Turpentine | | | 293 | |
| Water | 334 | 0 | 2260 (at 100°C) | 100 |

# "Water Chiller" Mechanical Refrigeration

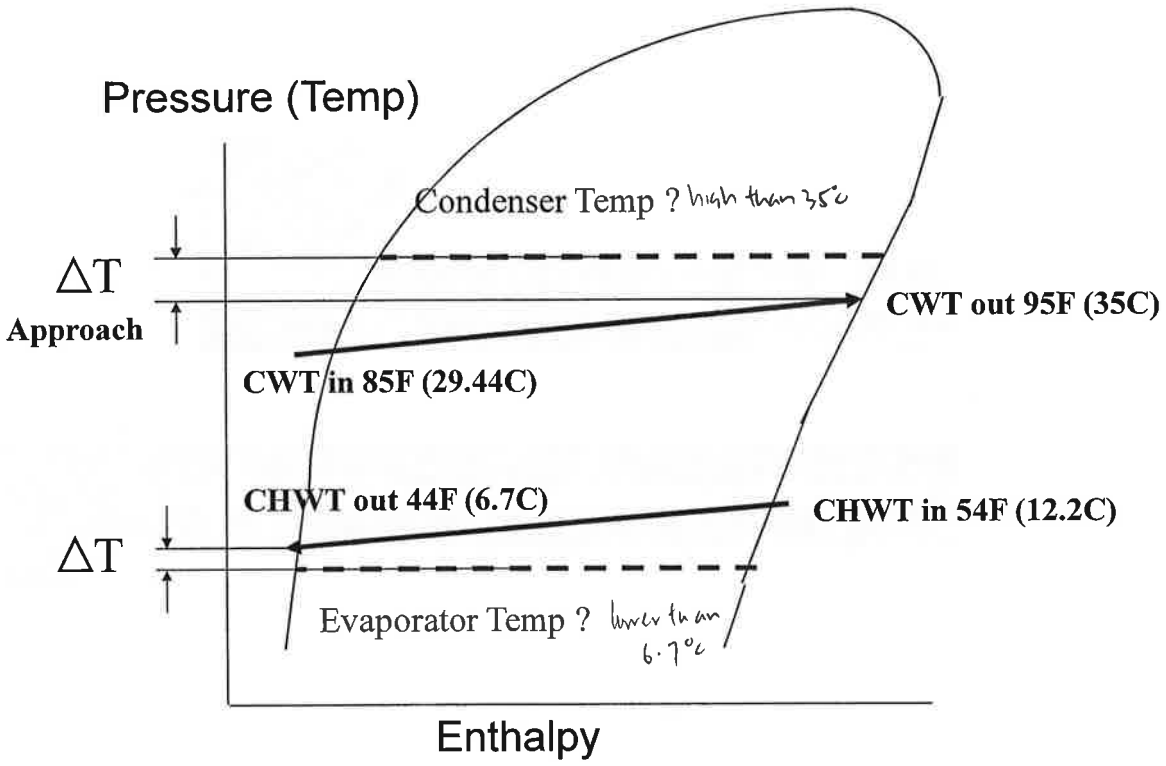




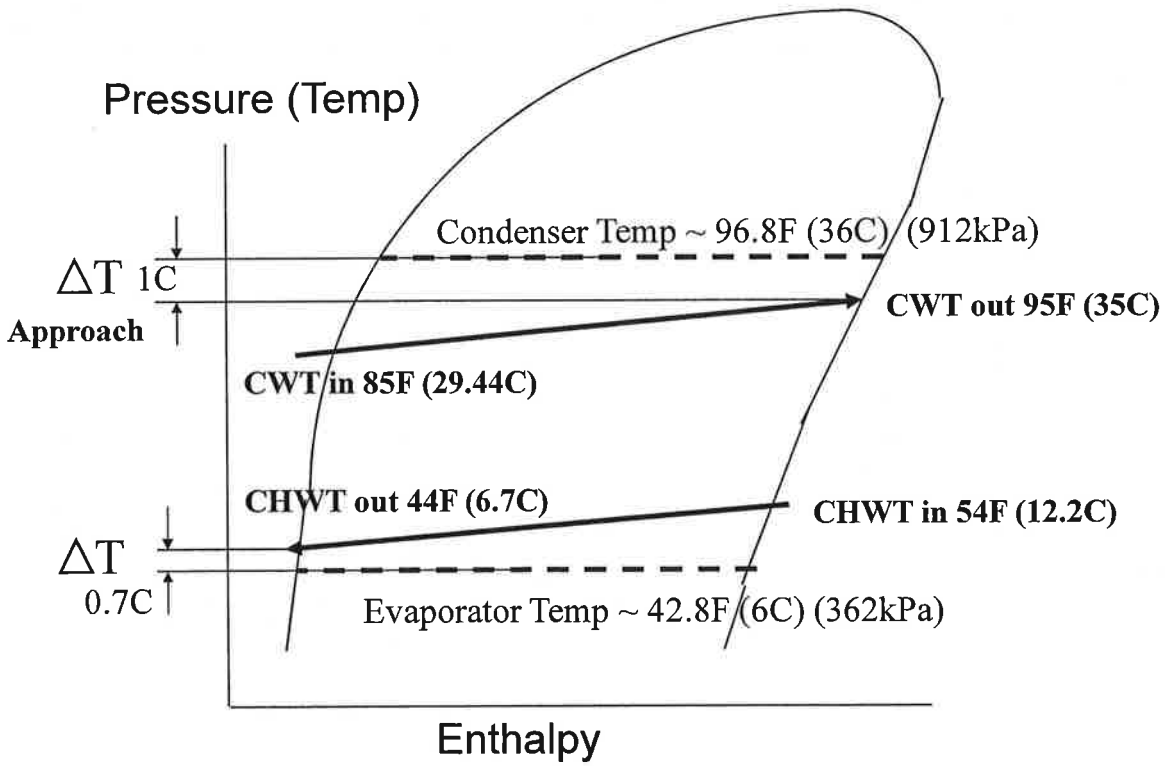

**Refrigerant 134a (1,1,1,2-Tetrafluoroethane) Properties of Saturated Liquid and Saturated Vapor**

| Temp.,* °C | Pressure, MPa | Density, kg/m³ Liquid | Volume, m³/kg Vapor | Enthalpy, kJ/kg Liquid | Enthalpy, kJ/kg Vapor | Entropy, kJ/(kg·K) Liquid | Entropy, kJ/(kg·K) Vapor | Specific Heat $c_p$, kJ/(kg·K) Liquid | Specific Heat $c_p$, kJ/(kg·K) Vapor | $c_p/c_v$ Vapor | Velocity of Sound, m/s Liquid | Velocity of Sound, m/s Vapor | Viscosity, μPa·s Liquid | Viscosity, μPa·s Vapor | Thermal Cond., mW/(m·K) Liquid | Thermal Cond., mW/(m·K) Vapor | Surface Tension, mN/m | Temp., °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| −10.00 | 0.20060 | 1327.1 | 0.09959 | 186.70 | 392.66 | 0.9506 | 1.7334 | 1.316 | 0.854 | 1.167 | 668. | 146.9 | 308.6 | 10.33 | 96.5 | 10.66 | 13.02 | −10.00 |
| −8.00 | 0.21693 | 1320.8 | 0.09242 | 189.34 | 393.87 | 0.9606 | 1.7320 | 1.320 | 0.863 | 1.169 | 658. | 146.9 | 300.6 | 10.41 | 95.6 | 10.83 | 12.72 | −8.00 |
| −6.00 | 0.23428 | 1314.3 | 0.08587 | 191.99 | 395.06 | 0.9705 | 1.7307 | 1.325 | 0.871 | 1.171 | 649. | 147.0 | 292.9 | 10.49 | 94.7 | 11.00 | 12.43 | −6.00 |
| −4.00 | 0.25268 | 1307.9 | 0.07987 | 194.65 | 396.25 | 0.9804 | 1.7294 | 1.330 | 0.880 | 1.174 | 640. | 147.0 | 285.4 | 10.57 | 93.8 | 11.17 | 12.14 | −4.00 |
| −2.00 | 0.27217 | 1301.4 | 0.07436 | 197.32 | 397.43 | 0.9902 | 1.7282 | 1.336 | 0.888 | 1.176 | 631. | 147.0 | 278.1 | 10.65 | 92.9 | 11.34 | 11.85 | −2.00 |
| 0.00 | 0.29280 | 1294.8 | 0.06931 | 200.00 | 398.60 | 1.0000 | 1.7271 | 1.341 | 0.897 | 1.179 | 622. | 146.9 | 271.1 | 10.73 | 92.0 | 11.51 | 11.56 | 0.00 |
| 2.00 | 0.31462 | 1288.1 | 0.06466 | 202.69 | 399.77 | 1.0098 | 1.7260 | 1.347 | 0.906 | 1.182 | 612. | 146.9 | 264.3 | 10.81 | 91.1 | 11.69 | 11.27 | 2.00 |
| 4.00 | 0.33766 | 1281.4 | 0.06039 | 205.40 | 400.92 | 1.0195 | 1.7250 | 1.352 | 0.916 | 1.185 | 603. | 146.8 | 257.6 | 10.90 | 90.2 | 11.86 | 10.99 | 4.00 |
| 6.00 | 0.36198 | 1274.7 | 0.05644 | 208.11 | 402.06 | 1.0292 | 1.7240 | 1.358 | 0.925 | 1.189 | 594. | 146.7 | 251.2 | 10.98 | 89.4 | 12.04 | 10.70 | 6.00 |
| 8.00 | 0.38761 | 1267.9 | 0.05280 | 210.84 | 403.20 | 1.0388 | 1.7230 | 1.364 | 0.935 | 1.192 | 585. | 146.5 | 244.9 | 11.06 | 88.5 | 12.22 | 10.42 | 8.00 |
| 10.00 | 0.41461 | 1261.0 | 0.04944 | 213.58 | 404.32 | 1.0485 | 1.7221 | 1.370 | 0.945 | 1.196 | 576. | 146.4 | 238.8 | 11.15 | 87.6 | 12.40 | 10.14 | 10.00 |
| 12.00 | 0.44301 | 1254.0 | 0.04633 | 216.33 | 405.43 | 1.0581 | 1.7212 | 1.377 | 0.956 | 1.200 | 566. | 146.2 | 232.9 | 11.23 | 86.7 | 12.58 | 9.86 | 12.00 |
| 14.00 | 0.47288 | 1246.9 | 0.04345 | 219.09 | 406.53 | 1.0677 | 1.7204 | 1.383 | 0.967 | 1.204 | 557. | 146.0 | 227.1 | 11.32 | 85.9 | 12.77 | 9.58 | 14.00 |
| 16.00 | 0.50425 | 1239.8 | 0.04078 | 221.87 | 407.61 | 1.0772 | 1.7196 | 1.390 | 0.978 | 1.209 | 548. | 145.7 | 221.5 | 11.40 | 85.0 | 12.95 | 9.30 | 16.00 |
| 18.00 | 0.53718 | 1232.6 | 0.03830 | 224.66 | 408.69 | 1.0867 | 1.7188 | 1.397 | 0.989 | 1.214 | 539. | 145.5 | 216.0 | 11.49 | 84.1 | 13.14 | 9.03 | 18.00 |
| 20.00 | 0.57171 | 1225.3 | 0.03600 | 227.47 | 409.75 | 1.0962 | 1.7180 | 1.405 | 1.001 | 1.219 | 530. | 145.1 | 210.7 | 11.58 | 83.3 | 13.33 | 8.76 | 20.00 |
| 22.00 | 0.60789 | 1218.0 | 0.03385 | 230.29 | 410.79 | 1.1057 | 1.7173 | 1.413 | 1.013 | 1.224 | 520. | 144.8 | 205.5 | 11.67 | 82.4 | 13.53 | 8.48 | 22.00 |
| 24.00 | 0.64578 | 1210.5 | 0.03186 | 233.12 | 411.82 | 1.1152 | 1.7166 | 1.421 | 1.025 | 1.230 | 511. | 144.5 | 200.4 | 11.76 | 81.6 | 13.72 | 8.21 | 24.00 |
| 26.00 | 0.68543 | 1202.9 | 0.03000 | 235.97 | 412.84 | 1.1246 | 1.7159 | 1.429 | 1.038 | 1.236 | 502. | 144.1 | 195.4 | 11.85 | 80.7 | 13.92 | 7.95 | 26.00 |
| 28.00 | 0.72688 | 1195.2 | 0.02826 | 238.84 | 413.84 | 1.1341 | 1.7152 | 1.437 | 1.052 | 1.243 | 493. | 143.6 | 190.5 | 11.95 | 79.8 | 14.13 | 7.68 | 28.00 |
| 30.00 | 0.77020 | 1187.5 | 0.02664 | 241.72 | 414.82 | 1.1435 | 1.7145 | 1.446 | 1.065 | 1.249 | 483. | 143.2 | 185.8 | 12.04 | 79.0 | 14.33 | 7.42 | 30.00 |
| 32.00 | 0.81543 | 1179.6 | 0.02513 | 244.62 | 415.78 | 1.1529 | 1.7138 | 1.456 | 1.080 | 1.257 | 474. | 142.7 | 181.1 | 12.14 | 78.1 | 14.54 | 7.15 | 32.00 |
| 34.00 | 0.86263 | 1171.6 | 0.02371 | 247.54 | 416.72 | 1.1623 | 1.7131 | 1.466 | 1.095 | 1.265 | 465. | 142.1 | 176.6 | 12.24 | 77.3 | 14.76 | 6.89 | 34.00 |
| 36.00 | 0.91185 | 1163.4 | 0.02238 | 250.48 | 417.65 | 1.1717 | 1.7124 | 1.476 | 1.111 | 1.273 | 455. | 141.6 | 172.1 | 12.34 | 76.4 | 14.98 | 6.64 | 36.00 |
| 38.00 | 0.96315 | 1155.1 | 0.02113 | 253.43 | 418.55 | 1.1811 | 1.7118 | 1.487 | 1.127 | 1.282 | 446. | 141.0 | 167.7 | 12.44 | 75.6 | 15.21 | 6.38 | 38.00 |
| 40.00 | 1.0166 | 1146.7 | 0.01997 | 256.41 | 419.43 | 1.1905 | 1.7111 | 1.498 | 1.145 | 1.292 | 436. | 140.3 | 163.4 | 12.55 | 74.7 | 15.44 | 6.13 | 40.00 |
| 42.00 | 1.0722 | 1138.2 | 0.01887 | 259.41 | 420.28 | 1.1999 | 1.7103 | 1.510 | 1.163 | 1.303 | 427. | 139.7 | 159.2 | 12.65 | 73.9 | 15.68 | 5.88 | 42.00 |
| 44.00 | 1.1301 | 1129.5 | 0.01784 | 262.43 | 421.11 | 1.2092 | 1.7096 | 1.523 | 1.182 | 1.314 | 418. | 138.9 | 155.1 | 12.76 | 73.0 | 15.93 | 5.63 | 44.00 |
| 46.00 | 1.1903 | 1120.6 | 0.01687 | 265.47 | 421.92 | 1.2186 | 1.7089 | 1.537 | 1.202 | 1.326 | 408. | 138.2 | 151.0 | 12.88 | 72.1 | 16.18 | 5.38 | 46.00 |
| 48.00 | 1.2529 | 1111.5 | 0.01595 | 268.53 | 422.69 | 1.2280 | 1.7081 | 1.551 | 1.223 | 1.339 | 399. | 137.4 | 147.0 | 13.00 | 71.3 | 16.45 | 5.13 | 48.00 |
| 50.00 | 1.3179 | 1102.3 | 0.01509 | 271.62 | 423.44 | 1.2375 | 1.7072 | 1.566 | 1.246 | 1.354 | 389. | 136.6 | 143.1 | 13.12 | 70.4 | 16.72 | 4.89 | 50.00 |

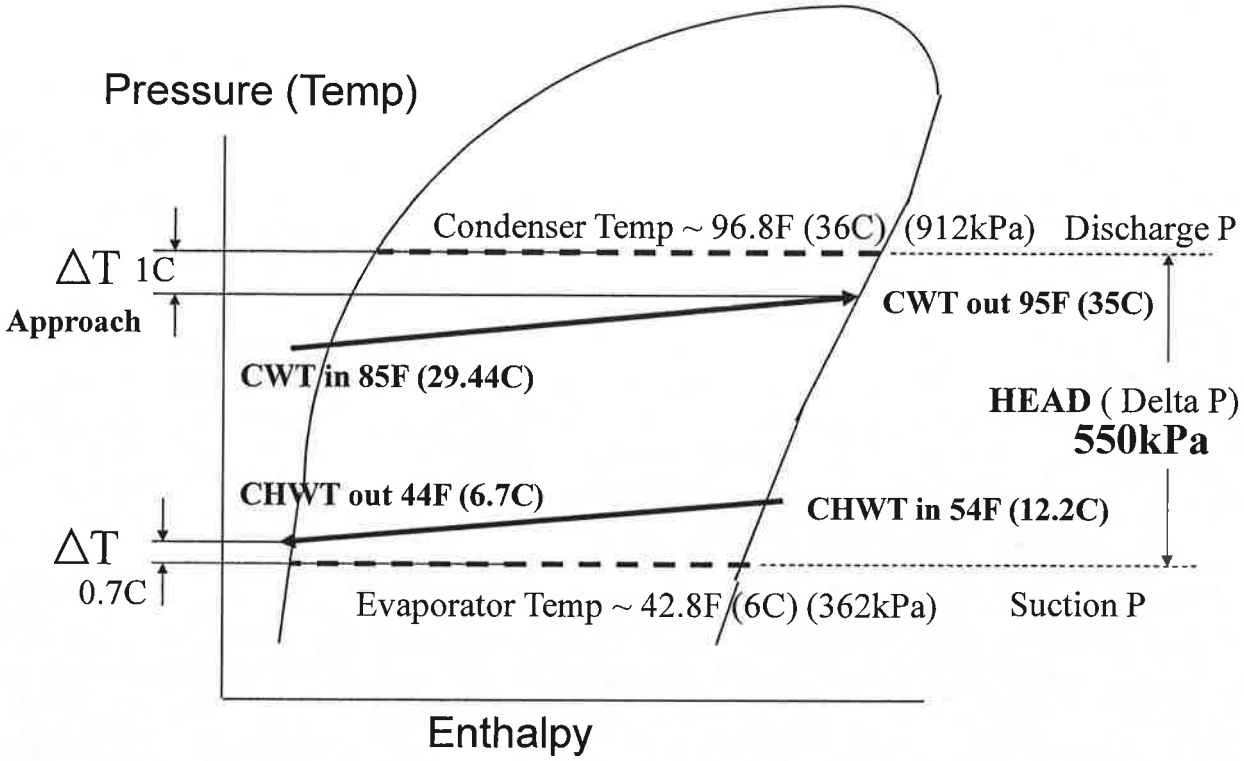
# Pressure - Enthalpy Chart




# Pressure - Enthalpy Chart



# Pressure - Enthalpy Chart





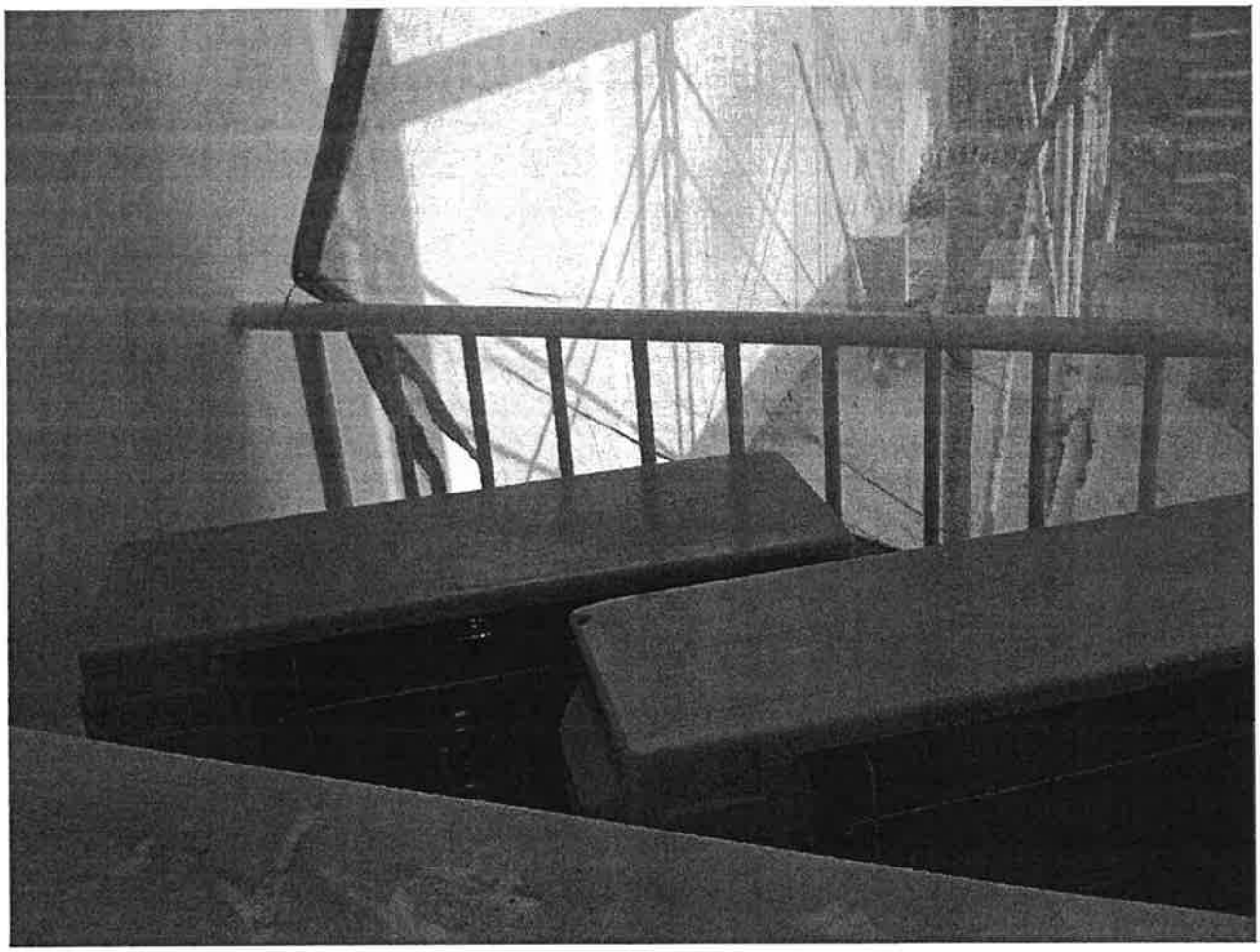





**Table 1 – Unitary air-conditioners and condensing units, electrically operated – Minimum efficiency requirements**

| Equipment type | Size category | Sub-category or rating condition | Minimum efficiency | Test procedure |
|---|---|---|---|---|
| Air-conditioners, air-cooled | < 19 kW | Inverter systems | 3.37 COP | JIS C 9612 |
| | | Non-inverter | 2.49 COP | ISO 5151 |
| | ≥ 19 kW and < 40 kW | Split system and single package | 3.02 COP | ARI 340/360 |
| | ≥ 40 kW and < 70 kW | Split system and single package | 2.84 COP | |
| | ≥ 70 kW and < 223 kW | Split system and single package | 2.78 COP | |
| | ≥ 223 kW | Split system and single package | 2.70 COP | |
| Air-conditioners, water and evaporatively cooled | < 19 kW | Split system and single package | 3.35 COP | ARI 210/240 |
| | ≥ 19 kW and < 40 kW | Split system and single package | 3.37 COP | ARI 340/360 |
| | ≥ 40 kW and < 70 kW | Split system and | | |
| | | package | 2.70 COP | |
| Condensing units, air-cooled | ≥ 40 kW | | 2.96 COP | ARI 365 |
| Condensing units, water or evaporatively cooled | ≥ 40 kW | | 3.84 COP | |

What is COP stand for?

*Coefficient of Performance (COP).* A ratio of the cooling capacity in watts [W] to the Total Power Input, in watts [W] at any given set of Rating Conditions, expressed in watts/watt [W/W].

3.37 COP = 1kW/(3.37kW/3.5172) = 1.044kW/Ton

input 1kw of power → remove 3.37 kw of heat

SS 530 : 2006

Table 2 – Water chilling packages – Minimum efficiency requirements

| Equipment type | Size category | Sub-category or rating condition | Minimum efficiency[a] | Test procedure |
|---|---|---|---|---|
| Air-cooled, with condenser, electrically operated | All capacities | | 2.80 COP | ARI 550/590 |
| Air-cooled, without condenser, electrically operated | All capacities | | 3.10 COP | |
| Water-coo electrical operated, pc displacem (Reciproca | Water-cooled, electrically operated, centrifugal | < 528 kW | | 5.00 COP |
| Water-coo electrica operated, pc displacem (Rotary Scre Scroll) | | ≥ 528 kW and < 1055 kW | | 5.55 COP |
| | | ≥ 1055 kW | | 6.10 COP |
| Water-cooled, electrically operated, centrifugal | ≥ 528 kW and < 1055 kW | | 5.55 COP | ARI 550 |
| | ≥ 1055 kW | | 6.10 COP | |
| Air-cooled absorption single effect | All capacities | | 0.60 COP | |
| Water-cooled absorption single effect | All capacities | | 0.70 COP | |
| Absorption double effect, indirect-fired | All capacities | | 1.00 COP | |
| Absorption double effect, direct-fired | All capacities | | 1.00 COP | |

[a] The chiller equipment efficiency requirements do not apply for chillers used in low temperature applications where the designed leaving fluid temperature is less than 4.4°C.

**300RT & Above**
**0.577kW/Ton or better**

**Table 3. Part-Load Conditions for Rating**

| | IPLV | | NPLV | |
|---|---|---|---|---|
| *Evaporator (All Types)* | | | | |
| 100% load LWT | [2]44.0 °F | 6.7 °C | [2]Selected LWT | [2]Selected LWT |
| 0% load LWT | 44.0 °F | 6.7 °C | Same as 100% load | Same as 100% load |
| Flow Rate (gpm) | [2]2.4 gpm/ton | 0.043 L/s per kW | [2]Selected gpm/ton | [2][L/s per kW] |
| F.F.A. | 0.0001 h · ft2 · °F/Btu | 0.000018 m² · °C/ W | As Specified | As Specified |
| [1]*Water-Cooled Condenser* | | | | |
| 100% load EWT | [2]85.0°F | 29.4 °C | [2]Selected EWT | [2]Selected EWT |
| 75% load EWT | 75.0 °F | 23.9 °C | [4] | [4] |
| 50% load EWT | 65.0 °F | 18.3 °C | [4] | [4] |
| 25% load EWT | 65.0 °F | 18.3 °C | [4] | [4] |
| 0% load EWT | 65.0 °F | 18.3 °C | 65.0 °F | 18.3 °C |
| Flow rate (gpm) [L/s] | [3]3.0 gpm/ton | 0.054 L/s per kW | [3]Selected gpm/ton | [3]L/s per kW |
| F.F.A. | 0.00025 h · ft2 · °F/Btu | 0.000044 m² · °C/ W | As Specified | As Specified |
| [1]*Air-Cooled Condenser* (Use Figure 2) | | | | |
| 100% load EDB | 95.0 °F | 35.0 °C | | |
| 75% load EDB | 80.0 °F | 26.7 °C | | |
| 50% load EDB | 65.0 °F | 18.3 °C | No Rating Requirements | |
| 25% load EDB | 55.0 °F | 12.8 °C | | |
| 0% load EDB | 55.0 °F | 12.8 °C | | |
| F.F.A. | 0.0 h·ft²·°F/Btu | 0.0 m²·°C/W | | |
| [1]*Evaporatively-Cooled Condenser* | | | | |
| 100% load EWB | 75.0 °F | 23.9 °C | No Rating Requirements | |
| 0% load EWB | 50.0 °F | 10.0 °C | | |
| F.F.A. | 0.0 h·ft²·°F/Btu | 0.0 m²·°C/W | | |
| *Air-Cooled Without Condenser* | | | | |
| 100% load SDT | 125.0 °F | 51.7 °C | No Rating Requirements | |
| 0% load SDT | 55.0 °F | 12.8 °C | | |
| *Water and Evaporatively-Cooled Without Condenser* | | | | |
| 100% load SDT | 105.0 °F | 40.6 °C | No Rating Requirements | |
| 0% load SDT | 65.0 °F | 18.3 °C | | |

1 If the unit Manufacturer's recommended minimum temperatures are greater than those specified in Table 3, then those may be used in lieu of the specified temperatures.
2 Corrected for Fouling Factor Allowance by using the calculation method described in C6.3
3 The flow rates are to be held constant at full load values for all part-load conditions.
4 For part-load entering condenser water temperatures, the temperature should vary linearly from the selected EWT at 100% load to 65.0 °F at 50% loads, and fixed at 65.0°F for 50% to 0% loads.

SDT – saturated discharge temperature
LWT – leaving water (liquid) temperature
EWT – entering water (liquid) temperature
EDB – entering air dry-bulb temperature
EWB – entering air wet-bulb temperature
F.F.A. – Fouling Factor Allowance

YORK
A JOHNSON CONTROLS COMPANY

Issue Date: 7/07
Project: Project
Engineer: Sales Eng
Customer: customer

Program: I TC
Rev: v1_74.ddd
Date: 09/25/07
Page: 2 of 2

| MODEL | YRXDXDT3550Q | (MOTOR SELECTED BY USER) | |
|---|---|---|---|
| REFRIGERANT | 134A | | |
| RATED CAPACITY (TR) | 350 | SPECIFIED CAPACITY (TR) | 350 |
| INPUT POWER (KW) | 164 | MAX MOTOR LOAD (KW) | 200 |
| VOLTAGE / HZ | 460 / 60 | | |
| ORIFICE (VARY) | VALVE 3 | | |
| ISOLATION VALVE | NO | | |
| RLA | 302 | LRA | 2145 |
| MIN CIR. AMPS. | 377 | MAX C.B. | 600 |
| INRUSH (AMPS) | 920 | | |
| SSS SIZE | 14LAK 80 | | |
| FULL LOAD (KW/TR) | 0.526 | NPLV | 0.427 |

STARTER TYPE (1) SOLID STATE STARTER - 3 LEAD

| | Evaporator | Condenser |
|---|---|---|
| FLUID | WATER* | WATER* |
| % BY WEIGHT | 0.0* | 0.0* |
| TUBE MTI NO. | 281* | 260* |
| PASSES | 2* | 2* |
| FOUL FACTOR | 0.00010* | 0.00025* |
| FLUID ENT TEMP (°F) | 60.80 | 85.00* |
| FLUID LEV TEMP (°F) | 46.40* | 94.22 |
| FLUID FLOW (gpm) | 583.3* | 1050.0* |
| FLUID PRDROP (ft) | 7.9 | 13.9 |

(*) Designates Specified Input

PART LOAD PERFORMANCE:

| Pct Load | CAP (TR) | Pct Power | Inp Pwr (KW) | EEFT (°F) | ELFT (°F) | CEFT (°F) | CLFT (°F) | Sys Perf (KW/TR) |
|---|---|---|---|---|---|---|---|---|
| 100.0 | 350.0 | 100.0 | 164 | 60.80 | 46.40 | 85.00 | 94.22 | 0.526 |
| 90.0 | 315.0 | 88.0 | 162 | 59.36 | 46.40 | 85.00 | 93.20 | 0.514 |
| 80.0 | 280.0 | 78.3 | 144 | 57.92 | 46.40 | 85.00 | 92.35 | 0.514 |
| 70.0 | 245.0 | 69.0 | 127 | 56.48 | 46.40 | 85.00 | 91.45 | 0.518 |
| 60.0 | 210.0 | 61.4 | 113 | 55.04 | 46.40 | 85.00 | 90.55 | 0.539 |
| 50.0 | 175.0 | 54.9 | 101 | 53.60 | 46.40 | 85.00 | 89.67 | 0.577 |
| 40.0 | 140.0 | 50.0 | 92 | 52.16 | 46.40 | 85.00 | 88.81 | 0.657 |
| 30.0 | 105.0 | 46.7 | 86 | 50.72 | 46.40 | 85.00 | 87.97 | 0.819 |
| 25.4 | 88.9 | 45.7 | 84 | 50.06 | 46.40 | 85.00 | 87.59 | 0.945 |

Rating certified in accordance with ARI STD. 550/590.
Water-chilling packages using the vapor compression cycle certification program.
Compliant with ASHRAE 90.1

Materials and construction per mechanical specifications - Form 160.81-EG1.

YORK
A JOHNSON CONTROLS COMPANY

Issue Date: 7/07
Project: Project
Engineer: Sales Eng
Customer: customer

Program: LTC
Rev: v1 74.idd
Date: 09/25/07
Page: 2 of 2

| MODEL | YKKKKMH95COP | (MOTOR SELECTED BY USER) | |
|---|---|---|---|
| REFRIGERANT | 134A | GEAR CODE | RKISPEC |
| RATED CAPACITY (TR) | 750 | SPECIFIED CAPACITY (TR) | 750 |
| INPUT POWER (KW) | 373 | MAX MOTOR LOAD (KW) | 397 |
| VOLTAGE / HZ | 400 / 50 | | |
| ORIFICE (VARY) | VALVE3 | OPTISOUND CONTROL | YES |
| ISOLATION VALVE | NO | | |
| FLA | 625 | LRA | 4633 |
| MIN CIR. AMPS. | 779 | MAX C.B. | 1200 |
| INRUSH (AMPS) | 1980 | | |
| SSS SIZE | 26LBK-50 | | |
| FULL LOAD (KW/TR) | 0.497 | NPLV | 0.425 |

STARTER TYPE (1) SOLID STATE STARTER - 3 LEAD

| | Evaporator | Condenser |
|---|---|---|
| FLUID | WATER* | WATER* |
| % BY WEIGHT | 0.0* | 0.0* |
| TUBE MTI NO. | 271* | 260* |
| PASSES | 2* | 2* |
| FOUL FACTOR | 0.00010* | 0.00025* |
| FLUID ENT TEMP (°F) | 60.80 | 85.00* |
| FLUID LEV TEMP (°F) | 45.40* | 91.10 |
| FLUID FLOW (gpm) | 1250.0* | 2250.0* |
| FLUID PRDROP (ft) | 8.8 | 16.3 |

(*) Designates Specified Input

PART LOAD PERFORMANCE:

| Pct Load | CAP (TR) | Pct Power | Inp Pwr (KW) | EEFT (°F) | ELFT (°F) | CEFT (°F) | CLFT (°F) | Sys Perf (KW/TR) |
|---|---|---|---|---|---|---|---|---|
| 100.0 | 750.0 | 100.0 | 373 | 60.80 | 45.40 | 85.00 | 94.11 | 0.497 |
| 90.0 | 675.0 | 90.6 | 338 | 59.36 | 45.40 | 85.00 | 93.20 | 0.501 |
| 80.0 | 600.0 | 81.2 | 303 | 57.92 | 45.40 | 85.00 | 92.30 | 0.505 |
| 70.0 | 525.0 | 73.7 | 275 | 56.48 | 45.40 | 85.00 | 91.42 | 0.524 |
| 60.0 | 450.0 | 64.6 | 241 | 55.04 | 45.40 | 85.00 | 90.51 | 0.536 |
| 50.0 | 375.0 | 56.2 | 206 | 53.60 | 45.40 | 85.00 | 89.61 | 0.549 |
| 40.0 | 300.0 | 46.1 | 172 | 52.16 | 45.40 | 85.00 | 88.70 | 0.573 |
| 30.0 | 225.0 | 37.3 | 139 | 50.72 | 45.40 | 85.00 | 87.80 | 0.618 |
| 20.0 | 150.0 | 28.4 | 106 | 49.28 | 45.40 | 85.00 | 86.90 | 0.707 |
| 16.6 | 124.6 | 25.5 | 95 | 48.79 | 45.40 | 85.00 | 86.59 | 0.763 |

Rating certified in accordance with ARI STD. 550/590.
Water-chilling packages using the vapor compression cycle certification program.
Compliant with ASHRAE 90.1

Materials and construction per mechanical specifications - Form 160.73-EG1.

b. Use the following equation to calculate the IPLV or NPLV.

integrated part load value

$$\text{IPLV or NPLV} = 0.01A + 0.42B + 0.45C + 0.12D$$

non-standard part load value

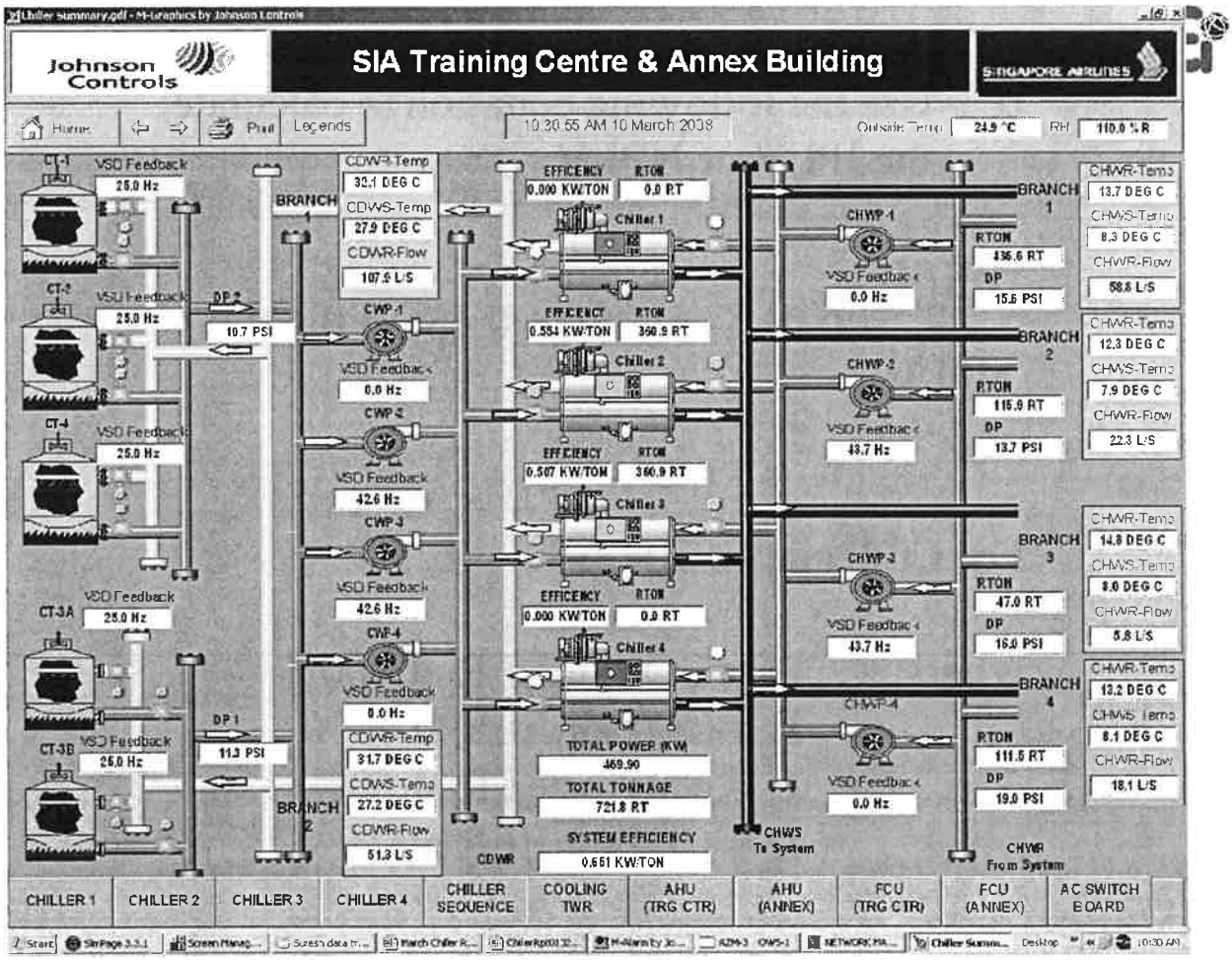
For COP and EER:

where: A = COP or EER at 100%
B = COP or EER at 75%
C = COP or EER at 50%
D = COP or EER at 25%

For kW/ton:

$$\text{IPLV or NPLV} = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}}$$

where: A = kW/Ton at 100%
B = kW/Ton at 75%
C = kW/Ton at 50%
D = kW/Ton at 25%



# Plantroom Efficiency

| | Benchmark Reference | Version 4 (kW/Ton) |
|---|---|---|
| **Chiller (Centrifugal > 300RT)** | SS530 | 0.577 |
| **Chilled Water Pumps** | CP13 | 0.0533 |
| **Condenser Water Pumps** | CP13 | 0.046 |
| **Cooling Towers** | CP24 | 0.058 |
| **Total Plantroom System** | | 0.734 |

Minimum requirement for GM version 4

## Version 4 – Pre-requisite Requirements

BCA Green Mark Gold$^{plus}$ and Platinum Rating

Air-Conditioned Buildings

## Projects should achieve:

At least 25% energy savings to qualify GM Gold$^{plus}$ rating

At least 30% energy savings to qualify for GM Platinum rating

# Version 4 – Pre-requisite Requirements

Air-Conditioned Buildings

## Projects should achieve:

ETTV of 42 W/m$^2$ to qualify GM Gold$^{plus}$ rating

ETTV of 40 W/m$^2$ to qualify for GM Platinum rating

## Prescribed System Efficiency of Air-Conditioning System

For Buildings using Water-cooled Central Chilled-Water Plant:

| Green Mark Rating | Cooling Load (RT) | |
|---|---|---|
| | < 500 | ≥ 500 |
| | Efficiency (kW/RT) | |
| Certified | **0.8** | **0.7** |
| Gold | 0.8 | 0.7 |
| Goldplus | 0.7 | 0.65 |
| Platinum | 0.7 | 0.65 |

Expected Operating efficiency of the system at part-load condition or full-installed capacity

# Prescribed System Efficiency of Air-Conditioning System

For Buildings using Air-cooled Central Chilled-Water Plant or Unitary Air-Conditioners:

| Green Mark Rating | Cooling Load (RT) | |
|---|---|---|
| | < 500 | ≥ 500 |
| | Efficiency (kW/RT) | |
| **Certified** | **0.9** | **0.8** |
| Gold | 0.9 | Not Applicable |
| Goldplus | 0.85 | |
| Platinum | 0.78 | |

Expected Operating efficiency of the system at part-load condition or full-installed capacity

# Water-Cooled Chilled-Water Plant

**Peak Building Cooling Load ≥ 500RT**

15 points for meeting the prescribed chiller plant efficiency of 0.7 kW/RT

0.25 points for every percentage improvement in the chiller plant efficiency over the baseline

Points scored = 0.25 x (% improvement)

(Up to 20 points)

# Water-Cooled Chilled-Water Plant

## Peak Building Cooling Load < 500RT

12 points for meeting the prescribed chiller plant efficiency of 0.8kW/RT

0.45 points for every percentage improvement in the chiller plant efficiency over the baseline

Points scored = 0.45 x (% improvement)

(Up to 20 points)

# Air-Cooled Chilled-Water Plant / Unitary Air-Conditioners

## Peak Building Cooling Load ≥ 500RT

12 points for meeting the prescribed chiller plant efficiency of 0.8kW/RT

1.3 points for every percentage improvement in the chiller plant efficiency over the baseline

Points scored = 1.3 x (% improvement)

(Up to 20 points)

# Air-Cooled Chilled-Water Plant / Unitary Air-Conditioners

**Peak Building Cooling Load < 500RT**

10 points for meeting the prescribed chiller plant efficiency of 0.9kW/RT

0.6 points for every percentage improvement in the chiller plant efficiency over the baseline

Points scored = 0.6 x (% improvement)

(Up to 20 points)

# Air Distribution System

Baseline: SS 553 : 2009 Table 2 – Fan Power Limitation in Air-Conditioning System.

| Constant Volume | Variable Volume |
|---|---|
| 1.7 kW/$m^3$/sec<br>0.472 W / CMH | 2.4 kW/$m^3$/sec<br>0.667 W / CMH |

motor power →

Points awarded = 0.2 x (% improvement) (Up to 6 Points)

(30% improvement up to 6 points)

## Provision of Permanent measuring instruments (water-cooled plant efficiency in accordance to ASHRAE Guide 22 – 1 Pre-requisite point

Detail Requirements

1) Location & installation of measuring devices to meet the manufacturer's recommendation
2) Data acquisition system : Analog-to-digital or A/D converter used should have a minimum resolution of 16-bit
3) Data logging software should trend at 1 minute sampling time interval
4) Flow meters/temperature sensors must comply to NEA guidelines
5) Provision of spare thermo-wells or hot-tapping points for side-by-side sensors verification of accuracy.

## Basic M&V Requirement

- Understanding the system to measurement
- Get audit objective or expected result
- Select correct instrument to use
- Understanding the instrument characteristic to maintain *Accuracy*
- Input correct range in the instrument & data logger

# Variable Speed Controls

1 point provision of VSD controls for chilled-water pumps and cooling tower fans to ensure better part-load plant efficiency.

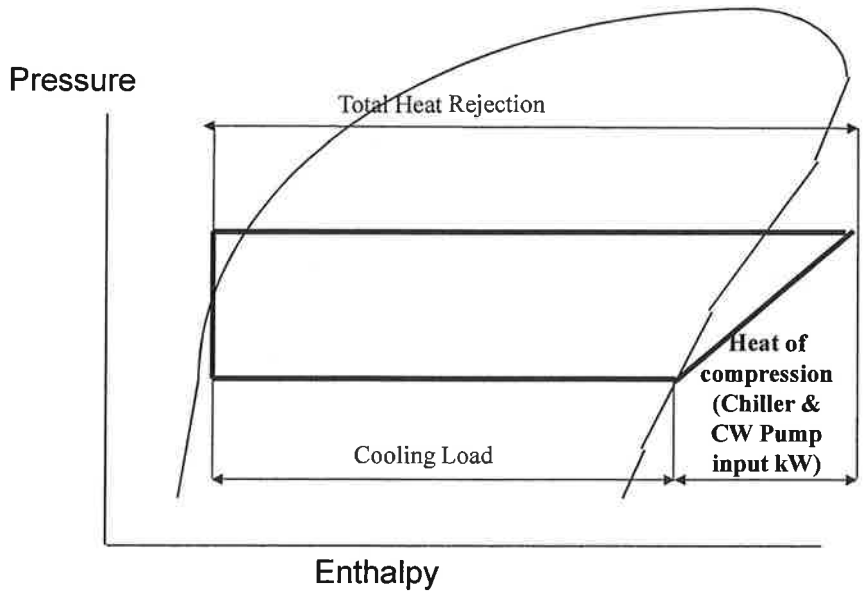
# Sensors / Automatic Control Devices

To regulate outdoor air flow to maintain concentration of carbon dioxide in accordance to SS 554:2009.

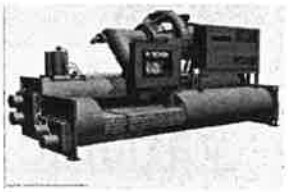
1 point awarded for the use of carbon dioxide sensors

Central Chilled-Water Plant Efficiency Verification:

Heat Balance – Substantiating test – 1 point



# CHILLER:



- ✓ To configure Chiller Plant in a way that it operates at most efficient zone at most time;
- ✓ Design should allow minimum water pressure loss at both shells while maintaining turbulence flow at water tubes
- ✓ Design parameters should allow for low compressor head capability, increase evaporator mean saturated temp/pressure by variable flow thus improve chiller efficiency and prevent pipe freeze;
- ✓ Off-peak operating chiller should provide flexibility with load fluctuation and yet maintain good efficiency
- ✓ Explore hybrid system (brand and refrigerant)
- ✓ To Install Auto Tube Cleaning System at Condenser Water Side to maintain Chiller Efficiency.
- ✓ Chiller should also comes with good motor efficiency and power factor

## Parameters Affecting Chiller Selection and Performance

### Calculation of Chiller Operating Cost Based On:

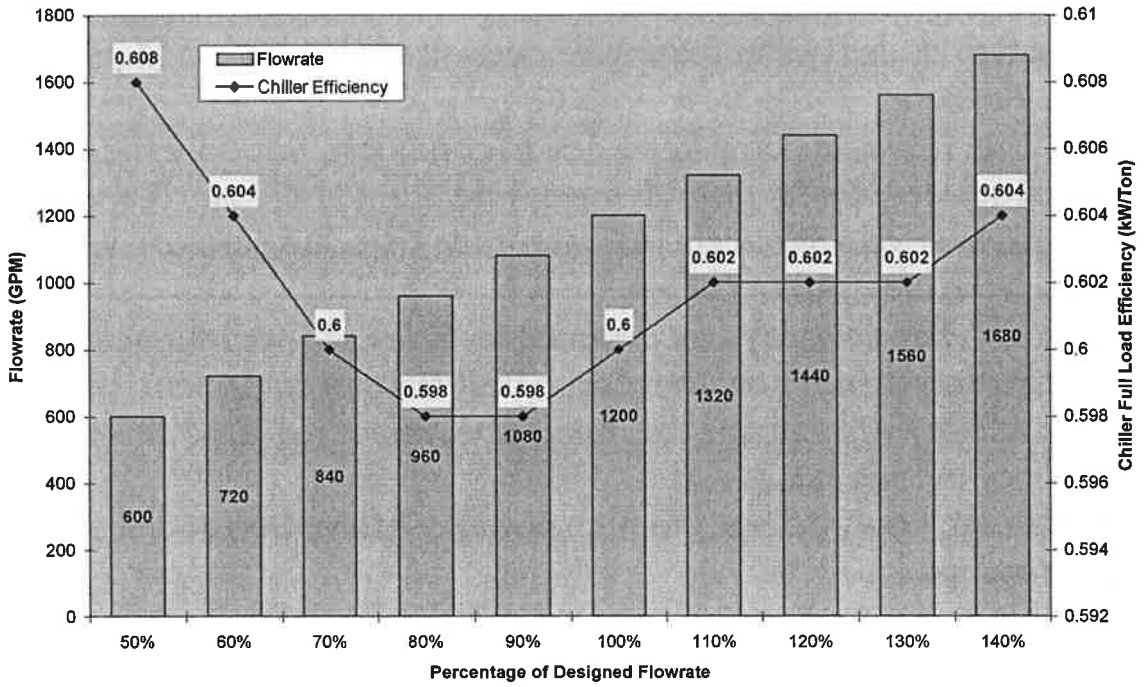
| | |
|---|---|
| Chiller Type: | R134A Water-cooled Centrifugal |
| Model: | YKCFCFP65CLF (500Tons) |
| Average Operating Load: | 800 Ton (2 x 500Tons) |

## *High Chilled water Flowrate in chiller*

1. Very often chilled-water pumps are over-sized that lead to high chilled water Flowrate.
2. With over Flowrate compare to design condition, not only the chiller cannot achieve low set point temperature during full load, it also leads to high water velocity in chilled water tube that cause erosion which shorten the life-span of chiller.
3. As most tubes nowadays are designed to have enhanced surface so as to create turbulence flow to increase heat transfer coefficient, high water velocity will damage the inner tube surface reducing chiller efficiency in long run.
4. Over design flow also leads to high power consumption at chilled water pumps.

## *Low Chilled water Flowrate in Chiller*

1. In the event when supply chilled water Flowrate is too low compare to designed condition, there's an increase risk of freezing, this will lead to power variation in the chiller and supply water temperature to the point at which control of the output temperature may become unstable.
2. Every evaporator shell comes with a minimum recommended Flowrate. The minimum chilled water Flowrate of evaporator shell varies because all shells have different water velocity in tubes, higher the water velocity, more rooms to reduce the flow.
3. The recommended Flowrate of chilled water is 2.4 gallons per minute per refrigerant tonnage (According to ARI standard) and water velocity in tubes range 1 to 3.3 metres per second.

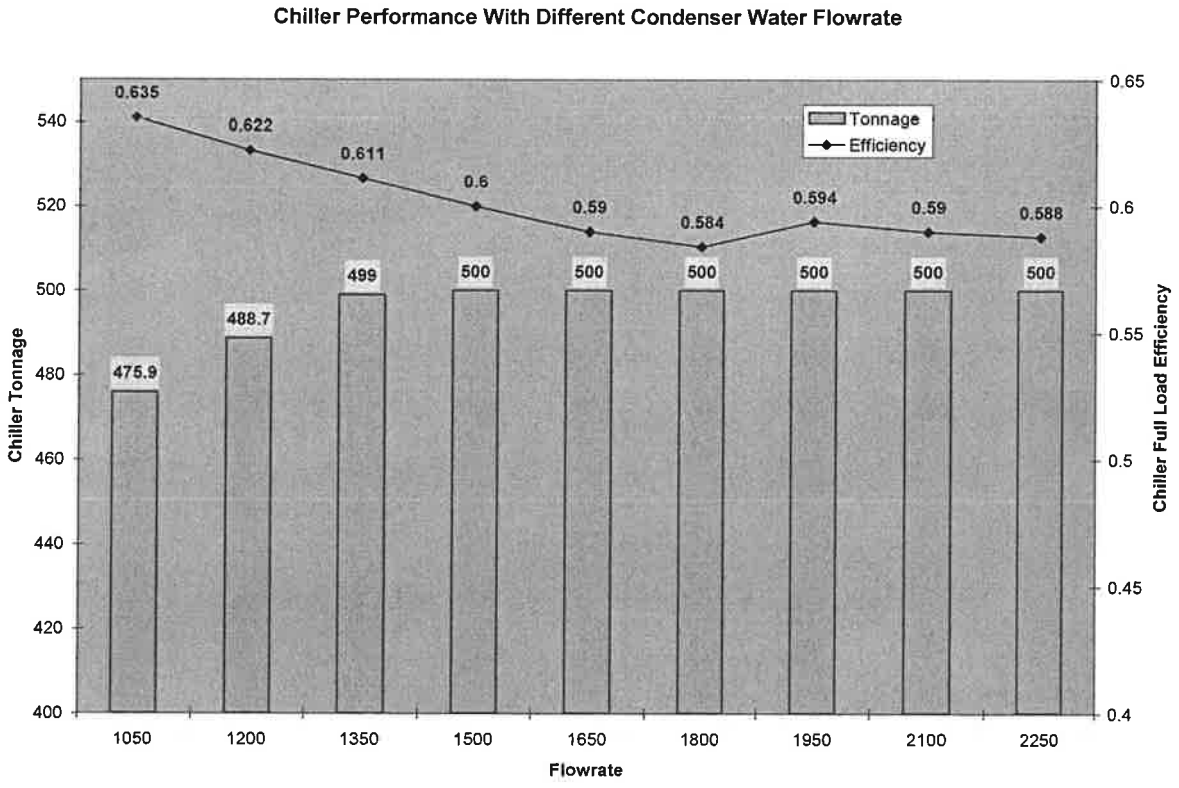



## Too high Condenser water Flowrate in chiller

1. Over flow in condenser shell will helps to improve slightly on chiller efficiency but it leads to the same issue like the evaporator, causing erosion at condenser inner tube surface shortening tubes life-span.
2. Over pumping of condenser water also leads to high power consumption at condenser pumps.

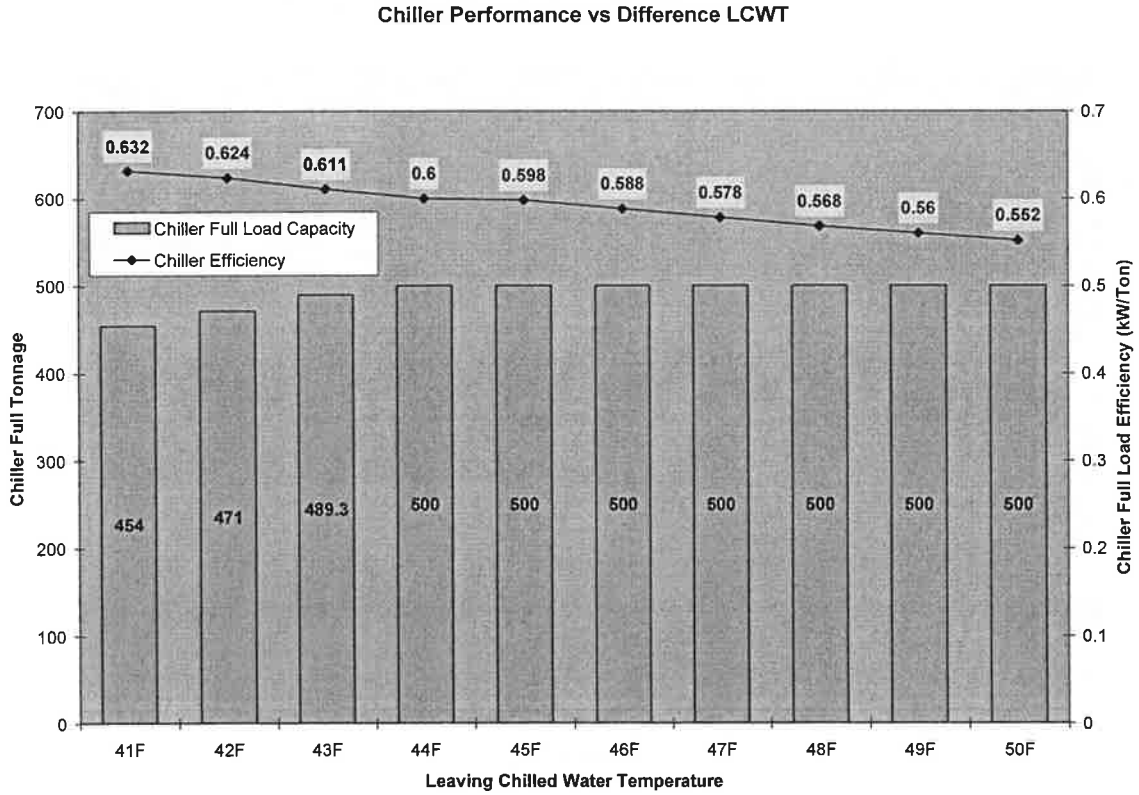
## *Too Low Condenser water Flowrate in Chiller*

1. It is strongly recommended to ensure condenser Flowrate should not be lower than recommended Flowrate of 3 gallons per minute per refrigerant tonnage (According to ARI standard).
2. In the event when condenser flow is too low, it will leads to poor chiller efficiency, capacity shortage at chiller, high compressor head causing surge and vibration which is very damaging to chiller life-span.



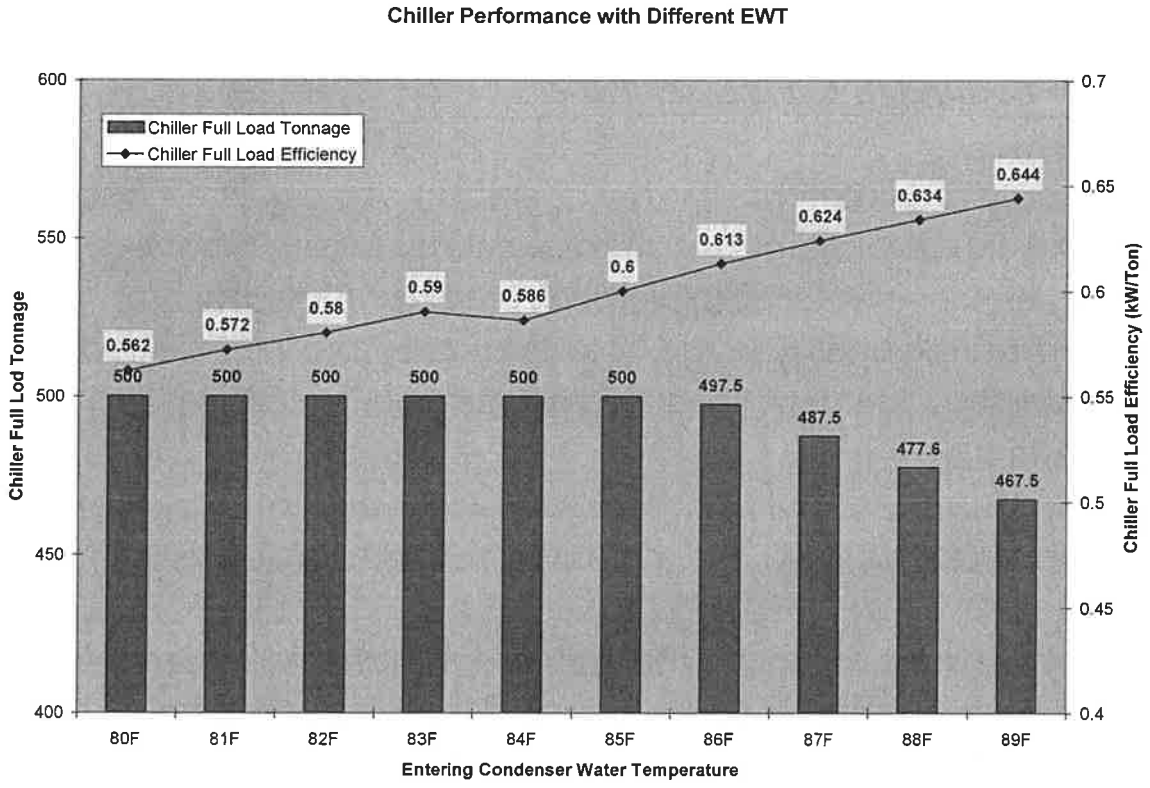
## *Different Leaving Chilled Water Temperature*

1. The design set point of the chilled water supply temperature is normally selected to satisfy the demand of the associated cooling coils under worst cooling conditions.
2. During normal operations, the building loads are usually lower than the designed worst cooling conditions. The worst case set point will be wasting energy by requiring the chilled water to be unnecessarily cold.
3. Chiller efficiency improves by 2% every 1˚C increase in chilled water supply temperature. Chilled water supply temperature setting on chillers can be reset manually or automatically with microprocessor controlled device.



# Different Entering Condenser Water Temperature

1. It is strongly recommended to design low entering condenser water temperature.
2. Very often the entering water temperature which is also the cooling tower supply temperature is depends on ambient wet bulb condition. Even though at times the wet bulb condition may be high, it is advisable to design cooling tower water leaving water temperature below 30 C. In the event when designer uses high entering water temperature, the cooling tower will be smaller as compare to low entering water temperature.
3. Chillers design using high entering water temperature, need bigger condenser shell, compressor and motor size. Not only it hurts initial investment, it also increases chance of surging and operating cost.
4. Lowering the cooling water temperature gives better chiller efficiency. It is always advisable to operate more cooling towers using variable speed drive to reduce power consumption at cooling tower motors and lowering condenser water temperature to improve chiller efficiency.



| Condenser Leaving (F) | 95 | 96 | 97 | 98 | 99 | 100 |
|---|---|---|---|---|---|---|
| Condenser Entering (F) | 85 | 86 | 87 | 88 | 89 | 90 |
| 500TR | | | | | | |
| Chiller Model | YTJ3C2E25CMJ | YTJ3C2E25CMJ | YTK1C3E25CMJ | YTK3C4E25CMJ | YTL1D1E25CMJ | YTL3D3E25CMJ |
| PD Evaporator (ft) | 12.3 | 12.3 | 10.6 | 7.9 | 6.7 | 5.1 |
| PD Condenser (ft) | 18.8 | 18.8 | 15.7 | 13.1 | 10.9 | 7.5 |
| Pump kW Evap. | 4.089 | 4.089 | 3.524 | 2.626 | 2.227 | 1.695 |
| Pump kW Cond. | 7.812 | 7.812 | 6.524 | 5.444 | 4.530 | 3.117 |
| Chiller Kw/Ton | 0.55 | 0.562 | 0.57 | 0.58 | 0.59 | 0.6 |
| Chiller input kW | 275 | 281 | 285 | 290 | 295 | 300 |
| Chiller Cost (US$) | 109,564 | 109,564 | 116,229 | 121,518 | 126,377 | 134,203 |
| | | | | | | |
| **SHINWA** | | | | | | |
| Cooling Tower | | | | | | |
| Fan kW | 22.5 | 19.6 | 16.8 | 13.9 | 11 | 11 |
| Cost (US$) | 22,000 | 20,250 | 18,500 | 16,750 | 15,000 | 15,000 |
| | | | | | | |
| Total kW | 309.40 | 312.50 | 311.85 | 311.97 | 312.76 | 315.81 |
| Total Cost (US$) | 131,564 | 129,814 | 134,729 | 138,268 | 141,377 | 149,203 |

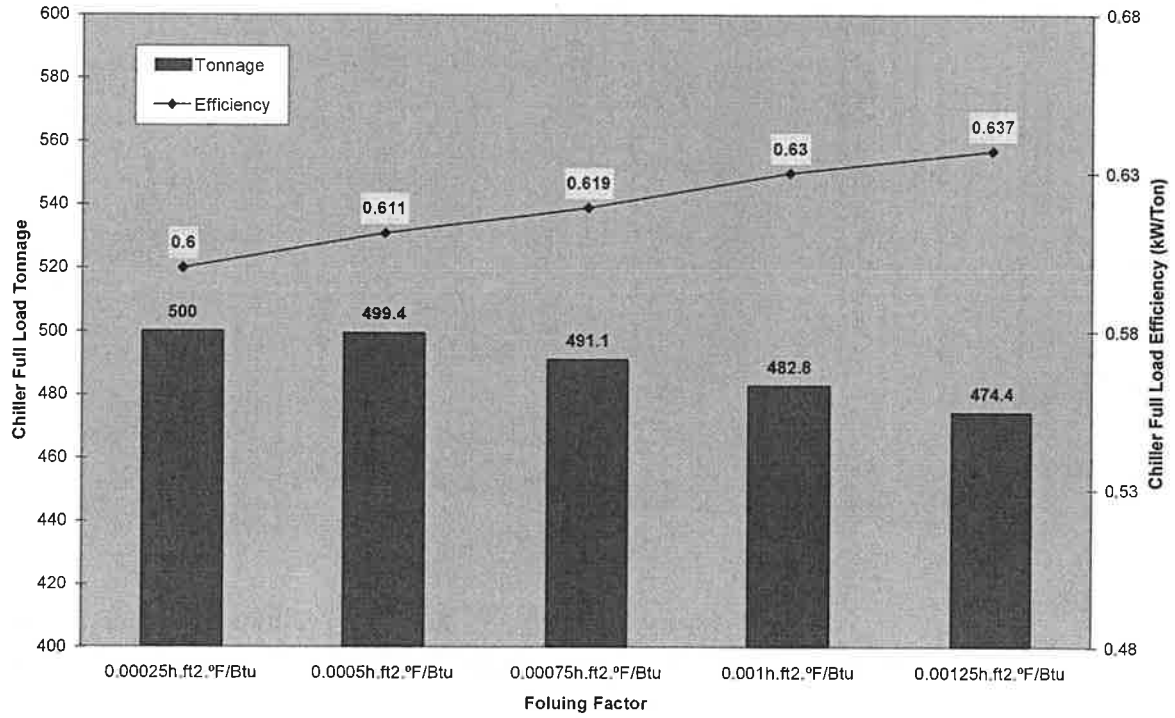



$$\frac{\text{GPM} \times \Delta P \text{ (ft)}}{3960 \times \text{pump eff.} \times \text{motor eff.}} \times 0.746$$

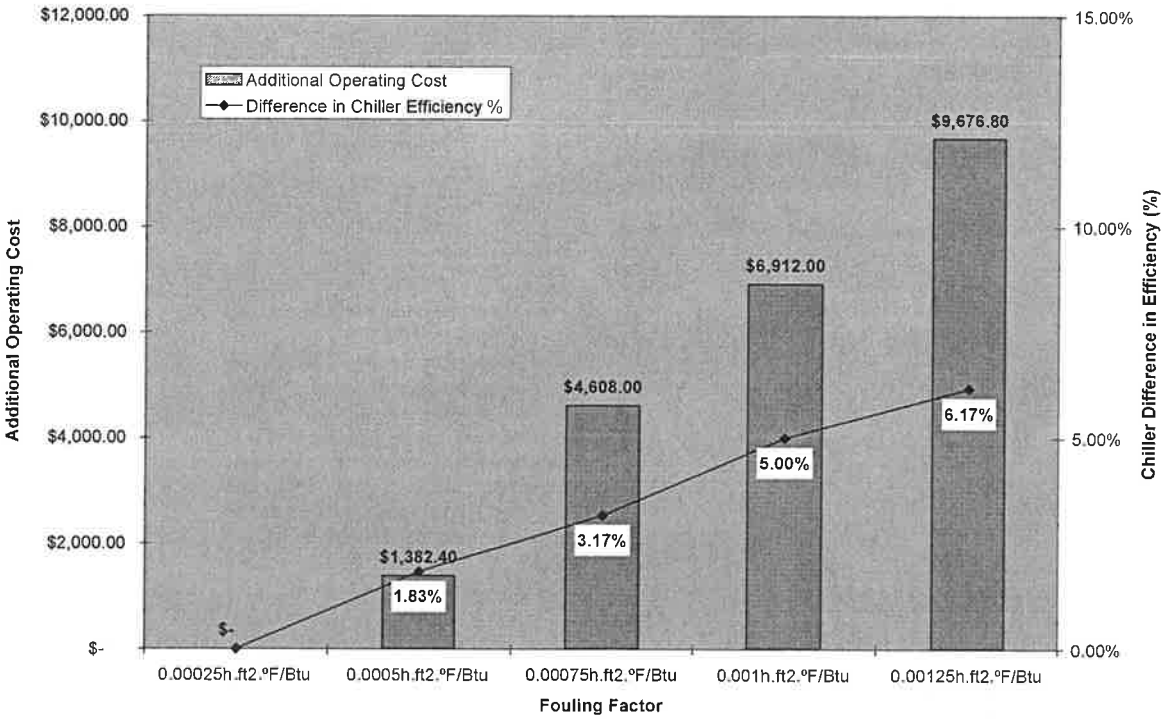
## *Chiller Fouling in Condenser Tubes*

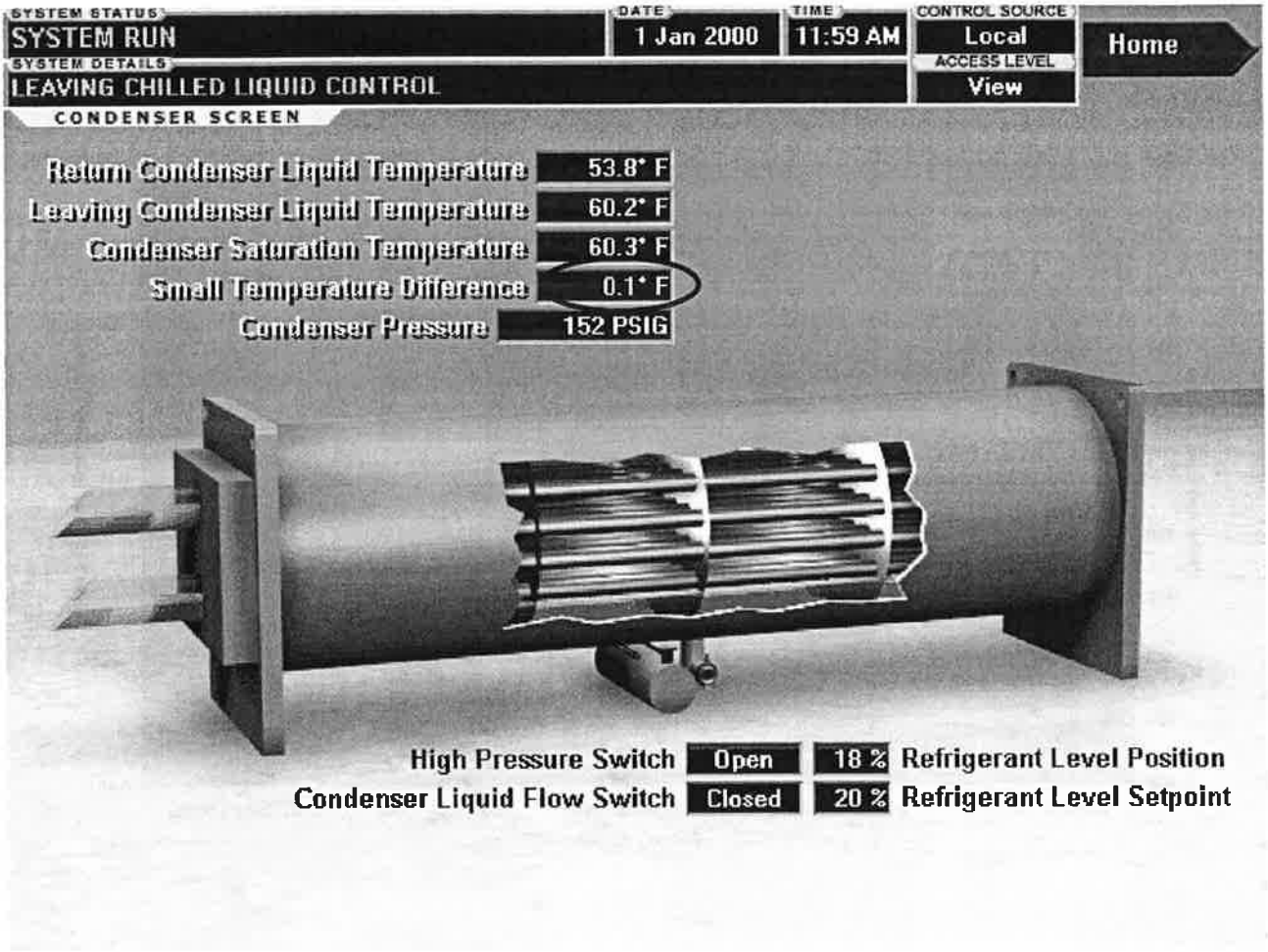
1. Energy requirements for the operation of a chiller account for a significant amount of total energy requirements.
2. An effective water management program is essential in controlling energy usage. However, even the very best water management programs do not totally eliminate scaling.
3. Minimum levels of even soft scale accumulation on condenser tubes will greatly increase the annual energy expense.
4. Today, there are many innovative solutions available that will improve chiller performance by eliminating scale, translating into substantial energy savings.

## Chiller Performance with Different Fouling Factors




## Chiller Annual Additional Operating Cost*






C6.3 *Method for Simulating Fouling Factor Allowance at Full Load and Part-Load Conditions.*

C6.3.1 Obtain the log mean temperature difference (LMTD) for the evaporator and/or Condenser using the following equation at the specified Fouling Factor Allowance ($ff_{sp}$).

$$LMTD = \frac{R}{\ln\left(1+\frac{R}{S}\right)} \qquad C1$$

R = Water temperature range
= absolute value ($t_{wl} - t_{we}$). °F[°C]

S = Small temperature difference
= absolute value ($t_s - t_{wl}$). °F [°C]

C6.3.2 Derivation of LMTD:

$$LMTD = \frac{(t_s - t_{we}) - (t_s - t_{wl})}{\ln\left[\frac{t_s - t_{we}}{t_s - t_{wl}}\right]}$$

$$= \frac{(t_{wl} - t_{we})}{\ln\left[\frac{(t_s - t_{wl}) + (t_{wl} - t_{we})}{t_s - t_{wl}}\right]}$$

The Incremental LMTD (ILMTD) is determined using the following equation:

$$ILMTD = ff_{sp}\ (\frac{q}{A}) \qquad C2$$

C6.3.3 The water temperature needed to simulate the additional fouling, $TD_a$, can now be calculated:

$$TD_a = S_{sp} - S_c \qquad C3a$$

$$TDa = S_{sp} - \frac{R}{e^z - 1} \qquad C3b$$

where:

$$Z = \frac{R}{LMTD - ILMTD}$$

$$S_c = \frac{R}{e^z - 1}$$

$S_{sp}$ = Small temperature difference as specified, °F [°C]
$S_c$ = Small temperature difference as tested in cleaned condition, °F[°C]

The water temperature difference, $TD_a$, is then added to the Condenser entering water temperature or subtracted from the evaporator leaving water temperature to simulate the additional Fouling Factor.

C6.3.4 *Example-Condenser Fouling Inside Tubes* (in I.P Units for clarity):

Specified Fouling Factor Allowance,
$ff_{sp}$ =0.00025 h · ft² ·°F/Btu
Condenser load, q = 2,880,000 Btu/h

Specified Condenser leaving water temp,
$T_{wl}$ = 95°F

Specified Condenser entering water temp,
$T_{we}$ = 85 °F

Inside* tube surface area, $A_i$ = 550 ft²

*(Since fouling is inside tubes in this example)

Saturated condensing temperature,
$t_s$ = 101 °F

$$S_{sp} = t_s - t_{wl} = 101 - 95 = 6\ °F$$

$$R = t_{wl} - t_{we} = 95 - 85 = 10\ °F$$

$$LMTD = \frac{R}{\ln(1+R/S)}$$

$$= \frac{10}{\ln(1+10/6)} = 10.2$$

$$ff_{sp} = 0.00025$$

$$ILMTD = ff_{sp}\left(\frac{q}{A}\right)$$

$$= 0.00025\left[\frac{2,880,000}{550}\right]$$

$$= 1.31$$

$$TD_a = S_{sp} \cdot \frac{R}{e^{\frac{Z}{}} - 1}$$

where:

$$Z = \frac{R}{LMTD - ILMTD}$$

$$Z = \frac{10}{10.2 - 1.31} = 1.125$$

$$TD_a = 6.0 - \frac{10}{e^{1.125} - 1}$$

$$= 6.0 - 4.8 = 1.2°F$$

The entering Condenser water temperature for testing is then raised 1.2°F to simulate the Fouling Factor Allowance of 0.00025 h · ft² · °F/Btu. The entering condenser water temperature will be 85 + 1.2 or 86.2°F.

* Impt

# Conclusion on Chiller Performance

| | | |
|---|---|---|
| Low | Power Consumption | High |
| Low (Limit) | Chilled water Flowrate | High |
| High (Limit) | Condenser Water Flowrate | (Damaging) Low |
| High | Leaving Chilled Water Temp | Low |
| Low | Entering Condenser Water Temp | (Damaging) High |
| Low | Chiller Fouling | (Damaging) High |
| Good | Chiller Efficiency | Bad |

# New Building



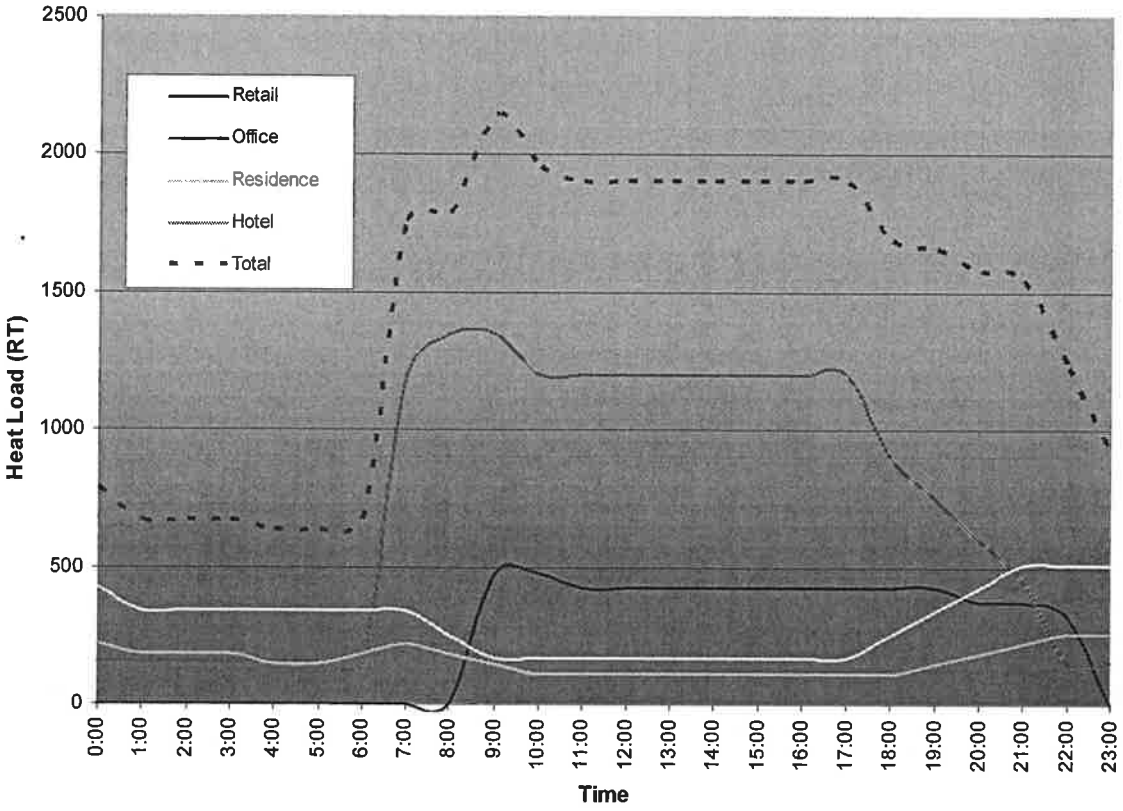
## Chiller Configuration

# Expected Cooling Load Requirement

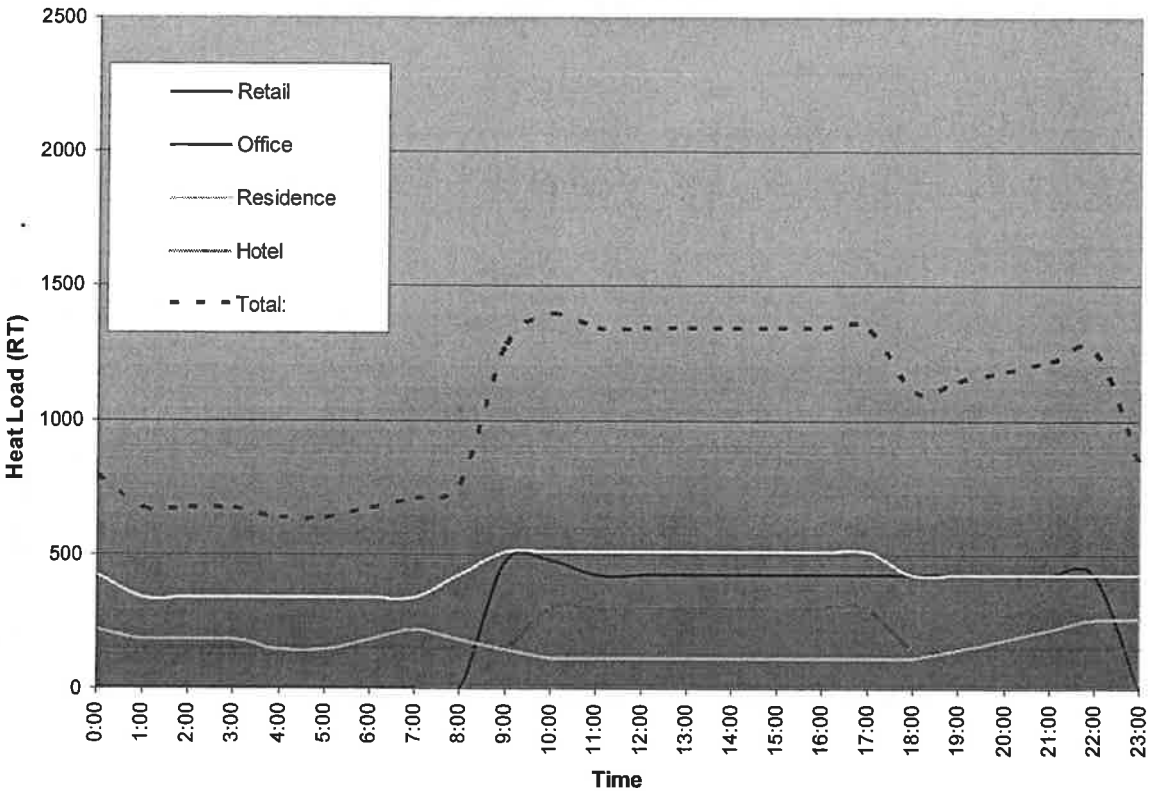
| | sq.ft | sq.m | BTU/Ft2 | Installed TonnageRT |
|---|---|---|---|---|
| Hotel | 110,523 | 10,268 | 40.00 | 368 |
| Residence | 253,668 | 23,567 | 40.00 | 846 |
| Retail | 141,189 | 13,117 | 45.00 | 529 |
| Office | 399,584 | 37,123 | 45.00 | 1,498 |
| | 904,964 | 84,074 | | 3,242 |

| Aera | Time | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Retail | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 477 | 477 | 424 | 424 | 424 | 424 | 424 | 424 | 424 | 424 | 424 | 371 | 371 | 318 | 0 |
| Office | | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 1199 | 1349 | 1349 | 1199 | 1199 | 1199 | 1199 | 1199 | 1199 | 1199 | 1199 | 899 | 749 | 599 | 450 | 150 | 150 |
| Residence | | 423 | 338 | 338 | 338 | 338 | 338 | 338 | 338 | 254 | 169 | 169 | 169 | 169 | 169 | 169 | 169 | 169 | 169 | 254 | 338 | 423 | 507 | 507 | 507 |
| Hotel | | 221 | 184 | 184 | 184 | 147 | 147 | 184 | 221 | 184 | 147 | 111 | 111 | 111 | 111 | 111 | 111 | 111 | 111 | 111 | 147 | 184 | 221 | 258 | 258 |
| **Total:** | | **794** | **672** | **672** | **672** | **635** | **635** | **672** | **1758** | **1786** | **2142** | **1955** | **1902** | **1902** | **1902** | **1902** | **1902** | **1902** | **1902** | **1687** | **1658** | **1577** | **1549** | **1233** | **915** |
| | **Heat Load (RT)** | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 |
| Retail | **529** | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 90% | 90% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 70% | 70% | 60% | 0% |
| Office | **1498** | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 80% | 90% | 90% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 60% | 50% | 40% | 30% | 10% | 10% |
| Residence | **846** | 50% | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 30% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 20% | 30% | 40% | 50% | 60% | 60% | 60% |
| Hotel | **368** | 60% | 50% | 50% | 50% | 40% | 40% | 50% | 60% | 50% | 40% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 40% | 50% | 60% | 70% | 70% |
| Total: | **3242** | 24% | 21% | 21% | 21% | 20% | 20% | 21% | 54% | 55% | 66% | 60% | 59% | 59% | 59% | 59% | 59% | 59% | 59% | 52% | 51% | 49% | 48% | 38% | 28% |

## Forecasted Building Tonnage - Weekdays

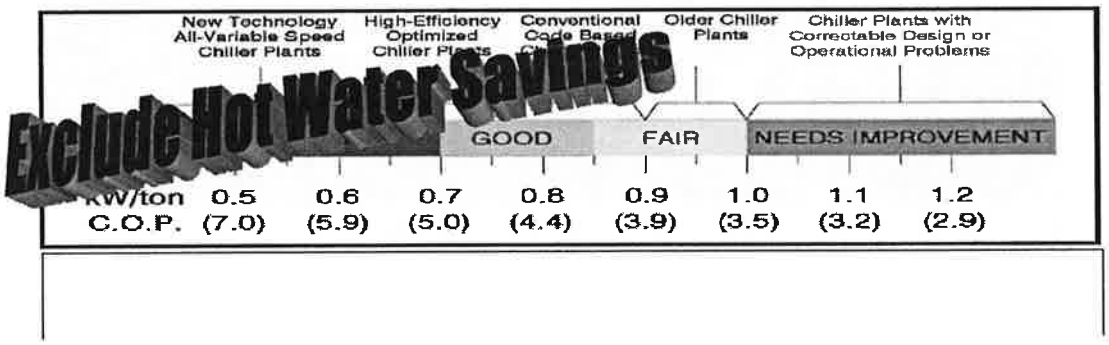



## Forecasted Building Tonnage - Weekends



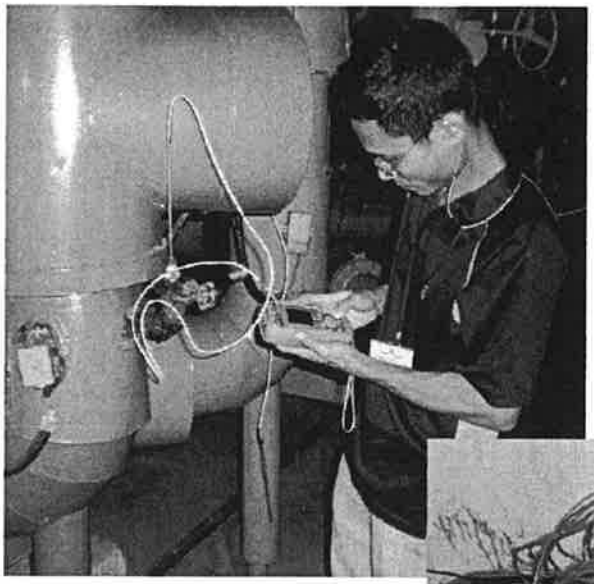
# Saving and Cash Flow Evaluation

| | Chiller Configuration | Refrigerant | Peak Hours | Off-Peak Hours | Expected Additional Annual Saving | Investment | ROI (years) | Peak Load Redundancy (1900RT) | Off-Peak Load Redundancy (600RT) | Flexibility in Tonnage | System Efficiency (kW/Ton) | NPV @ 4% using 15 years life cycle | IRR using 15 years life cycle |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current | 5 x 475RT | R134a | 4 x 475RT | 2 x 475RT | - | - | - | (1900) Good | Good | Good | 0.9 Fair | | |
| Proposal 1 | 5 x 475RT | R134a | 4 x 475RT | 2 x 475RT | $ 500,000 | $ 700,000 | 1.4 | (1900) Good | Good | Good | 0.75 Fair | $4,859,193.72 | 71.4% |
| Proposal 2 | 3 x 800RT + 1 x 350RT | R134a | 3 x 800RT | 1 x 800RT | $ 650,000 | $ 1,600,000 | 2.5 | (1950RT) Good | Good | Good | 0.7 Good | $5,626,951.83 | 40.4% |
| Proposal 3 | 3 x 800RT + 1 x 350RT | R123 + R134a | 3 x 800RT | 1 x 800RT | $ 800,000 | $ 1,750,000 | 2.2 | (1950RT) Good | Good | Good | 0.65 Very Good | $7,144,709.95 | 45.6% |
| Proposal 4 | 4 x 650RT | R134a | 3 x 650RT | 1 x 650RT | $ 650,000 | $ 1,600,000 | 2.5 | (1950RT) Very Good | Good | Good | 0.7 Good | $5,626,951.83 | 40.4% |
| Proposal 5 | 4 x 650RT | R123 | 3 x 650RT | 1 x 650RT | $ 800,000 | $ 1,800,000 | 2.3 | (1950RT) Very Good | Good | Good | 0.65 Very Good | $7,094,709.95 | 44.3% |
| Proposal 6 | 3 x 600RT + 2 x 350RT | R134a | 3 x 600RT + 1 x 350RT | 1 x 600RT | $ 650,000 | $ 1,600,000 | 2.5 | (1900) Good | Good | Good | 0.7 Good | $5,626,951.83 | 40.4% |
| Proposal 7 | 3 x 600RT + 2 x 350RT | R123 + R134a | 3 x 600RT + 1 x 350RT | 1 x 600RT | $ 800,000 | $ 1,700,000 | 2.1 | (1900) Good | Good | Good | 0.65 Good | $7,194,709.95 | 46.9% |



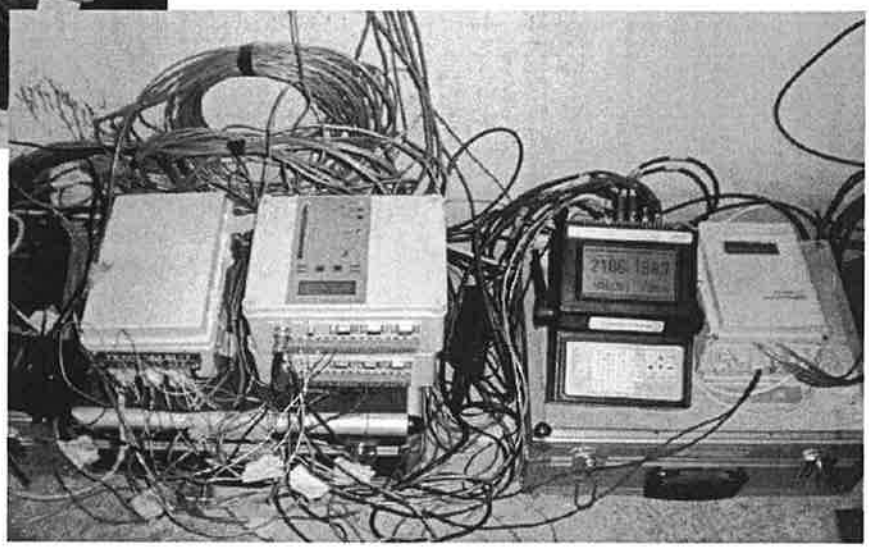

# Allow Multiple Suppliers' Sweet Spot

| | Option A (2 x 500 RT VSD + 1 x 200RT ) | | | | | Option B (3 x 350RT + 1 x 200RT) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Airelated | Air System | BinTai | Command-Air | Thermal | Airelated | Air System | BinTai | Command-Air | Thermal |
| others | | | | | | | | | | |
| To provide all builder's work including wall and floor penetration and make good finishing of any pipe openings with Professional Structural Engineers approval as shown/stated on the specification drawings. | $ 16,000 | $ 30,000 | $ 4,200 | $ 10,000 | $ 5,000 | $ 16,000 | $ 30,000 | $ 4,200 | $ 10,000 | $ 5,000 |
| To provide dust-proofing painting for the entire floor and 150mm height skirting around the wall at chiller plant room after completion of all installation work. | $ 10,000 | $ - | $ 59,800 | $ 10,000 | $ 15,000 | $ 10,000 | $ - | $ 59,800 | $ 10,000 | $ 15,000 |
| Optional | | | | | | | | | | |
| Dismantle and dispose off site AHU cooling coil except AHU 1-1 and AHU 2-1 and supply, delivery, installation, testing and commissioning new cooling coil as stated on equipment specifcation and specification drawings. | $ 100,088 | $ 90,000 | $ 251,376 | $ 165,000 | $ 156,500 | $ 100,088 | $ 90,000 | $ 251,376 | $ 165,000 | $ 156,500 |
| *Grand total* | *$ 3,133,363* | *$ 2,853,000* | *$ 3,035,291* | *$ 3,025,000* | *$ 3,714,423* | *$ 3,146,668* | *$ 3,073,000* | *$ 3,035,291* | *$ 3,145,000* | *$ 3,395,829* |
| *To be carried forward to Form of Tender Part II pages FT-2* | 2 | 5 | 3 | 4 | 1 | 2 | 4 | 5 | 3 | 1 |
| **Exclude Option:** | $ 3,033,275 | $ 2,763,000 | $ 2,783,915 | $ 2,860,000 | $ 3,557,923 | $ 3,046,580 | $ 2,983,000 | $ 2,783,915 | $ 2,980,000 | $ 3,239,329 |
| | | | | | | | | | | $ 3,437,706 |
| | 2 | 5 | 4 | 3 | 1 | 2 | 3 | 5 | 4 | 1 |
| Chiller/Offered | Carrier / Hitachi | York or Equal | Carrier | Trane | Carrier | Trane / Hitachi | York or Equal | Trane / Hitachi | Trane | Trane |
| BMS | Johnson Control | TBA | JC/Siemens/Quantum | TAC | Johnson Control | | | | | |
| VSD | Danfoss | Danfoss | Danfoss or Equal | Danfoss | Danfoss | | | | | |
| Maintenance for 5 years | $ 476,000 | $ 485,000 | $ - | $ 635,000 | $ 283,000 | $ 536,000 | $ 570,000 | $ - | $ 685,000 | $ 375,000 |
| Base + Maintenance | $ 3,609,363 | $ 3,338,000 | $ 3,035,291 | $ 3,660,000 | $ 3,997,423 | $ 3,682,668 | $ 3,643,000 | $ 3,035,291 | $ 3,830,000 | $ 3,770,829 |



# Existing Building

## Perform Data Acquisition

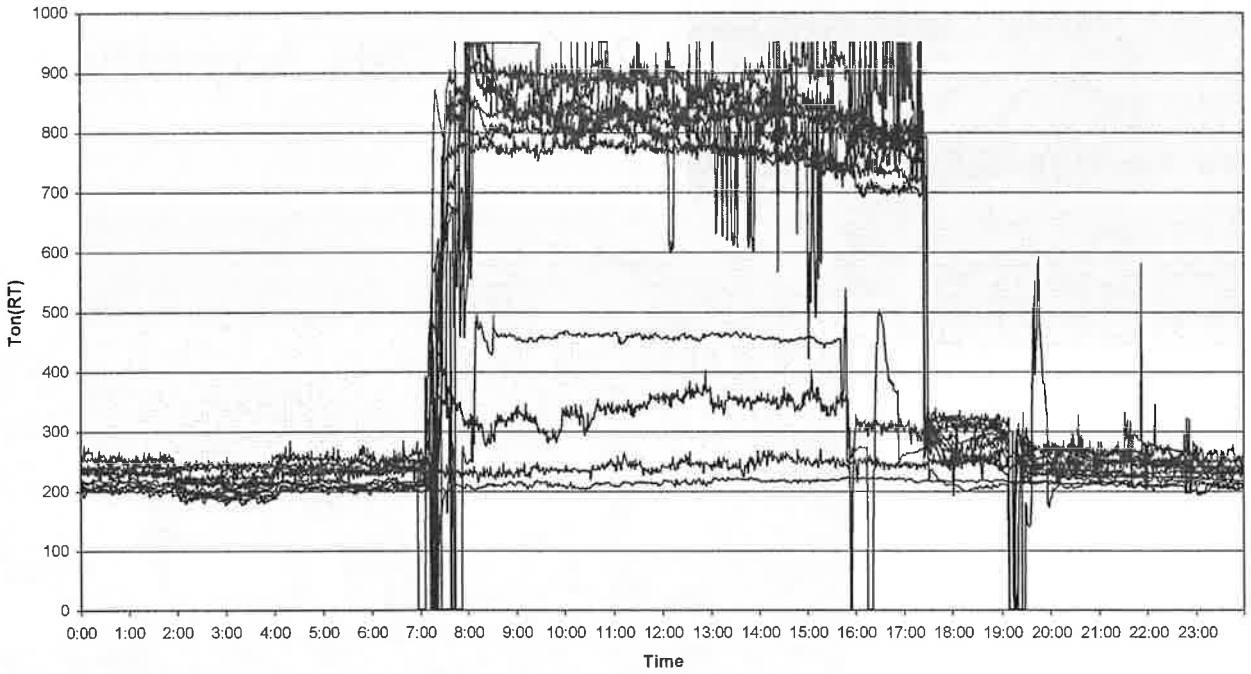


# CHILLER PLANT ROOM (Existing)

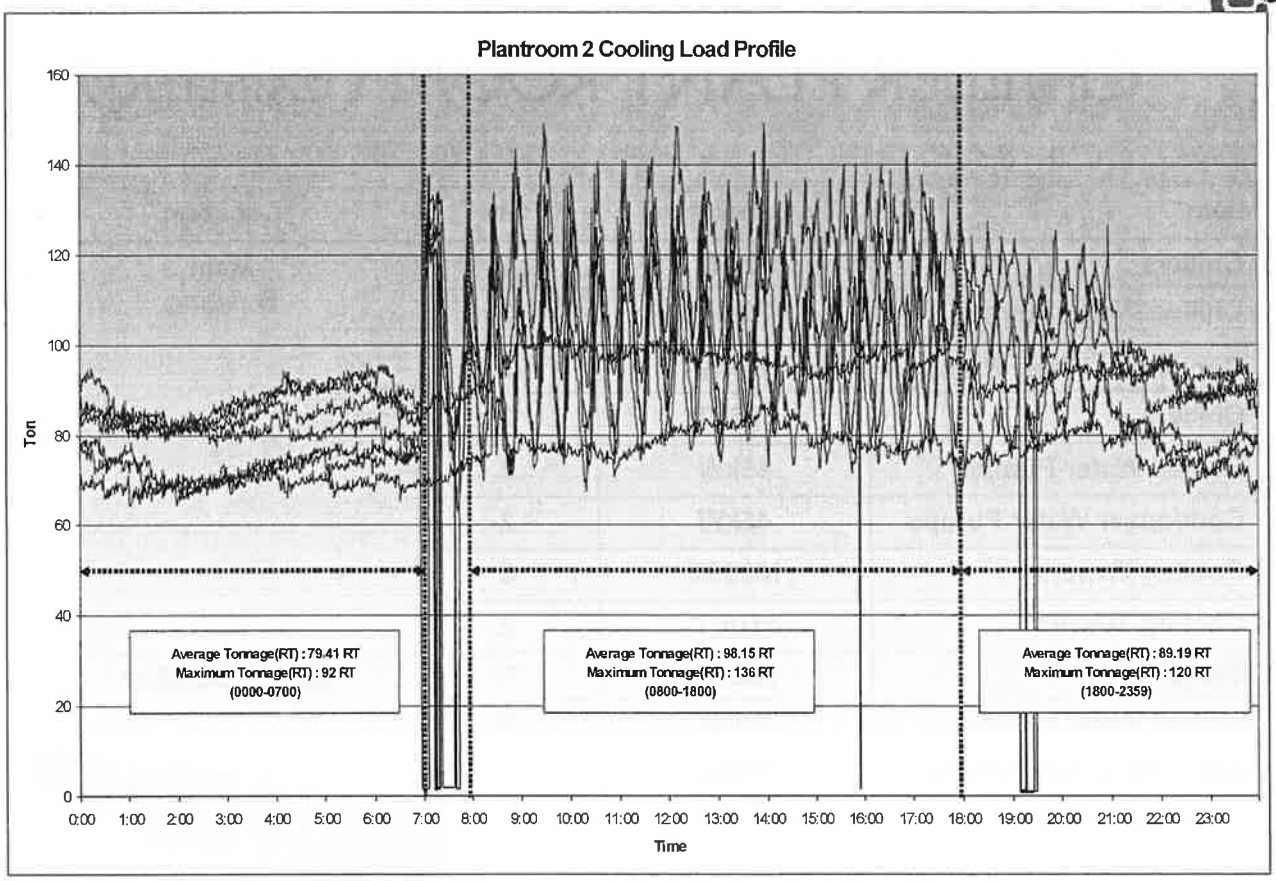
| Item | Capacity | Qty | Location |
|---|---|---|---|
| Chillers | 600RT | 3 | Main Building |
| Chilled Water Pumps | 75kW | 3 | |
| Condenser Water Pumps | 75kW | 3 | |
| Chillers | 326RT | 2 | |
| Chilled Water Pumps | 45kW | 2 | |
| Condenser Water Pumps | 45kW | 2 | |
| Cooling Towers | 1000RT | 3 | |
| Cooling Towers | 550RT | 2 | |
| Chillers | 300RT | 2 | Annex Building |
| Chilled Water Pumps | 30kW | 2 | |
| Condenser Water Pumps | 18kW | 2 | |
| Cooling Towers | 450RT | 2 | |

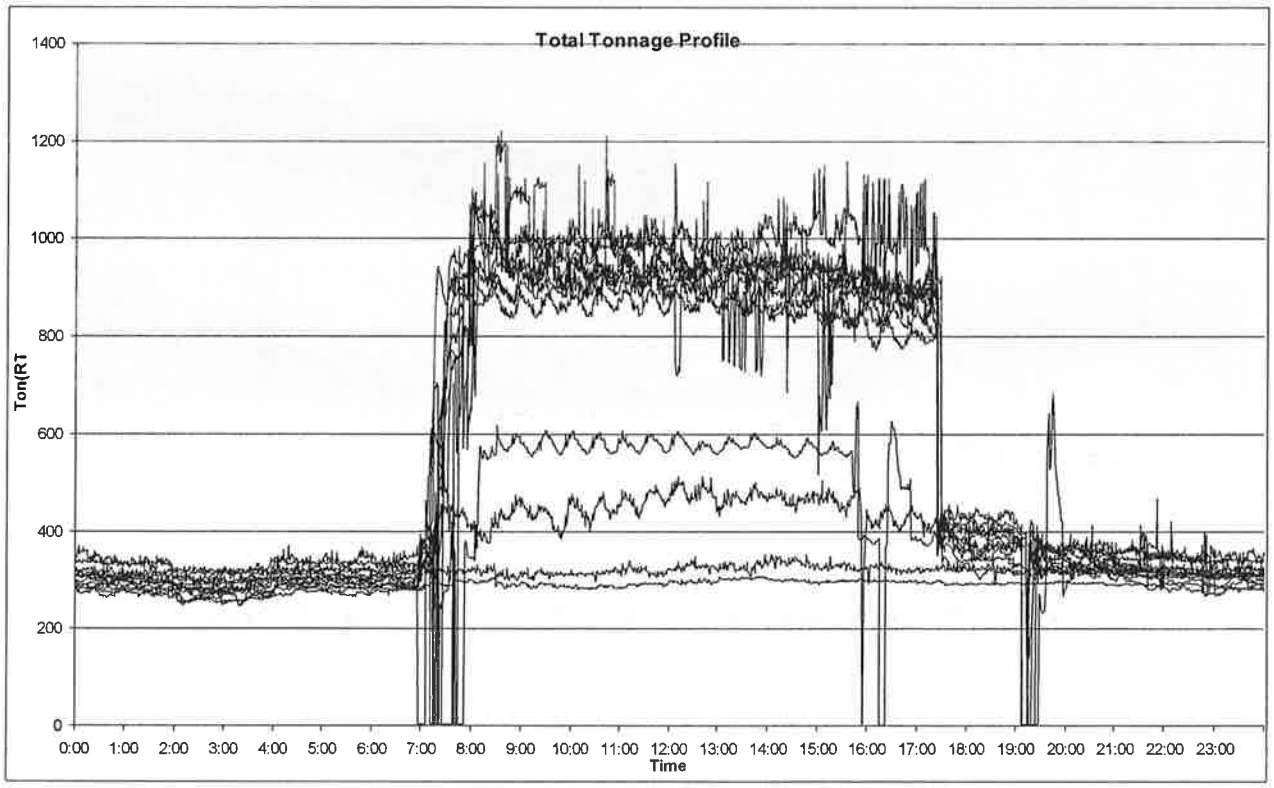
Total 3050RT

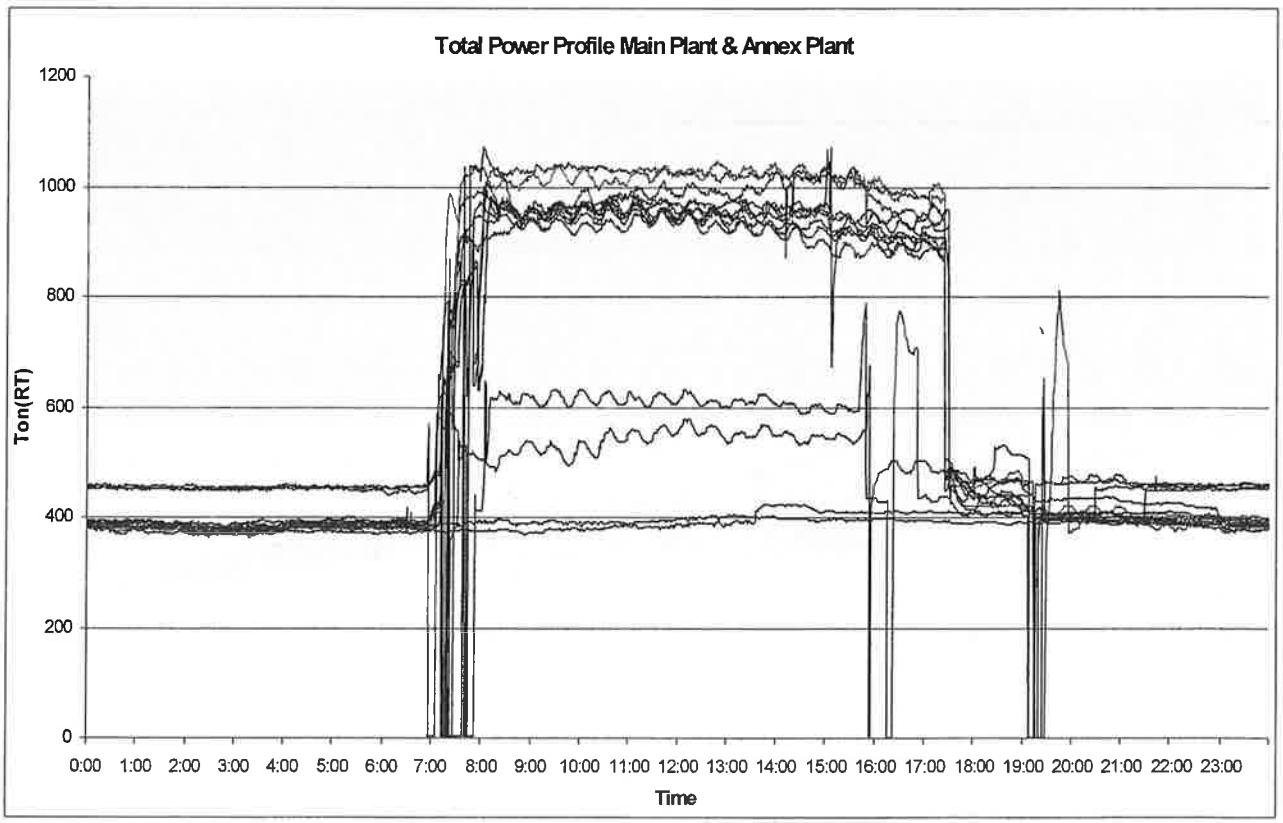
## Plantroom 1 Cooling Load Profile

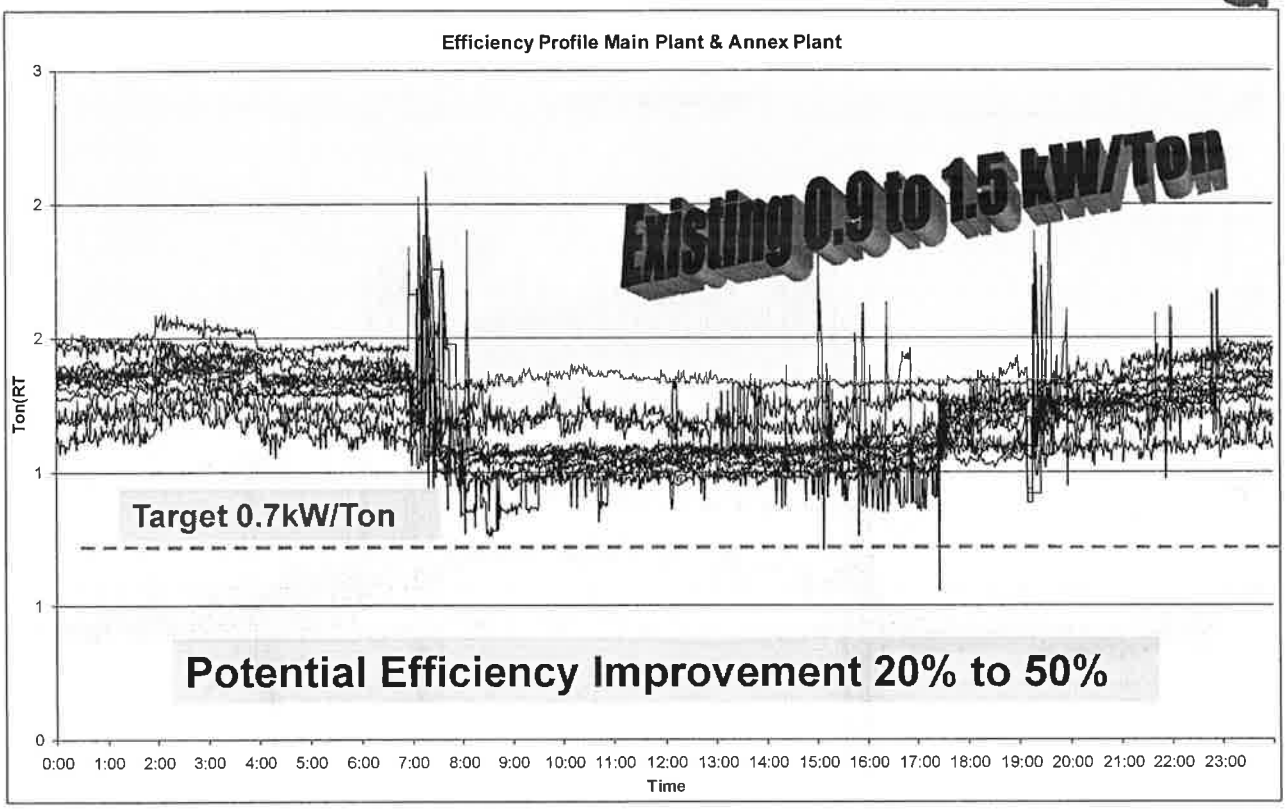


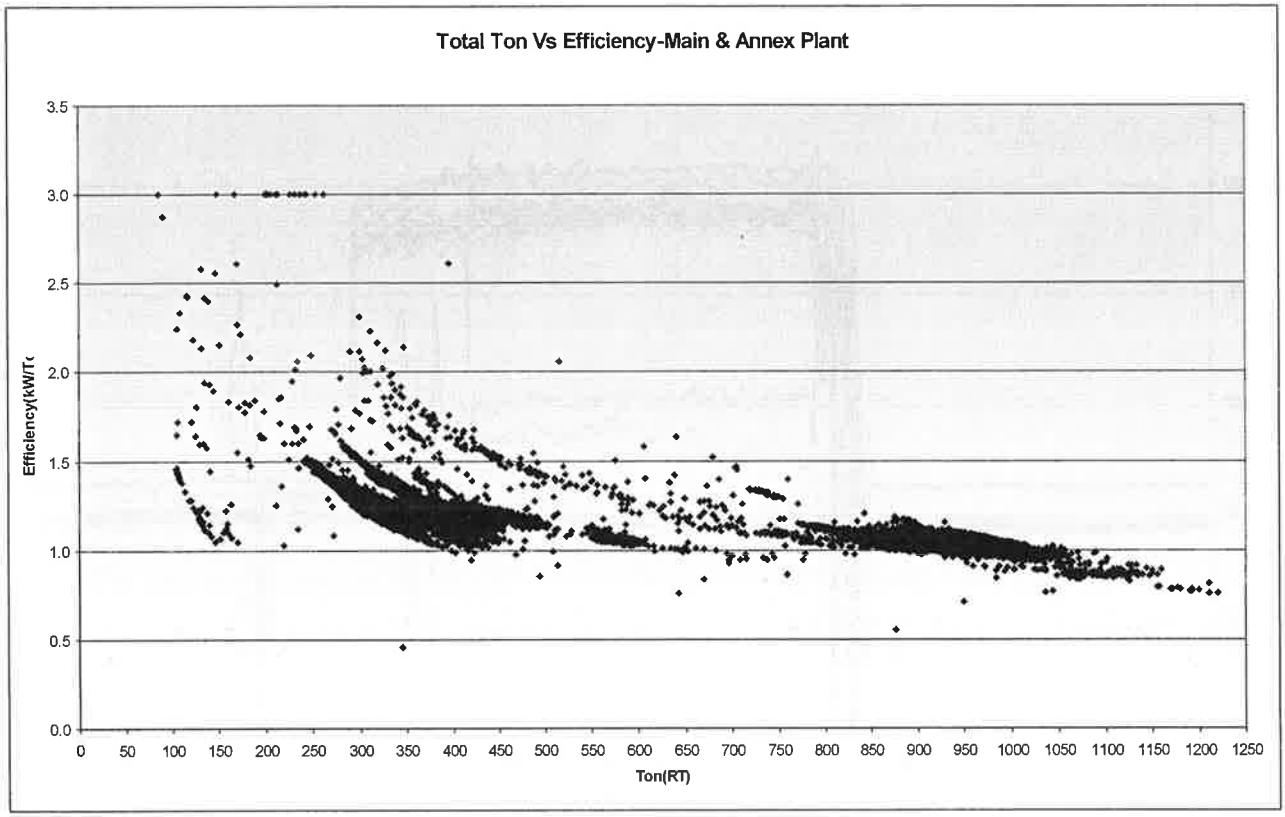

## Plantroom 2 Cooling Load Profile

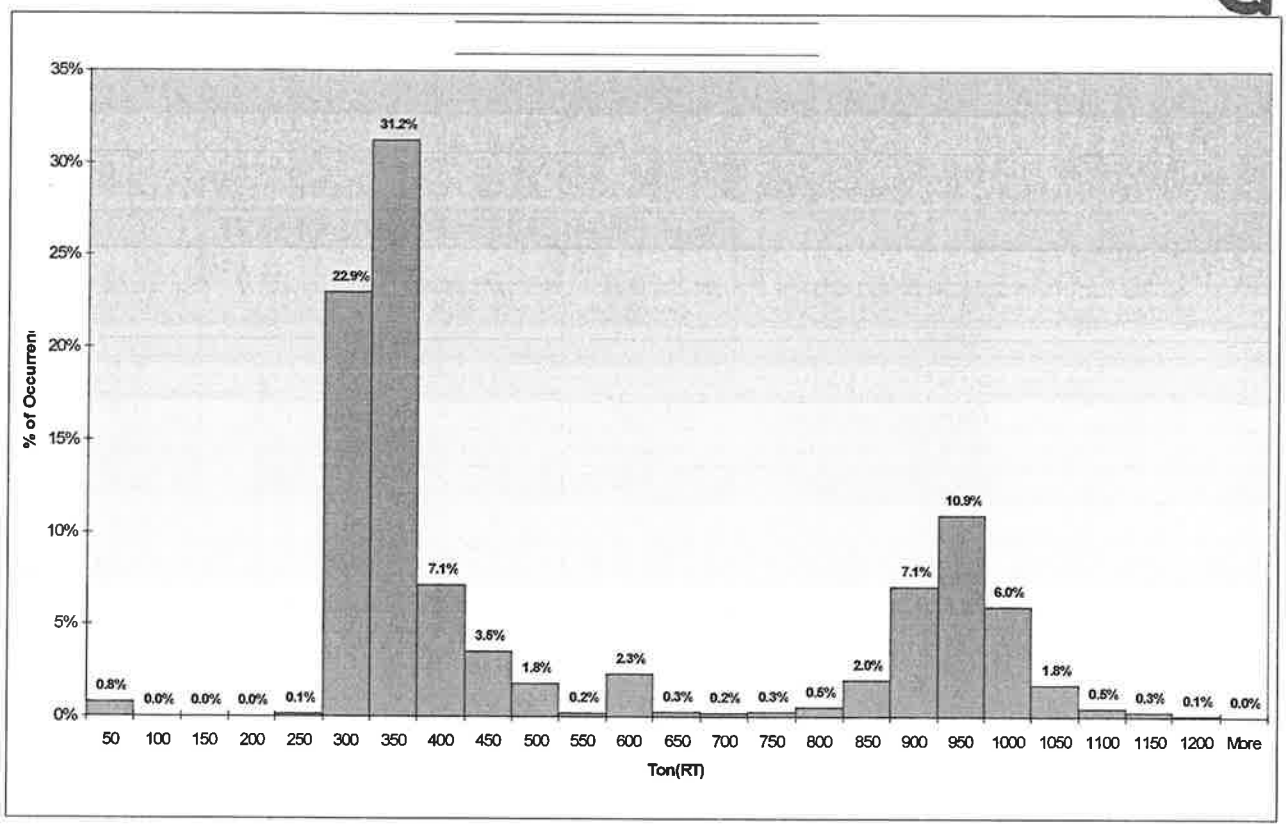



Total Tonnage Profile
Ton(RT
1400
1200
1000
800
600
400
200
0
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time


Total Power Profile Main Plant & Annex Plant
Ton(RT)
1200
1000
800
600
400
200
0
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Time


Efficiency Profile Main Plant & Annex Plant
Existing 0.9 to 1.5 kW/Ton
Target 0.7kW/Ton
Potential Efficiency Improvement 20% to 50%
Ton(RT
Time
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00


Total Ton Vs Efficiency-Main & Annex Plant
Efficiency(kW/T
Ton(RT)
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 1200 1250




New Proposal: ALL-VSD Plantroom (3 x 500RT) = 1,500RT (with Standby)

## Plantroom design to operate 3 x 500RT chillers

| Output Type | Full Load | Part Load | Part Load | Part Load | Part Load | Part Load | Part Load | Part Load |
|---|---|---|---|---|---|---|---|---|
| Percent Load | 100.00 | 90.00 | 80.00 | 70.00 | 60.00 | 50.00 | 40.00 | 35.00 |
| Chiller Capacity | 500 Tons | 450 Tons | 400 Tons | 350 Tons | 300 Tons | 250 Tons | 200 Tons | 175 Tons |
| Chiller Input kW | 273 kW | 236 kW | 204 kW | 175 kW | 148 kW | 124 kW | 103 kW | 93 kW |
| Chiller Input Power | 0.546 kW/Ton | 0.524 kW/Ton | 0.510 kW/Ton | 0.499 kW/Ton | 0.494 kW/Ton | 0.498 kW/Ton | 0.513 kW/Ton | 0.531 kW/Ton |
| **Cooler** | | | | | | | | |
| Entering Temp. | 54.0 ° F | 54.0 ° F | 54.0 ° F | 54.0 ° F | 54.0 ° F | 54.0 ° F | 54.0 ° F | 54.0 ° F |
| Leaving Temp. | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F |
| Flow Rate | 1200.0 gpm | 1080.0 gpm | 960.0 gpm | 840.0 gpm | 720.0 gpm | 600.0 gpm | 480.0 gpm | 420.0 gpm |
| Pressure Drop | 14.0 ft wg | 11.6 ft wg | 9.3 ft wg | 7.3 ft wg | 5.6 ft wg | 4.0 ft wg | 2.7 ft wg | 2.1 ft wg |
| **Condenser** | | | | | | | | |
| Leaving Temp. | 94.3 ° F | 93.3 ° F | 92.3 ° F | 91.4 ° F | 90.5 ° F | 89.6 ° F | 88.7 ° F | 88.2 ° F |
| Entering Temp. | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F |
| Flow Rate | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm |
| Pressure Drop | 13.1 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg |
| **Motor** | | | | | | | | |
| Motor Rated Load Amps | 393 | 380 | 369 | 359 | 349 | 339 | 332 | 329 |
| Motor OLTA | 425 | | | | | | | |
| Chiller Rated Line Amps | 413 | 358 | 311 | 269 | 230 | 195 | 163 | 149 |
| Chiller Inrush Amps | 413 | | | | | | | |
| Max Fuse/CB Amps | 800 | | | | | | | |
| Min Circuit Ampacity | 516 | | | | | | | |
| Cooler Tube Vel | 4.35 ft/s | 3.91 ft/s | 3.48 ft/s | 3.04 ft/s | 2.61 ft/s | 2.17 ft/s | 1.74 ft/s | 1.52 ft/s |

Chiller Efficiencies at Different Chilled Water Temperature

| 500RT | Chiller Efficiency @ 85F constant ECWT | | | | |
|---|---|---|---|---|---|
| LCHWT(F) | 44 | 45 | 46 | 47 | 48 |
| 100% | 0.546 | 0.530 | 0.515 | 0.501 | 0.488 |
| 90% | 0.525 | 0.511 | 0.498 | 0.485 | 0.472 |
| 80% | 0.510 | 0.497 | 0.484 | 0.472 | 0.460 |
| 70% | 0.500 | 0.487 | 0.474 | 0.462 | 0.452 |
| 60% | 0.494 | 0.481 | 0.469 | 0.459 | 0.450 |
| 50% | 0.498 | 0.484 | 0.474 | 0.464 | 0.453 |
| 40% | 0.513 | 0.501 | 0.490 | 0.478 | 0.466 |
| 30% | 0.559 | 0.545 | 0.531 | 0.517 | 0.503 |
| 20% | 0.674 | 0.654 | 0.636 | 0.618 | 0.601 |





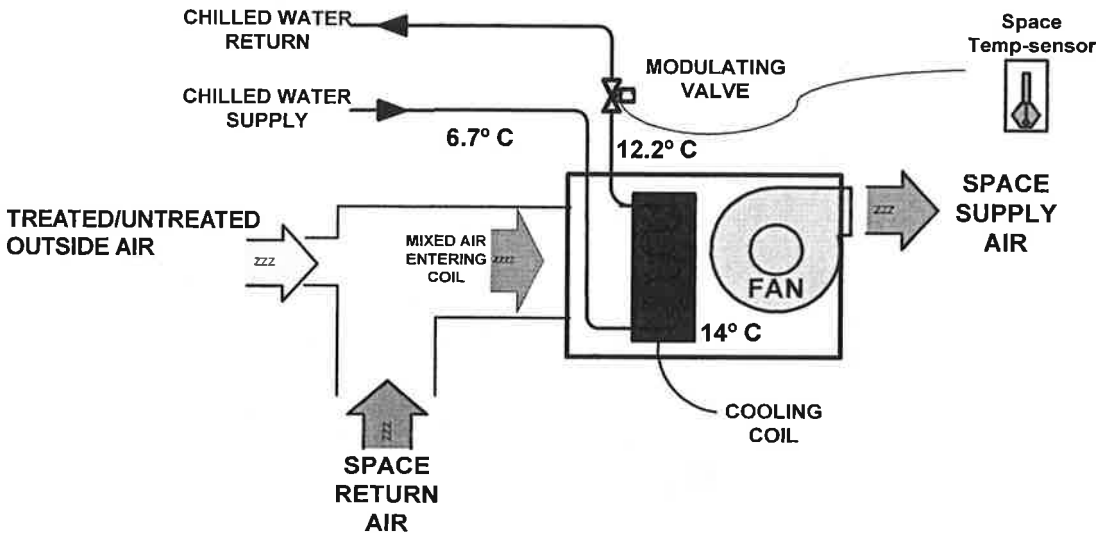
## TYPICAL AHU ROOMS:

- To adopt independent control system to treat fresh air (moisture removal and volume);
- To allow low air pressure drop with low face velocity (<2m/s)
- Increase AHU Coil area to allow less Row / Nos. Fins per Inch
- VSD control room temp with Valves control off-coil temp to provide good thermal comfort while maintaining system efficiency.
- To explore application of VAV diffuser rather than VAV boxes.

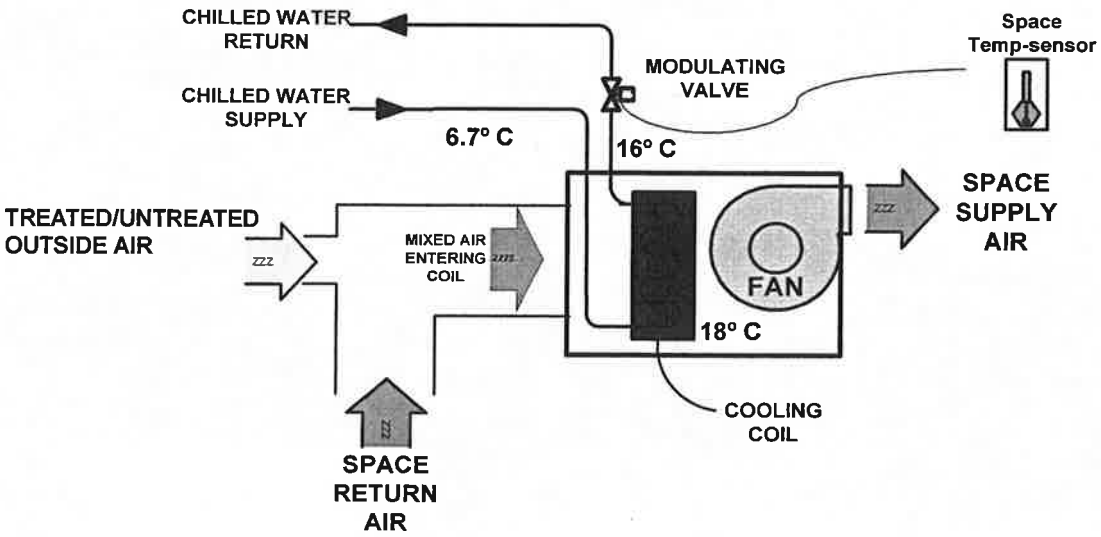
## TYPICAL CHILLED WATER FCUS:

- To minimize system pressure drop;
- To introduce inverter fan motor for ALL FCU if possible

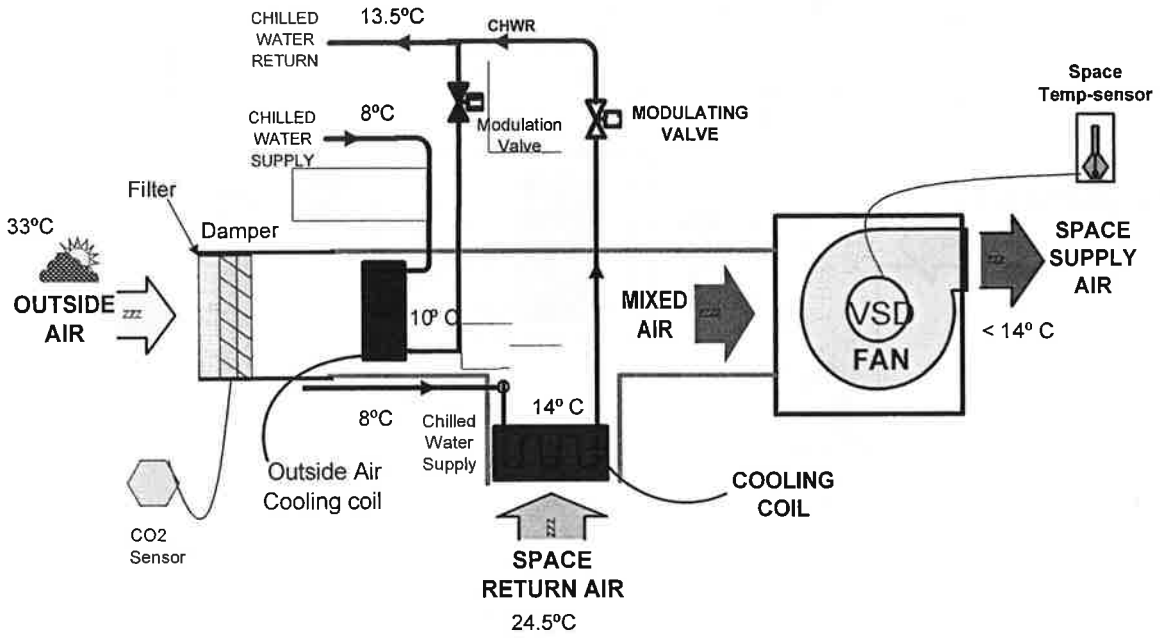
# Conventional Air Handling System



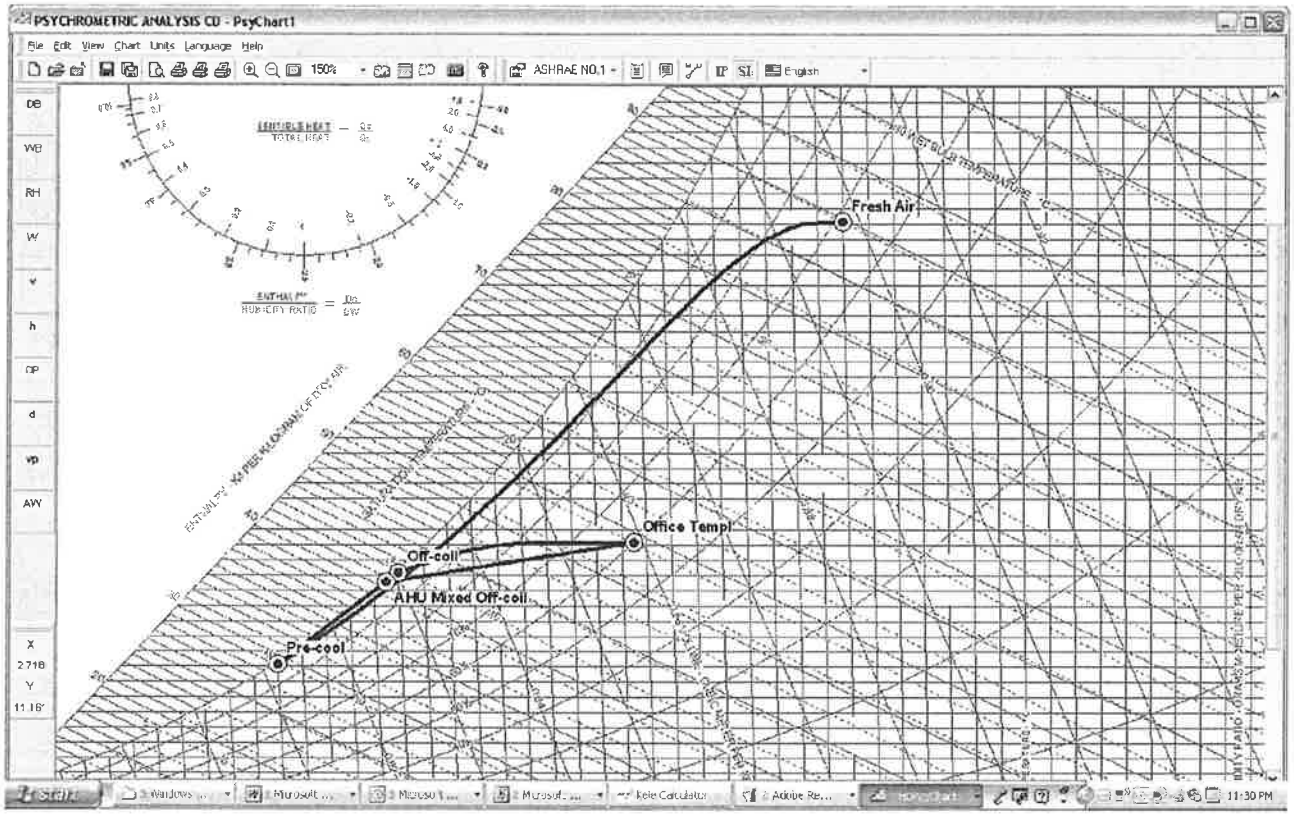

# Conventional Air Handling System (When Room temperature gets low)



# New Invention, Air Handling System






## STATE POINT & PROCESS REPORT

**Report** Date: Monday, March 10, 2008
**Project** Information:

Altitude: 0 (Meters)
Barometric Pressure: 760.001 (mm Hg)
Atmospheric Pressure: 101.325 (kPa)

### 1. Fresh Air

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,216 | 33.000 | 28.000 | 48.7 | 22.67 | 0.896 | 89.230 | 20.478 | 1.1391 | 25.906 | 24.100 |

### 2. Pre-cool

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,216 | 10.000 | 9.017 | 90.9 | 7.54 | 0.812 | 29.163 | 8.9504 | 1.2315 | 9.1166 | 9.343 |

Process: Cooling Coil

| Start Point Name | Total Cooling (kW/ton) | Total Energy (W/hr) | Sensible Energy (W/hr) | Latent Energy (W/hr) | Dehumidification (kg/hr) | Sensible Heat Ratio | Enthalpy Humidity Ratio (kJ/kg / g/kg) |
|---|---|---|---|---|---|---|---|
| Fresh Air | -102.904 | -102.904 | -39.858 | -63.123 | 65.3 | 0.387 | 4.142 |

### 3. AHU On Coil

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,216 | 24.000 | 19.031 | 60.9 | 11.59 | 0.859 | 54.126 | 16.2340 | 1.1784 | 13.8474 | 13.806 |

### 4. Off-coil

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,216 | 15.000 | 14.900 | 99.9 | 10.56 | 0.830 | 41.852 | 13.8341 | 1.2178 | 12.6640 | 12.751 |

Process: Cooling Coil

| Start Point Name | Total Cooling (kW/ton) | Total Energy (W/hr) | Sensible Energy (W/hr) | Latent Energy (W/hr) | Dehumidification (kg/hr) | Sensible Heat Ratio | Enthalpy Humidity Ratio (kJ/kg / g/kg) |
|---|---|---|---|---|---|---|---|
| AHU On Coil | -169.159 | -169.159 | -145.960 | -54.199 | 55.8 | 0.792 | 16.206 |

### 5. AHU Mixed Off-coil

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,216 | 14.500 | 14.432 | 99.4 | 10.28 | 0.826 | 40.641 | 13.4064 | 1.2202 | 12.3116 | 12.417 |

Process: Air Mixing

| State Point No. 1 Name | Air Flow Standard (L/s) | Dry Bulb (°C) | Humidity Ratio (g/kg) | | State Point No. 2 Name | Air Flow Standard (L/s) | Dry Bulb (°C) | Humidity Ratio (g/kg) |
|---|---|---|---|---|---|---|---|---|
| Pre-cool | 1,216.0 | 10.0 | 7.6 | | Off-coil | 1,216.0 | 15.0 | 10.6 |

### 6. Office Temp

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,216 | 24.000 | 19.031 | 60.9 | 11.59 | 0.859 | 54.126 | 16.2340 | 1.1784 | 13.8474 | 13.806 |

Process: Connect States

| Start Point Name | | Total Energy (W/hr) | Sensible Energy (W/hr) | Latent Energy (W/hr) | Moisture Difference (kg/hr) | Sensible Heat Ratio | Enthalpy Humidity Ratio (kJ/kg / g/kg) |
|---|---|---|---|---|---|---|---|
| AHU Mixed Off-coil | | 290.477 | 174.434 | 84.182 | 80.0 | 0.767 | N/A |

# With Pre-cool Coil

### 4, Off-coil

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 12,743 | 15.000 | 14.902 | 99.0 | 10.58 | 0.830 | 41.832 | 14.8441 | 1.2179 | 12.6540 | 12.751 |

Process: Cooling Coil

| Start Point Name | Total Cooling (kW/hr) | Total Energy (W/hr) | Sensible Energy (W/hr) | Latent Energy (W/hr) | Dehumidification (kg/hr) | Sensible Heat Ratio | Enthalpy/ Humidity Ratio (kJ/kg / g/kg) |
|---|---|---|---|---|---|---|---|
| AHU On Coil | -188.159 | -188,159 | -149,959 | -39,199 | -55.4 | 0.792 | 12.205 |

### 5. AHU Mixed Off-coil

STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 14,159 | 14.500 | 14.442 | 99.4 | 10.28 | 0.828 | 40.561 | 14.4064 | 1.2202 | 12.3110 | 12.417 |

Process: Air Mixing

| State Point No. 1 Name | Air Flow Standard (L/s) | Dry Bulb (°C) | Humidity Ratio (g/kg) | | State Point No. 2 Name | Air Flow Standard (L/s) | Dry Bulb (°C) | Humidity Ratio (g/kg) |
|---|---|---|---|---|---|---|---|---|
| Pre-cool | 1,416.0 | 10.0 | 7.6 | | Off-coil | 12,743.0 | 15.0 | 10.6 |

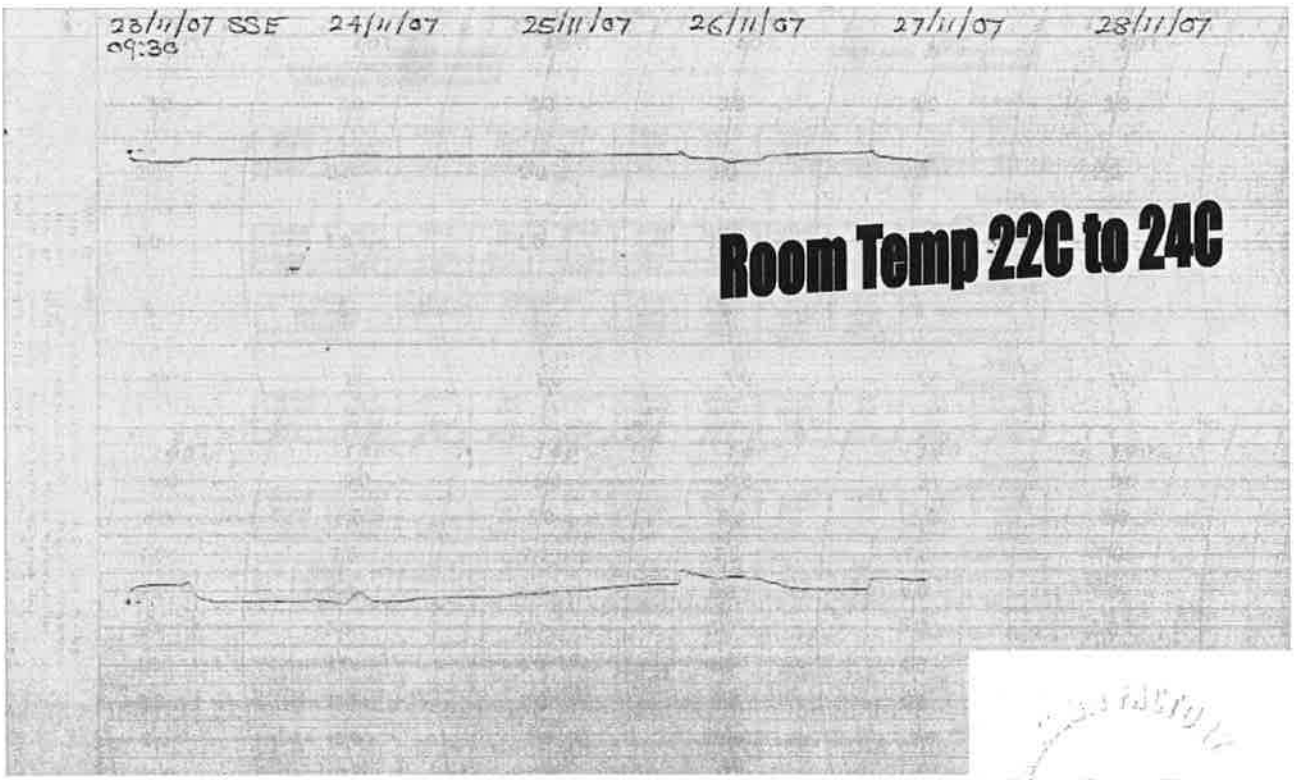
### 6. Office Temp

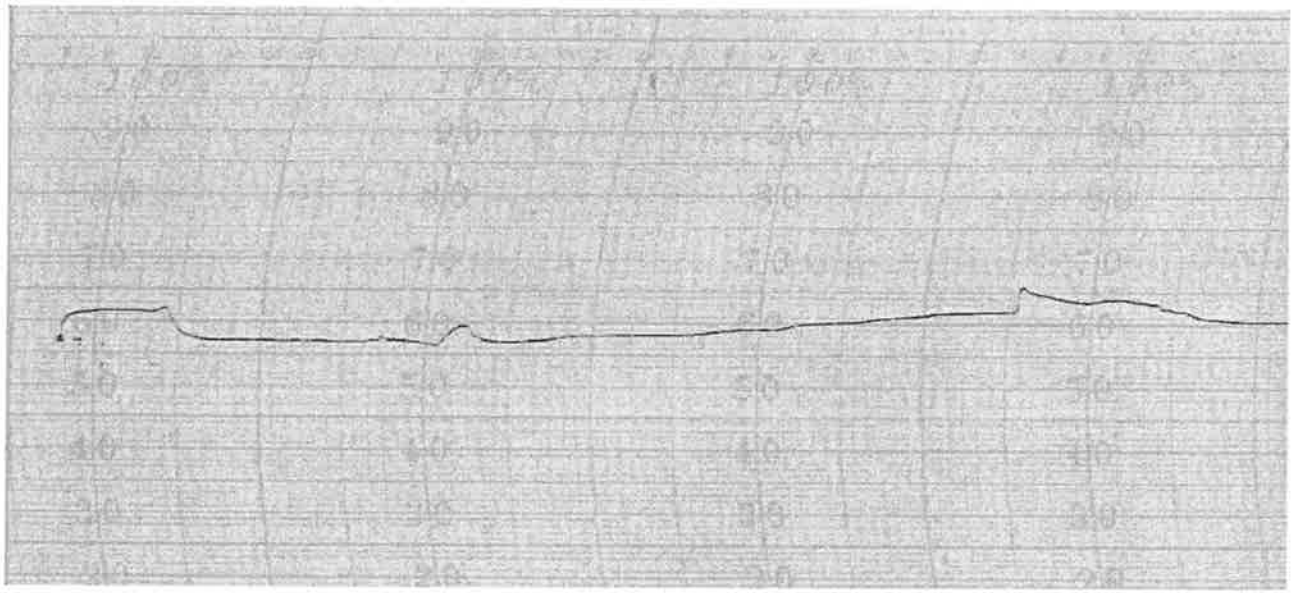
STATE POINT DATA

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 14,159 | 24.500 | 19.031 | 60.0 | 11.59 | 0.859 | 54.126 | 16.2348 | 1.1784 | 13.8454 | 13.496 |

Process: Connect States

| Start Point Name | | Total Energy (W/hr) | Sensible Energy (W/hr) | Latent Energy (W/hr) | Moisture Difference (kg/hr) | Sensible Heat Ratio | Enthalpy/ Humidity Ratio (kJ/kg / g/kg) |
|---|---|---|---|---|---|---|---|
| AHU Mixed Off-coil | | 230,677 | 174,546 | 56,132 | 90.0 | 0.757 | NA |

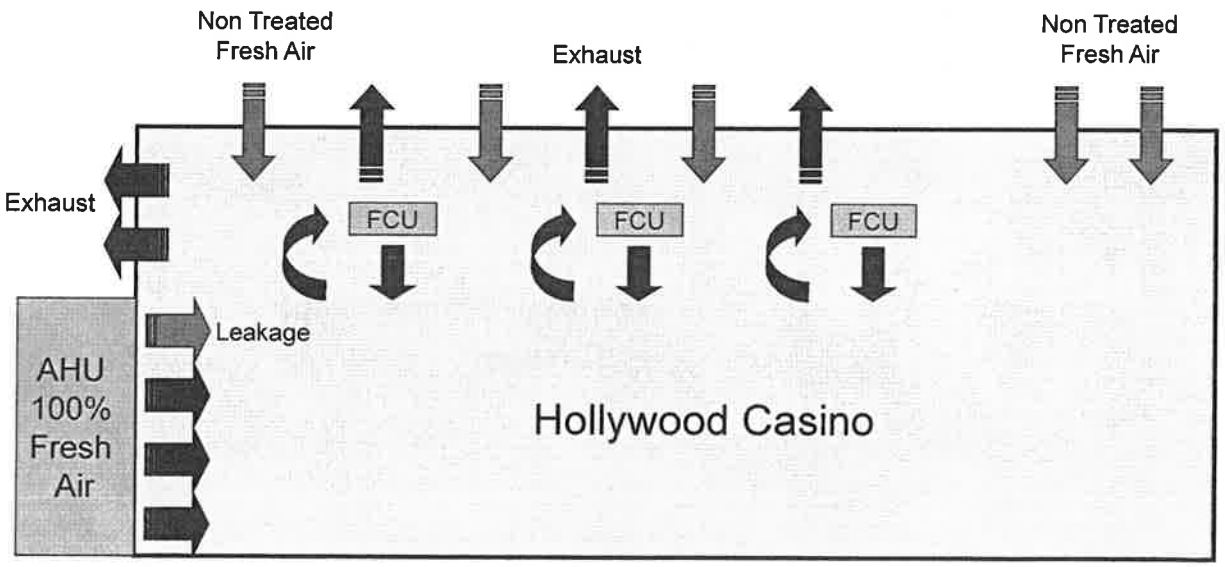


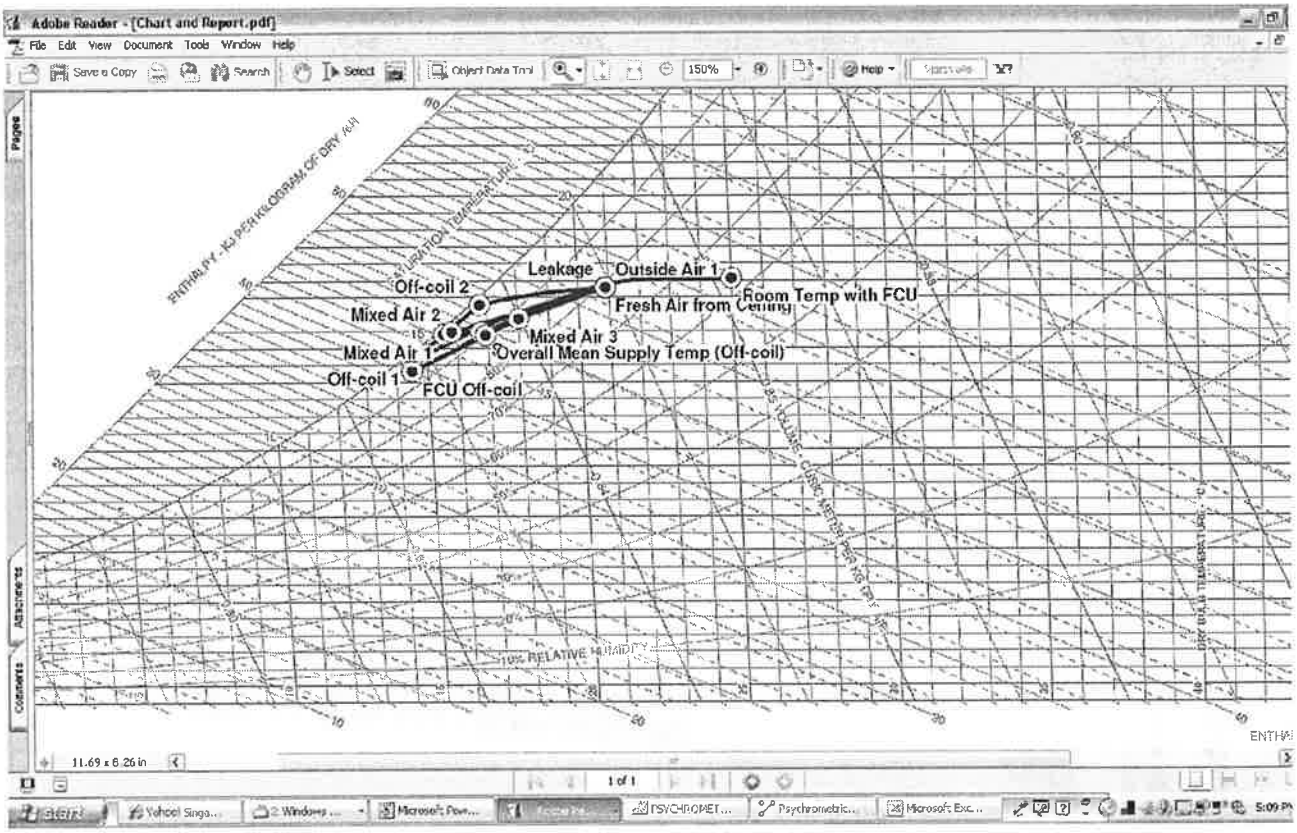


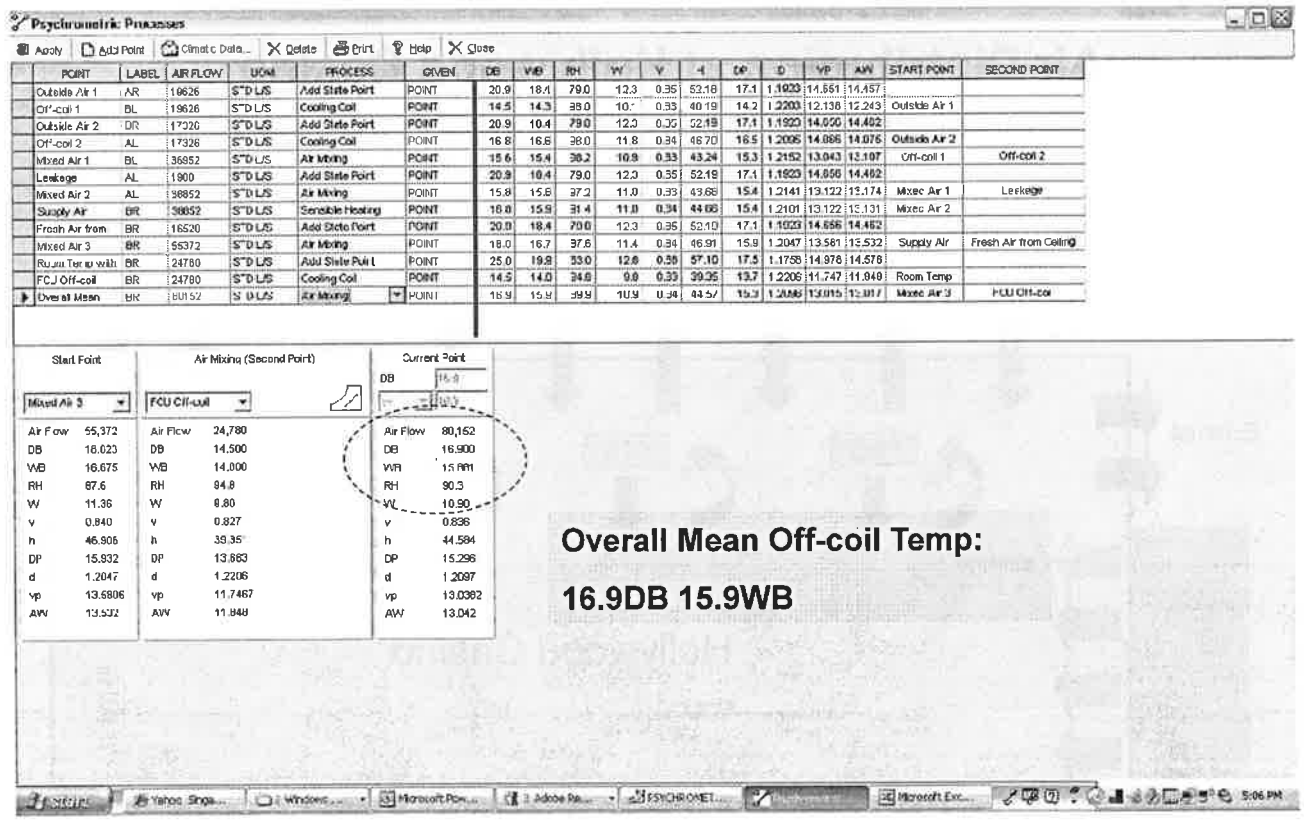


**Maintain at 60% RH**

## Air Distribution at Hollywood Casino




Adobe Reader - [Chart and Report.pdf]
Leakage
Outside Air 1
Off-coil 2
Room Temp with FCU
Fresh Air from Ceiling
Mixed Air 2
Mixed Air 3
Mixed Air 1
Overall Mean Supply Temp (Off-coil)
Off-coil 1
FCU Off-coil
10% RELATIVE HUMIDITY
11.69 x 8.26 in
1 of 1


Psychrometric Processes
Apply
Add Point
Climatic Data...
Delete
Print
Help
Close
Start Point
Air Mixing (Second Point)
Current Point
Mixed Air 3
FCU Off-coil
Overall Mean Off-coil Temp:
16.9DB 15.9WB

CARBON DIOXIDE

## CX SERIES

## $CO_2$ Sensors

CO2 PRINT IN ONE UNIT!



### Applications

- Control HVAC in response to user needs – save up to 30% on energy by providing ventilation as required
- Improve tenant comfort
- Facilitate compliance with ASHRAE 62-1989 standard for air quality

### Microprocessor-based to reduce long-term drift and calibration requirements

- Non-dispersive infrared technology (N.D.I.R.) repeatable to ±20 ppm. 0-2000 ppm range
- Innovative self calibration algorithm
- 5-year calibration interval (recommended)
- Low ambient sensitivity

### Versions for wall and duct applications

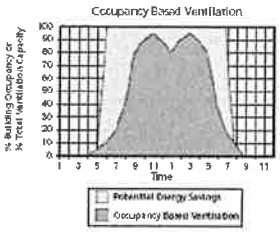
- Field selectable 0-10, 0-5 VDC /4-20 mA output
- LCD display option
- Duct mount version available
- Optional relay output to trigger HVAC equipment at predetermined levels (e.g., one/two position damper)

### OPERATION

The CX series carbon dioxide sensor is designed for use in HVAC control applications. By controlling fresh air to occupant need as determined by $CO_2$ requirements, energy can be saved and tenant comfort improved. Inside buildings, people are the major source of $CO_2$. Typical outdoor air levels of $CO_2$ range between 350 to 400 ppm. Ideal ventilation is typically around 1000 ppm.

The CX series ensures that adequate ventilation will be provided, while maximizing energy savings by ventilating at the optimum level.

The CX series is available with relative humidity and temperature sensors for lowest installed cost.



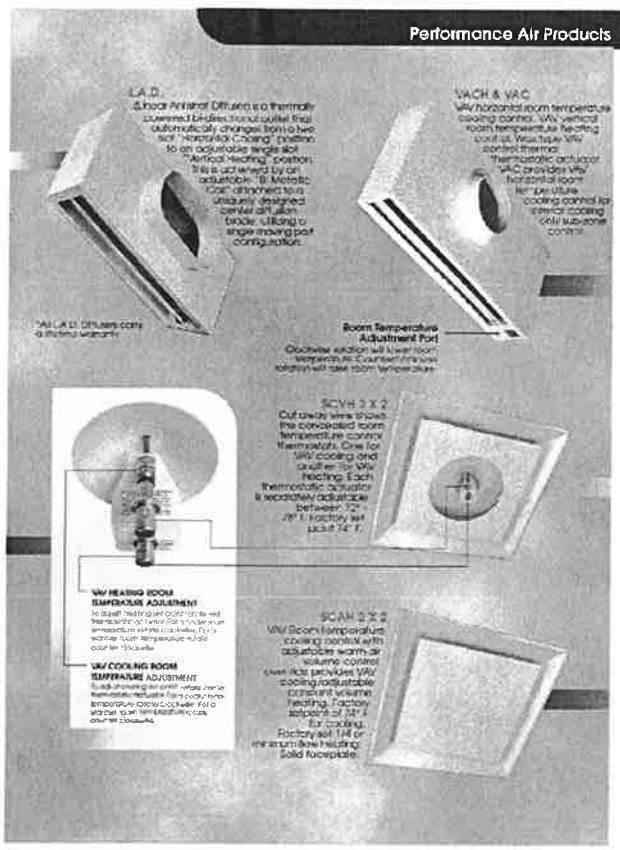

## Save Up To 30% On Energy Costs

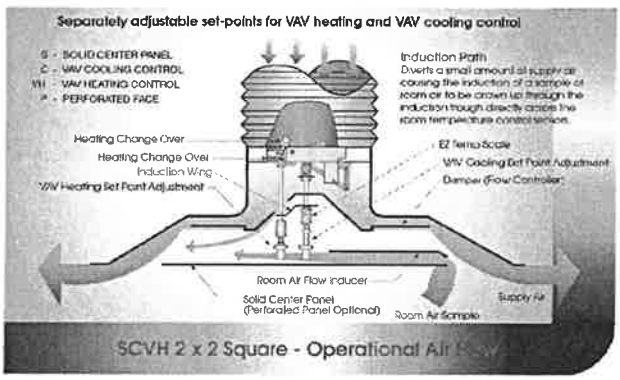
### Demand Ventilation

- Improve comfort and facilitate compliance with ASHRAE 62-1989 standard for air quality
- Optional relay with set point for direct ventilation control
- Output 4-20 mA or 0-10, 0-5V for control system interface
- Non-dispersive infrared technology (NDIR) for high accuracy and long term stability

To replace VAV box.
Thermal diffuser
No need power.

## Performance Air Products 4 Performance Air Products




SCVH 2 x 2 Square - Operational Air Flow

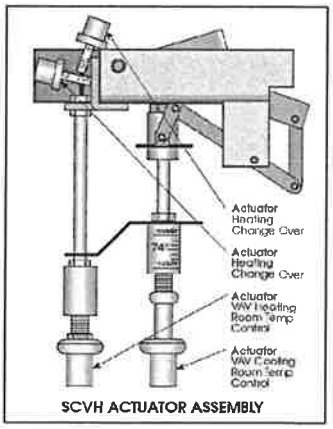
### How it works

Model SCVH "Smart" diffuser is a 24x24 ceiling diffuser with a temperature responsive VAV damper. The extruded aluminum damper moves to modulate air flow. The damper is mechanically activated by temperature sensing thermal actuators. The diffuser is completely self contained and self powered. Average room temperature is monitored by inducing a sample of room air across the thermostatic actuators. This is achieved by a simple, yet effective induction wing. A small amount of supply air is diverted away from the thermostatic actuators thus inducing a sample of room air through an induction trough directly across the actuators. Change over between heating and cooling is determined by supply air temperature.

### Operation

VAV cooling control is initiated when supply air drops below 68° F. This engages the room temperature control actuator which will sense room temperature and vary the supply air when cooling. A rise in room temperature and the damper will open allowing cool air into the space until desired room temperature is achieved. Set point is adjustable between 72° - 78° F. Factory setting 74° F.

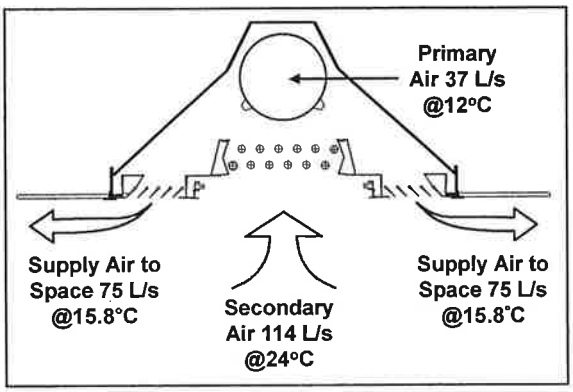
VAV heating control is initiated when supply air rises above 78° F. This engages the heating change over actuators located in the supply path inlet collar. This allows warm air into the space until desired room temperature is achieved. The red room temperature control actuator will sense room temperature and vary the supply air when heating. Set point is adjustable between 72° - 78° F. Factory setting 74° F.



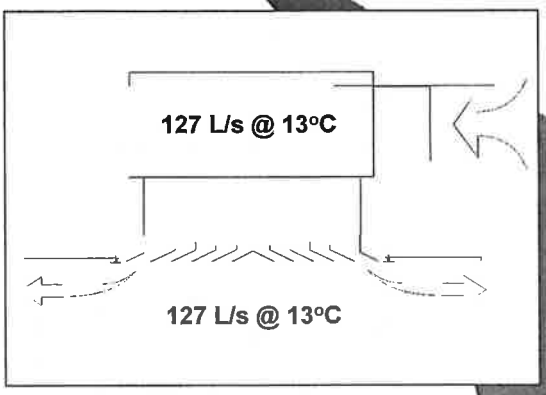

SCVH ACTUATOR ASSEMBLY

# What You Get Out Is Not Always What You Put In!

- DADANCO **ACB**

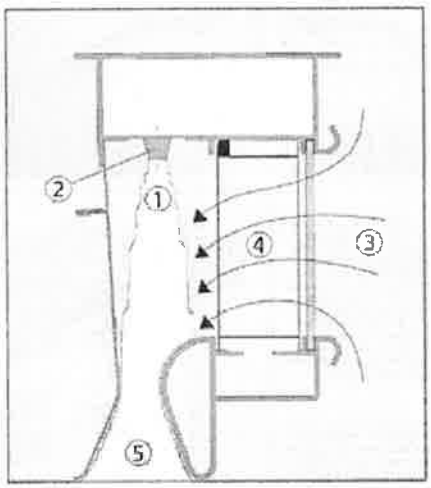


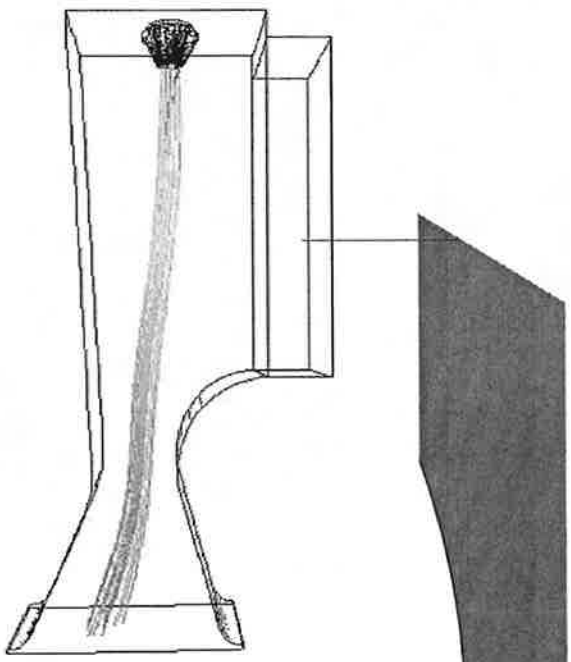

- All Air System



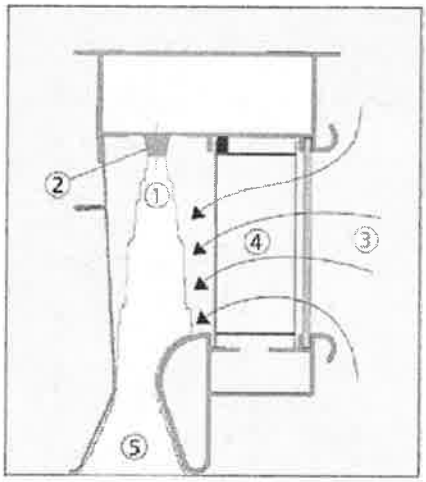

Air Qty Required For 20 $m^2$ with 1700 W Sensible Cooling Load

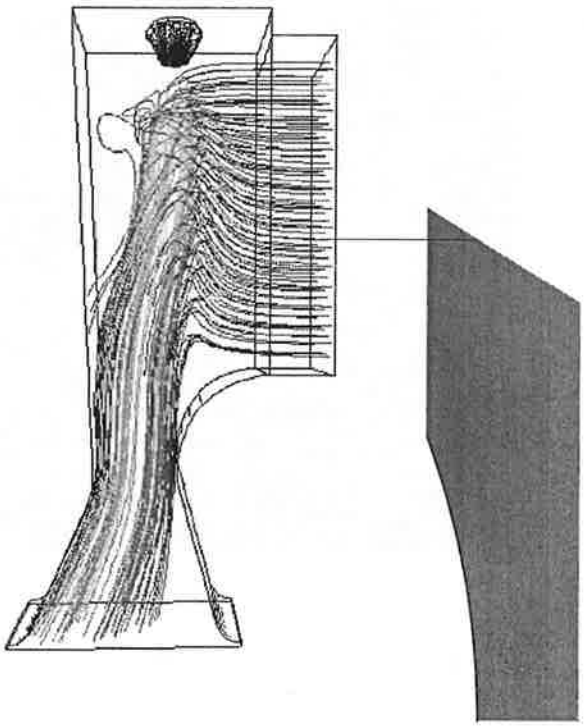
# Induction Process-Primary Air



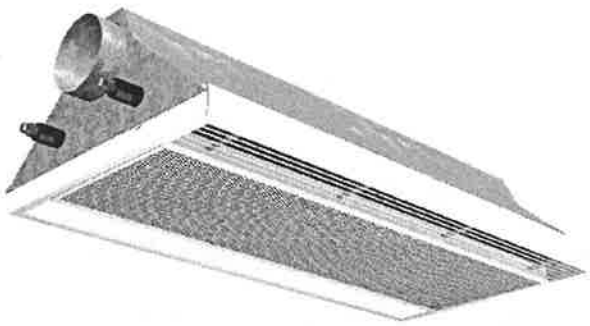
# Induction Process
# Secondary Air



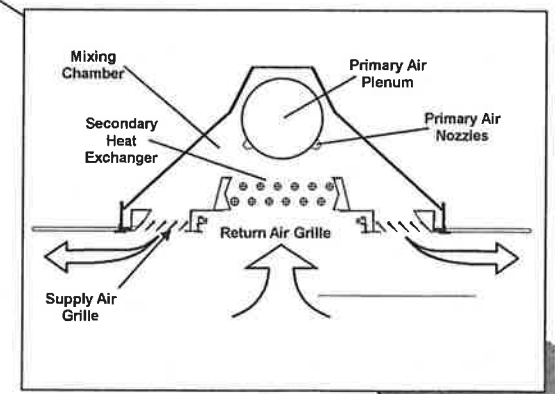



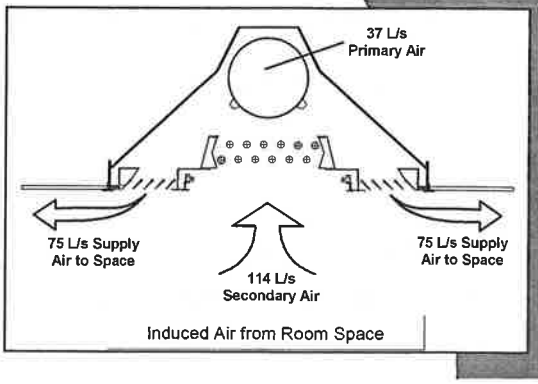
# Cassette Style Active Chilled Beam
# Working Principle

**Dadanco ACB40**

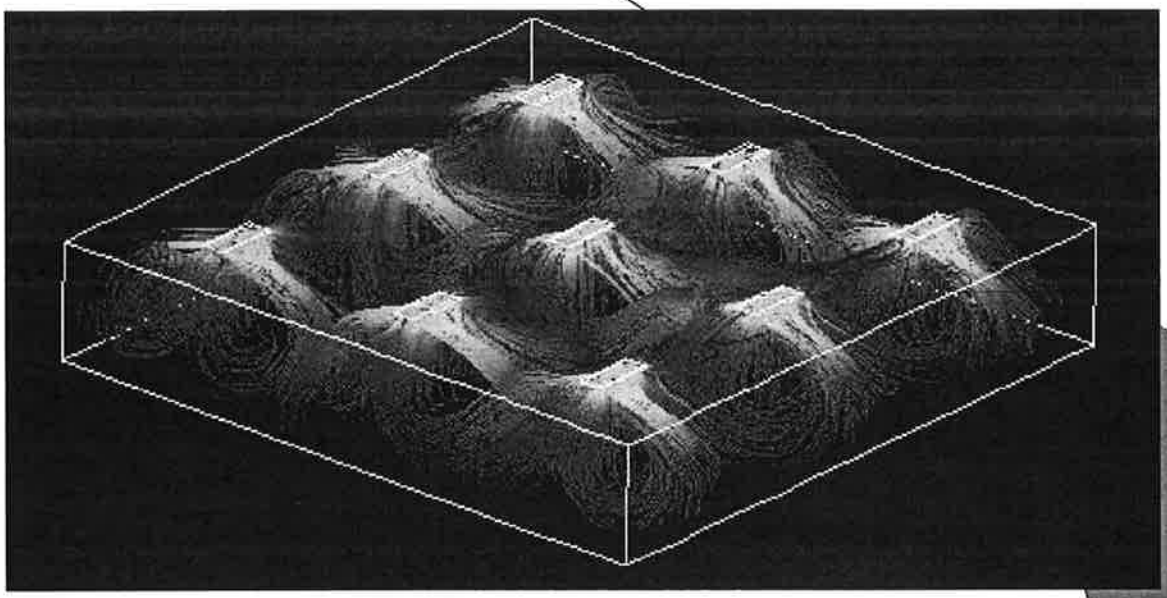


DADANCO



# Air Diffusion



DADANCO

## COOLING TOWERS:

- ✓ To operate CT with less power and bigger surface area for better heat rejection;
- ✓ To Install equalizing pipe to link up all CTs;
- ✓ Design should use low condenser water temperature with reasonable high ambient wet bulb condition;
- ✓ Always good to oversize cooling tower as the cost is low and has high impact on system efficiency; (fastest deterioration rate)
- ✓ Should operate with VSDs using DDC to balance heat rejection and power consumption; use only ONE VSD to control multiple fans
- ✓ Cold condensate water can be recovered back into cooling tower that help to further improve chiller efficiency;

# Cooling Tower Efficiency

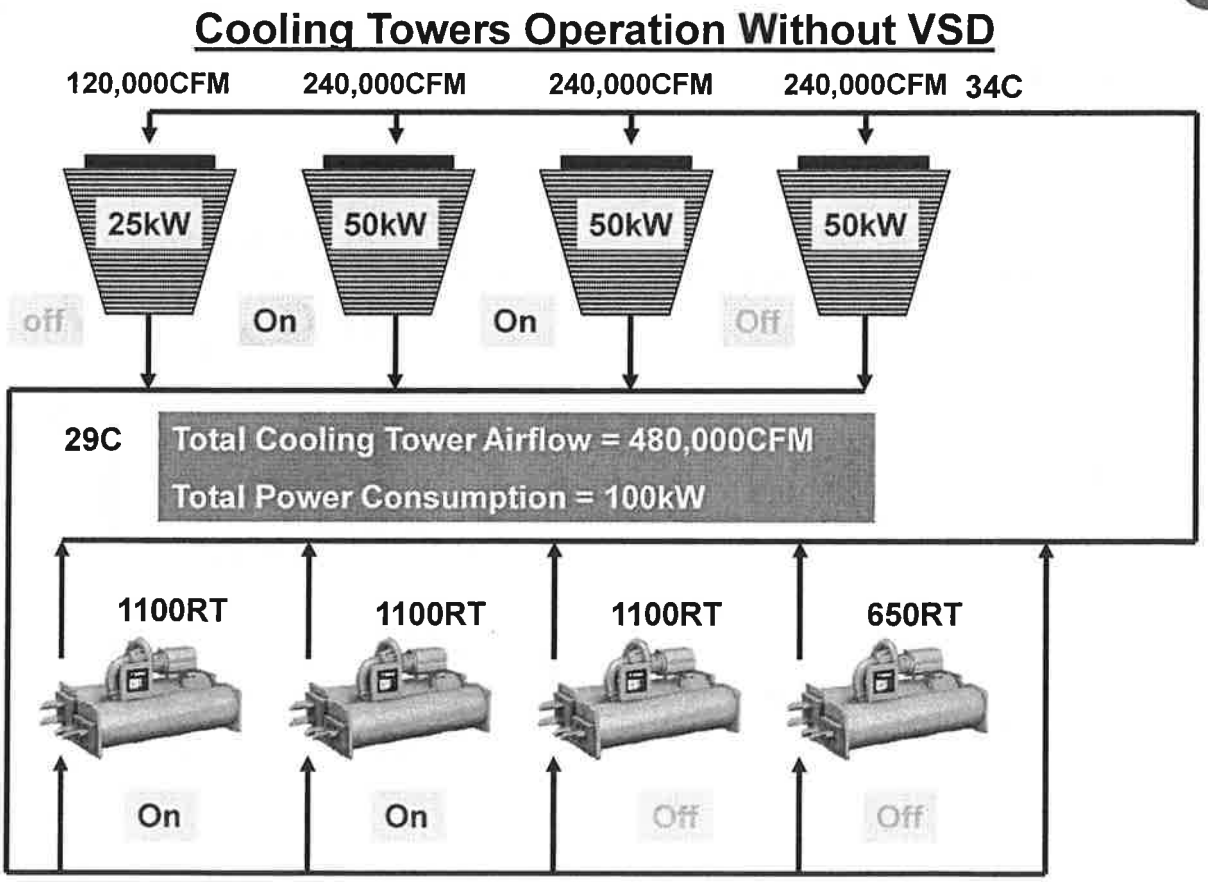
Conventional:

One to One Cooling tower operation or

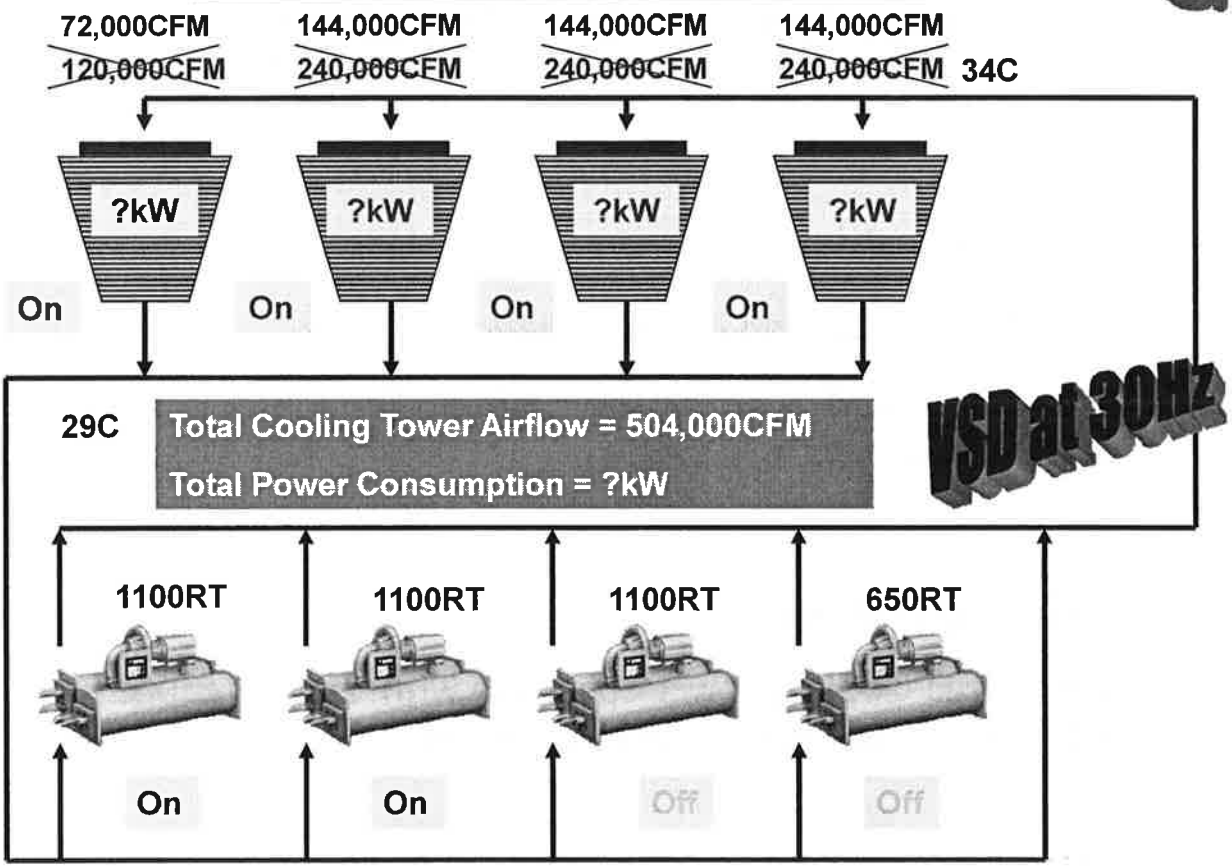
Using Cooling Tower Fan VSD to limit Condenser Water Temperature

G-Energy Proposal:

Optimized Cooling tower operation with VSD to reduce CT power consumption and Chiller efficiency.



## Cooling Towers Operation With VSD



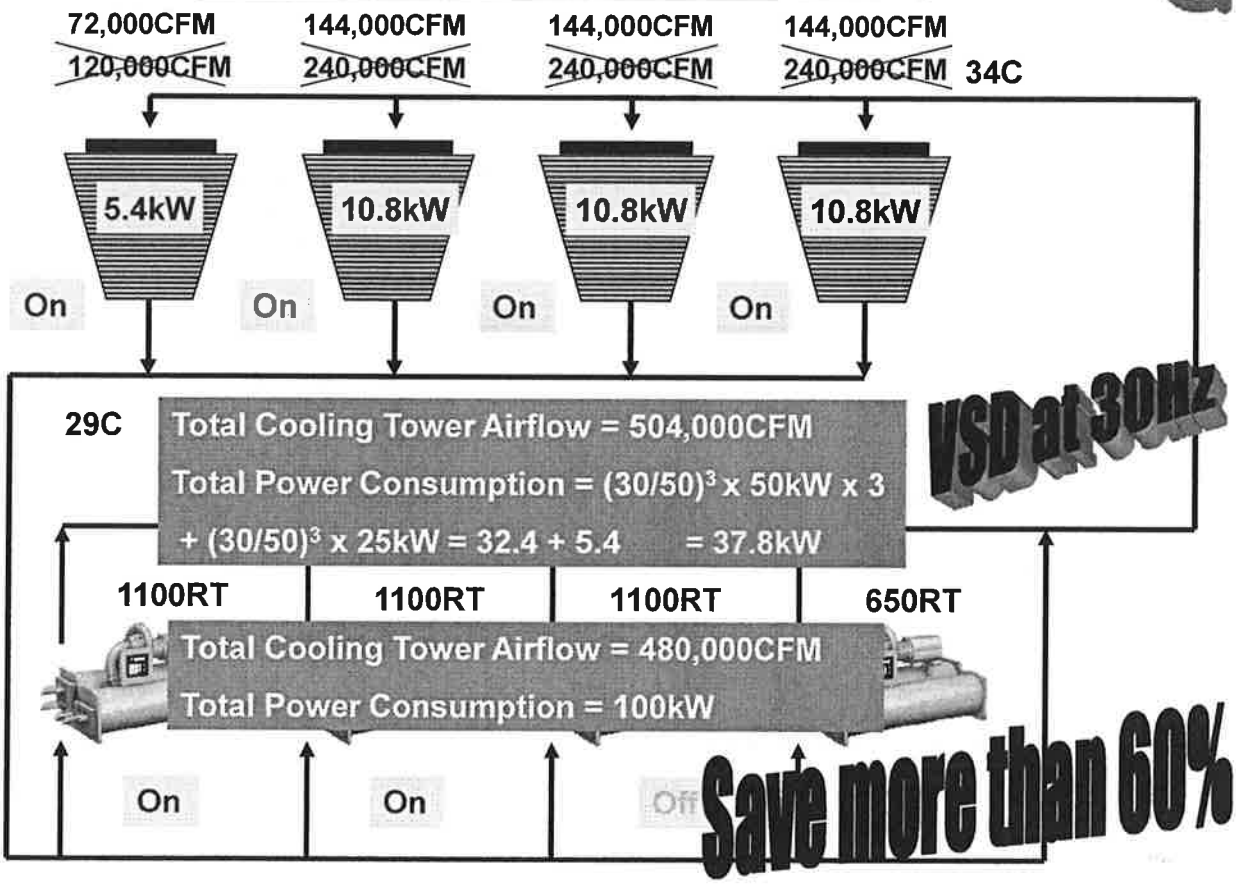

# Fan Laws

$$GPM_{Required} = GPM_{Actual} \times \left( \frac{RPM_{Required}}{RPM_{Actual}} \right)$$

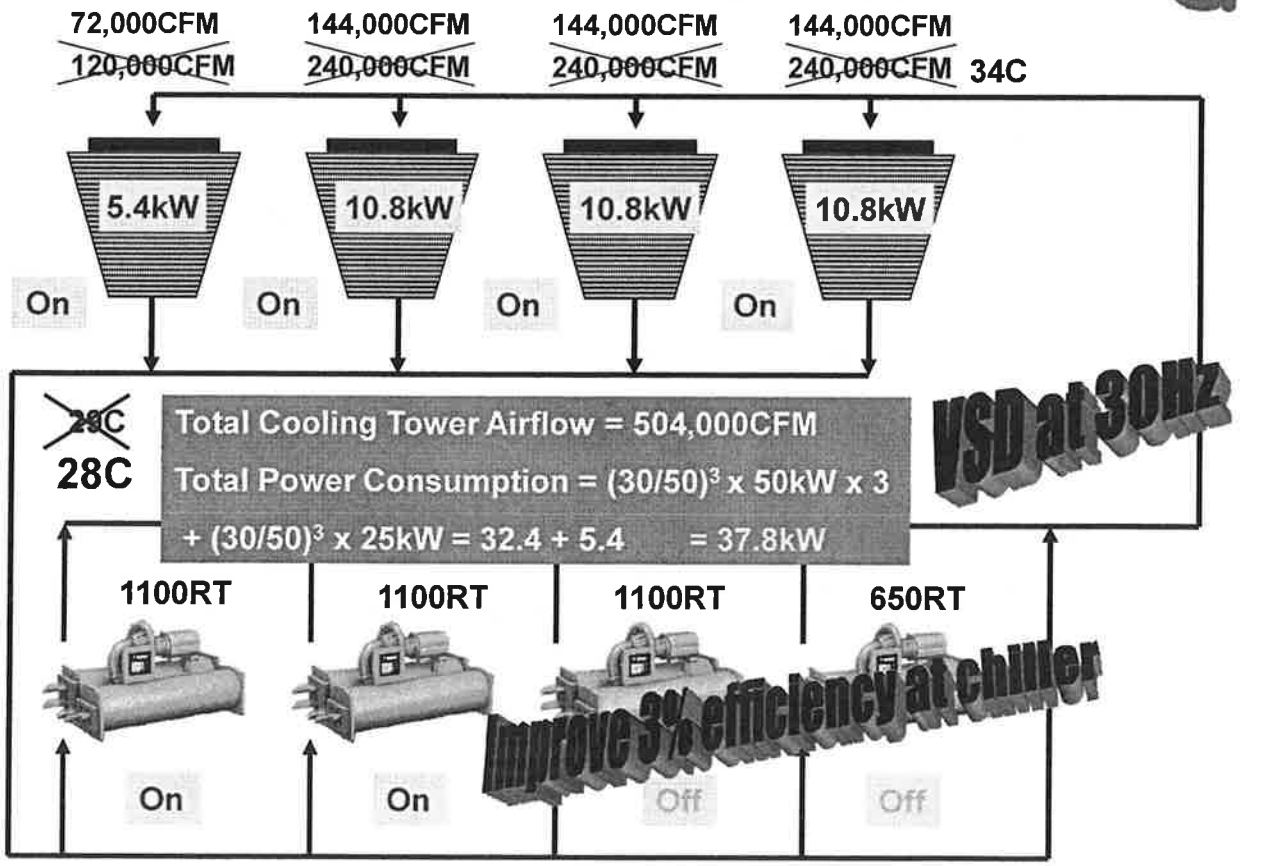
$$TSP_{Required} = TSP_{Actual} \times \left( \frac{RPM_{Required}}{RPM_{Actual}} \right)^2$$

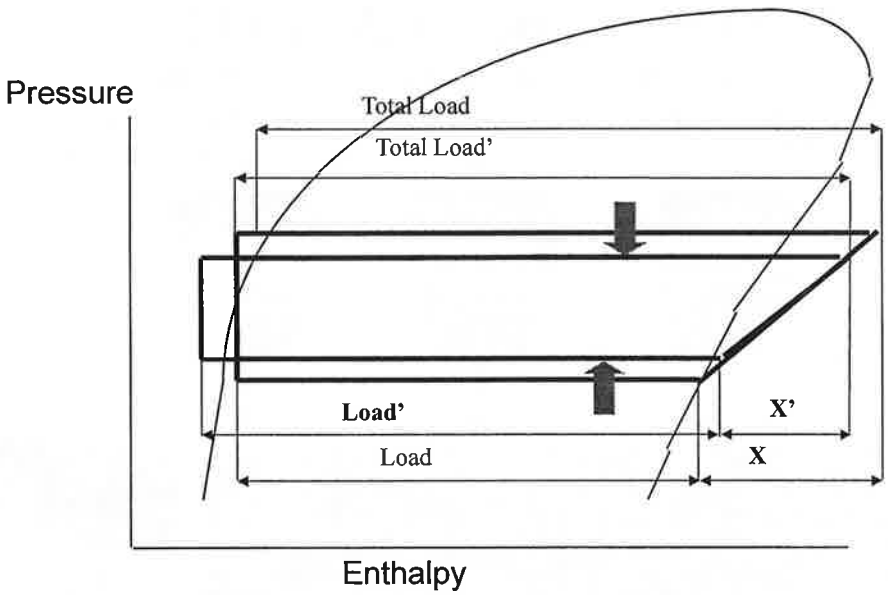
$$HP_{Required} = HP_{Actual} \times \left( \frac{RPM_{Required}}{RPM_{Actual}} \right)^3$$

# Cooling Towers Operation With VSD




# Cooling Towers Operation With VSD






Plantroom Operating parameter must design to gives:

- less motor power input thus reducing operating cost
- less stress on compressor
- lower part-load (reduce chances on surge)
- smaller chiller size (less cost)
- less water loss at cooling tower

# Evaporative Rate

W - tower cooling duty (kW)

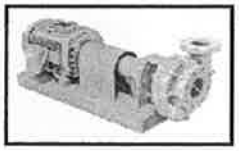
ρ = density of water (kg/m$^3$ ) (constant)

$$E = \frac{W \times \rho}{h_{fg} \times 1{,}000}$$

E = evaporative rate (L/sec) (water consumption)

$h_{fg}$ = enthalpy of vaporization of water (kJ/kg) (constant)

# CONDENSER/CHILLED WATER PUMPS:



- To minimize system pressure drop by reducing water velocity in pipes and remove unnecessary valves
- To design with variable condenser water flow while maintaining condenser saturated temp/pressure;
- Secondary pumps are not necessary unless great difference on delta P among branches.
- To design with variable primary chilled water flow while maintaining chilled water system pressure differential;
- Optimize efficiency by selecting the appropriate impeller, obtain impeller curve and ensure efficiency maintain with wide flow range

To minimize system pressure drop by reducing water velocity in pipes and remove unnecessary valves

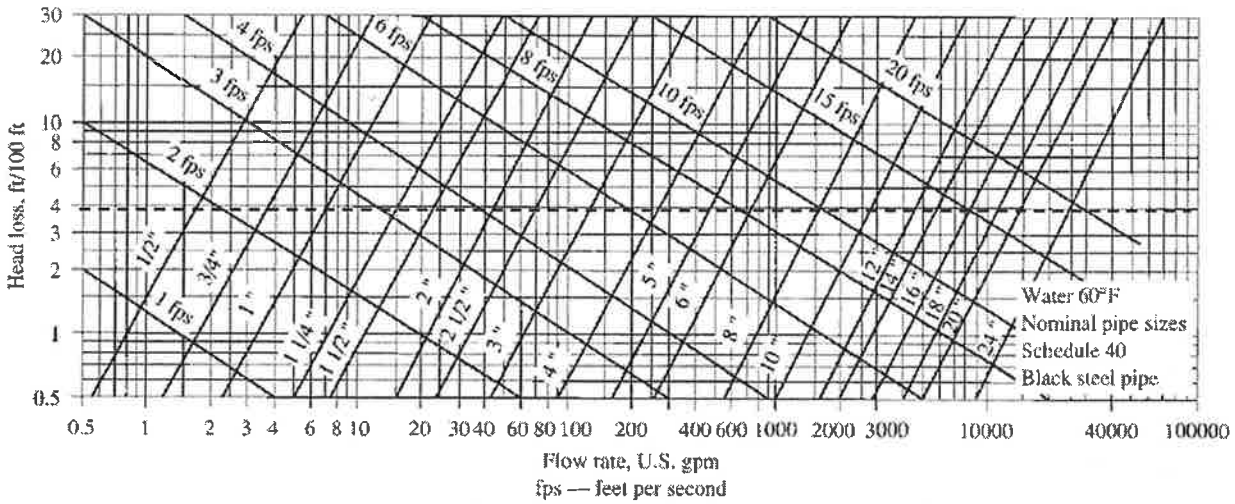



FIGURE 7.2 Friction chart for water in steel pipes (Schedule 40). (*Source: ASHRAE Handbook 1989 Fundamentals. Reprinted with permission.*)

# Chiller Performance at 100% CW Flowrate

| Output Type | Full Load | Part Load | Part Load | Part Load | Part Load |
|---|---|---|---|---|---|
| Percent Load | 100.00 | 90.00 | 80.00 | 70.00 | 60.00 |
| Chiller Capacity | 500 Tons | 450 Tons | 400 Tons | 350 Tons | 300 Tons |
| Chiller Input kW | 273 kW | 236 kW | 204 kW | 175 kW | 148 kW |
| Chiller Input Power | 0.546 kW/Ton | 0.525 kW/Ton | 0.510 kW/Ton | 0.500 kW/Ton | 0.494 kW/Ton |
| **Cooler** | | | | | |
| Entering Temp. | 54.0 ° F | 53.0 ° F | 52.0 ° F | 51.0 ° F | 50.0 ° F |
| Leaving Temp. | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F | 44.0 ° F |
| Flow Rate | 1200.0 gpm | 1200.0 gpm | 1200.0 gpm | 1200.0 gpm | 1200.0 gpm |
| Pressure Drop | 14.0 ft wg | 14.0 ft wg | 14.0 ft wg | 14.0 ft wg | 14.1 ft wg |
| **Condenser** | | | | | |
| Leaving Temp. | 94.3 ° F | 93.3 ° F | 92.3 ° F | 91.4 ° F | 90.5 ° F |
| Entering Temp. | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F | 85.0 ° F |
| Flow Rate | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm | 1500.0 gpm |
| Pressure Drop | 13.1 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg | 13.2 ft wg |

# Chiller Performance at 70% CW Flowrate

| Output Type | Full Load | Part Load | Part Load | Part Load | Part Load |
|---|---|---|---|---|---|
| Percent Load | 100.00 | 90.00 | 80.00 | 70.00 | 60.00 |
| Chiller Capacity | 500 Tons | 450 Tons | 400 Tons | 350 Tons | 300 Tons |
| Chiller Input kW | 298 kW | 256 kW | 219 kW | 186 kW | 157 kW |
| Chiller Input Power | 0.597 kW/Ton | 0.570 kW/Ton | 0.548 kW/Ton | 0.532 kW/Ton | 0.523 kW/Ton |
| **Cooler** | | | | | |
| Entering Temp. | 54.0 °F | 53.0 °F | 52.0 °F | 51.0 °F | 50.0 °F |
| Leaving Temp. | 44.0 °F | 44.0 °F | 44.0 °F | 44.0 °F | 44.0 °F |
| Flow Rate | 1200.0 gpm | 1200.0 gpm | 1200.0 gpm | 1200.0 gpm | 1200.0 gpm |
| Pressure Drop | 14.0 ft wg | 14.0 ft wg | 14.0 ft wg | 14.0 ft wg | 14.1 ft wg |
| **Condenser** | | | | | |
| Leaving Temp. | 98.4 °F | 97.0 °F | 95.6 °F | 94.2 °F | 92.9 °F |
| Entering Temp. | 85.0 °F | 85.0 °F | 85.0 °F | 85.0 °F | 85.0 °F |
| Flow Rate | 1050.0 gpm | 1050.0 gpm | 1050.0 gpm | 1050.0 gpm | 1050.0 gpm |
| Pressure Drop | 6.9 ft wg | 6.9 ft wg | 6.9 ft wg | 6.9 ft wg | 6.9 ft wg |

# Total Power at 70% Load

| | | |
|---|---|---|
| CW Flowrate | 100% | 70% |
| Chiller Power | 175kW | 186kW |
| CWP Power | 37kW | 13kW |
| Total Power | 212kW | 199kW |

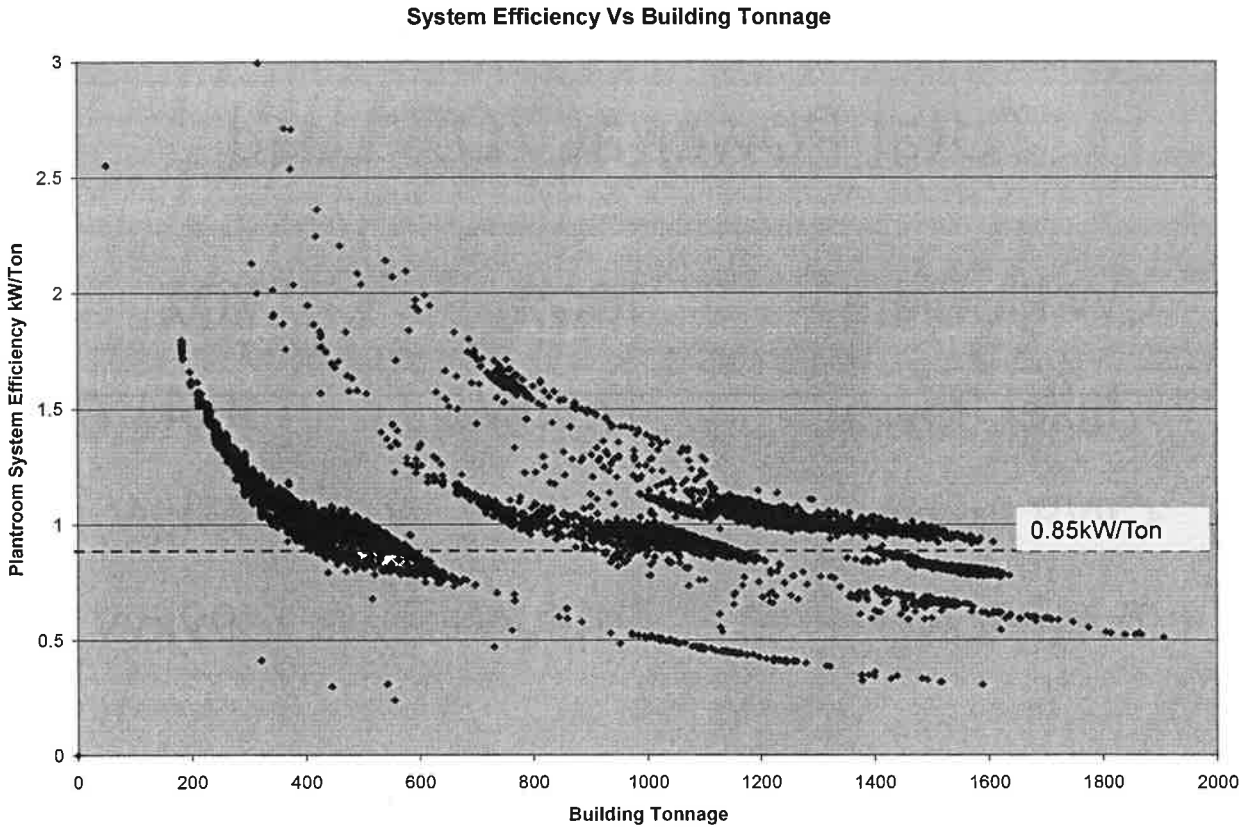
# Case Study – Airline House

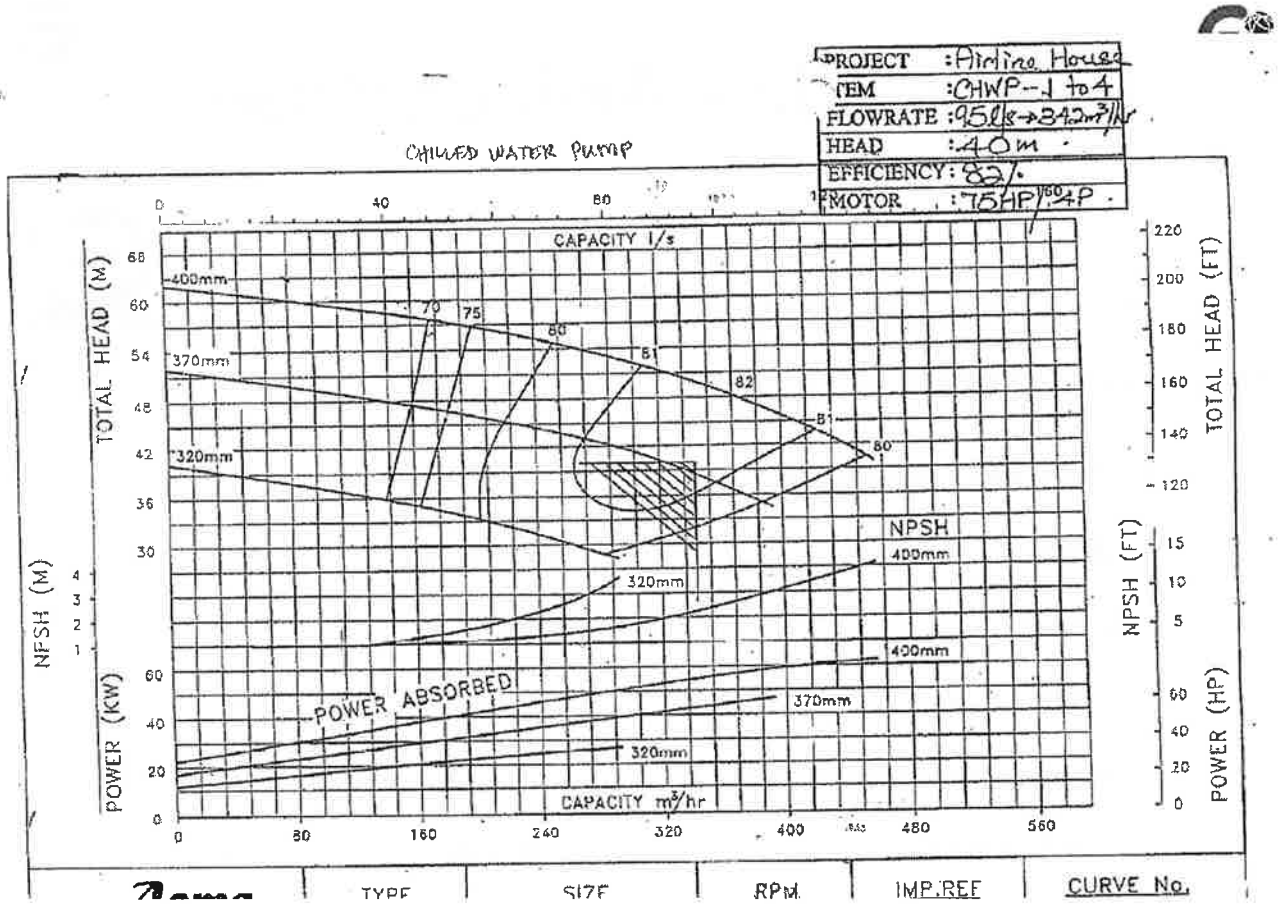


## III. PRESENT SITUATION

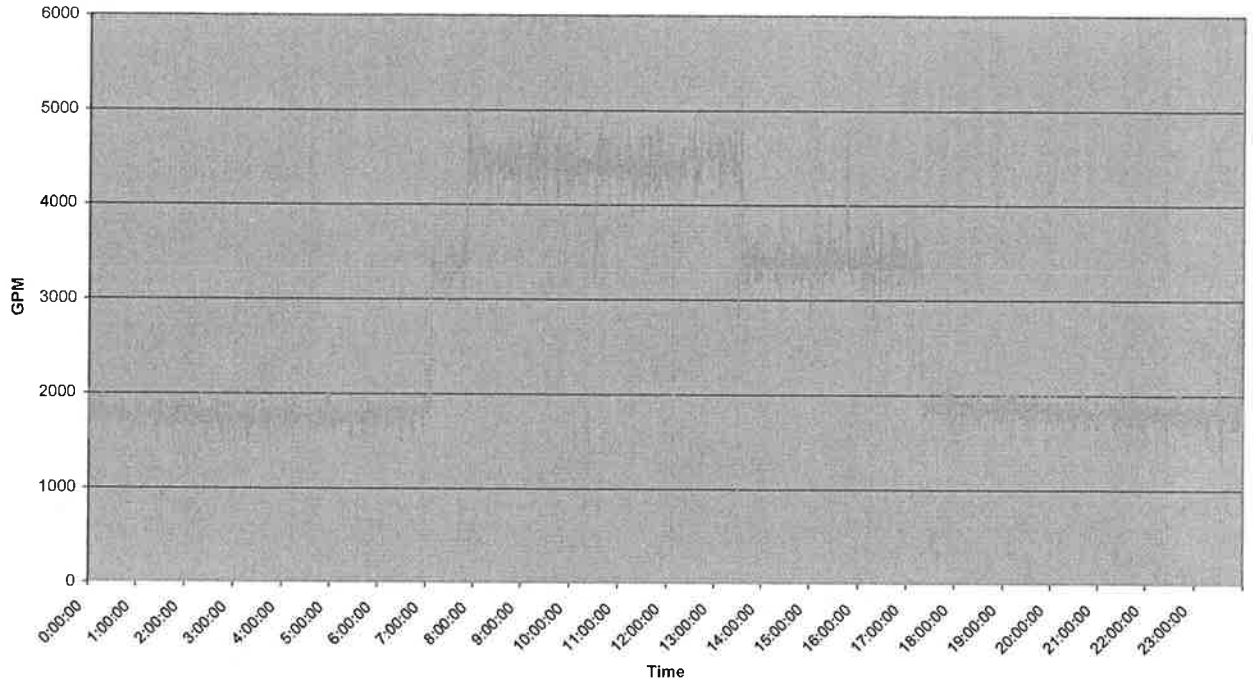
### 1. Existing Equipment

| Item | Capacity | Qty |
|---|---|---|
| Chillers | 600 Tons | 4 |
| Chilled Water Pumps | 55 KW | 4 |
| Condenser Water Pumps | 55 KW | 4 |
| Cooling Towers | 30 kW | 4 |

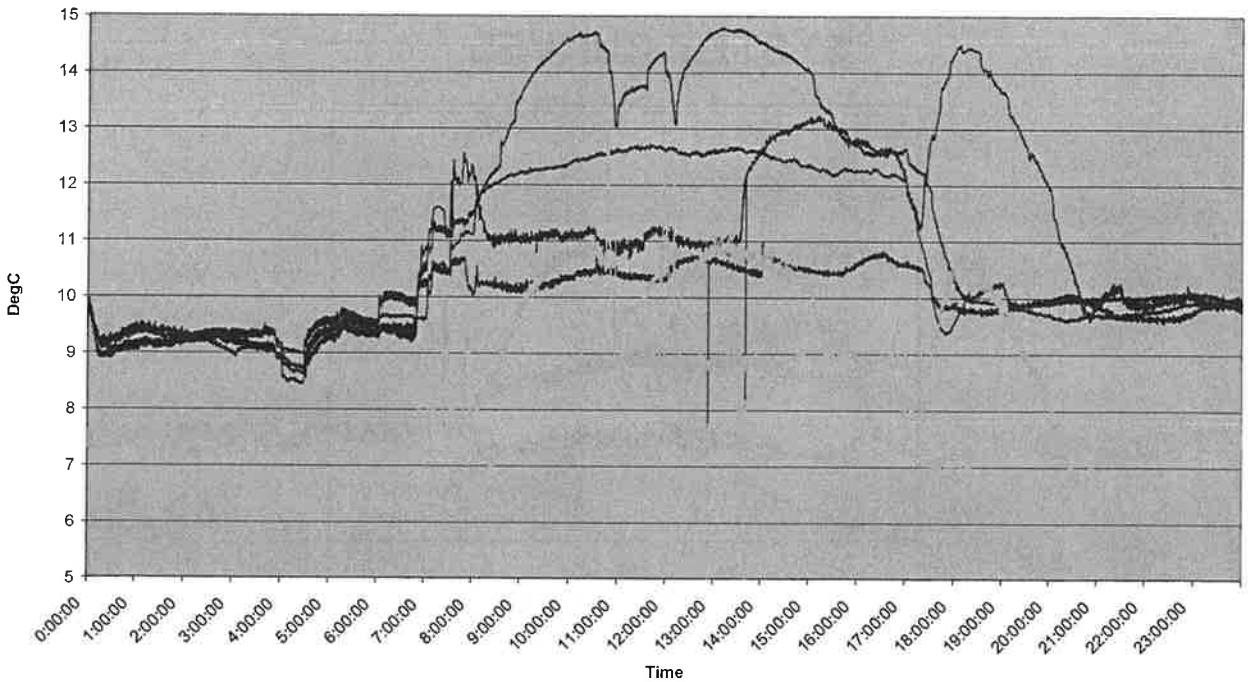

System Efficiency Vs Building Tonnage
Plantroom System Efficiency kW/Ton
Building Tonnage
0.85kW/Ton
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200
1400
1600
1800
2000

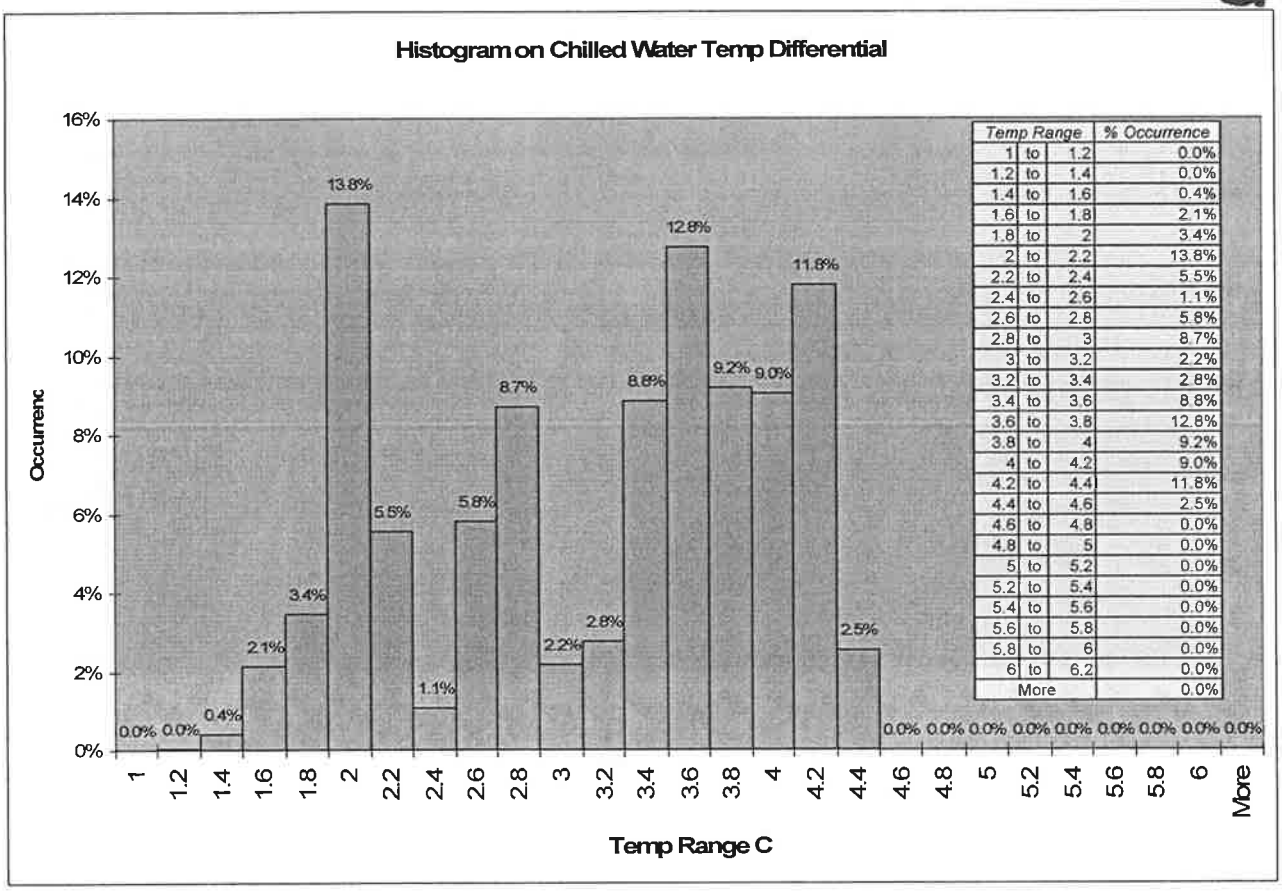

PROJECT : Airline House
ITEM : CHWP-1 to 4
FLOWRATE : 95l/s → 342m³/hr
HEAD : 40m
EFFICIENCY : 82%
MOTOR : 75HP/60/4P
CHILLED WATER PUMP
CAPACITY l/s
CAPACITY m³/hr
TOTAL HEAD (M)
TOTAL HEAD (FT)
NPSH (M)
NPSH (FT)
POWER (KW)
POWER (HP)
POWER ABSORBED
NPSH
400mm
370mm
320mm
70
75
80
81
82
TYPE
SIZE
RPM
IMP.REF
CURVE No.

## Airline House - CHWR Flow




## Airline House - CHWR Temp

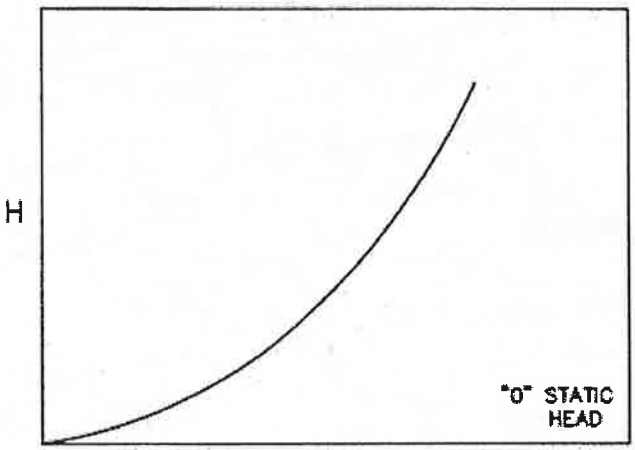




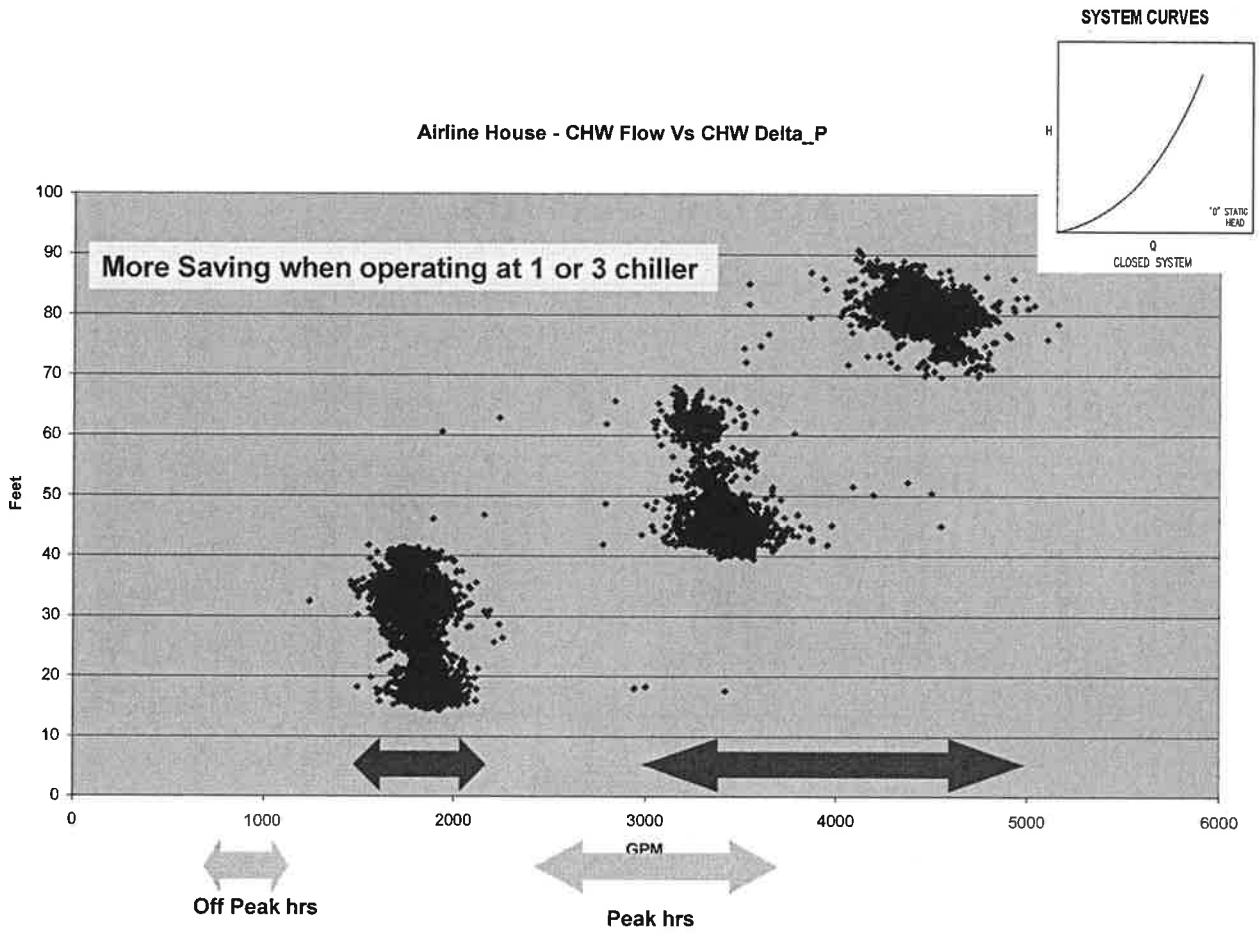

| Temp Range | | | % Occurrence |
|---|---|---|---|
| 1 | to | 1.2 | 0.0% |
| 1.2 | to | 1.4 | 0.0% |
| 1.4 | to | 1.6 | 0.4% |
| 1.6 | to | 1.8 | 2.1% |
| 1.8 | to | 2 | 3.4% |
| 2 | to | 2.2 | 13.8% |
| 2.2 | to | 2.4 | 5.5% |
| 2.4 | to | 2.6 | 1.1% |
| 2.6 | to | 2.8 | 5.8% |
| 2.8 | to | 3 | 8.7% |
| 3 | to | 3.2 | 2.2% |
| 3.2 | to | 3.4 | 2.8% |
| 3.4 | to | 3.6 | 8.8% |
| 3.6 | to | 3.8 | 12.8% |
| 3.8 | to | 4 | 9.2% |
| 4 | to | 4.2 | 9.0% |
| 4.2 | to | 4.4 | 11.8% |
| 4.4 | to | 4.6 | 2.5% |
| 4.6 | to | 4.8 | 0.0% |
| 4.8 | to | 5 | 0.0% |
| 5 | to | 5.2 | 0.0% |
| 5.2 | to | 5.4 | 0.0% |
| 5.4 | to | 5.6 | 0.0% |
| 5.6 | to | 5.8 | 0.0% |
| 5.8 | to | 6 | 0.0% |
| 6 | to | 6.2 | 0.0% |
| More | | | 0.0% |

## PUMP AND SYSTEM BASICS

### SYSTEM CURVES




CLOSED SYSTEM



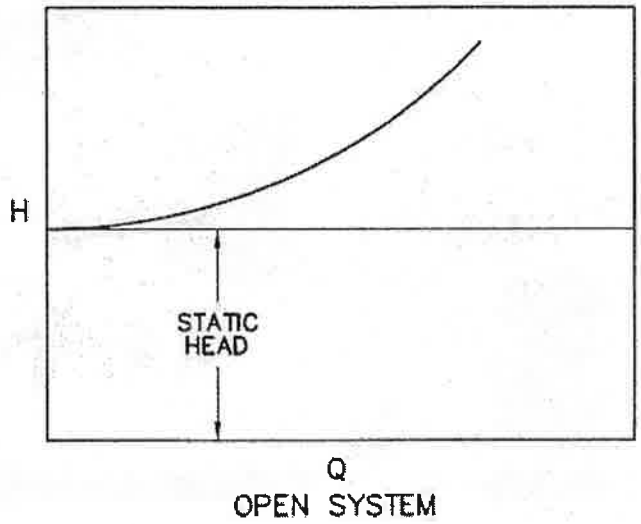

# Proposal

- To install up to 3 VSD at Chilled Water Pumps if budget allows;
- Existing Starter panel can still be used as standby.

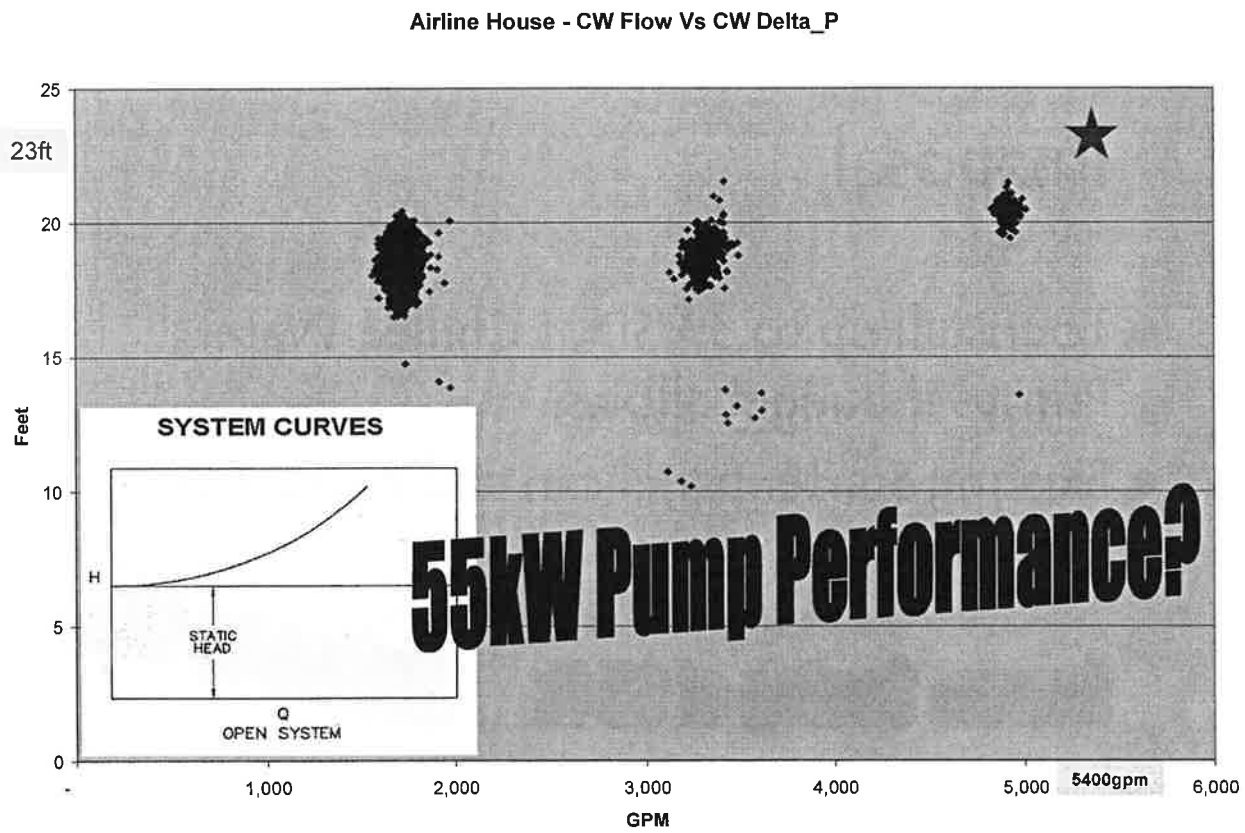
**Annual Saving of $54k**

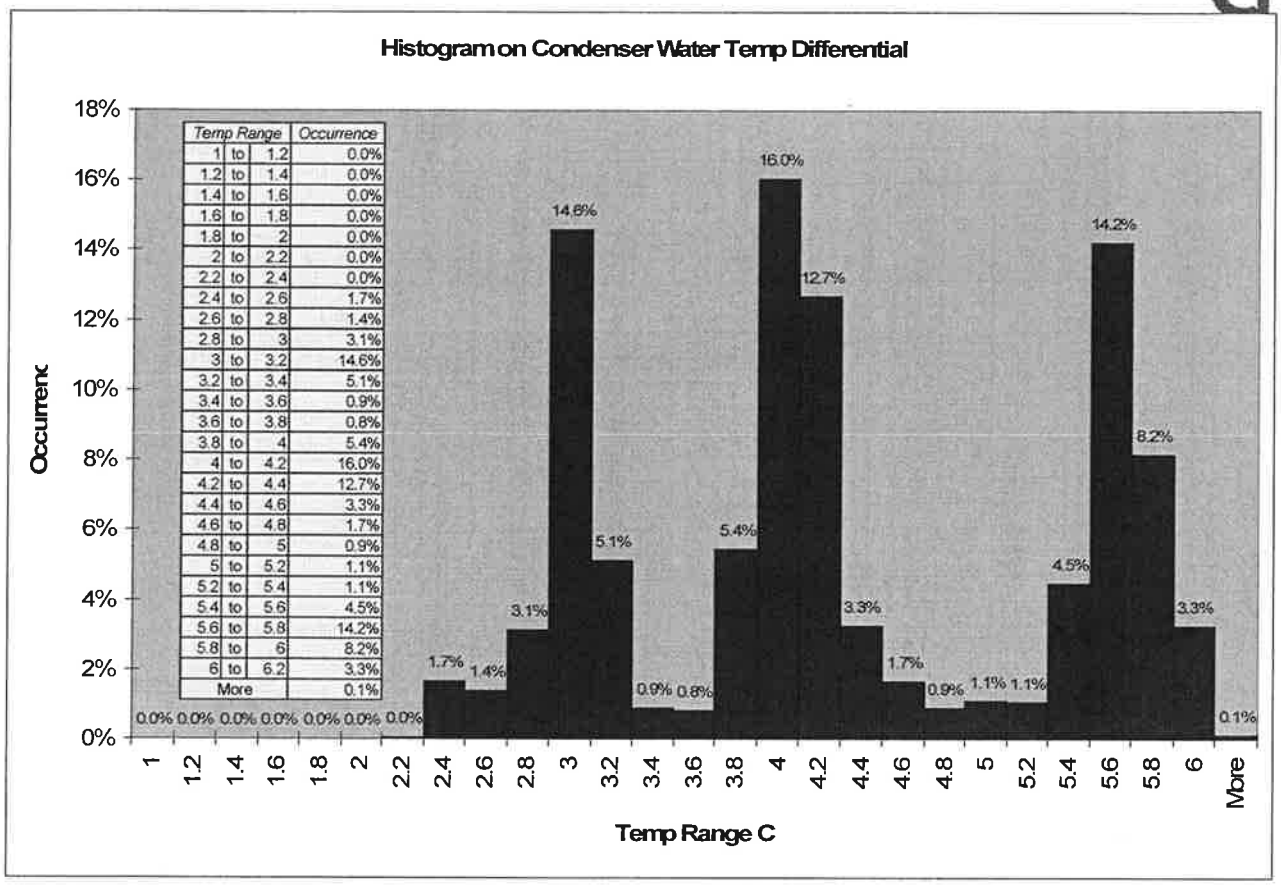
**Reduce by 40%**

## SYSTEM CURVES




Condenser Water Pumps

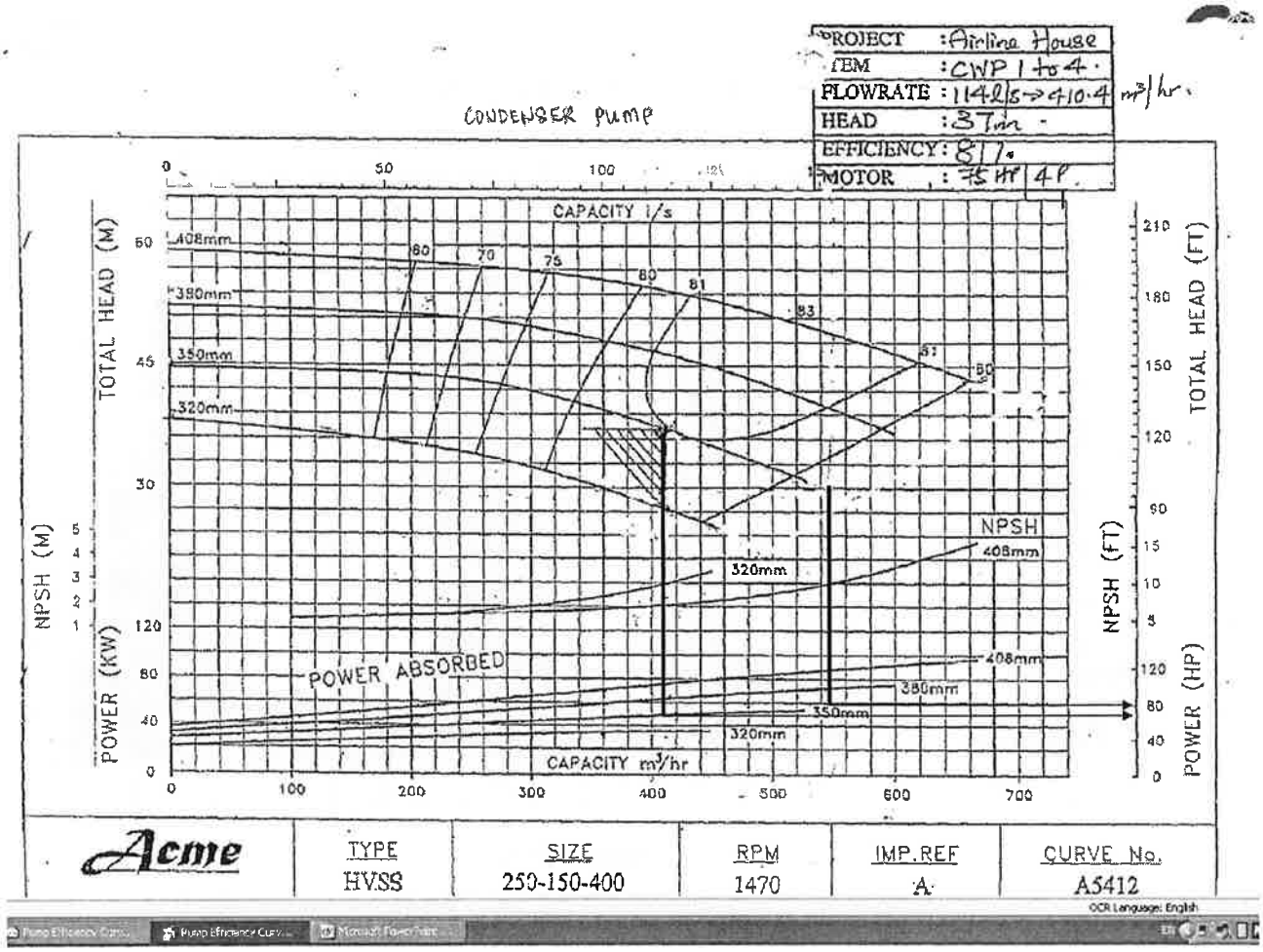





| Temp Range | | | Occurrence |
|---|---|---|---|
| 1 | to | 1.2 | 0.0% |
| 1.2 | to | 1.4 | 0.0% |
| 1.4 | to | 1.6 | 0.0% |
| 1.6 | to | 1.8 | 0.0% |
| 1.8 | to | 2 | 0.0% |
| 2 | to | 2.2 | 0.0% |
| 2.2 | to | 2.4 | 0.0% |
| 2.4 | to | 2.6 | 1.7% |
| 2.6 | to | 2.8 | 1.4% |
| 2.8 | to | 3 | 3.1% |
| 3 | to | 3.2 | 14.6% |
| 3.2 | to | 3.4 | 5.1% |
| 3.4 | to | 3.6 | 0.9% |
| 3.6 | to | 3.8 | 0.8% |
| 3.8 | to | 4 | 5.4% |
| 4 | to | 4.2 | 16.0% |
| 4.2 | to | 4.4 | 12.7% |
| 4.4 | to | 4.6 | 3.3% |
| 4.6 | to | 4.8 | 1.7% |
| 4.8 | to | 5 | 0.9% |
| 5 | to | 5.2 | 1.1% |
| 5.2 | to | 5.4 | 1.1% |
| 5.4 | to | 5.6 | 4.5% |
| 5.6 | to | 5.8 | 14.2% |
| 5.8 | to | 6 | 8.2% |
| 6 | to | 6.2 | 3.3% |
| More | | | 0.1% |

# If condenser pumps are designed at 37m (120ft+), where's the additional static comes from?

Installer had deliberately closed the globe valve due to overflow so as to prevent motor from overloading till burnt




# Proposed Condenser Water Pump kW

| | Feet |
|---|---|
| Supply and Return Pressure Drop from plantroom header to Cooling Tower | 23 |
| Pressure Drop across Plantroom (normally 7 to 12) | 15 |
| Pressure Drop across Chiller Condenser Shell | 25 |
| Safety (10%) | 7 |
| Total Head | 70 |
| | |
| Pump Efficiency | 0.86 |
| Motor Efficiency | 0.92 |
| Flowrate requirement (GPM) | 1800 |
| Condenser Pump kW requirement (kW) | 30.0 |

**Annual Saving of $63k**

**Reduce by 45%**

# Chiller Plantroom System Control

Optimum Sequencing of equipment

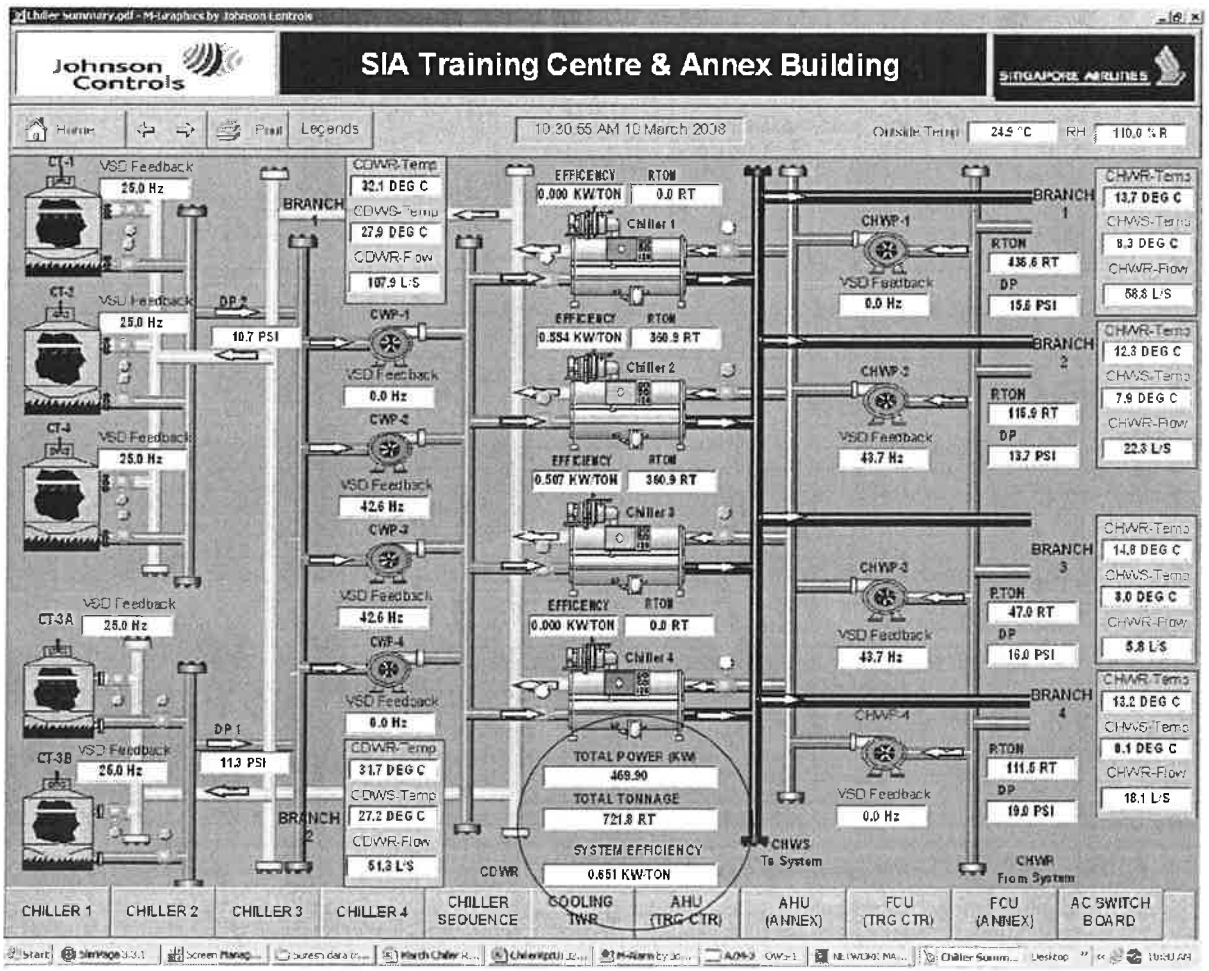
Variable speed for all pumps and cooling towers using BAS intelligence

Trending features for analysis

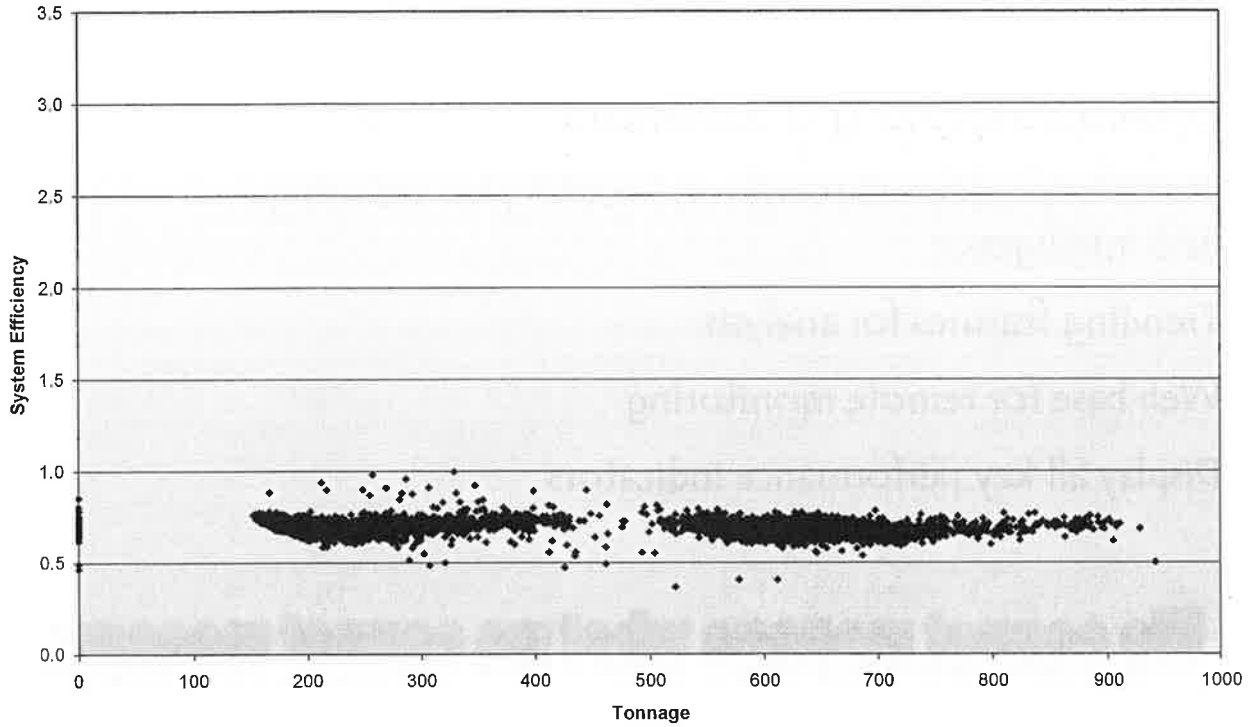
Web base for remote monitoring

Display all key performance indicators

**We cannot manage what we cannot measure**



**SIA Training Centre**
**Efficiency vs Tonnage (After Improvement)**




**SAVINGS FOR THE MONTH OF JAN 08**

| S/NO | AHU | AHU ( NEW LABEL) | Measured current (Amp) | Absorb power using star/delta starter (kW) | Operating Hour/Day | No. of Days | Misc. A/C Request | Consumption (kWh) | | Saving (kWh) | Saving ($)*$0.18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before VSD operating | | | | | Before VSD | After VSD | | |
| 1 | 1P 2-1 | 1A-CAN | 12 | 6.9 | 9 | 22 | 1 | 1373.16 | 1291 | 82.16 | $14.79 |
| 2 | BP 2-1 | BA-CAN | 11 | 6.3 | 7 | 22 | 1 | 980.42 | 797 | 183.42 | $33.01 |
| 3 | 1-1A | 4A-S1-1A | 33 | 19.0 | 10 | 22 | 0 | 4174.67 | 2035.00 | 2139.67 | $385.14 |
| 4 | 1-1B | 4A-S3-1A | 23 | 13.2 | 10 | 22 | 2.5 | 2942.69 | 1287.00 | 1655.69 | $298.02 |
| 5 | 3-2A | 5BC-AUD | 15 | 8.6 | 76 | 1 | 0 | 655.53 | 381.00 | 274.53 | $49.41 |
| 6 | 3-3A | 5BC-M-LB | 20 | 11.5 | 10 | 22 | 1 | 2541.61 | 1792.00 | 749.61 | $134.93 |
| 7 | R3-3 | RB-S-LOU | 6 | 3.5 | 14 | 1 | 1 | 51.75 | 14.00 | 37.75 | $6.80 |
| 8 | BP 4-1 | BC-CET | 45 | 25.9 | 10 | 22 | 25 | 6339.64 | 2273.00 | 4066.64 | $732.00 |
| 9 | 4-1A | 5C-S6-1C | 33 | 19.0 | 10 | 22 | 1 | 4193.65 | 4157.00 | 36.65 | $6.60 |
| 10 | R3-1 | RC-C-LB | 3.7 | 2.1 | 10 | 22 | 0 | 468.07 | 89.00 | 379.07 | $68.23 |
| 11 | 1-2A | 4A-S1-2A | 34 | 19.6 | 12 | 22 | 9 | 5337.37 | 2309.00 | 3028.37 | $545.11 |
| 12 | 1-2B | 4A-S3-2A | 15 | 8.6 | 12 | 22 | 48 | 2691.11 | 1641.00 | 1050.11 | $189.02 |
| 13 | 2-2B | 5B-2AB | 11.5 | 6.6 | 10 | 22 | 1 | 1461.42 | 1007.00 | 454.42 | $81.80 |
| 14 | 2-2A | 5B-2BC | 8 | 4.6 | 10 | 22 | 1 | 1016.64 | 1000.00 | 16.64 | $3.00 |
| 15 | 3-3C | 5BC-SIM1 | 12 | 6.9 | 24 | 31 | 0 | 5133.81 | 2221.00 | 2912.81 | $524.31 |
| 16 | 3-3D | 5BC-SIM2 | 11 | 6.3 | 24 | 31 | 0 | 4706.00 | 1846.00 | 2860.00 | $514.80 |
| 17 | 4-2B | 5C-2C | 14 | 8.1 | 24 | 31 | 0 | 5989.45 | 3751.00 | 2238.45 | $402.92 |
| 18 | 4-2A | 5C-S6-2C | 11 | 6.3 | 10 | 22 | 14.5 | 1483.27 | 1255.00 | 228.27 | $41.09 |
| 19 | 1-3A | 4A-S1-3A | 35 | 20.1 | 10 | 22 | 48 | 5393.73 | 5314.00 | 79.73 | $14.35 |
| 20 | 1-3B | 4A-S3-3A | 25 | 14.4 | 10 | 22 | 0 | 3162.63 | 680.00 | 2482.63 | $446.87 |
| 21 | 2-3A | 5B-3AB | 22.5 | 12.9 | 10 | 22 | 17 | 3066.32 | 2546.00 | 520.32 | $93.66 |
| 22 | 3-3B | 5BC-3C | 12 | 6.9 | 10 | 22 | 1 | 1524.96 | 1319.00 | 205.96 | $37.07 |
| 23 | 4-3A | 5C-3C | 30 | 17.3 | 10 | 22 | 1 | 3812.41 | 1974.00 | 1838.41 | $330.91 |
| 24 | 2-4A | 5B-4A | 15 | 8.6 | 10 | 22 | 18 | 2052.84 | 1244.00 | 808.84 | $145.59 |
| 25 | 4-4A | 5C-S6-4C | 23.5 | 13.5 | 12 | 22 | 1 | 3580.96 | 2063.00 | 1517.96 | $273.23 |
| 26 | 4-4B | 5C-4C | 15 | 8.6 | 12 | 22 | 0 | 2277.10 | 1600.00 | 677.10 | $121.88 |
| 27 | 3-4A | 5BC-4B | 23 | 13.2 | 10 | 22 | 0 | 2909.62 | 1579.00 | 1330.62 | $239.51 |
| 28 | R2 | R-ANX2 | 8 | 4.6 | 24 | 31 | 0 | 3422.54 | 495 | 2927.54 | $526.96 |
| 29 | R3-1/r3-2 | R-SIM1/R-SIM2 | 10.3 | 5.9 | 24 | 31 | 0 | 4406.52 | 1662.00 | 2744.52 | $494.01 |
| 30 | R3-3 | R-ANX3 | 16.5 | 9.5 | 10 | 22 | 0 | 2087.34 | 623.00 | 1464.34 | $263.58 |
| | | | | | | | 192.00 | 89237.23 | 50245.00 | 38992.23 | $7,018.60 |

## Projected Saving on Plantroom Only

**14. Total Chiller System Consumption for Main Building & Annexe**

**From Apri 06 till Nov 07, reading taken from Measuring pt : 303, 304, 305, 306 & 706**

**For month Dec 07, New chiller fully commission and support both Main & Annexe aircon system.**

| MONTH | Total KWH Consumption for Chillers System | | KWH Difference (compared to previous period) | % Difference (compared to previous period) | KWH Difference (compared to previous month) | % Difference (compared to previous month) |
|---|---|---|---|---|---|---|
| | KWH CONSUMPTION FY 2006/07 | KWH CONSUMPTION FY 2007/08 | | | | |
| APRIL | 425,890 | 386,650 | -39,240 | -9.21 | -53,100 | -12.08 |
| MAY | 430,950 | 444,690 | 13,740 | 3.19 | 58,040 | 15.01 |
| JUNE | 435,850 | 445,940 | 10,090 | 2.32 | 1,250 | 0.28 |
| JULY | 431,520 | 409,740 | -21,780 | -5.05 | | -8.12 |
| AUGUST | 428,340 | 426,480 | -1,860 | | | 4.09 |
| SEPTEMBER | 410,260 | 405,960 | | | | -4.81 |
| OCTOBER | 408,610 | 405,[illegible] | | | -490 | -0.12 |
| NOVEMBER | 406,1[illegible] | | | [illegible].85 | -92,176 | -22.73 |
| DECEMBER | 394,1[illegible] | | [illegible].08 | -49.53 | -114,402 | -36.52 |
| JANUARY | 411,6[illegible] | | 234,113 | -56.87 | -21,365 | -10.74 |
| FEBRUARY | 366,3[illegible] | [illegible],751 | -206,639 | -56.40 | -17,776 | -10.01 |
| MARCH | 439,7[illegible] | | | | | |

**Total Saving > $600K per year**

**240,320** kWhr per month

**$ 519,091.51** per year





Carbon Calculator

Calculation Explanation - Electricity

- Home
- CO2 Effects
- Carbon Calculator
- Shopping Calculator
- Calculation Explanation
- Emission Reductions
- National Averages

To calculate the carbon emissions due to electricity production the website takes your bill and finds from this the number of kilowatt-hours (kWh) you use in a year. This is based on the average cost of electricity in the UK. After taking into account the different methods of electricity generation in the UK, the average CO2 emission per kWh is 0.47 kg. This can be multiplied by the number of kWh used to find the total CO2 emission. For campus accommodation we use an 'average electricity use per bedroom' figure that was supplied by the university and for green tariffs it is assumed that the carbon emission contribution from electricity is zero.



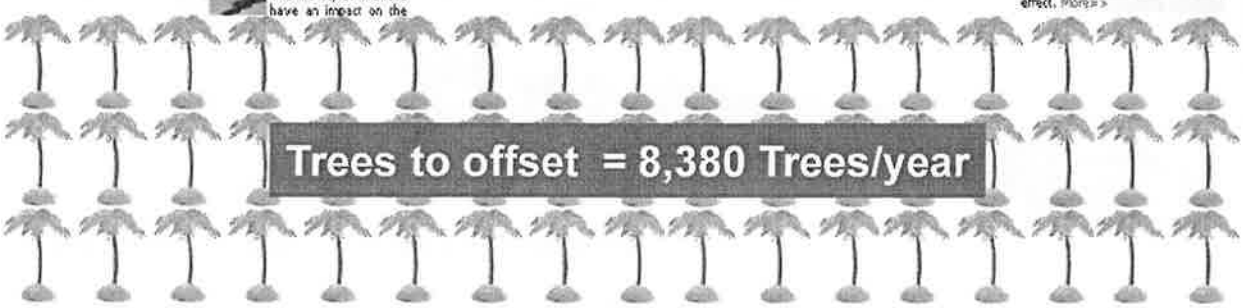
**Reduction of 1,676,000kg CO2 emmission per year**

Effects of $CO_2$

The life style: we lead have an impact on the

[illegible] Emissions

[illegible] things you can do to decrease your carbon dioxide emissions which contribute to the global warming effect. More »



**Trees to offset = 8,380 Trees/year**




# Total Power Consumption reduction from Standard Code of Practice

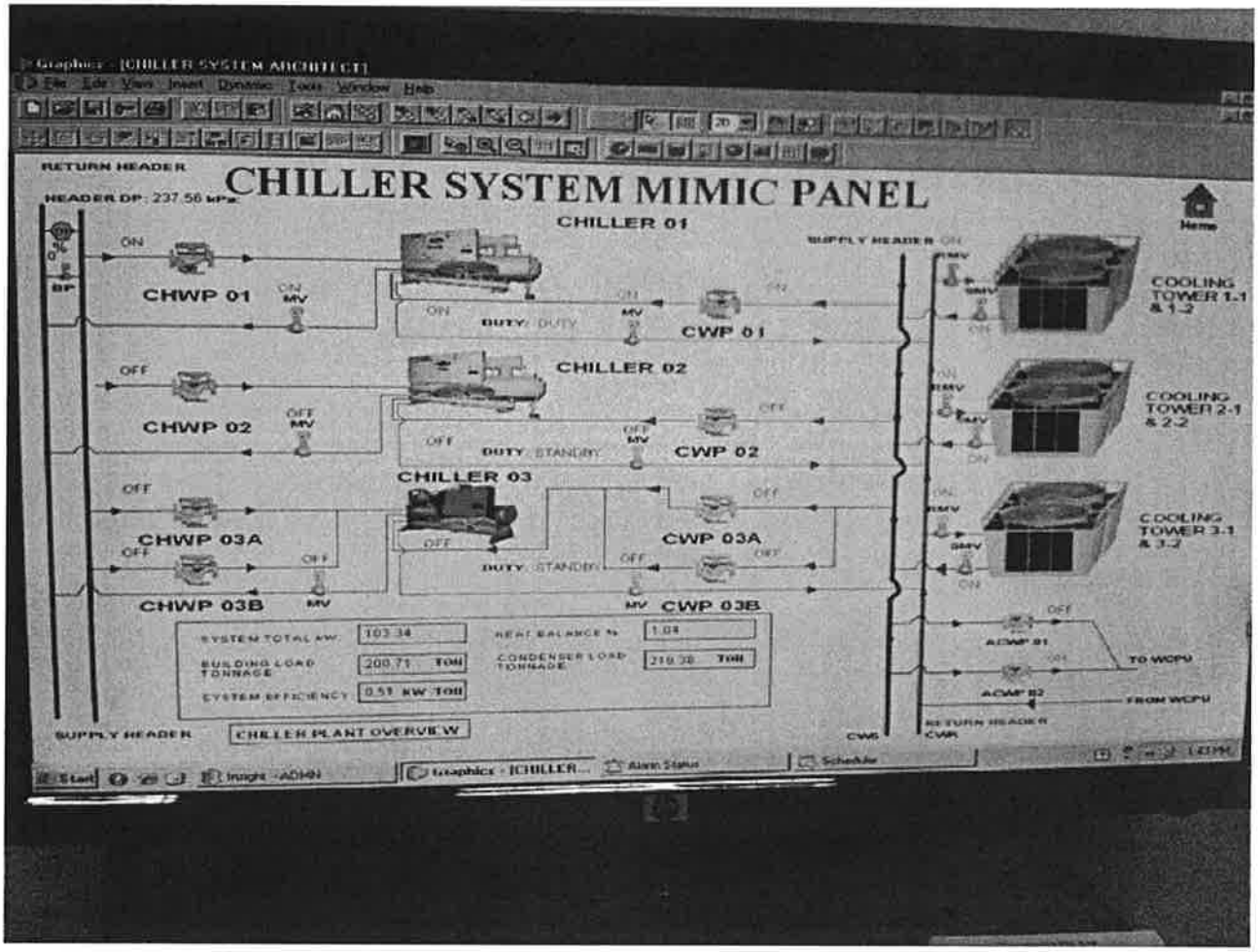
| Items | Standard Design | City Square Design | % Improvement |
|---|---|---|---|
| Plantroom Consumption | 37,293 | 24,434 | 34% |
| Total Fan Power for Air Conditioning | 18,360 | 10,231 | 44% |
| Lift | 1,109 | 998 | 10% |
| Escalator | 4,392 | 3,074 | 30% |
| Sanitary & Plumbing System | 456 | 456 | 0% |
| Mechanical Fan for Ventilation | 12,924 | 6,059 | 53% |
| Lighting System | 5,620 | 3,876 | 31% |
| TOTAL | 80,153 | 49,128 | 39% |

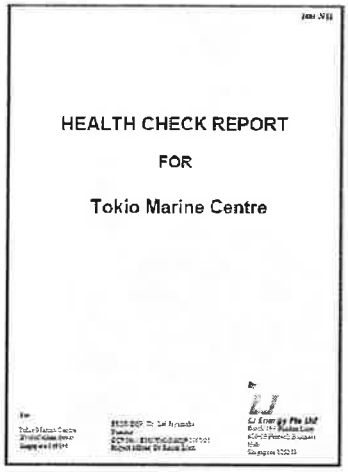
**Reduction of 31,025kWhr per day**

**Above calculation exclude**

**VSD operations on all AHUs and FCUs**

**Hot water power to raise water to 50C**



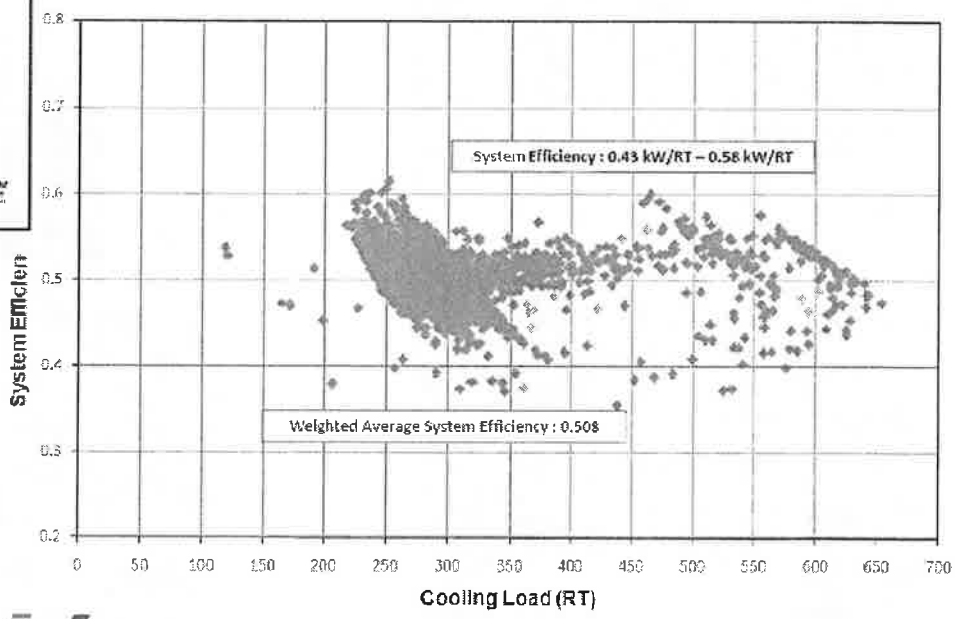



HEALTH CHECK REPORT

FOR

Tokio Marine Centre

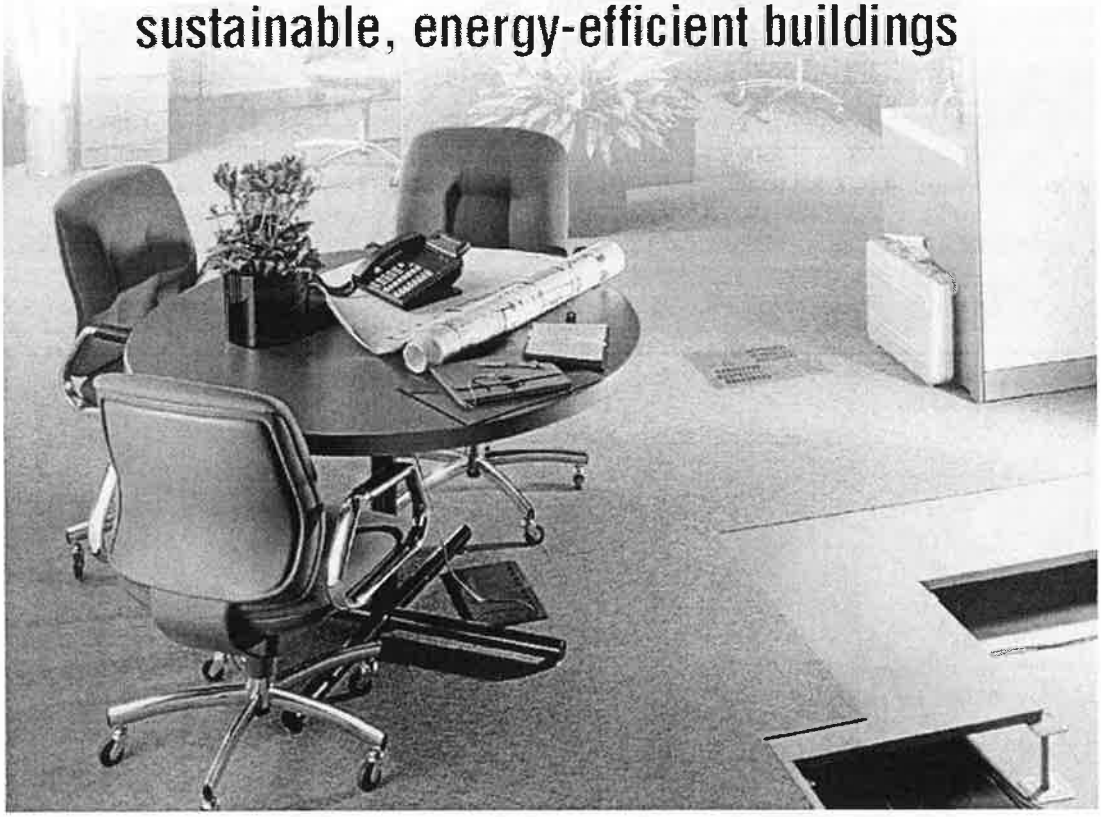
Combined plant room (560 RT × 2): System Efficiency vs Cooling Load

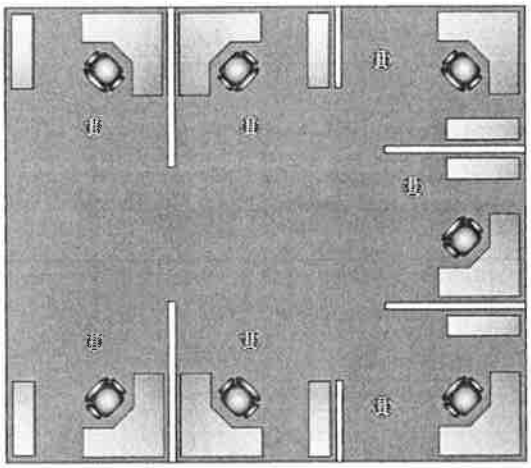


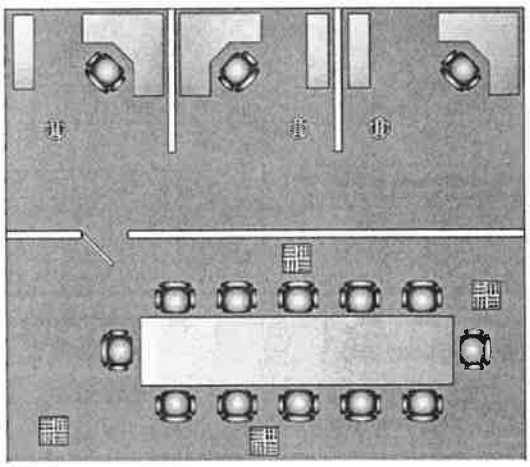

LJ Energy Pte Ltd

Tokio Marine Centre

# Underfloor-air distribution for today's sustainable, energy-efficient buildings

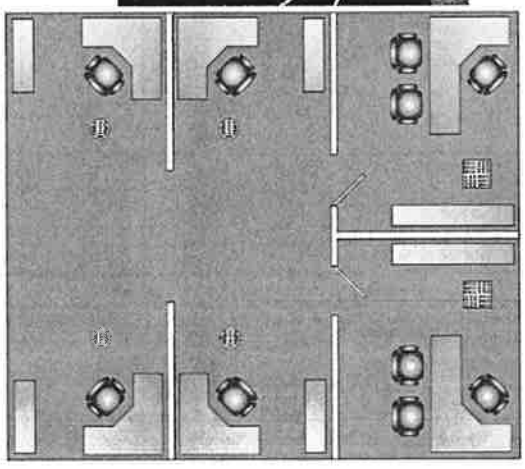


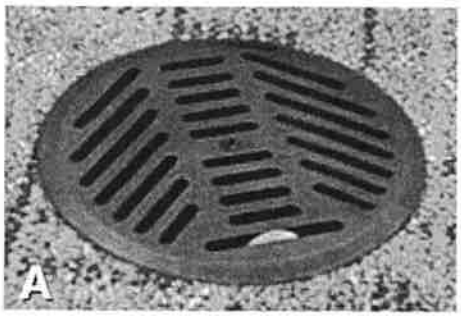


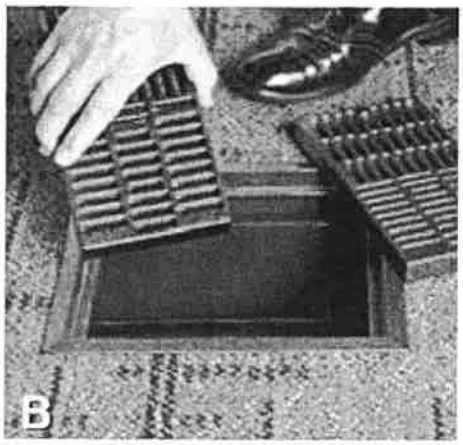


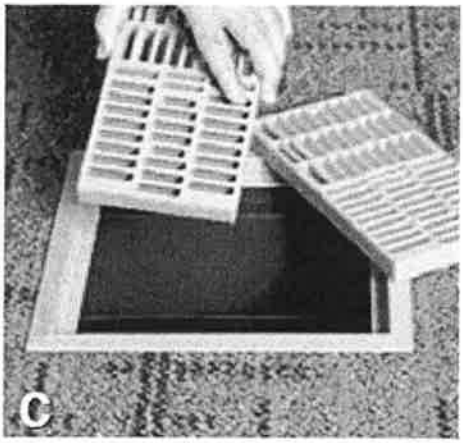


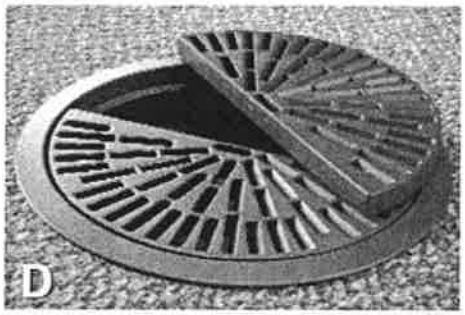
*VAV units can be installed anywhere in the floor grid.*






# Cost savings at every phase of the building life

## Reduced construction costs

Perhaps the most compelling advantage of the FlexSys System is that it offers all the benefits of improved flexibility and comfort at a cost that is competitive with traditional designs. If you're already planning on a raised floor for data, power and telecommunications, the addition of UFAD using the FlexSys System can cost less than a traditional HVAC system, because it:

- Eliminates overhead ductwork
- May reduce building height, typically 6" per floor
- Simplifies modifications to the air system, prior to and after occupant move-in, which reduces labor costs and speeds occupancy
- Allows more energy-saving daylighting opportunities through decreased plenum height and the elimination of overhead ductwork.

## Reduced life-cycle costs

The FlexSys System really pays off when you consider life-cycle costs, because it:

- Reduces costs — and disruptions — caused by "churn"
- Provides greater energy efficiency than an overhead Variable Air Volume (VAV) system — fan energy is only .05" static pressure, instead of the static pressure typically needed by overhead VAV systems — which translates into 30% fan-energy operating savings annually
- Affords more hours of economizer cycling by delivering 60°–63°F air, versus a conventional 55°F supply air temperature
- May qualify for accelerated tax-depreciation based on the FlexSys System plug-and-play modular design. Consult your tax advisor for more information.

**Figure: 3 Overhead VAV:**

- Some ventilation air completely bypasses the space – from supply diffuser to return
- Ventilation air mixed in entire space from floor to ceiling

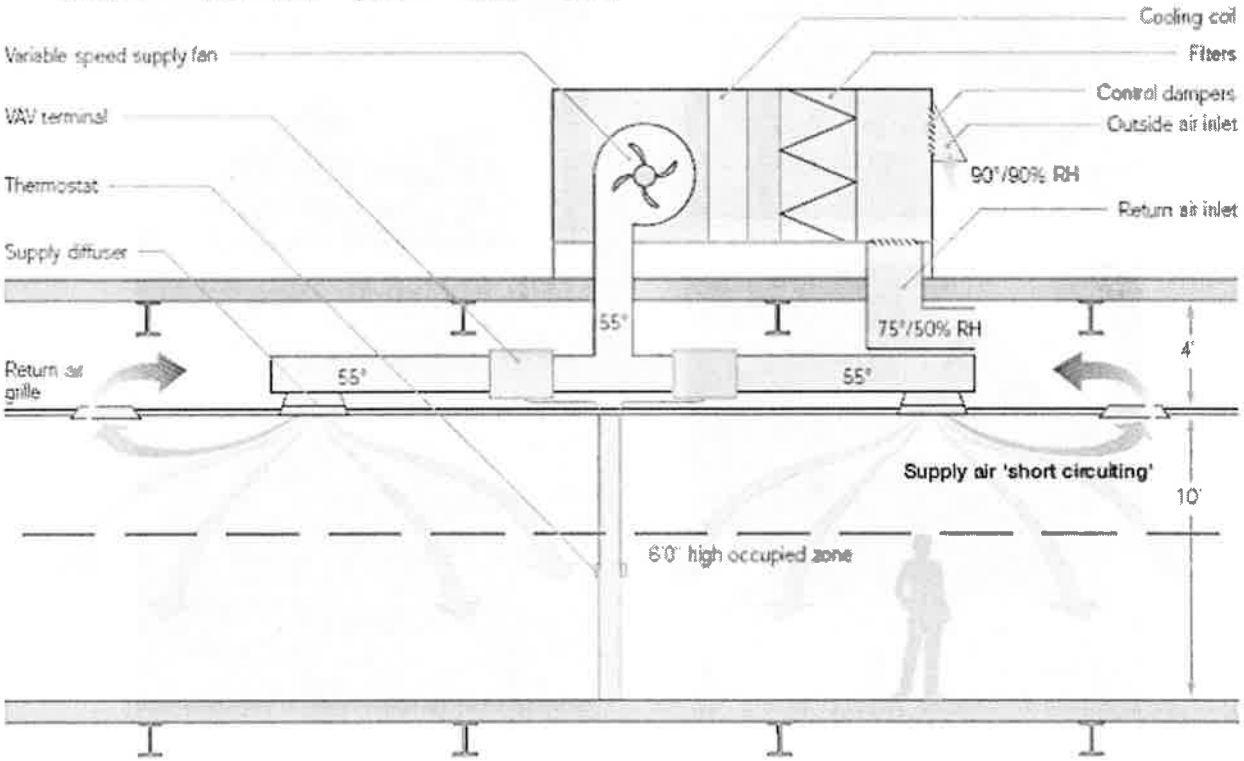
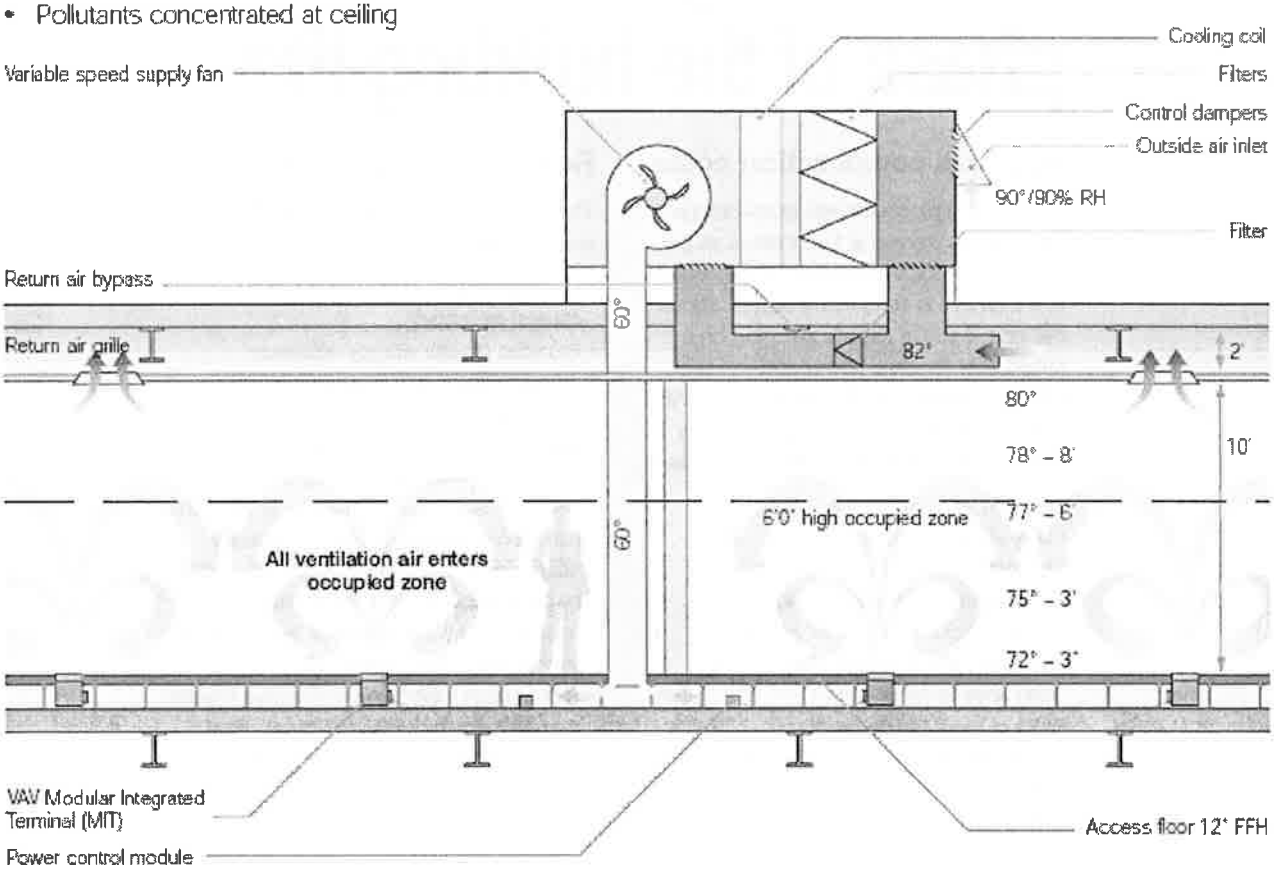


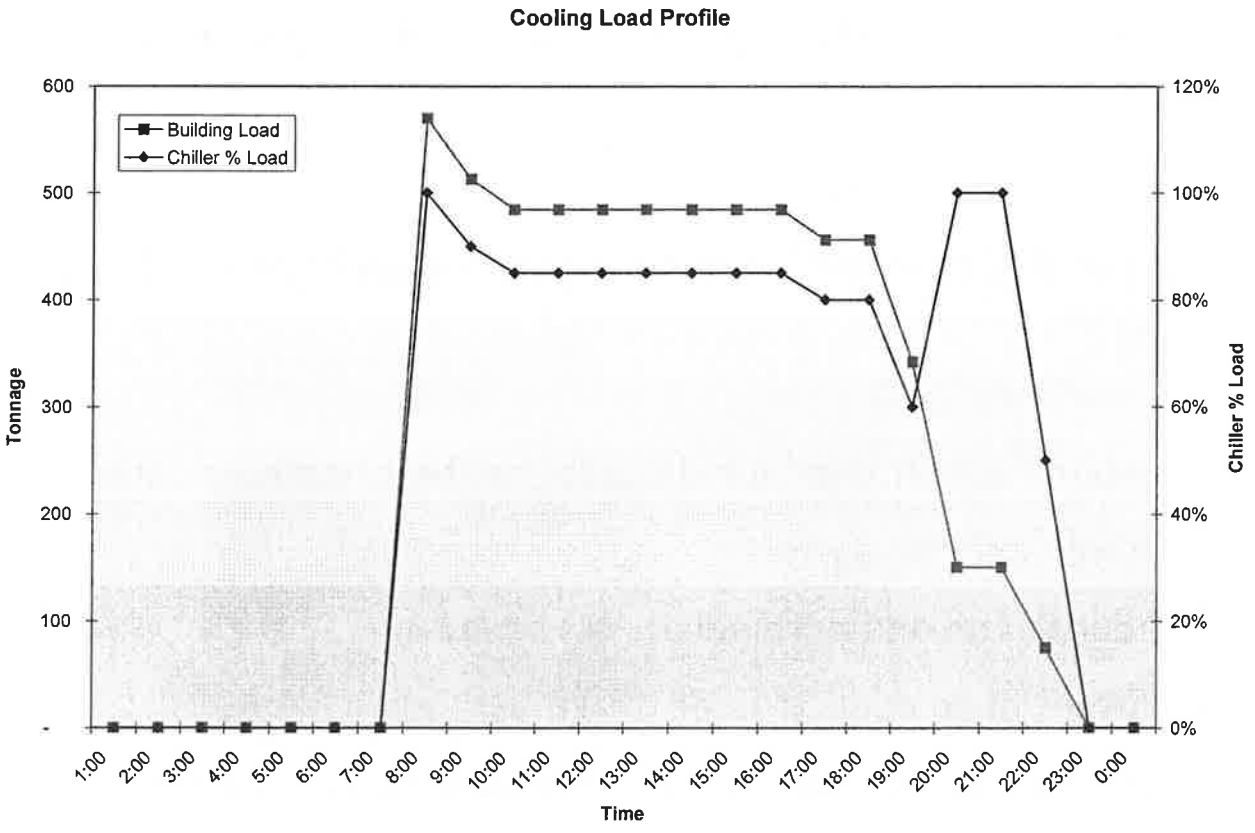

**Figure: 4 FlexSys™ VAV Underfloor Air**

- All of the intended ventilation air enters the occupied zone directly
- Pollutants concentrated at ceiling






# Cost Comparison Between Initial Investment & Operation Cost Reduction



| Price Reduction from Original Design | Unit Price | Qty per floor | Floor | |
|---|---|---|---|---|
| 1 Thermal Grill | $ 250 | 35 | 17 | $ 148,750 |
| 2 Insulated Ducting | $ 40,000 | 1 | 17 | $ 680,000 |
| 3 Construction | | | | - |
| | | | Total Cost | $ 828,750 |
| Additional Cost | | | | |
| 1 Underfloor Diffuser Variable flow | $ 560 | 25 | 17 | $ 238,000 |
| 2 Underfloor Diffuser Constant flow | $ 150 | 25 | 17 | $ 63,750 |
| 3 Floor height increment | $ 3 | 612 | 17 | $ 31,212 |
| 4 Insulation | $ 45 | 612 | 17 | $ 468,180 |
| | | | Total Cost | $ 801,142 |

| Operating Cost Saving Compare to Original | | | |
|---|---|---|---|
| kWhr Per Day | | 4119 | |
| Operating Cost Per Day (Base on $0.21 per kWhr) | | $ 864.99 | |
| Operating Cost Per Year (Using 5.5 Days per week) | | $ 247,387.14 | |
| Expected Saving on Energy are from: | | | |
| Higher Chilled Water Temp | 5% | | $ 12,369 |
| Lower Air Volume/Fan Speed | 2% | | $ 4,948 |
| Lesser Fresh Air | 5% | | $ 12,369 |
| Thermal Loss due to leakage and Themal Difference | 5% | | $ 12,369 |
| TOTAL SAVING PER YEAR | | | $ 42,056 |

## CONCLUSION -Main Advantages and Benefits of UFA

1. Lower churn costs

- allows for fast and inexpensive reconfiguration of office space,

2. Improved IAQ

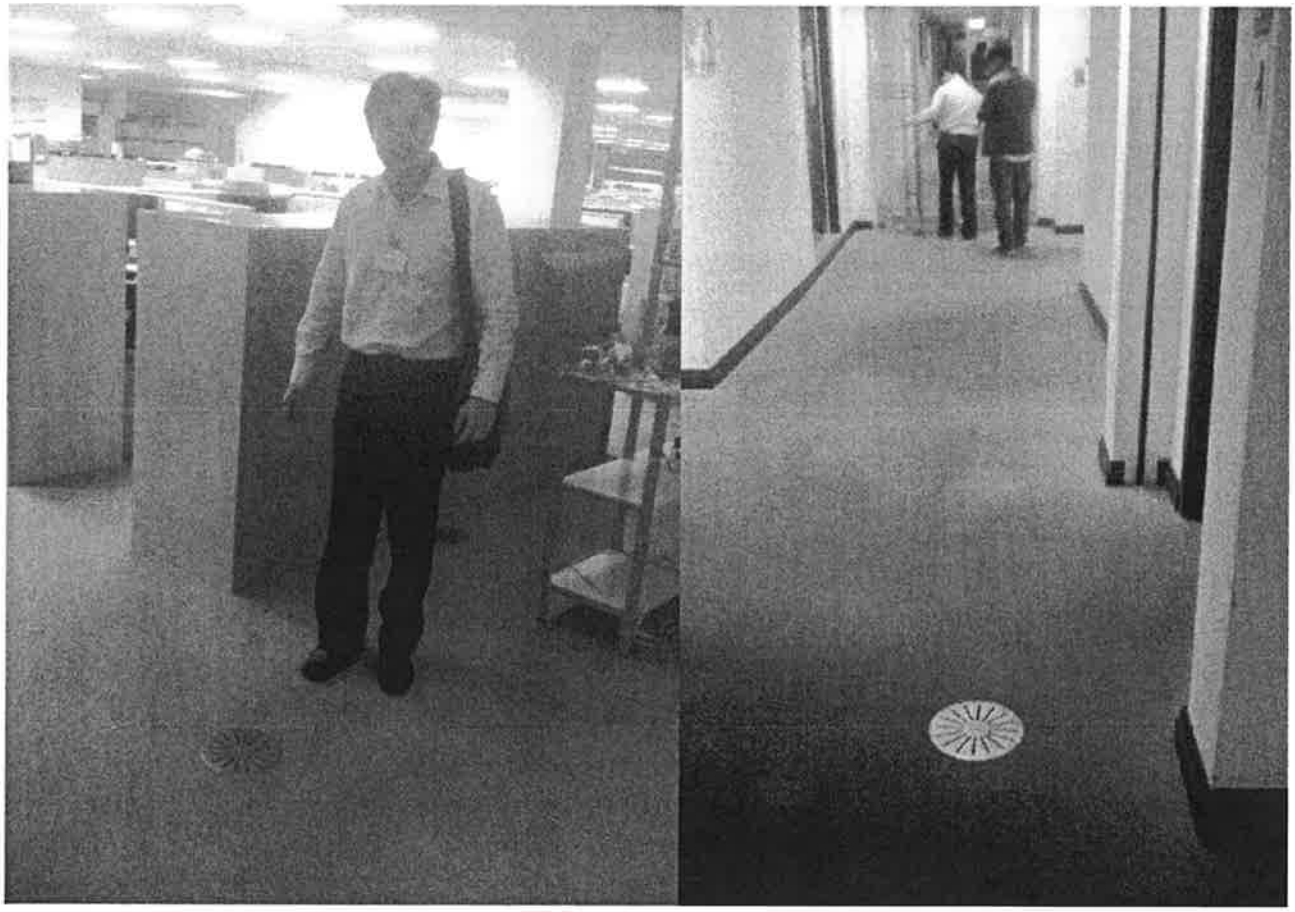
- supplies conditioned air directly to the breathing zone,

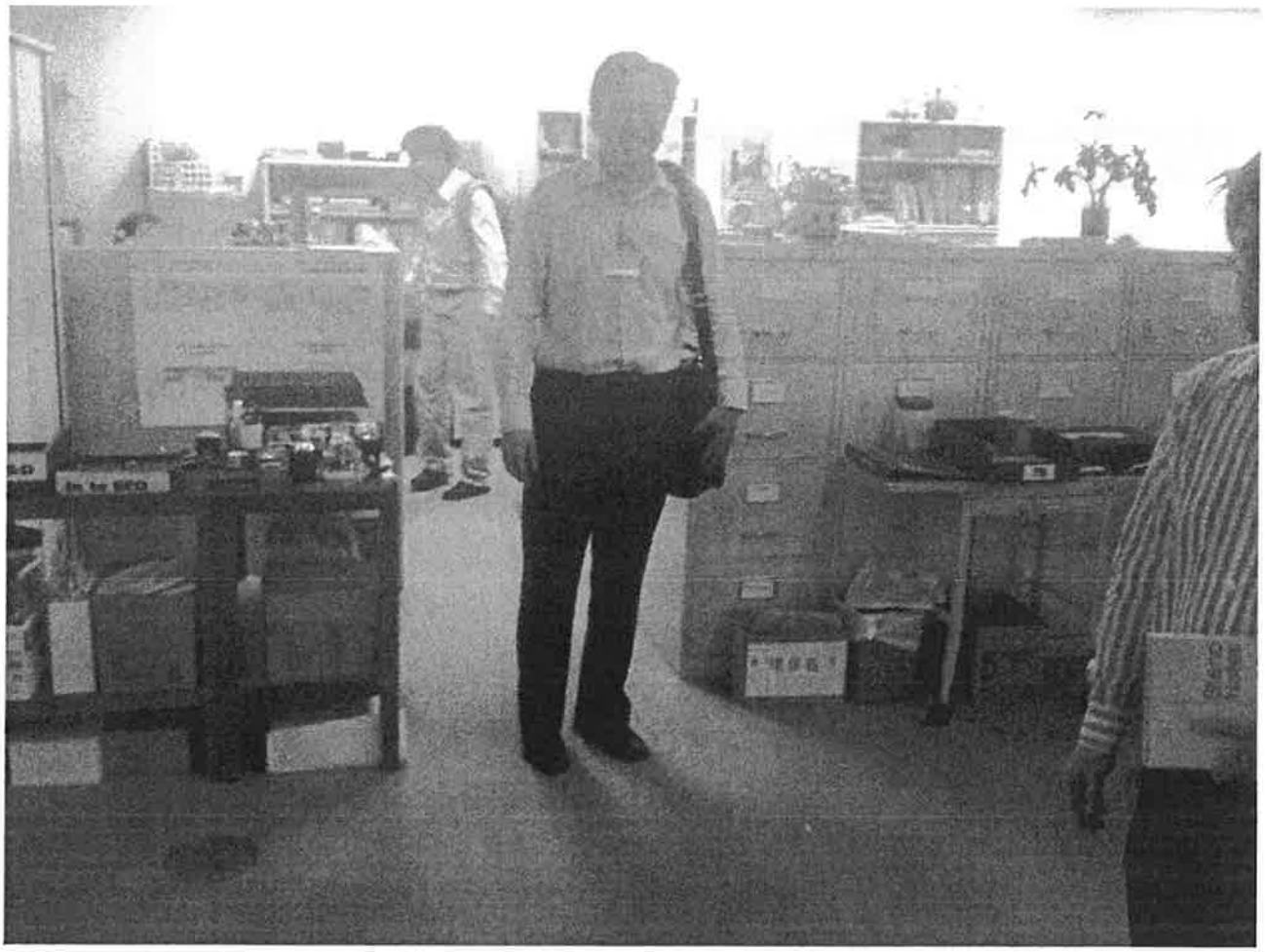
3. Lower energy costs

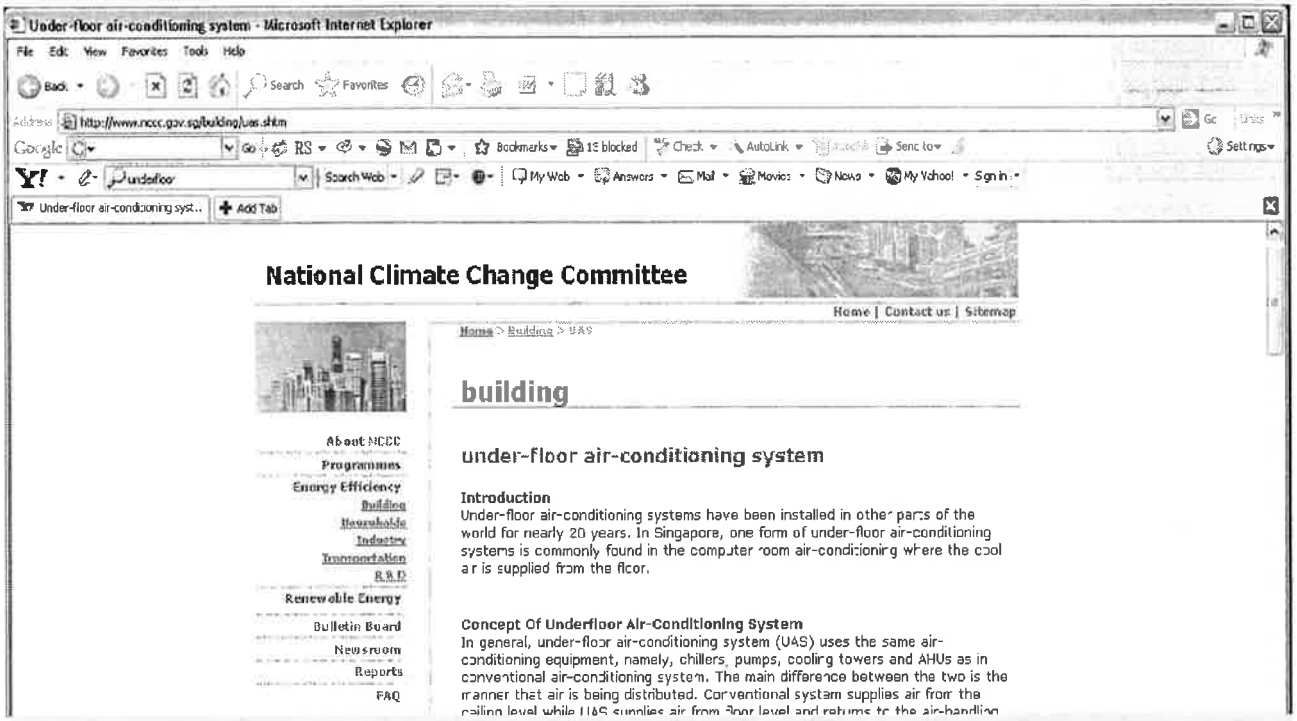
- reduces fan and refrigeration energy, and

4. Potential to reduce floor-to-ceiling heights

- creates cost savings in structural and façade systems.








## Conclusion

Despite the advantages of under-floor systems, there are barriers to widespread adoption of UAS technology. There is a perceived higher risk to designers and building owners due to a lack of objective information and standardized design guidelines, perceived higher costs, problems with standards and codes, and a lack of documented case studies with whole-building performance and cost-savings data.

| LEED Credit Category | Steps Taken | Points Earned |
|---|---|---|
| Energy & Atmosphere (EA) Credit 1: Optimize Energy Performance | Building exceeds the requirements of ASHRAE/ IESNA Standard 90.1-1999 | 4 points |
| Energy & Atmosphere (EA) Credit 4: Ozone Depletion | Mechanical equipment uses environmentally responsible HFC-407C refrigerant | 1 point |
| Indoor Environmental Quality (EQ) Credit 1: Carbon Dioxide ($CO_2$) Monitoring | System incorporates $CO_2$ sensors throughout to monitor and control $CO_2$ levels | 1 point |
| Indoor Environmental Quality (EQ) Credit 2: Increase Ventilation Effectiveness | Uses a FlexSys UFAD system to increase air-change effectiveness | 1 point |
| Indoor Environmental Quality (EQ) Credit 6.2: Controllability of Systems | Each FlexSys floor terminal is regulated by the temperature-control system | 1 point |

*The FlexSys system design helped earn LEED points by impacting energy performance, indoor environmental quality, ventilation effectiveness and system controls.*

### Indoor Environmental Quality (EQ) Credit 1: Carbon Dioxide ($CO_2$) Monitoring

than overhead-distribution systems. The conditioned air is delivered directly into the occupants' breathing zone. Contaminated air in the room warms, and natural convection carries it to the ceiling, where it is removed.

### Indoor Environmental Quality (EQ) Credit 6.2: Controllability of Systems

Unlike overhead-duct distribution, each FlexSys floor terminal is regulated by the temperature-control system. This control feature earns the system 1 LEED credit.

### Additional LEED points earned

Other LEED points were earned as the result of additional commissioning steps performed by Workstage (EA Credit 3), measurement and verification specified by MDS (EA Credit 5), the management of indoor environmental quality during construction by GVSU (EQ Credit 3.1), indoor chemical-and-pollutant source control (EQ Credit 5), and water efficiency due to water-saving plumbing fixtures and landscaping (WE Credits 3.1 and 3.2).

### More than just LEED credits

Just as important as the LEED credits contributed by the FlexSys system was its flexibility and redundancy. "With a FlexSys underfloor system, it's substantially easier

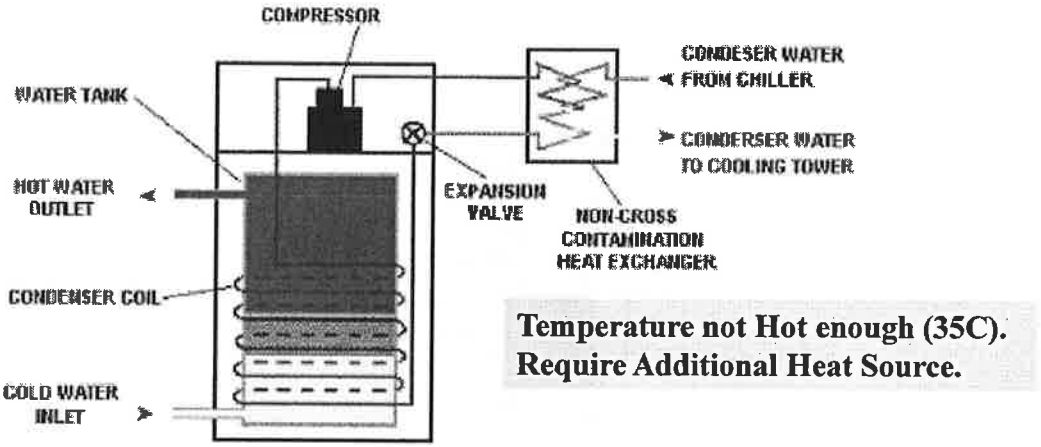
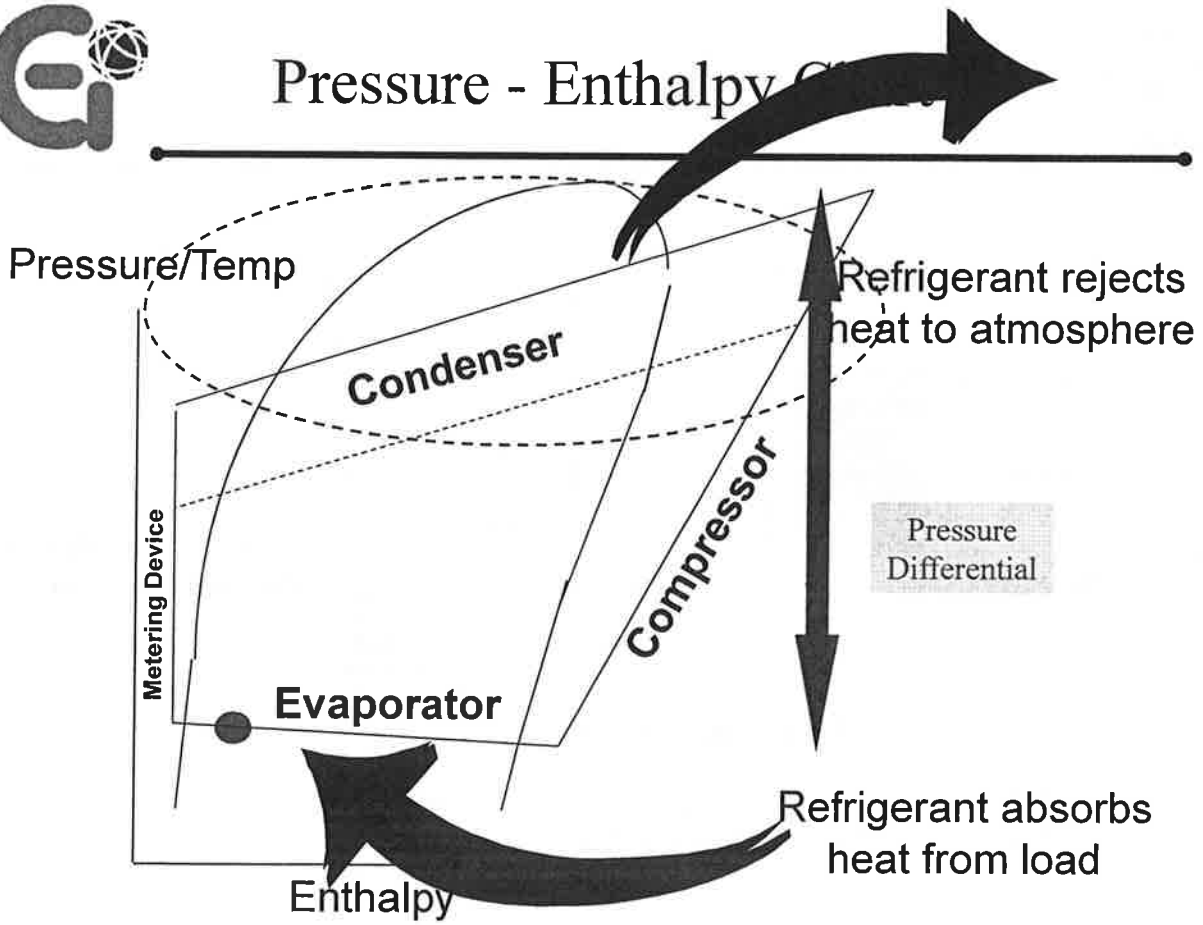



Fig. 3 – Type 1 Heat Pump

1. Heat pumps that reclaims waste heat from the condenser water of the air-conditioning chiller. (Fig. 3)



## To reduce Pressure Differential - Increase evaporator temperature/pressure

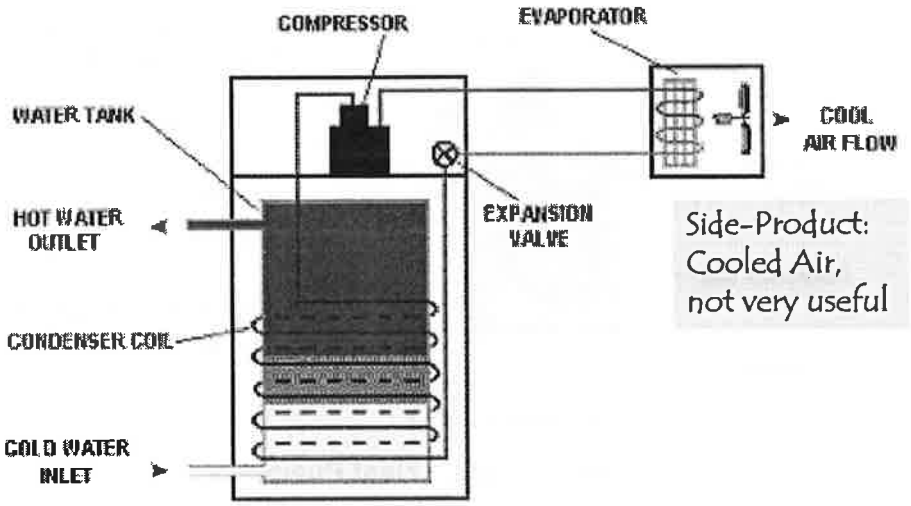



**Fig. 4 – Type 2 Heat Pump**

2. Heat pumps that supply cool air to ventilate the chiller plant room and has its refrigerant compressor enclosed within its storage tank shell. (fig. 4)

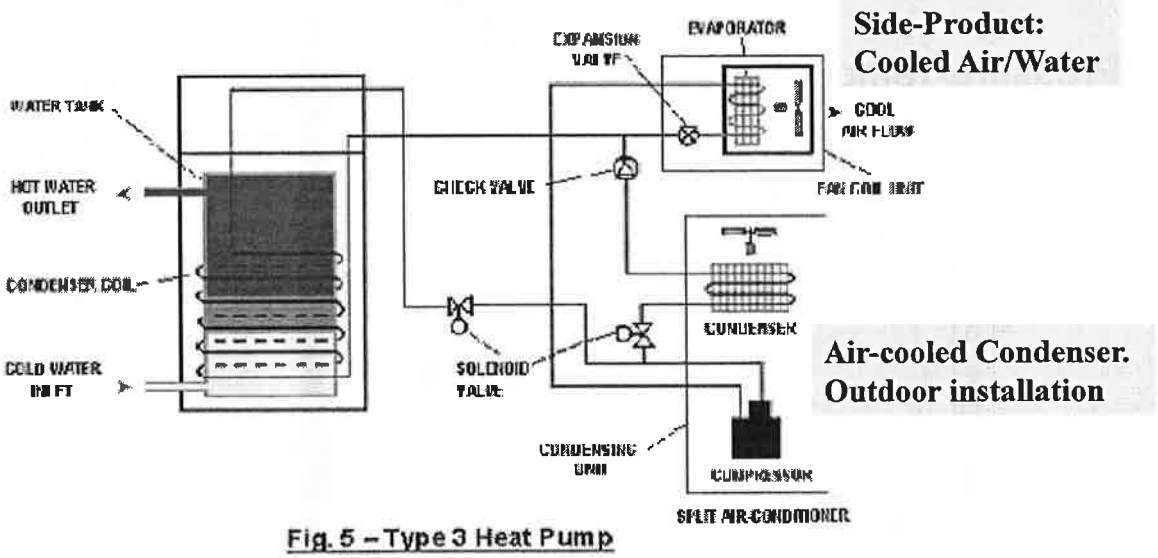



**Fig. 5 – Type 3 Heat Pump**

3. Heat pumps without refrigerant compressor that is connected to existing split air-conditioners. (Fig. 5)

# "Water-to-Water" System

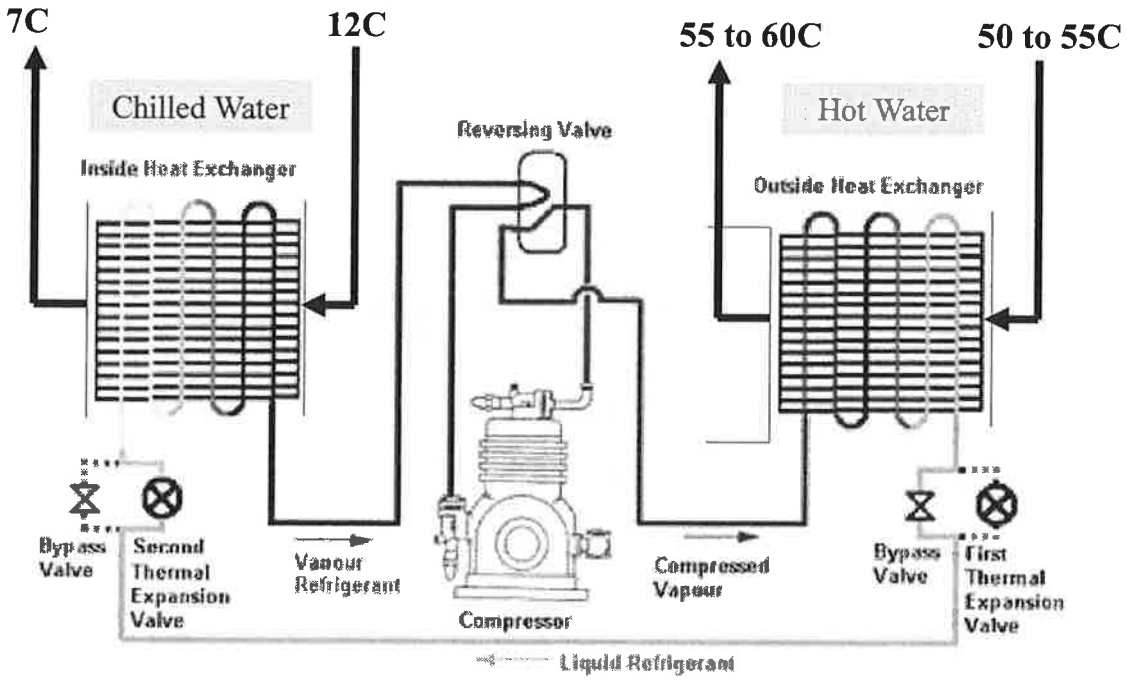
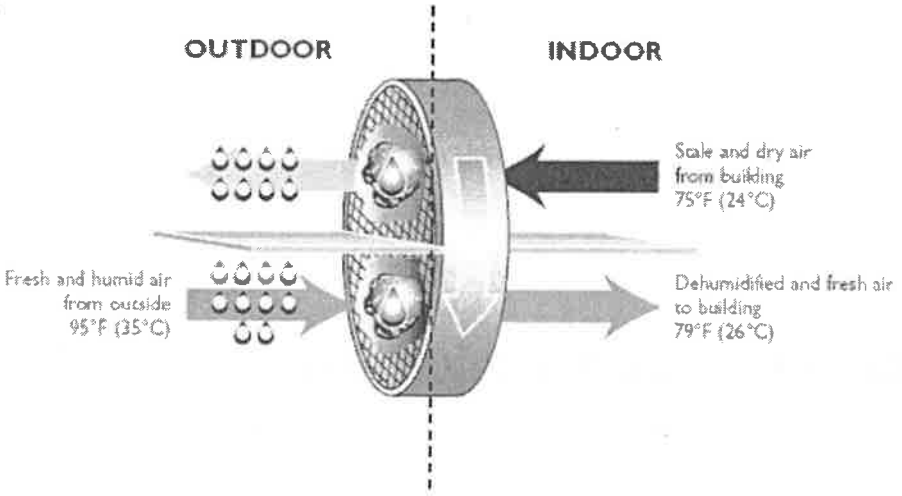



Fig. 1 - Heat Pump in Cooling Mode

# Heat Recovery Wheel

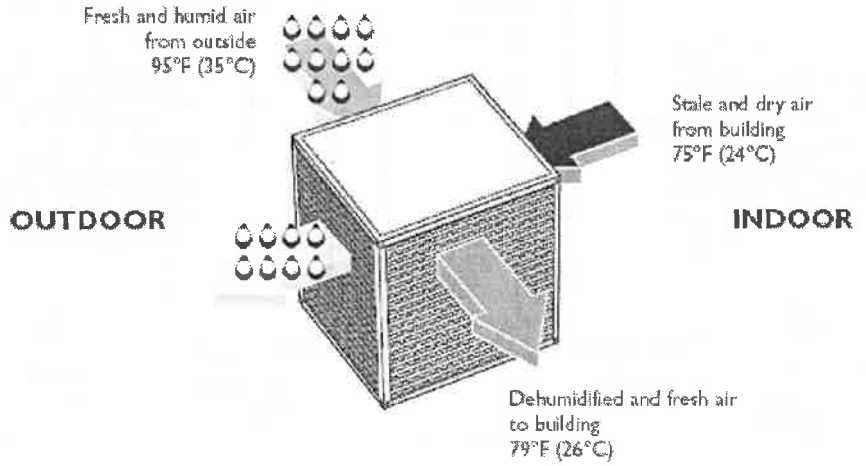
COOLING SEASON

The PEVV500 recovers the heat and the moisture from the outside fresh air and transfers it to the stale outgoing air.



## COOLING SEASON

The EHE500 recovers the heat and the moisture from the outside fresh air and transfers it to the stale outgoing air.






Heat Recovery Wheel

# Installation Considerations:

**Filtration requirements:**
Performance specifications are based upon clean air and clean surface. It is required that adequate filtration be used in both air streams to insure optimum performance and minimum maintenance.

**Access doors:**
Access doors should be provided to allow periodic inspection of the enthalpy exchanger and to facilitate cleaning when necessary.

**Code requirements:**
The installation of the exchanger should conform with all codes, laws and regulations applicable to the job site.

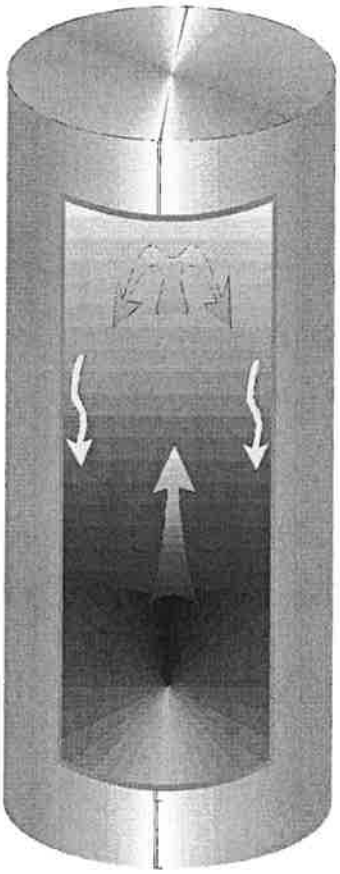
# Maintenance Considerations:

Enthalpy exchanger should be cleaned twice a year with a vacuum on the surface of the exchanger.

Heat Pipe Technology, Inc.

# Heat Pipe Basics

**Heat Pipe are fabricated with carving micro-sized grooves inside the wall and charged with either R-22 or R-134a.**



Heat Pipe Technology, Inc.

The amount of energy transferred by a basic vertical tube Heat Pipe is many times greater than what can be achieved by natural convection using a single phase fluid .

## *Why???*

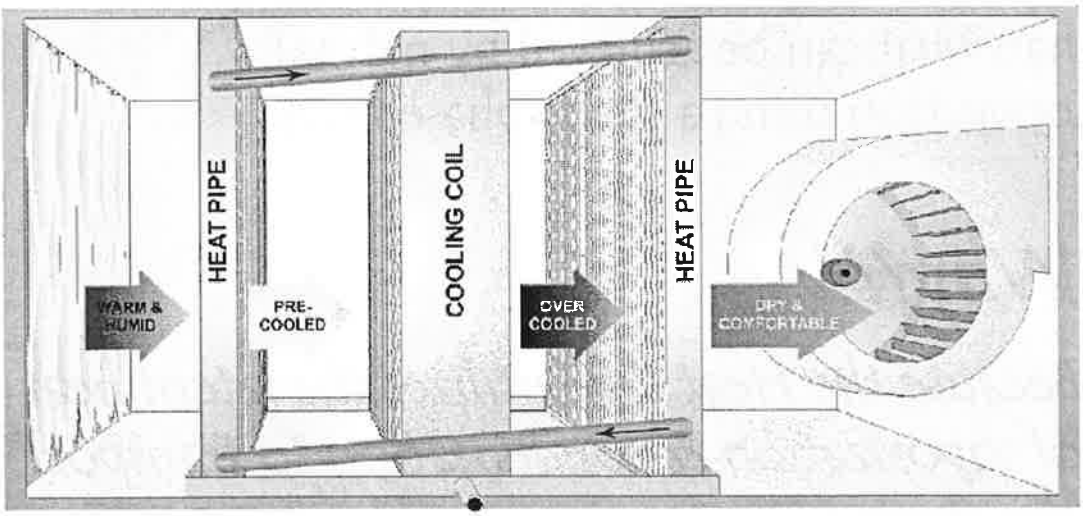
*Because the Heat Pipe utilizes the latent heat of vaporization & condensation to transport the energy.*

Heat Pipe Technology, Inc.

# HEAT PIPES for Dehumidification

Heat Pipe Technology, Inc.

## Heat Pipe Dehumidification




**Precool** **Reheat**

**Increased Condensate**

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# DEHUMIDIFYING HEAT PIPES

# Configurations & Designs

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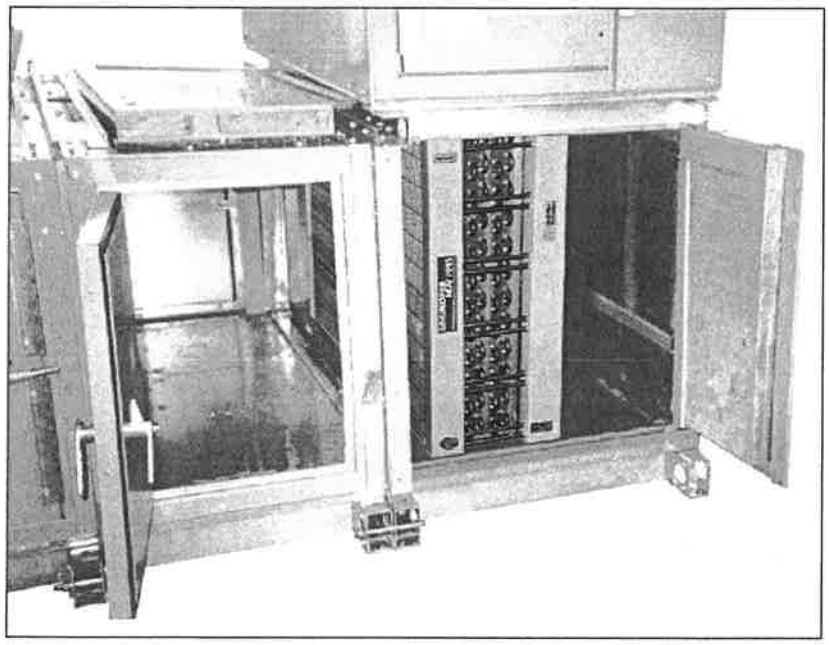
## Standard Wrap-Around Heat Pipe Installation



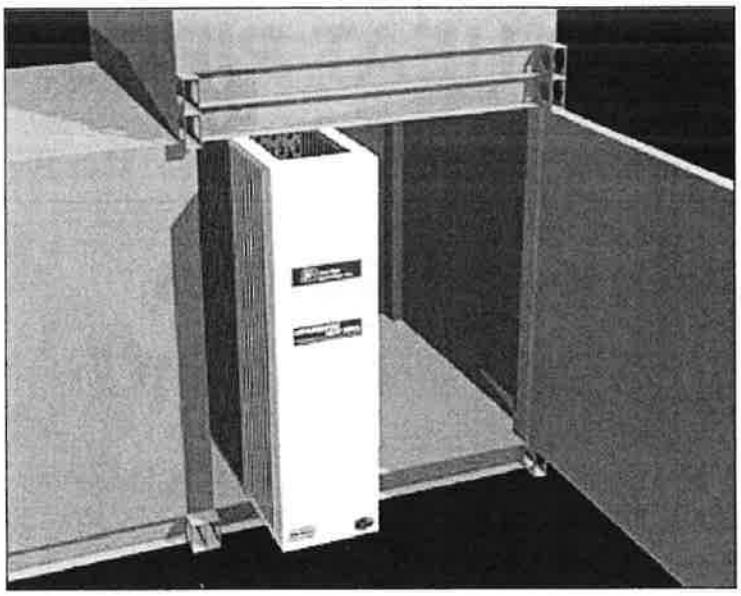
## Applications

- Most Common Factory or Field Retrofit

Heat Pipe Technology, Inc.

# DHP-U

## U-Framed Dehumidifier Heat Pipes



### Applications

- **Custom Built Units**
- **OEM Applications**
- **Field Retrofits**

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## Benefits of Heat Pipes

1.Substantial Energy Saving

2.No Mechanical or Electrical Input

3.Low Maintenance

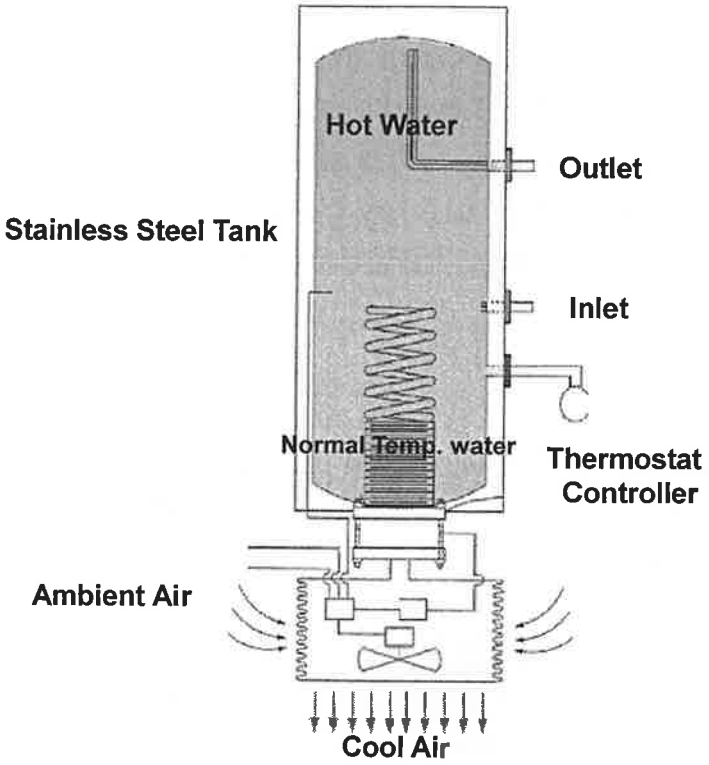
4.Improves Indoor Air Quality

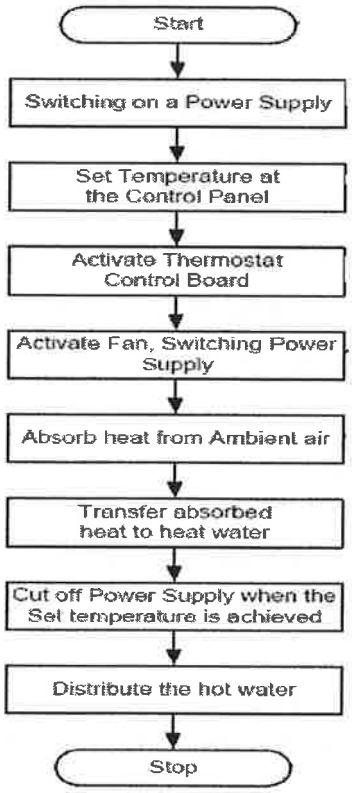
5.Provides Healthier, More Comfortable Working Environment

6.Durable Copper Heat Pipes Provide Long Service

7.It is Passive, no moving parts

# System Diagram




## ECONOMIC ANALYSIS TECHNIQUES

Analysis of overall owning and operating costs and comparisons of alternatives require an understanding of the cost of lost opportunities, inflation, and the time value of money. This process of economic analysis of alternatives falls into two general categories:

•simple payback analysis and
•detailed economic analyses (life-cycle cost analyses).

A simple payback analysis reveals options that have short versus long paybacks. Often, however, alternatives are similar and have similar paybacks. For a more accurate comparison, a more comprehensive economic analysis is warranted. Many times it is appropriate to have both a simple payback analysis and a detailed economic analysis. The simple payback analysis shows which options should not be considered further, and the detailed economic analysis determines which of the viable options are the strongest. The strongest options can be accepted or further analyzed if they include competing alternatives.

## *Simple Payback*

**In the simple payback technique, a projection of the revenue stream, cost savings, and other factors is estimated and compared to the initial capital outlay. This simple technique ignores the cost of borrowing money (interest) and lost opportunity costs. It also ignores inflation and the time value of money.**

*Example*

**Equipment item 1 costs $10 000 and will save $2000 per year in operating costs; equipment item 2 costs $12 000 and saves $3000 per year. Which item has the best simple payback?**

**Item 1 $10 000/($2000/yr) = 5 year simple payback**
**Ttem 2 $12 000/($3000/yr) = 4 year simple payback**

## *Single Payment Present Value Analysis.*

The cost or value of money is a function of the available interest rate and inflation rate.
The future value ***F*** of a present sum of money ***P*** over ***n*** periods with compound interest rate *i* per period is

$$F = P(1+i)^n \qquad (1)$$

Conversely, the present value or present worth P of a future sum of money F is given by

$$P = F/(1+i)^n \qquad (2)$$

or

$$P = F \times \mathrm{PWF}(i,n)_{sgl} \qquad (3)$$

where the single payment present worth factor $\mathrm{PWF}(i,n)sgl$ is defined as

$$\mathrm{PWF}(i,n)_{sgl} = 1/(1+i)^n \qquad (4)$$

**Example 3.** Calculate the value in 10 years at 10% per year interest of a system presently valued at $10 000.

$$F = P(1+i)^n = \$10\,000(1+0.1)^{10} = \$25\,937.42$$

**Example 4.** Using the present worth factor for 10% per year interest and an analysis period of 10 years, calculate the present value of a future sum of money valued at $10 000. (Stated another way, determine what sum of money must be invested today at 10% per year interest to yield $10 000 10 years from now.)

$$P = F \times \mathrm{PWF}(i,n)_{sgl}$$

$$P = \$10\,000 \times 1/(1+0.1)^{10}$$

$$= \$3855.43$$

**Series of Equal Payments.** The present worth factor for a series of future equal payments (e.g., operating costs) is given by

$$\mathrm{PWF}(i,n)_{ser} = \frac{(1+i)^n - 1}{i(1+i)^n} \qquad (5)$$

## ***Present Value (Present Worth) Analysis.***

All sophisticated economic analysis methods use the basic principles of present value analysis to account for the time value of money. Therefore, a good understanding of these principles is important.

The total present value (present worth) for any analysis is determined by summing the present worth of all individual items under consideration, both future single payment items and series of equal future payments. The scenario with the highest present value is the preferred alternative.

Sometimes also known as Net Present Value (NPV)



## ***Present Value (Present Worth) Analysis.***

NPV = (present worth factor x Saving per Year) – Investment

Example:
Life cycle: 15 years, Interest: 2.5%
Initial investment: $410,000, Annual Saving: $90,272

P.W.F = 12.382
Net Present Value = (12.382 x $90,272) - $410,000
= $707,748

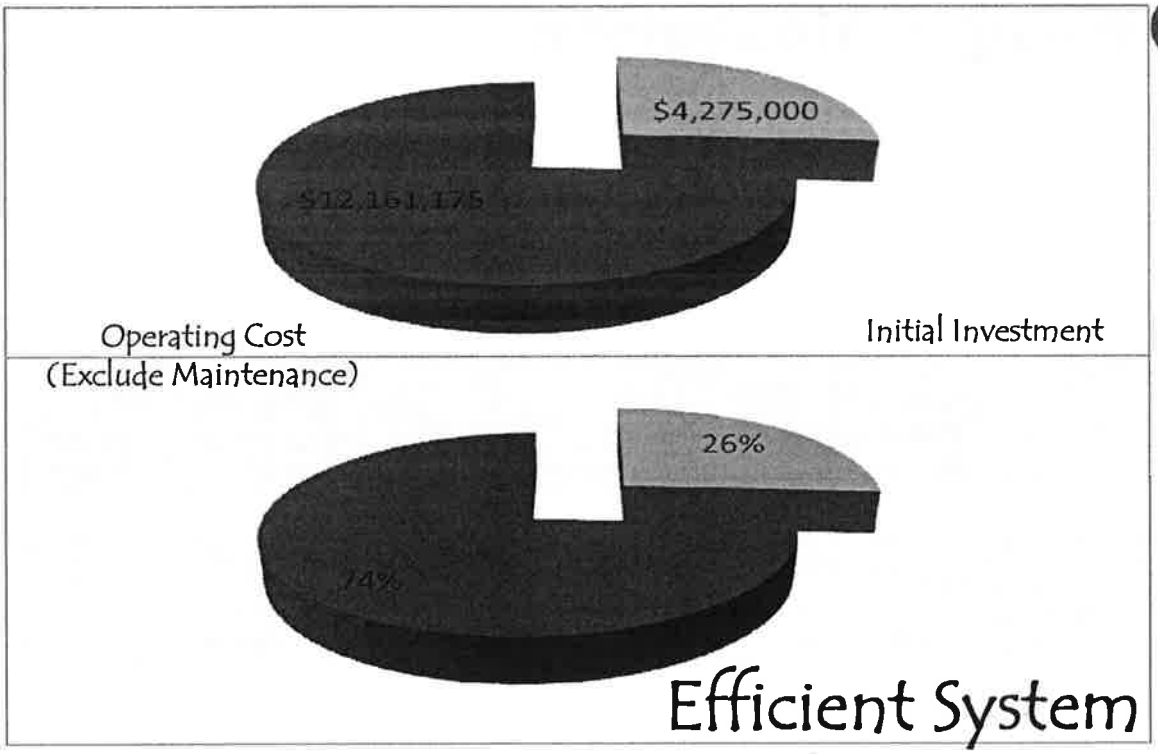


# Saving Calculation

Cont'

| | Proposed Chiller Configuration | Expected Saving | Investment | ROI (years) | NPV @ 2.5% using 15 years life cycle | IRR using 15 years life cycle |
|---|---|---|---|---|---|---|
| Option 1 (60C) | 2 x 120RT | $ 90,272 | $ 410,000 | 4.5 | $ 707,688 | 20.7% |
| Option 2 (60C) | 2 x 60RT | $ 49,327 | $ 310,000 | 6.3 | $ 300,740 | 13.5% |
| Option 3 (55C) | 2 x 63RT | $ 67,046 | $ 310,000 | 4.6 | $ 520,124 | 20.3% |
| Option 4 (50C) | 2 x 67RT | $ 78,420 | $ 310,000 | 4.0 | $ 660,943 | 24.3% |

| | | |
|---|---|---|
| Cooling Load per day (RT) | 18,000 | 18,000 |
| System Efficiency | 0.85 | 0.65 |
| Plantroom kW Consumption per day | 15,300 | 11,700 |
| Operating days per year | 365 | 365 |
| Annual Power consumption (kWhr) | 5,584,500 | 4,270,500 |
| Annual Operating Cost @ $0.23 / kWhr | $ 1,284,435 | $ 982,215 |
| Installed Tonnage | $ 2,250 | $ 2,250 |
| Dollar per RT | $ 1,400 | $ 1,900 |
| Initial Investment | $ 3,150,000 | $ 4,275,000 |
| Year 1 | $ 1,284,435 | $ 982,215 |
| Year 2 | $ 1,284,435 | $ 982,215 |
| Year 3 | $ 1,284,435 | $ 982,215 |
| Year 4 | $ 1,284,435 | $ 982,215 |
| Year 5 | $ 1,284,435 | $ 982,215 |
| Year 6 | $ 1,284,435 | $ 982,215 |
| Year 7 | $ 1,284,435 | $ 982,215 |
| Year 8 | $ 1,284,435 | $ 982,215 |
| Year 9 | $ 1,284,435 | $ 982,215 |
| Year 10 | $ 1,284,435 | $ 982,215 |
| Year 11 | $ 1,284,435 | $ 982,215 |
| Year 12 | $ 1,284,435 | $ 982,215 |
| Year 13 | $ 1,284,435 | $ 982,215 |
| Year 14 | $ 1,284,435 | $ 982,215 |
| Year 15 | $ 1,284,435 | $ 982,215 |
| Present Value @ 2.5% interest | $ 19,053,075 | $ 16,436,175 |
| Life Cycle Cost per year | $ 1,270,205 | $ 1,095,745 |




| | | | | | |
|---|---|---|---|---|---|
| Investment | $ | 3,150,000 | 17% | $ 4,275,000 | 26% |
| Operating Cost (PV) | $ | 15,903,075 | 83% | $ 12,161,175 | 74% |
| LCC (15yrs) | $ | 19,053,075 | | $ 16,436,175 | |
| LCC per Yr | $ | 1,270,204.99 | | $ 1,095,744.99 | |

# Conclusion

- Air conditioning System is one of the areas that has the most Energy Conservation Opportunities
- A huge saving can be achieved with little improvement on System Efficiency. By following conventional design method, unlikely to obtain Green Mark Award.
- By adopting Proper Data Acquisition approach for existing buildings, there are huge areas of improvement we could identify in HVAC system in a more professional and accurate methodology.

# ThAnK YoU!

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