How many engineers does it take to change a planet?

Back to Basics
Chiller Plant Applications

Melbourne 28th April 2016
Many Considerations

- Climate
- Accessibility
- Comfort
- Criticality
- Redundancy
- Indoor space
- Outdoor space
- Energy
- Water
- Noise
- Marketing
- Codes/Standards
Chiller Plant Operating Costs =

Consumables + Water + Maintenance + ENERGY

Energy Cost of Plant =

Load \times \text{Hours} \times \text{Efficiency} \times \text{Rate Structure}

Holistic Chiller Plant Approach
Automation is a key component of the optimization process but optimization is not just smart controls.

- **Design Decisions**
  - Design system infrastructure to max efficiency potential
  - Select components effectively, optimally
  - Apply components effectively, optimally
  - Automate System
  - Optimize System
  - Measure & Verify
  - Maintain

- **Operating Decisions**
Design Energy Vs. Annual Energy Usage

**Design Performance**
- Chiller: 58%
- Fans: 24%
- Pumps: 13%
- Tower: 5%

**Annual Energy Usage**
- Chiller: 33%
- Fans: 43%
- Pumps: 22%
- Tower: 2%

Efficiency  
Sustainability  
Flexibility  
Life Cycle

Johnson Controls - Proprietary & Confidential
<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat rejection medium</td>
<td>Air</td>
<td>Water</td>
</tr>
<tr>
<td>Performance</td>
<td>dry bulb based</td>
<td>wet bulb based</td>
</tr>
<tr>
<td>Full Load Efficiency</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Part load efficiency</td>
<td>Lower*</td>
<td>Higher</td>
</tr>
<tr>
<td>Chiller Size</td>
<td>larger</td>
<td>baseline</td>
</tr>
<tr>
<td>Water usage</td>
<td>NO*</td>
<td>YES</td>
</tr>
<tr>
<td>Location</td>
<td>Outdoors</td>
<td>Indoors (plant-room)</td>
</tr>
<tr>
<td>Installation</td>
<td>Less complex</td>
<td>More complex</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Less complex</td>
<td>More complex</td>
</tr>
</tbody>
</table>

* Power generating stations use water to produce electricity

# Plant efficiencies are dependent on climate, control, and other factors
VSD technology unlocks efficiency benefit of natural weather conditions

- **Constant Speed, Constant CEFT**
- **Constant Speed, AHRI Relief**
- **Variable Speed, AHRI Relief**
- **Variable Speed, AHRI Relief + oil-free**

Chillers operate for 85% of the time within this capacity range.

Note: Above is based on water cooled centrifugal compressor technology.
The design process

- Minimize ‘transport’ energy
- Maximize the economics of high efficiency components
- Optimize ‘lift’
Pressure-enthalpy diagram

1. Metering device
2. Evaporator
3. Compressor
4. Condenser

Pressure

enthalpy
Water cooled chillers

*Standard design lift condition*

- **Lift or Differential Pressure**
  - 6.7°C
  - 12.2°C
  - 29.4°C
  - 35°C

Pressure vs. Enthalpy graph

Johnson Controls - Proprietary
What is Heat Recovery?


- “In many large buildings, internal heat gains require year-round chiller operation. The chiller condenser water heat is often wasted through a cooling tower”…“[Heat recovery] uses otherwise wasted heat to provide heat at the higher temperatures required for space heating, reheat, and domestic water heating”

Heat recovery creates and uses energy at higher chiller lift condition to improve overall building efficiency
What is Heat Recovery?

Example – reheat cooled and de-humidified O/A to neutral condition for use with a passive chilled beam system with site recovered energy.
Why use a heat recovery chiller?

Economic Advantages
- Operational savings

Social / Environmental Advantages
- CO₂ reductions
- Reduced water consumption

Coincident heating and cooling

- Cooling capacity: 680 kWr
- Heat rejection: 820 kWr
- Power input: 140 kW

Total COP = 1500 / 140 = 10.7
What is lift relief?

Lower tower water temps

AND / OR

Higher chilled water temps

Less compressor work = lower input kWe
Reduce lift

Capitalizing on ‘off-design’ conditions - most of the time

- Lowering Condenser Water Temperature
- Lowers the Lift
- Reduces Compressor Work
- Reduces Energy Consumption

Pressure

Lift

Enthalpy

Evaporator

Condenser

Expansion

Compressor

Johnson Controls - Proprietary
Reduce lift

Capitalizing on ‘off-design’ conditions - most of the time

- Reduces Energy Consumption
- Reduces Compressor Work
- Lowers the Lift
- Raising Chilled Water Temperature

Evaporator
Condenser
Compressor
Expansion

Pressure
Lift
Enthalpy

Johnson Controls - Proprietary
How does lower LIFT (compression ratio) impact efficiency?

Variable Speed Chiller Energy Usage Analogy -

- Condenser Temp. 29.4°C ECWT
- 12.8°C ECWT
- 44°F (6.7°C) LCHWT

100%
50%
0%

1. Energy

Load (weight of rock)

Off- Design Lift

Evaporator Temp.

Johnson Controls - Proprietary
Legionella growth is dormant below 20°C
York chillers can operate at low condenser water temperatures

<table>
<thead>
<tr>
<th>Water Temperature</th>
<th>Legionella Growth Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>below 20°C</td>
<td>dormant</td>
</tr>
<tr>
<td>20 – 25°C</td>
<td>virtually dormant although very slow growth is possible</td>
</tr>
<tr>
<td>25 – 30°C</td>
<td>slow growth if other factors are satisfied</td>
</tr>
<tr>
<td>30 – 43°C</td>
<td>heat shock mechanism changes Legionella metabolism so it may become virulent</td>
</tr>
<tr>
<td>37 – 43°C</td>
<td>most dangerous temperature range</td>
</tr>
<tr>
<td>45°C</td>
<td>maximum temperature for growth</td>
</tr>
<tr>
<td>46°C</td>
<td>stationary phase (dies over say 1 week)</td>
</tr>
<tr>
<td>50°C</td>
<td>dies slowly (say 10 hours)</td>
</tr>
<tr>
<td>55°C</td>
<td>dies in less than one hour</td>
</tr>
<tr>
<td>63°C</td>
<td>“official” kill temperature – Legionella dies in a few minutes</td>
</tr>
<tr>
<td>70°C</td>
<td>dies in seconds</td>
</tr>
</tbody>
</table>

Table 1: Dependence of Legionella pneumophila on water temperature for growth. (2)

Cold tower water assists to control Legionella growth
Water Consumption is a function of TOTAL HEAT REJECTION.

HEAT REJECTION = Cooling Capacity + Shaft Power + Condenser Pump Power

Thus, Lower Shaft Power = Lower Water Consumption!
# Benefits of Cold Cond. Water on High Temp Chiller (i.e. 14C leaving evap. YMC²)

<table>
<thead>
<tr>
<th>CEFT (°C)</th>
<th>100%</th>
<th>90%</th>
<th>80%</th>
<th>70%</th>
<th>60%</th>
<th>50%</th>
<th>40%</th>
<th>30%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.00°</td>
<td>9.938</td>
<td>10.52</td>
<td>11.12</td>
<td>11.73</td>
<td>12.20</td>
<td>12.25</td>
<td>12.15</td>
<td>11.80</td>
<td>11.00</td>
</tr>
<tr>
<td>21.00°</td>
<td>11.66</td>
<td>12.46</td>
<td>13.34</td>
<td>14.33</td>
<td>15.11</td>
<td>15.53</td>
<td>15.82</td>
<td>15.68</td>
<td>14.70</td>
</tr>
<tr>
<td>15.00°</td>
<td>17.14</td>
<td>19.02</td>
<td>21.38</td>
<td>24.08</td>
<td>27.46</td>
<td>31.37</td>
<td>35.91</td>
<td>40.26</td>
<td>43.53</td>
</tr>
<tr>
<td>12.00°</td>
<td>20.58</td>
<td>23.47</td>
<td>27.37</td>
<td>31.61</td>
<td>36.19</td>
<td>41.29</td>
<td>46.28</td>
<td>46.69</td>
<td>34.13</td>
</tr>
<tr>
<td>9.00°</td>
<td>23.88</td>
<td>26.92</td>
<td>31.43</td>
<td>37.58</td>
<td>43.98</td>
<td>51.74</td>
<td>59.03</td>
<td>41.78</td>
<td>24.33</td>
</tr>
<tr>
<td>6.00°</td>
<td>24.04</td>
<td>27.41</td>
<td>32.62</td>
<td>40.04</td>
<td>47.56</td>
<td>57.50</td>
<td>61.29</td>
<td>41.88</td>
<td>23.16</td>
</tr>
<tr>
<td>3.00°</td>
<td>22.49</td>
<td>25.95</td>
<td>30.53</td>
<td>37.49</td>
<td>45.71</td>
<td>56.05</td>
<td>64.64</td>
<td>45.24</td>
<td>22.28</td>
</tr>
</tbody>
</table>

*Values are in COP.R*
## Opportunities for Lower Lift

**Lower Condenser Water Temperature**
- Lower CW Design Temperatures
- Oversize Towers
- Climate wet bulb relief
- Control Strategy
  - Chiller / Tower optimization
- Series Counter-flow

**Higher Chilled Water Temperature**
- Higher CHW Design temperatures
- Climate wet bulb relief
- Control strategy
  - chilled water reset
- Series & Series Counter-flow
- Multiple CHW loops
  - HT loop & LT loop
Series chillers

Lift is reduced 4 degrees C

6 deg C  10 deg C  14 deg C
Enhanced efficiency through **series counter-flow**

![Diagram showing enhanced efficiency through series counter-flow](image)

**ECWT**
- **ECHWT**: 14°C
- **LCWT**: 35°C
- **ECWT**: 29°C

**LCHWT**
- **LCWT**: 35°C
- **LCHWT**: 6°C
- **ECWT**: 29°C

**Pressure vs. Enthalpy**
- **Lift 1**: Evaporator 1 to Condenser 1
- **Lift 2**: Evaporator 2 to Condenser 2

**Temperature Summary**
- Evaporator: 10°C, 32°C
- Condenser: 14°C, 35°C
Enhanced efficiency through series counter-flow

<table>
<thead>
<tr>
<th></th>
<th>Parallel Chillers</th>
<th>SCF Chillers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Capacity (kWr)</td>
<td>2 x 1500</td>
<td>2 x 1500</td>
</tr>
<tr>
<td>Evap Flow Total (L/s)</td>
<td>44.7 x 2 = 89.4</td>
<td>89.4</td>
</tr>
<tr>
<td>Evap DP (kPa)</td>
<td>82.4</td>
<td>78.9</td>
</tr>
<tr>
<td>Cond Flow Total (L/s)</td>
<td>69.8 x 2 = 139.6</td>
<td>138.7</td>
</tr>
<tr>
<td>Cond DP (kPa)</td>
<td>76.9</td>
<td>54.2</td>
</tr>
<tr>
<td>R134a Charge (kg)</td>
<td>2 x 603 = 1206</td>
<td>2 x 438 = 876</td>
</tr>
<tr>
<td>Cost ($)</td>
<td>BASE</td>
<td>Less than BASE</td>
</tr>
<tr>
<td>VPF Evap min (L/s)</td>
<td>13</td>
<td>22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load (kWr)</th>
<th>Parallel (kWe)</th>
<th>SCF (kWe)</th>
<th>Saving (kWe)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>471.0</td>
<td>446.5</td>
<td>24.5</td>
<td>5.2%</td>
</tr>
<tr>
<td>2700</td>
<td>378.0</td>
<td>355.5</td>
<td>22.5</td>
<td>6.0%</td>
</tr>
<tr>
<td>2400</td>
<td>297.8</td>
<td>276.3</td>
<td>21.5</td>
<td>7.2%</td>
</tr>
<tr>
<td>2100</td>
<td>229.4</td>
<td>210.0</td>
<td>19.4</td>
<td>8.5%</td>
</tr>
<tr>
<td>1800</td>
<td>171.5</td>
<td>154.4</td>
<td>17.1</td>
<td>10.0%</td>
</tr>
<tr>
<td>1500</td>
<td>122.7</td>
<td>108.6</td>
<td>14.1</td>
<td>11.5%</td>
</tr>
<tr>
<td>1200</td>
<td>100.2</td>
<td>87.5</td>
<td>12.7</td>
<td>12.7%</td>
</tr>
<tr>
<td>900</td>
<td>80.9</td>
<td>69.5</td>
<td>11.4</td>
<td>14.1%</td>
</tr>
<tr>
<td>600</td>
<td>65.2</td>
<td>56.9</td>
<td>8.3</td>
<td>12.7%</td>
</tr>
<tr>
<td>300</td>
<td>75.4</td>
<td>66.0</td>
<td>9.3</td>
<td>12.4%</td>
</tr>
</tbody>
</table>

Johnson Controls - Proprietary
"...we are reaching maximum technological limits at a component level and that in the future the industry will have to look at the full HVAC system for further improvements. AHRI is in the process of forming a new working group to address systems approaches for efficiency improvements and will work closely with Standard 90.1."

Primary / Secondary System

- Know the benefits and limitations of the system type
- P/S System: Recommend to Size Primary Pumps for more flow than Secondary Pumps
- VPF System: Pump Head of Low Load Chiller
Variable Chilled Water Flow

Partload Data (Unloading per Std. Condition Set)

<table>
<thead>
<tr>
<th>% Load</th>
<th>Net Capacity (kW)</th>
<th>% Power</th>
<th>Input Power (kW)</th>
<th>EEFT (°C)</th>
<th>ELFT (°C)</th>
<th>Evap Flow (L/s)</th>
<th>Evap PD (kPa)</th>
<th>CEFT (°C)</th>
<th>CLFT (°C)</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1200</td>
<td>100</td>
<td>198.6</td>
<td>12.00</td>
<td>6.00</td>
<td>48</td>
<td>70.7</td>
<td>29.50</td>
<td>35.00</td>
<td>6.041</td>
</tr>
<tr>
<td>90</td>
<td>1080</td>
<td>79</td>
<td>157.0</td>
<td>12.00</td>
<td>6.00</td>
<td>43</td>
<td>58.6</td>
<td>27.30</td>
<td>32.16</td>
<td>6.877</td>
</tr>
<tr>
<td>80</td>
<td>960</td>
<td>61</td>
<td>121.4</td>
<td>12.00</td>
<td>6.00</td>
<td>38</td>
<td>47.5</td>
<td>25.00</td>
<td>29.25</td>
<td>7.906</td>
</tr>
<tr>
<td>70</td>
<td>840</td>
<td>47</td>
<td>93.0</td>
<td>12.00</td>
<td>6.00</td>
<td>33</td>
<td>37.5</td>
<td>22.80</td>
<td>26.46</td>
<td>9.028</td>
</tr>
<tr>
<td>60</td>
<td>720</td>
<td>35</td>
<td>68.7</td>
<td>12.00</td>
<td>6.00</td>
<td>29</td>
<td>28.5</td>
<td>20.60</td>
<td>23.69</td>
<td>10.481</td>
</tr>
<tr>
<td>50</td>
<td>600</td>
<td>24</td>
<td>48.0</td>
<td>12.00</td>
<td>6.00</td>
<td>24</td>
<td>20.6</td>
<td>18.30</td>
<td>20.84</td>
<td>12.508</td>
</tr>
<tr>
<td>40</td>
<td>480</td>
<td>19</td>
<td>38.4</td>
<td>12.00</td>
<td>6.00</td>
<td>19</td>
<td>13.7</td>
<td>18.30</td>
<td>20.33</td>
<td>12.505</td>
</tr>
<tr>
<td>30</td>
<td>360</td>
<td>16</td>
<td>30.8</td>
<td>12.00</td>
<td>6.00</td>
<td>14</td>
<td>7.7</td>
<td>18.30</td>
<td>19.84</td>
<td>11.690</td>
</tr>
<tr>
<td>20</td>
<td>240</td>
<td>12</td>
<td>22.8</td>
<td>10.89</td>
<td>6.00</td>
<td>12</td>
<td>5.1</td>
<td>18.30</td>
<td>19.33</td>
<td>10.526</td>
</tr>
<tr>
<td>12</td>
<td>141</td>
<td>9</td>
<td>17.9</td>
<td>8.86</td>
<td>6.00</td>
<td>12</td>
<td>5.1</td>
<td>18.30</td>
<td>19.33</td>
<td>7.837</td>
</tr>
</tbody>
</table>

Certified in accordance with the AHRI Water-Cooled Water Chilling Packages Using Vapor Compressor Cycle Certification Program, which is based on AHRI Standard 550/590 (I-P) and AHRI 551/591 (SI). Certified units may be found in the AHRI Directory at www.ahridirectory.org. Auxiliary components included in total kW: Chiller Controls.

Compliant with ASHRAE 90.1-2004.
Compliant with ASHRAE 90.1-2007.
Compliant with ASHRAE 90.1-2010.

Compliant with the requirements of the LEED Energy and Atmosphere Enhanced Refrigerant Management Credit (EAc4).
Materials and construction per mechanical specifications - Form 160.78-EG1.
Auxiliary components included in total kW - Chiller controls.
The role of controls in the optimization process

Best-in-class algorithms that take a holistic, system-level approach

All variable speed plant
AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, tower fans, and condenser & chilled water pumping)
Most Energy Efficient Chiller Plant Design

JEM is identified as the “Greenest Building” in Singapore (2013)

Table 4: Summary of Chilled Water Plant Performance

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiller(s) Efficiency</td>
<td>0.424</td>
<td>kW/RT</td>
</tr>
<tr>
<td>Chilled water pump(s) efficiency</td>
<td>+ 0.032</td>
<td>kW/RT</td>
</tr>
<tr>
<td>Condenser Water Pump(s)</td>
<td>+ 0.049</td>
<td>kW/RT</td>
</tr>
<tr>
<td>Cooling Tower(s) efficiency</td>
<td>+ 0.022</td>
<td>kW/RT</td>
</tr>
<tr>
<td>Overall chiller plant efficiency</td>
<td>≈ 0.527</td>
<td>kW/RT</td>
</tr>
</tbody>
</table>

6.7 Plant COP

JEM is identified as the “Greenest Building” in Singapore (2013)
System efficiency targets ...

New Technology All-Variable Speed Chiller Plants
High-efficiency Optimized Code Based Chiller Plants
Conventional Code Based Chiller Plants
Older Chiller Plants
Chiller Plants with Correctable Design or Operational Problems

EXCELLENT
GOOD
FAIR
NEEDS IMPROVEMENT

kW/ton
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

C.O.P.
(7.0)
(5.9)
(5.0)
(4.4)
(3.9)
(3.5)
(3.2)
(2.9)

AVG. ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, tower fans, and condenser & chilled water pumping)

Singapore Green Mark v4
Platinum rating @ 0.55
kW/Ton = 6.4 plant COP

Traditional chiller plant COP

JEM Project delivering 0.527 kW/TR system efficiency:
Low temp loop = 9/18 deg C with 2 x YORK YK series counter-flow CSD chiller pairs
High temp loop = 15/20 deg C with 2 x YORK YK VSD chillers

Johnson Controls - Proprietary
Efficient System Design Concepts applied to HVAC system ...

DOAS

AHU(s)

HT CHW loop

15 C

18 C

9 C

LT CHW loop

13.5 C

VPF

20 C

Johnson Controls - Proprietary
Today’s variable speed chillers with optimized control strategies deliver outstanding real world plant-room efficiencies!
Currently used HFC and Natural refrigerants

- R410a
- R134a
- R245fa
- H₂O
- R717
- Hydrocarbon

Johnson Controls - Proprietary
Legislation has driven refrigerant direction. Investments are long-term and require thoughtful insight to how the equipment will be used and operated throughout its lifetime.

Towards the end of this decade we will start to see the introduction of new low GWP refrigerants (HFO). HFC’s with an acceptable GWP such as R134a will continue to be available.
SUMMARY

Optimization is a process. Innovative design is the foundation.

Chiller & Plant COP is improved when lift is reduced.

Where energy is recovered and used, Plant COP can be improved when lift is increased.

Further efficiency increases are currently being delivered at the system level.

JCI offers responsible refrigerant solutions for numerous applications.

R&D is progressing with next generation refrigerants.

QUESTIONS?