Life Cycle Costing Analysis of Water-cooled Chillers

Chillventa
Nuremburg, Germany
LIFE CYCLE COST ANALYSIS

Description

Life Cycle Cost Analysis is a method of determining and comparing the total costs of investment alternatives over a period of time. For HVAC mechanical equipment the costs include:

• The acquisition costs. This is normally done versus a base case of the lowest first cost alternative.

• The energy costs. The annual energy costs can be estimated with a variety of tools. DTC has used an 8760 hour by hour energy modeling program.

• The maintenance costs. The annual maintenance costs have been calculated based on normal and recommended maintenance for the various types of chillers.

\[ \text{LCC} = \text{Acquisition Price} + \text{Energy} + \text{Maintenance} \text{ over a 20 year period} \]
LIFE CYCLE COST ANALYSIS

Investment Economic Assumptions

• Exchange Rates:
  • .77 Euro/$US

• No VAT is included in chiller, energy or labor prices

• 2% energy and labor inflation is assumed

• No purchase price inflation is assumed

• No currency inflation or deflation is assumed

• The minimum attractive rate of return is 5%
### Chiller Performance Models

#### All Costs in Euro

<table>
<thead>
<tr>
<th>Generic Chiller Compressor Model Type</th>
<th>COP</th>
<th>ESEER</th>
<th>Sell Price Each</th>
<th>Sell Price For 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Compressor Constant Speed Oil Lubricated Scroll - DX</td>
<td>4.0</td>
<td>5.51</td>
<td>55500</td>
<td>111000</td>
</tr>
<tr>
<td>Single Compressor Constant Speed Oil Lubricated Screw - Flooded</td>
<td>5.1</td>
<td>5.32</td>
<td>63900</td>
<td>127800</td>
</tr>
<tr>
<td>Dual Compressor Constant Speed Oil Lubricated Screw - DX</td>
<td>5.1</td>
<td>5.73</td>
<td>63900</td>
<td>127800</td>
</tr>
<tr>
<td>Dual Compressor Variable Speed Oil Lubricated Screw - DX</td>
<td>4.5</td>
<td>7.20</td>
<td>75900</td>
<td>151800</td>
</tr>
<tr>
<td>Single Compressor Constant Speed Oil Lubricated Screw - Flooded</td>
<td>5.5</td>
<td>5.75</td>
<td>71600</td>
<td>143200</td>
</tr>
<tr>
<td>Dual Compressor Constant Speed Oil Lubricated Screw - Flooded</td>
<td>5.5</td>
<td>6.14</td>
<td>75400</td>
<td>150800</td>
</tr>
<tr>
<td>Single Compressor Constant Speed Oil Lubricated Centrifugal</td>
<td>5.5</td>
<td>5.43</td>
<td>69300</td>
<td>138600</td>
</tr>
<tr>
<td>Single Compressor Variable Speed Oil Lubricated Centrifugal</td>
<td>5.5</td>
<td>7.59</td>
<td>79300</td>
<td>158600</td>
</tr>
<tr>
<td>Dual Compressor Variable Speed Oil Free Centrifugal</td>
<td>5.5</td>
<td>9.05</td>
<td>93900</td>
<td>187800</td>
</tr>
</tbody>
</table>

Chiller performance is based on actual selections, and normalized to averages that are considered typical for the generic type of compressor/chiller. Differences between manufactures do exist and will change results to some degree. All chillers include grooved connections, unit mounted reduced voltage starter or VFD, main disconnect and thermal insulation of the evaporator.
Entering condenser water temperature declines 1.4 C for each 10 % of unloading

CS – Constant speed
VS – Variable speed
## Single Compressor Constant Speed Oil Lubricated Screw Chiller @ 5.1 COP

<table>
<thead>
<tr>
<th>Condenser EWT (°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>26.7</td>
<td>5.563</td>
<td>5.460</td>
<td>5.343</td>
<td>5.224</td>
<td>5.110</td>
<td>5.001</td>
<td>4.883</td>
<td>4.758</td>
<td>4.596</td>
</tr>
<tr>
<td>23.9</td>
<td>6.104</td>
<td>5.990</td>
<td>5.889</td>
<td>5.773</td>
<td>5.680</td>
<td>5.590</td>
<td>5.502</td>
<td>5.443</td>
<td>4.931</td>
</tr>
</tbody>
</table>
Weather, Cities and Building Loads

- Four cities were chosen representing Hot, Warm, Cool and Cold climates around the world.

- Similar European cities would be Barcelona, Rome, Paris and Moscow

- Since weather affects building loads, all results are normalized to 500 tons (1758 KW) peak building load with two 288 ton (1011 KW) chillers.
### Life Cycle Cost Analysis

**Building H – High Internal Load Ratio**

<table>
<thead>
<tr>
<th>15(4.6)</th>
<th>70 (21.3)</th>
<th>15(4.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15(4.6)</td>
<td>157.5(48)</td>
<td>15(4.6)</td>
</tr>
</tbody>
</table>

- 13 stories
- ASHRAE construction
- 40% glazing
- 13 ft.(4m) floor to floor
- ASHRAE ventilation and internal loads for office
- Dimensions in feet (meters)
- Short side faces north
- 59% internal area
### Building L – Low Internal Load Ratio

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>45(13.7)</td>
<td>10(3)</td>
<td>45(13.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27(8.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>135(41.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27(8.2)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 15 stories
- ASHRAE construction
- 40% glazing – east and west only
- 13 ft.(4m) floor to floor
- ASHRAE ventilation and internal loads for a hotel/residence
- Dimensions in feet (meters)
- Short side faces north
- 10% internal area
Building Types

- HLE – (H)igh internal load ratio, (L)ow occupancy (ASHRAE standard office building), (E)conomizer (airside)
- HHE - (H)igh internal load ratio, (H)igh occupancy - 24/7 operation, (E)conomizer (airside)
- HLN - (H)igh internal load ratio, (L)ow occupancy (ASHRAE standard office building), (N) no economizer (airside)
- HHN - (H)igh internal load ratio, (H)igh occupancy - 24/7 operation, (N) no economizer (airside)
- LLE – (L)ow internal load ratio, (L)ow occupancy (ASHRAE standard office building), (E)conomizer (waterside)
- LHE - (L)ow internal load ratio, (H)igh occupancy - 24/7 operation, (E)conomizer (waterside)
- LLN - (L)ow internal load ratio, (L)ow occupancy (ASHRAE standard office building), (N) no economizer (waterside)
- LHN - (L)ow internal load ratio, (H)igh occupancy - 24/7 operation, (N) no economizer (waterside)
LIFE CYCLE COST ANALYSIS

HVAC Systems

Building H – ASHRAE Standard Office Building

- Floor by floor VFD AHU with VAV electric reheat terminals
- Two equal sized chillers in parallel with variable speed secondary pumps, cooling tower per chiller with VFD fans, two way valves at AHU with primary-secondary bypass
- Chillers oversized by 15%
- Airside economizer option

Building L – ASHRAE Standard Hotel

- Room fancoils with electric heat
- Central constant volume ventilation air system with cooling coil and electric heat
- Two equal sized chillers in parallel with variable speed secondary pumps, cooling tower per chiller with VFD fans, two way valves at AHU/fan-coils with primary-secondary bypass
- Chillers oversized by 15%
- Waterside economizer option
Energy Consumption and Operating Cost Results

- Fan, pump, cooling tower fan, electric heating, lighting and miscellaneous equipment energy consumption have been excluded.

- The results shown are for chiller energy usage only, excluding oil pumps and oil heaters.

- Operating cost is calculated at €.12 / KW-HR.
LIFE CYCLE COST ANALYSIS

Annual Energy Consumption in KW-HR by Climate
LIFE CYCLE COST ANALYSIS
Annual Operating Cost at .12 € / KW-HR

All Building Average - Annual Chiller Energy Cost - Euro/Year

- Hot
- Warm
- Cool
- Cold
- Average
LIFE CYCLE COST ANALYSIS

Annual Energy Consumption in KW-HR by Building - Warm Climate
LIFE CYCLE COST ANALYSIS

Energy Cost Average of Results - €/Year

<table>
<thead>
<tr>
<th>Chiller Type</th>
<th>Hot</th>
<th>Warm</th>
<th>Cool</th>
<th>Cold</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>M Scroll 4.0 COP 5.51 ESEER</td>
<td>122,315</td>
<td>79,500</td>
<td>67,221</td>
<td>52,323</td>
<td>80,340</td>
</tr>
<tr>
<td>Screw 5.1 COP 5.32 ESEER</td>
<td>113,557</td>
<td>74,690</td>
<td>63,104</td>
<td>48,895</td>
<td>75,062</td>
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<tr>
<td>Dual Screw 5.1 COP 5.73 ESEER</td>
<td>99,900</td>
<td>65,302</td>
<td>54,323</td>
<td>40,910</td>
<td>65,108</td>
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<tr>
<td>Screw 5.5 COP 5.75 ESEER</td>
<td>105,216</td>
<td>69,210</td>
<td>58,478</td>
<td>45,318</td>
<td>69,556</td>
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<tr>
<td>Centrifugal 5.5 COP 5.43 ESEER</td>
<td>107,521</td>
<td>71,846</td>
<td>61,606</td>
<td>47,840</td>
<td>72,203</td>
</tr>
<tr>
<td>Dual Screw 5.5 COP 6.14 ESEER</td>
<td>92,567</td>
<td>60,512</td>
<td>50,336</td>
<td>37,908</td>
<td>60,331</td>
</tr>
<tr>
<td>VS Centrifugal 5.5 COP 7.59 ESEER</td>
<td>85,621</td>
<td>53,975</td>
<td>43,634</td>
<td>32,382</td>
<td>53,903</td>
</tr>
<tr>
<td>Dual VS Centrifugal 5.5 COP 9.05 ESEER</td>
<td>77,391</td>
<td>48,358</td>
<td>39,293</td>
<td>29,140</td>
<td>48,546</td>
</tr>
<tr>
<td>VS Dual Screw 4.5 COP 7.2 ESEER</td>
<td>100,434</td>
<td>63,522</td>
<td>53,087</td>
<td>40,356</td>
<td>64,349</td>
</tr>
</tbody>
</table>
## LIFE CYCLE COST ANALYSIS

### Summary of Results - % Reduction in Operating Cost

<table>
<thead>
<tr>
<th>Chiller Type</th>
<th>Hot</th>
<th>Warm</th>
<th>Cool</th>
<th>Cold</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scroll 4.0 COP 5.51 ESEER</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Screw 5.1 COP 5.32 ESEER</td>
<td>-7.2%</td>
<td>-6.1%</td>
<td>-6.1%</td>
<td>-6.6%</td>
<td>-6.6%</td>
</tr>
<tr>
<td>Centrifugal 5.5 COP 5.43 ESEER</td>
<td>-12.1%</td>
<td>-9.6%</td>
<td>-8.4%</td>
<td>-8.6%</td>
<td>-10.1%</td>
</tr>
<tr>
<td>Screw 5.5 COP 5.75 ESEER</td>
<td>-14.0%</td>
<td>-12.9%</td>
<td>-13.0%</td>
<td>-13.4%</td>
<td>-13.4%</td>
</tr>
<tr>
<td>Dual Screw 5.1 COP 5.73 ESEER</td>
<td>-18.3%</td>
<td>-17.9%</td>
<td>-19.2%</td>
<td>-21.8%</td>
<td>-19.0%</td>
</tr>
<tr>
<td>Dual Screw 4.5 COP 7.2 ESEER</td>
<td>-17.9%</td>
<td>-20.1%</td>
<td>-21.0%</td>
<td>-22.9%</td>
<td>-19.9%</td>
</tr>
<tr>
<td>Dual Screw 5.5 COP 6.14 ESEER</td>
<td>-24.3%</td>
<td>-23.9%</td>
<td>-25.1%</td>
<td>-27.5%</td>
<td>-24.9%</td>
</tr>
<tr>
<td>VS Centrifugal 5.5 COP 7.59 ESEER</td>
<td>-30.0%</td>
<td>-32.1%</td>
<td>-35.1%</td>
<td>-38.1%</td>
<td>-32.9%</td>
</tr>
<tr>
<td>Dual VS Centrifugal 5.5 COP 9.05 ESEER</td>
<td>-36.7%</td>
<td>-39.2%</td>
<td>-41.5%</td>
<td>-44.3%</td>
<td>-39.6%</td>
</tr>
</tbody>
</table>
For the purpose of the Life Cycle Cost, it is assumed that 3.5% oil concentration occurs after 2 years of operation for flooded evaporator systems.

"An ASHRAE study determined that the vast majority of installed chillers have an excess amount of oil in the cooling system."

ASHRAE research study 601

3.5% of oil in the refrigerant charge reduces system efficiencies by 8%
LIFE CYCLE COST ANALYSIS

Maintenance Cost Totals – 77 € / Hour

All Costs in Euro

<table>
<thead>
<tr>
<th>Generic Chiller Compressor Model Type</th>
<th>Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual</td>
</tr>
<tr>
<td>Multiple Compressor Constant Speed Oil Lubricated Scroll - DX</td>
<td>904</td>
</tr>
<tr>
<td>Single Compressor Constant Speed Oil Lubricated Screw - Flooded</td>
<td>1032</td>
</tr>
<tr>
<td>Dual Compressor Constant Speed Oil Lubricated Screw - DX</td>
<td>904</td>
</tr>
<tr>
<td>Dual Compressor Variable Speed Oil Lubricated Screw - DX</td>
<td>904</td>
</tr>
<tr>
<td>Single Compressor Constant Speed Oil Lubricated Screw - Flooded</td>
<td>1032</td>
</tr>
<tr>
<td>Dual Compressor Constant Speed Oil Lubricated Screw - Flooded</td>
<td>2064</td>
</tr>
<tr>
<td>Single Compressor Constant Speed Oil Lubricated Centrifugal</td>
<td>1032</td>
</tr>
<tr>
<td>Single Compressor Variable Speed Oil Lubricated Centrifugal</td>
<td>1212</td>
</tr>
<tr>
<td>Dual Compressor Variable Speed Oil Free Centrifugal</td>
<td>724</td>
</tr>
</tbody>
</table>

- Prices include recommended preventative maintenance and parts replacement, excluding tube cleaning, open motor shaft seals and bearing, low pressure purge and catastrophic failures

- At 15th year, it is assumed that oil lubricated chillers will have a bearing inspection performed on one compressor per chiller only

- For scroll chillers, it is assumed that two compressors will be replaced at the 15th year
## LIFE CYCLE COST ANALYSIS

### Maintenance Cost Assumption Detail

<table>
<thead>
<tr>
<th>Compressor Type</th>
<th>DX Scroll</th>
<th>DX Screw</th>
<th>Flooded Screw</th>
<th>Flooded Centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed Speed</td>
<td>Variable Speed</td>
<td>Fixed Speed</td>
<td>Variable Speed</td>
</tr>
<tr>
<td>Chiller Configuration</td>
<td>Dual</td>
<td>Dual</td>
<td>Single</td>
<td>Dual</td>
</tr>
<tr>
<td>Bearing Type</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td>Starter Type and Installation</td>
<td>Conventional Starters</td>
<td>VSD Fully Integrated</td>
<td>Conventional Starters</td>
<td>VSD Fully Integrated</td>
</tr>
</tbody>
</table>

### Annual Maintenance Costs

- **Oil analysis (annual)**: 543, 543, 543, 271, 543, 271, 271, 0
- **Oil Filter / Gaskets**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil Cooler Maintenance**: 0, 0, 0, 154, 308, 154, 154, 0
- **Oil Heater Maintenance**: 0, 0, 0, 154, 308, 154, 154, 0
- **Electrical Starter Maintenance**: 362, 362, 362, 181, 362, 181, 0, 0
- **VFD Maintenance**: 0, 0, 0, 0, 0, 0, 0, 0

### Total Annual Maintenance Costs: 905, 905, 905, 1032, 2063, 1032, 1212, 725

### 5 Year Maintenance Costs

- **Oil analysis (annual)**: 543, 543, 543, 271, 543, 271, 271, 0
- **Oil Filter / Gaskets**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil Cooler Maintenance**: 308, 308, 308, 154, 308, 154, 154, 0
- **Oil Heater Maintenance**: 308, 308, 308, 154, 308, 154, 154, 0
- **Electrical Starter Maintenance**: 362, 362, 362, 0, 181, 181, 0, 0
- **VFD Maintenance**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil / Parts**: 1086, 1086, 1086, 633, 1267, 633, 633, 0
- **Oil pump rebuild**: 0, 0, 0, 0, 0, 0, 452, 452

### Total 5 Year Maintenance Costs: 2606, 2606, 2969, 1665, 3330, 2118, 2298, 725

### 10 Year Maintenance Costs

- **Oil analysis (annual)**: 543, 543, 543, 271, 543, 271, 271, 0
- **Oil Filter / Gaskets**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil Cooler Maintenance**: 308, 308, 308, 154, 308, 154, 154, 0
- **Oil Heater Maintenance**: 308, 308, 308, 154, 308, 154, 154, 0
- **Electrical Starter Maintenance**: 362, 362, 362, 0, 181, 181, 0, 0
- **VFD Maintenance**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil / Parts**: 1086, 1086, 1086, 633, 1267, 633, 633, 0
- **Oil pump rebuild**: 0, 0, 0, 0, 0, 0, 452, 452
- **Replace Capacitors**: 0, 0, 0, 0, 0, 0, 0, 3620
- **IGV Inspection**: 0, 0, 0, 0, 0, 0, 0, 905

### Total 10 Year Maintenance Costs: 2606, 2606, 2969, 1665, 3330, 2118, 2298, 5250

### 15 Year Maintenance Costs

- **Oil analysis (annual)**: 543, 543, 543, 271, 543, 271, 271, 0
- **Oil Filter / Gaskets**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil Cooler Maintenance**: 308, 308, 308, 154, 308, 154, 154, 0
- **Oil Heater Maintenance**: 308, 308, 308, 154, 308, 154, 154, 0
- **Electrical Starter Maintenance**: 362, 362, 362, 0, 181, 181, 0, 0
- **VFD Maintenance**: 0, 0, 0, 0, 0, 0, 0, 0
- **Oil / Parts**: 1086, 1086, 1086, 633, 1267, 633, 633, 0
- **Oil pump rebuild**: 0, 0, 0, 0, 0, 0, 452, 452
- **Compressor Rebuild (one only)**: 0, 0, 0, 0, 0, 0, 0, 36199
- **Compressor Replacement (2)**: 0, 0, 0, 0, 0, 0, 0, 0
- **Compressor bearing/gear inspection (one only)**: 0, 0, 0, 0, 0, 0, 0, 0
- **Circuit Board Replacement**: 1810, 1810, 1810, 905, 1810, 905, 2715, 5430

### Total 15 Year Maintenance Costs: 12416, 15276, 15639, 17050, 19620, 39222, 41212, 6154
LIFE CYCLE COST ANALYSIS

Summary of Life Cycle Cost Results

The Total Present Worth is the amount of money that would have to be invested at 5% in order to cover all costs that occur for 20 years.

Total Present Worth - €

- Dual VS Oil-free Centrifugal 5.5/9.05: €931,313
- VS Centrifugal 5.5/7.59: €1,068,297
- DX Dual Screw 5.1/5.73: €1,126,798
- VS DX Dual Screw 4.5/7.2: €1,140,265
- Flooded Dual Screw 5.5/6.14: €1,161,626
- Flooded Screw 5.5/5.75: €1,285,120
- DX Multiple Scroll 4.0/5.51: €1,335,998
- Centrifugal 5.5/5.43: €1,338,064
- Flooded Screw 5.1/5.32: €1,358,043
LIFE CYCLE COST ANALYSIS

Conclusions

• Variable speed and dual compressor control deliver significant energy benefits, when applied to a wide range of building types and climates.

• Oil-free design eliminates oil fouling of flooded heat exchangers, which sustains energy efficiency over the life of the system.

• Oil-free, magnetic bearing design has lower annual maintenance and no periodic bearing inspections. Vibration monitoring is built-in to the compressor as standard.

• Every project is unique, and Life Cycle Costing is a valuable tool that can be used to look at the particular chiller options available.
LIFE CYCLE COST ANALYSIS

Why centrifugal?

• Centrifugal compressors enable oil-free chiller design.

• Variable speed centrifugal chillers optimize energy efficiency by matching speed to pressure requirements.

• Centrifugal chillers are able to achieve much higher EER’s than the study assumptions, especially with multi-stage economized configurations.

• Centrifugal chillers can move to Low GWP refrigerants cost effectively.
Thank you for attending our seminar from Danfoss Turbocor – the pioneer and world leader of magnetic bearing, variable speed, oil-free centrifugal compressors for the HVAC industry.

Questions?