Economic Perspectives from Chiller Design to Operation

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High Efficiency

Low Life Cycle Cost

Quietest Guarantee

Sound Level

Intelligent Control

Proven Durability

Legendary Reliability
Design x Construction

Building Operation
Design x Construction
Acoustic Treatment
Electrical Installation
High Efficiency
Pump Head Energy
Acoustic Treatment

Electrical Installation

High Efficiency

Pump Head Energy
Sound comparison of 300T chillers at full load

A-Weighted Sound Level (dBA) at AHRI Conditions

- Screw Chiller
- Scroll Chiller
- Trane Stealth Chiller
- Screw Chiller (low noise)
- Magnetic Multiple Comp
- Trane Stealth Chiller with InvisiSound Superior
- Trane Stealth Chiller with InvisiSound Ultimate
Tradition Noise Reduction

Silencer: Reduce Noise
Acoustic barrier: To prevent the sound wave reflection
Installation and Operation

Sound options

- **InvisiSound™ Standard**
  - compressor muffler
  - low noise fans

- **InvisiSound™ Superior**
  - suction and discharge wraps
  - lower speed fans

- **InvisiSound™ Ultimate**
  - compressor bellows
  - patented compressor enclosure
  - noise setback option

Acoustic reduction treatments provide freedom to choose the unit sound level that meets the job requirements.
Quietest Guarantee
Sound Level

Low Speed
~3,000rpm

Low Pressure
Acoustic Treatment

HK$200K to HK$350K

HK$200K
Acoustic Treatment
Electrical Installation
High Efficiency
Pump Head Energy
Electrical Installation (ACB / MCCB & Cables) :-

400A (50m Cables) : HK$100K
630A (50m Cables) : HK$130K (Diff. 30K)
800A (50m Cables) : HK$200K (Diff. 70K)
1000A (50m Cables) : HK$250K (Diff. 50K)
Acoustic Treatment
Electrical Installation
High Efficiency
Pump Head Energy
### Table 6.12b: Minimum Coefficient of Performance for Chiller at Full Load

<table>
<thead>
<tr>
<th>Type of Compressor</th>
<th>Air-cooled</th>
<th>Centrifugal</th>
<th>VSD Centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reciprocating</td>
<td>Scroll</td>
<td>Screw</td>
</tr>
<tr>
<td>Capacity Range (kW)</td>
<td>Below 400 kW</td>
<td>400 kW &amp; above</td>
<td>Below 400 kW</td>
</tr>
<tr>
<td>Minimum COP at cooling (free air flow)</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
</tr>
</tbody>
</table>

### Water-cooled

<table>
<thead>
<tr>
<th>Type of Compressor</th>
<th>Reciprocating / Scroll</th>
<th>Screw</th>
<th>VSD Screw</th>
<th>Centrifugal</th>
<th>VSD Centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Range (kW)</td>
<td>Below 500 kW</td>
<td>500 to 1000 kW</td>
<td>Above 1000 kW</td>
<td>Below 500 kW</td>
<td>500 to 1000 kW</td>
</tr>
<tr>
<td>Minimum COP (Cooling)</td>
<td>4.2</td>
<td>4.7</td>
<td>5.3</td>
<td>4.8</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Air-Cooled Screw Chiller (VSD & Constant Speed) :-

2.8 to 3.0 (BEC) vs (Installed) 3.55
18% to 26% up

Water Cooled Centrifugal Chiller (VSD & Constant Speed) :-

5.5 to 5.7 (BEC) vs (Installed) 6.4
12% to 16% up
## Technology Comparison

### Evaluation of Design Choice Advantages

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Design Choice</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor Speed</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Motor Layout</td>
<td>Open Drive</td>
<td>Semi-Hermetic</td>
</tr>
<tr>
<td>Operating Stability</td>
<td>Single-Stage</td>
<td>Multi-Stage</td>
</tr>
<tr>
<td>Number of Bearings</td>
<td>Over 6-8</td>
<td>Two</td>
</tr>
<tr>
<td>Operating Pressure</td>
<td>Med/High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Reliability through Simplicity of Design!
### Design Choices Impact Efficiency

#### Centrifugal Chiller Comparison

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>R-134a</th>
<th>0.460 kW/ton</th>
<th>R-513A</th>
<th>0.469 kW/ton</th>
<th>R-123</th>
<th>0.433 kW/ton</th>
<th>R-1233zd</th>
<th>0.436 kW/ton</th>
<th>R-514A</th>
<th>0.434 kW/ton</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Chiller Cycle</th>
<th>Sub-Cooler</th>
<th>0.415 kW/ton</th>
<th>Refrigerant Economizer</th>
<th>0.388 kW/ton</th>
</tr>
</thead>
</table>

| Compressor | Gear Drive | Direct Drive | | | |
|------------|------------|--------------|| | |
| Motor      | Open       | Single Stage | | | |
| Drive      | 95.0%      | 97.0%        | | | 95.0%        | 97.0%        | 97.0%        | |
| Train      | 97.9%      | 100%         | | | 100%         | 100%         | 100%         | |
| Impeller   | 82.8%      | 78.8%        | | | 81.4%        | 75.1%        | 83.3%        | |
| Gear Drive | Hermetic   | Mult Stage   | | | Direct Drive | 97.0%        | 100%         | 97.0%        | 100%         |
| Motor      | 95.0%      | 97.0%        | | | 100%         | 100%         | 100%         | 100%         |
| Drive      | 97.9%      | 100%         | | | 82.8%        | 78.8%        | 75.1%        | 83.3%        |
| Impeller   | 98.1%      | 78.8%        | | | 81.4%        | 75.1%        | 83.3%        | 84.1%        |

<table>
<thead>
<tr>
<th>Production</th>
<th>@ 300 tons</th>
<th>Maglev (Multi Stage)</th>
<th>0.540 kW/ton</th>
<th>IPLV</th>
<th>0.318 kW/ton</th>
<th>0.478 kW/ton</th>
<th>0.296 kW/ton</th>
<th>0.484 kW/ton</th>
<th>0.317 kW/ton</th>
<th>0.504 kW/ton</th>
<th>0.312 kW/ton</th>
<th>0.530 kW/ton</th>
<th>0.340 kW/ton</th>
<th>0.504 kW/ton</th>
<th>0.312 kW/ton</th>
</tr>
</thead>
</table>

#### Unit Design Choices Drive Real Efficiency Paybacks
### Application Reference

#### Job Showcase

**2012**

- **Project:** Hysan Place  
- **Type:** Commercial / Hysan Development Co Ltd  
- **Size:** 808,958 sq ft  
- **Award:** LEED Platinum, BEAM Plus Platinum

<table>
<thead>
<tr>
<th>Model</th>
<th>Qty.</th>
<th>Capacity (RTon)</th>
<th>COP_{adj}(^1)</th>
<th>vs BEC 2015(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVHF1070-142L-142L</td>
<td>5</td>
<td>950</td>
<td>6.39</td>
<td>Better <strong>14.11%</strong></td>
</tr>
</tbody>
</table>

1) Based on AHRI 550/590 conditions  
2) Min. requirement of BEC for VSD centrifugal chiller is 5.6 @>3000kW, 5.5>1000kW AND <3000kW
Application Reference

Job Showcase

2013

Project: HKU Centennial Campus
Type: Higher Education / University Of Hong Kong
Size: 793,124 sq ft
Award: LEED Platinum, BEAM Plus Platinum

<table>
<thead>
<tr>
<th>Model</th>
<th>Qty.</th>
<th>Capacity (RTon)</th>
<th>COP&lt;sub&gt;adj&lt;/sub&gt;</th>
<th>vs BEC 2015&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVHF770-142L-142L</td>
<td>4</td>
<td>900</td>
<td>6.25</td>
<td>Better 8.32%</td>
</tr>
<tr>
<td>CVHE450-080S-080L</td>
<td>2</td>
<td>360</td>
<td>6.34</td>
<td>Better 11.82%</td>
</tr>
</tbody>
</table>

1) Based on AHRI 550/590 conditions
2) Min. requirement of BEC for VSD centrifugal chiller is 5.6 @>3000kW, 5.5>1000kW AND <3000kW
Application Reference

Job Showcase

Project: HKUST Campus
Type: Higher Education / The Hong Kong University of Science and Technology
Size: 107,640 sq ft
Award: 2016 Energy Project of the Year Award (APR)

<table>
<thead>
<tr>
<th>Model</th>
<th>Qty.</th>
<th>Capacity (RTon)</th>
<th>$\text{COP}_{\text{adj}}^1$</th>
<th>vs BEC 2015$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVHF1100-142L-142L</td>
<td>3</td>
<td>1,200</td>
<td>6.63</td>
<td>Better 14.31%</td>
</tr>
</tbody>
</table>

1) Based on AHRI 550/590 conditions
2) Min. requirement of BEC for CSD centrifugal chiller is 5.8 @>3000kW
# Case Study

## District Cooling System (DCS)

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
<th>Trane CenTraVac™</th>
<th>Savings / Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>-</td>
<td>USA</td>
<td>-</td>
</tr>
<tr>
<td>Capacity (tons)</td>
<td>2500</td>
<td>2500</td>
<td>-</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>R134a</td>
<td>HFO-1233zd</td>
<td>-</td>
</tr>
<tr>
<td>Power Supply</td>
<td>11kV/3/50</td>
<td>11kV/3/50</td>
<td>-</td>
</tr>
<tr>
<td>Power Input (kW)</td>
<td>1490</td>
<td>1339.6</td>
<td>Less 150.4 kW</td>
</tr>
<tr>
<td>Full load COP (kW/kW)</td>
<td>5.9</td>
<td>6.56</td>
<td>11.19% better</td>
</tr>
<tr>
<td>Full load efficiency (kW/ton)</td>
<td>0.596</td>
<td>0.536</td>
<td>11.19% better</td>
</tr>
<tr>
<td>Evaporator water Pressure Drop (kPa)</td>
<td>65 (max)</td>
<td>21.7</td>
<td>Less 43.3kPa</td>
</tr>
<tr>
<td>Condenser water Pressure Drop (kPa)</td>
<td>70 (max)</td>
<td>20.3</td>
<td>Less 49.7kPa</td>
</tr>
</tbody>
</table>
Where is money spent over a 30 year lifetime?

- **Power**: 88.5%
- **Service**: 6.6%
- **First Cost**: 4.9%

Understanding the impact of unit performance on your electrical bill:

- "Demand" (kW) - rate of electricity used
- "Energy" (kWh) - quantity of electricity used
- Other charges
  - power factor
  - ratchets rates
  - time of use
  - seasonal (winter & summer)

A Balanced Approach, with a Focus on Efficiency
Refrigeration Cycle 冷媒循环

Control:
Electronic Expansion Device 電子膨脹裝置

Condenser 冷凝器

Compressor 壓縮機

Evaporator 蒸發器
CONDENSER
EVAPORATOR
COMPRESSOR
CONTROL
REFRIGERANT
Refrigeration Cycle

- Expansion Device
- Condenser
- Evaporator
- Compressor

Pressure

Enthalpy
Reliability Features
Adaptive Controls™

• “Smart” controller that adds reliability and helps to avoid nuisance trips
• Chiller will take corrective action based on its operating conditions

Corrective action:
- High condensing pressure
- Low suction pressure
- Overcurrent

High Condensing Pressure → Lower efficiency
Installation and Operation

Closest spacing in the industry

- Decorative walls
- Close spacing
- Pit applications
Efficiency drivers

- Condenser fan motor
  - Electronically Commutated (EC) fans
  - Integral VSD
  - Permanent magnet motor
  - 2% efficiency improvement at full load
  - 5% efficiency improvement at part load
Tips :-
1. **Keep the Condenser in good condition**
2. **Proper water treatment**
3. **Check the approach temperature (water vs condensing temp.)**
CONDENSER
EVAPORATOR
COMPRESSOR
CONTROL
REFRIGERANT
Traditional Shell and Tube
Evaporator Flow

Out               In

Heat In

Cool Out

Liquid Vapor Refrigerant Mixture

Refrigerant 99%
Oil 1%

Vapor
Liquid
How do we achieve these efficiency levels?

- Less Refrigerant
- Better Heat Transfer
- Oil Concentrator

Falling Film Evaporator
Efficiency drivers

New CHIL evaporator design
Compact, High-performance,
Integrated, Low-charge
Premium efficiency heat transfer tubes
Up to 40% less refrigerant
Tips:
1. Keep the Evaporator in good condition
2. Proper Water Treatment
3. Check the approach temperature (water vs condensing temp.)
Efficiency drivers

- New compressor design
  - Delivers peak efficiency under all operating conditions
  - Optimized for variable speed operation
  - Up to a 10% improvement in compressor efficiency
  - **Permanent magnet motors**

New specific speed compressor technology

Peak efficiency under all operating conditions!
Rotational Slip

Induction motor “slips” in order to establish a magnetic field in the rotor to produce torque. The power in the rotor is lost as heat. As more torque is required, more slip occurs.

Permanent Magnet Motor

Permanent magnet motor has its rotor magnetic field permanently provided by the magnets. No external power is necessary as in the induction motor.

Permanent Magnet motor eliminates losses due to slip…

Resulting in 2-4% higher efficiency.
Efficiency drivers

Permanent Magnet Motors
Full load vibration test (Nickel Test)

- Trane performs a vibration test on the assembled centrifugal chiller at the time of the 100 percent load test.
- The levels of vibration generated by the operating unit are so low, a nickel can balance on the edge of the main compressor-motor assembly.
Hermetic Type
Open Type

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compressor rotor</td>
</tr>
<tr>
<td>2</td>
<td>Radial AMB</td>
</tr>
<tr>
<td>3</td>
<td>Thrust AMB</td>
</tr>
<tr>
<td>4</td>
<td>High speed motor</td>
</tr>
<tr>
<td>5</td>
<td>Unshrouded impeller</td>
</tr>
<tr>
<td>6</td>
<td>Inlet</td>
</tr>
</tbody>
</table>

[Diagram of open type compressor with labeled parts 1 to 6.]
Multi-stage Advantages

- Surge resistant
- Higher Efficiency
  - Less Frictional Losses
  - One or two stage economizer cycle
Tips :-
1. Avoid running in Surge Zone (Especially in Night Mode)
2. Carry out vibration analysis
3. Carry out oil analysis before deciding change of oil
4. Check Shaft Seal Leakage for Open Type
CONDENSER
EVAPORATOR
COMPRESSOR
CONTROL
REFRIGERANT
Reliability Features
UC800 Controller with TD7 Interface

Adaptivew™ Controls
- Industry leading algorithms to optimize control during rapidly changing conditions
- Feedforward adaptive control
- Rapid Restart capability

TD7 Adaptivew™ Interface
- Color touchscreen display
- UV resistant
- IP56 compliant
- Historical diagnostics
- Standard and custom reports
- Stand alone control
Efficiency drivers

Industry leading efficiency and sound levels!

- **AFD³ Adaptive Frequency™ Drive**
  - Trane third-generation Adaptive Frequency™ drive
  - Part load efficiency improvement of more than 40%
  - Designed to work with new compressor design
Reliability Features
R-410A Screw Compressor, AFD3 Adaptive Frequency™ Drive

- Trane designed and manufactured
- Accelerated life testing
  - High pressure ratio tests
  - High/low tests
  - Flooded starts/stops tests
  - Start/stop tests

- Trane designed and manufactured
  - Robust fully integrated software
  - Chiller safeties and protections
  - Fluid cooled drive
  - Uses polymer film capacitors
  - Serviceable components

AFD3 designed to last the life of the chiller!
Providing a wide range of performances over 90.1 - 2013

Full Load

IPLV

Stealth (RTAE)

20 - 25%

26 - 45%

90.1 Min (Path B)

90.1 Min (Path A)

Demand

Consumption

Unit Efficiency

Full and IPLV Efficiency

Unit Capacity (Tons)

Unit Efficiency (kW/ton)

Screw

Stealth

( Path A)

( Path B)

57
Tips :-
1. Keep up to date Firmware
2. Use Genuine Parts
3. Analyze Operation History Data
Efficiency
Global Warming
Ozone Depletion
CONDENSER
EVAPORATOR
COMPRESSOR
CONTROL
REFRIGERANT
Regulatory Timeline

**HFCs**

- **2013 EU** began HFC phase down in non- HVAC applications
- **2017 US** begins HFC phase down in non- HVAC applications
- **2018 Japan** HFC phase out for room air conditioning if GWP > 750
- **2020 Japan** HFC phase out for commercial air conditioning if GWP > 750
- **2024 US** phase out of R-134a, R-407C and R-410A in new chillers
- **2025** EU HFC phase out in mini-splits if GWP > 750
- **2025 Canada** Proposal: HFC phase out in chillers if GWP > 700

**Proposed Regulations**

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**CFCs & HCFCs**

- **1996** R-11 & R-12 production ended (refrigerant & new equipment)
- **2000** Production of new R-22 equipment ended
- **2010** Production of new R-22 refrigerant ends (service tail)
- **2020** Production of new R-123 refrigerant ends (service tail)
- **2030** Production of new HCFCs ends
- **2040** Production of new HCFCs ends*

* The Montreal Protocol allows individual countries to establish their own timelines for individual HCFCs.
If traffic is stopped, then allowed to move suddenly, the cars will take off quickly and the trucks will take some time to rumble up to speed. Refrigerant acts quite similarly.

This is like the molecules in refrigerant A jumping quickly into the bubbles, while the molecules in refrigerant B stay in the liquid. The average speed is low, just as the boiling point is lower at this point.

If you stand about one mile down the road, you will see a bunch of cars go by with a truck or two, then you will see a bunch of trucks with a car or two. This is like the liquid and vapor being at different compositions. The average speed is higher; as the boiling point is getting higher.

Go 10 miles down the road and the trucks have caught up to the cars. Similarly, the refrigerant A and B molecules come together as vapor. The speed is higher still, like the boiling point.
Refrigerant Number

**ASHRAE Standard 34**

- **000 Series** Methane Based, e.g. R-11, -12, -22
- **100 Series** Ethane Based, e.g. R-123, -125, -134a,
- **200 Series** Propane Based
- **300 Series** Cyclic Organic Compounds
- **400 Series** Zeotrope, e.g. R-404A, -410A, -452A, -452B
- **500 Series** Azeotrope, e.g. R-513A, -514A, -515A
- **600 Series** Organic Compounds, e.g. R-600
- **700 Series** Inorganic Compounds, e.g. R-717, -744
- **1000 Series** Unsaturated Organic Compounds, e.g. R-1234yf, -1234ze(E), -1233zd(E), -1336mzz(Z), -1130(E)
# Refrigerant Table

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>ODP</th>
<th>GWP</th>
<th>Refrigerant Class</th>
<th>Atmospheric Life</th>
<th>Composition</th>
<th>Phase Out Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Pressure Refrigerant</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R123</td>
<td>0.02</td>
<td>79</td>
<td>B1</td>
<td>475 days</td>
<td>HCFC Homogeneous</td>
<td>Yes</td>
</tr>
<tr>
<td>R1233zd</td>
<td>Zero (0.0002)</td>
<td>1</td>
<td>A1</td>
<td>26 days</td>
<td>HFO Homogeneous</td>
<td>No</td>
</tr>
<tr>
<td>R514a (Opteon XP30)</td>
<td>Zero (0.00006)</td>
<td>1.75</td>
<td>B1</td>
<td>22 days</td>
<td>HFO Blend</td>
<td>No</td>
</tr>
<tr>
<td><strong>Medium Pressure Refrigerant</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R134a</td>
<td>Zero (0.000015)</td>
<td>1300</td>
<td>A1</td>
<td>4,900 days</td>
<td>HFC Homogeneous</td>
<td>Yes</td>
</tr>
<tr>
<td>R513a (Opteon XP10)</td>
<td>Zero</td>
<td>573</td>
<td>A1</td>
<td>2,158 days</td>
<td>HFO Blend</td>
<td>No</td>
</tr>
<tr>
<td><strong>High Pressure Refrigerant</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R410a</td>
<td>Zero</td>
<td>2100</td>
<td>A1</td>
<td>6,200 days</td>
<td>HFC Blend</td>
<td>Yes</td>
</tr>
<tr>
<td>R22</td>
<td>0.055</td>
<td>1810</td>
<td>A1</td>
<td>4,344 days</td>
<td>HCFC Homogeneous</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Efficiency impacted by Refrigerant Choice…
Centrifugal & Screw Chillers in particular

Global Warming Potential
- R-513A
- R-123
- R-11
- R-1233zd
- R-1234ze
- R-12
- R-134a
- R-513A

Operating Pressure (psig)
- Evap 42°F (5.5°C)
- Off Line 75°F (24°C)
- Cond 97°F (36°C)

Efficiency (COP)
- CO₂ = 1.0 GWP

Non ASME
- 2L BV 0.0

ASME Construction

Industry commitments and available options are increasing
Tips :-
1. MUST weight Refrigerant before dumping back